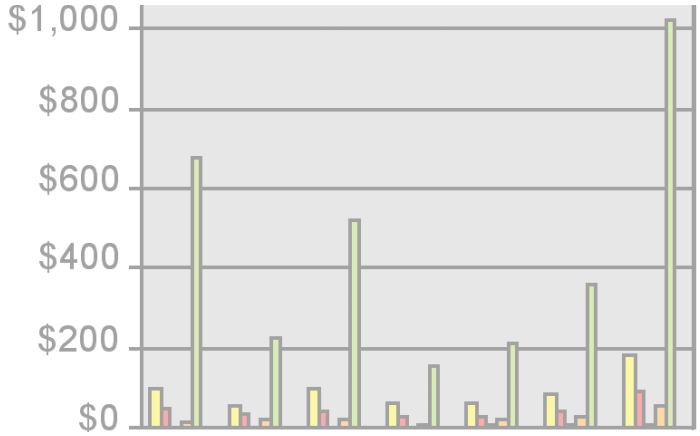
United States
Department of
Agriculture

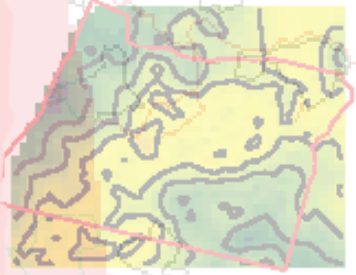
Forest Service

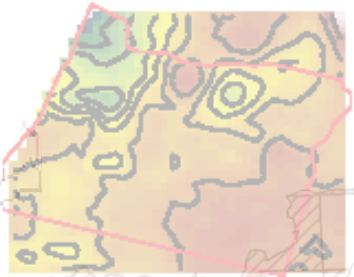
Pacific Southwest
Research Station

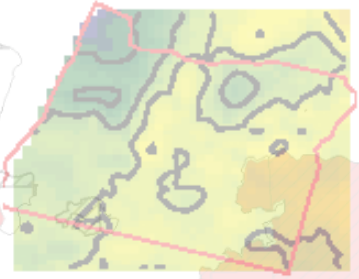
General Technical
Report
PSW-GTR-208 (English)
April 2008

Proceedings of the Second International Symposium on Fire Economics, Planning, and Policy: A Global View









The Forest Service of the U.S. Department of Agriculture is dedicated to the principle of multiple use management of the Nation's forest resources for sustained yields of wood, water, forage, wildlife, and recreation. Through forestry research, cooperation with the States and private forest owners, and management of the National Forests and National Grasslands, it strives—as directed by Congress—to provide increasingly greater service to a growing Nation.

The U.S. Department of Agriculture (USDA) prohibits discrimination in all its programs and activities on the basis of race, color, national origin, age, disability, and where applicable, sex, marital status, familial status, parental status, religion, sexual orientation, genetic information, political beliefs, reprisal, or because all or part of an individual's income is derived from any public assistance program. (Not all prohibited bases apply to all programs.) Persons with disabilities who require alternative means for communication of program information (Braille, large print, audiotape, etc.) should contact USDA's TARGET Center at (202) 720-2600 (voice and TDD). To file a complaint of discrimination, write USDA, Director, Office of Civil Rights, 1400 Independence Avenue, SW, Washington, DC 20250-9410 or call (800) 795-3272 (voice) or (202) 720-6382 (TDD). USDA is an equal opportunity provider and employer.

Technical Coordinator

Armando González-Cabán is a Research Economist, U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station, 4955 Canyon Crest Drive, Riverside, CA 92507.

Papers were provided by the authors in camera-ready form for printing. Authors are responsible for the content and accuracy. Opinions express may not necessarily relfect the position of the U.S. Department of Agriculture.

Proceedings of the Second International Symposium on Fire Economics, Planning, and Policy: A Global View

Armando González-Cabán
Technical Coordinator

U.S. Department of Agriculture, Forest Service
Pacific Southwest Research Station
Albany, California
General Technical Report PSW-GTR-208 (English)
April 2008

Abstract

González-Cabán, Armando. 2008. Proceedings of the second international symposium on fire economics, planning, and policy: a global view. Gen. Tech. Rep. PSW-GTR-208 (English). Albany, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station. 720 p.

These proceedings summarize the results of a symposium designed to address current issues of agencies with wildland fire protection responsibility at the federal and state levels in the United States as well as agencies in the international community. The topics discussed at the symposium included fire economics, theoretical and methodological approaches to strategic fire planning, wildland fires and sustainable forest management, incorporation of market and nonmarket economic evaluation techniques into fire management planning, public policies and wildland fires, tradeoffs between fuel treatment and suppression activities, and global and regional vision of the wildland fire problem. Representatives from international organizations with fire protection responsibilities in 14 countries presented and discussed their experiences on the same issues. Fifty-five invited and contributed papers and 20 posters were presented at the symposium that described the issues and presented state-of-the-art techniques to address technical issues on fire economics, planning, and policy currently faced by land and fire managers.

Keywords: Fire economics, fuel treatment tradeoffs, nonmarket valuation, public policy and wildland fires, strategic fire planning, sustainable forest management.

Preface

A World on Fire!

The economic relevance of wildland fire management and protection programs is ever growing, particularly considering mounting wildfire costs and losses globally, and the justifications required for budget allocations to management and protection of forest ecosystems. However, at the same time, the first symposium highlighted major difficulties in grappling with the problem of rapidly increasing wildland fire management costs. For example, in the United States from 2000 to 2002, more than $3 billion has been expended on fire suppression alone, affecting more than 8 million hectares of land. In 2003, in California alone, 300,000 hectares were burned, more than 3,500 homes destroyed, 22 people killed, and more than $3.5 billion in property losses!

Canada spends an average of between $400 to $800 million annually on fire suppression, prevention, and prescribed burning. This does not account for timber, recreation, health, and personal property losses. The mean annual area burned associated with these expenditures is 2.5 million hectares.

Mexico and the Central America region are also suffering tremendous losses to forest fires. For example, one of the worst forest fire years in record in the area was 1998 when more than 2.3 million hectares of forest land was affected, Mexico bearing the brunt of it with 850,000 hectares burned. Adding the area burned to agricultural uses in the region (5.3 million hectares) bring the total for 1998 to 7.7 million hectares. That is the equivalent of the entire country of Panama! Unfortunately, fire suppression expenditure information is not readily available in many Central America region countries. However, just three of the region countries (Guatemala, Honduras, and Mexico) spend over $21 million a year in personnel and equipment.

In the South American continent during the 1990s, Brazil, Argentina, and Bolivia burned annually an average of 1.03, 1.5 and 0.92 million hectares of forest lands. These three countries alone account for about 88 percent of the total annual area burned in the decade. As you will see later on this morning, some estimates of the financial losses of forest fires in South America go as high as $1.6 billion annually. This is a significant figure, particularly when the social and ecological consequences of the fires are not even considered!

Every year, on average, Europe experiences 45,000 forest fires, burning approximately a half million hectares of forest and woodlands. Between 1989 and 1993, close to 2.6 million hectares of land were burned. The year 2003 was a particularly bad forest fire year for Europe. Portugal lost more than 450,000 hectares; France saw an increase in area burned of more than 30 percent from the previous decade; and the Russian Federation lost 23.7 million hectares, an area about the size of the United Kingdom. It was not any better for the rest of the world; Australia, for example, lost more than 60 million hectares to forest fires.

Large forest fires in China, Mongolia, Indonesia, and other parts of the world demonstrate that forest fires are a world problem. No country is exempted from its impact. For example, let us remember for a moment the Indonesian fires and haze of 1997. The economic impact of that event to the economies of Indonesia,

Malaysia, and Singapore was recently estimated at about almost $4.5 billion. And this did not include long-term health damages, loss of life, reduced crop productivity, etc.

Worldwide, it is estimated that approximately 350 million hectares of forest lands are burned annually. This is equivalent to burning the area of the Indian subcontinent every year! An individual country response approach is no longer the solution.

A myriad of reasons have been identified as responsible for the increase in forest fire activities. Among the most prominent are changes in global weather patterns, increased population near forested areas (wildland/urban interface problem), changing land use patterns, and fire exclusion practices.

As has become evident in recent years, we have public and congressional oversight that demands greater accountability for fire management actions and expenditures. A diversity of wildland uses is affected, from recreation and wildlife interests to traditional commodity outputs. To achieve a balanced distribution of budget funds according to the priorities established in strategic and economic planning processes, appropriate analytical tools and methodologies are needed.

This second Fire Economics, Planning, and Policy: A Global View symposium being held here in Córdoba, Spain, 19-22 April, 2004 builds on the foundation established with the first symposium (Fire Economics, Planning, and Policy: Bottom Lines) conducted in San Diego, California, April 5-9, 1999. However, this second edition includes a broader scope of interests and a wider community of wildland fire managers and practitioners bringing together individuals from the Mediterranean Basin, Latin America, North America, and Australia with significant wildland fire problems. Based in the southern Europe Mediterranean Basin, the forum will provide its international audience the opportunity to exchange ideas regarding the economics of fire management, and to share the latest in development and technologies available for optimizing fire management expenditures.

The symposium is organized around eight major themes. The first theme is a regional and global vision of the forest fire problem. Because the majority of fire management activities are carried out by public land management agencies, we organized a panel with representatives from some of the preeminent fire management agencies in North America, Chile, Mexico, and Spain.

A second major theme is planning for fire management. Recognizing that no single perspective works best for all situations, a variety of speakers from countries around the world from different organizations and backgrounds are assembled to exchange their experiences and approaches. The unifying thread among all is the common interest in planning fire management expenditures, policy evolution, and valuation schemes. This last topic, valuation schemes, brings us to our next major symposium theme, where nonmarket and market valuation methods for incorporation into strategic fire planning will be discussed.

Catastrophic fires represent a real threat to the sustainability of fragile and non-fire-dependent ecosystems, and impact negatively large expanses of plantation forests. Therefore, another of the symposium's major themes of discussion is the relationship of forest fires and sustainable forest management. This is also closely tied with the issues of public policies and forest management. Globally, including pronouncements at the United Nations, there have been major changes in forest fire

management and suppression policies. It is a relevant topic that needs discussion and sharing among agencies from different countries with forest fire protection responsibilities.

Does increasing the level of forest fuels treated by prescribed burning activities really decrease fire suppression expenditures? The underlying belief in the fire community is that it does; it is intuitively correct. A complete session of the symposium is dedicated to discussing this issue and reviewing the state of the knowledge at this time. The experiences from colleagues around the world will help us assess the theory.

A poster session will present examples of national and regional fire management plans, and related research results.

The symposium closes with another roundtable in which a summary of the symposium discussions will be presented and the future economic implications of the forest fires discussed.

It is our sincerest belief that by bringing together world fire management practitioners and the research community, we will be better prepared to respond in an efficient and effective manner to the challenges of forest fires.

THANK YOU!

Armando González-Cabán
Córdoba, Spain
April 20, 2004

Contents

1 Findings and Conclusions of the Second International Symposium on Fire Economics, Planning, and Policy: A Global View
Armando González-Cabán

7 Approach to Reaching an Optimum Budget for Forest Fire Prevention, and its Application to the Forest Areas of Mediterranean Spain
Estbeban Castellano, Carolina Alum, Carolina Rodriquez

17 An Economic Assessment of Fuel Treatments at the Landscape Level
Hayley Hesseln, Don Helmbrecht, Janet Sullivan, Greg Jones, Keven Hyde

23 Social Impact of Large-Scale Forest Fires
José Mª Rábade, Carmen Aragoneses

35 Mechanisms for the Internalization of the Environmental Benefits of Forests and Their Application to Forest Fire Prevention
Ignacio Elorrieta, Concepción Rey

47 An Approach to a System for Monitoring the Impact of Extensive Forest Fires in Spain
Ricardo Vélez, Balbina López

53 Forest Fire Prevention Plans in National Parks: Ordes a National Park and Monte Perdido
Basilio Rada, Luis Marquina

63 Integral Plan for the Prevention of Forest Fires in Spain in the Case of the Community of Valencia
Javier Gómez, Ángel Guzmán

71 Program for Postfire Monitoring and Control in the Forest Ecosystems of Moratalle (Murcia, Spain)
Juan de Dios Cabezas, Remigio Masia

81 Development of Measures for Self-Protection Against Forest Fires: Application in Highly Vulnerable Installations
Francisco Sanz de Julián, Balvina López García

87 Macroeconimic Analysis of Investment in Fire Protection Using Social Accounting Matrixes: Application to the Navarre Region
Marcelino Pellitero, Patricia Suárez

93 Integrated Management System for Forest Fire Prevention: Its Application in the Valencia Region (Spain)
Luis Velasco, Jorge Suárez

99 Fire and Economics: Understanding the Amazonia's Fire Arch
Tatiana Schor, Arnaldo Carneiro Filho, Carlos de Almeida Toledo

111 The Influence of Ethnicity and Language on Economic Benefits of Forest Fire Prevention From Prescribed Burning and Mechanical Fuel Reduction Methods
John Loomis, Lindsey Ellingson, Armando González-Cabán, Hayley Hesseln

127 Legal Frameworks for Forest Fire Management: International Agreements and National Legislation
Mike Jurvélius

147 Methodological Proposal for Analyzing the Vulnerability and Potential Gravity of Forest Fires Within the Framework of Civil Protection
Carmen Aragoneses, José Mª Rábade

159 Economic Analysis in the Control of Fuel Loading in Mediterranean Forest Ecosystems: Prescribed Burning, an Alternative to Mechnical Methods
Francisco Rodríguez y Silva

169 A Model for the Financial Assessment of Forest Fire Prevention Plans in Mediterranean Forest Ecosystems
Francisco Rodríguez y Silva

181 United States Forest Service (USFS) NRIS-INFORMS-Fire/Fuels Analysis Tool
David S. Martinez

185 Fire History in the Mixed Pine-Oak Forest on the National Park Chipinque, in Monterrey, Nuevo Leon, Mexico
Marco Aurelio González Tagle, Javier Jiménez Pérez, Klaus von Gadow

189 Who Should Be Responsible for Forest Fires? Lessons From the Greek Experience
Gavriil Xanthopoulos

203 Control of Forest Fires as Part of the Spanish Forestry Plan
Ricardo Vélez Muñoz

213 Europe: Development and Fire
Ricardo Vélez Muñoz

221 Frameworks for Representing Large-Fire Decision Processes and Outcomes
Donald G. MacGregor, Armando González-Cabán

231 Using GIS to Test the Relationship Between Homeowner Willingness to Pay to Reduce Wildfire and Landscape Characteristics
Pamela Kaval, John Loomis

241 Costs and Benefits of Reducing Sediment Production From Wildfires Through Prescribed Burning: The Kinneloa Fire Case Study
Armando González-Cabán, Peter Wohlgemuth, John B. Loomis, David R. Weise

253 Managing Fire Risk in the Forests of the U.S. Inland Northwest: A Classic "Wicked Problem" in Public Land Policy
Matthew S. Carroll, Keith A. Blatner, Patricia J. Cohn, Charles E. Keegan III, Todd Morgan

265 Estimation of Risk Factors of Human Ignition of Fires in Spain by Means of Logistic Regression
Jesús Martínez, Emilio Chuvieco, Pilar Martín

279 Socioeconomic Value of Fire Weather Service: A Case Study of Fire Weather Information for Prescribed Burning
Don Gunasekera, Graham Mills, Tony Bannister

291 Reconstruction of Forest Areas Using Geostatistics as an Aid in the Evaluation of Burned Areas
J. Germán Flores G., David A. Moreno G., Francisco Rincón R.

303 Fuel Treatment Timing and Suppression for Wildfire Risk Mitigation
Mariam Lankoande, Jonathan Yoder

311 Wildland-Urban Interface Analyses for Fire Management Planning
Raffaella Marzano, Andrea Camia, Giovanni Bovio

319 Three Great Myths of Wildland Fire Management
Douglas B. Rideout, Pamela S. Ziesler

327 Defining Initial Response: Integrating Fire Use With Initial Attack
Stephen J. Botti, Douglas B. Rideout, Andrew G. Kirsch

339 The Effect of the Wildland-Urban Interface on Prescribed Burning Costs in the Pacific Northwestern United States
Hayley Hesseln, Alison H. Berry

353 Policy Incentives for Wildland Fire Management in the United States
Sara E. Jensen

367 Fire Management Planning—Developing Strategies and Setting Measureable Objectives for Adaptive Management
S.L. Robertson, H. Roose

377 Fire Program Analysis System—Preparedness Module
H. Roose, L. Ballard, J. Manley, N. Saleen, S. Harbert

385 A Model for Dynamic Programming to Back Strategic Planning for Fire Management in Chile
Patricia Pedernera A., Miguel Castillo S., Guillermo Julio A.

399 Comparison of Video and Phone Interview Survey Administration in Determining Public Support and Willingness to Pay for Prescribed Burning in California
John Loomis, Julie Miller, Armando González-Cabán, Joseph Champ

409 Forest Fire Spreading
Joseph Romanovsky, Vassili Shikin, Yuri Shur

421 Optimal Maneuvering of Forest Fire Protection Resources
Joseph Romanovsky, Vladimir Sapronov, Yuri Shur

431 Followup to Large-Scale Forest Fires to Aid in Evaluating Economic Losses
Miguel Castillo S., Patricio Pedernera A., Guillermo Julio A.

447 Fire Management Plan at Regional Scale in an Alpine Fire-Prone Area (Valle D'Aosta Region–Italy)
Giovanni Bovio, Elisa Guglielmet, Andrea Camia

455 Comparative Analysis Between the Forest Fire Prevention Systems in Sicily (Italy) and Andalusia (Spain)
Clara Quesada Fernández

465 Effects of Forest Fire Protection on Plant Diversity in a Tropical Deciduous Dipterocarp-Oak Forest, Thailand
Shesh Kanta Kafle

473 Wildland-Urban Interface Fire Risk Management: WARM Project
David Caballero

485 Evaluting Tradeoffs Between Wildfires and Fuel Treatments
Philip N. Omi

495 An Examination of State and Local Fire Protection Programs in the Wildland-Urban Interface
Margaret Reams, Terry Haines, Cheryl Renner

505 The National Wildfire Mitigation Programs Database: State, County, and Local Efforts to Reduce Wildfire Risk
Terry Haines, Cheryl Renner, Margaret Reams, James Granskog

513 An Evaluation of the Economic Tradeoffs of Fuel Treatment and Fire Suppression in the Angeles National Forest Using the Fire Effects Tradeoff Model
Mark D. Schaaf, Marc A. Wiitala, Maarten D. Schreuder, David R. Weise

525 Forest Harvest Can Increase Subsequent Forest Fire Severity
Carter Stone, Andrew Hudak, Panelope Morgan

535 An Accounting System for Use in Evaluating the Commercial and Environmental Effects of Public Spending on the Mitigation of Forest Fires in the Mediterranean Area
Pablo Campos-Palacín, José Luis Oviedo-Pro, Alejandro Caparrós-Gass

545 Fire Mediterranean Macchia: A Case Study in Southwest Sardinia
Ignazio Camarda, Guiseppe Brundu, Vincenzo Satta

549 The Increase in Forest Fires in Natural Woodland and Forestry Plantations in Chile
Eduardo Peña-Fernández, Luis Valenzuela-Palma

567 Practical Application of a Daily Prediction Model for the Occurrence of Human-Caused Forest Fires in Catalonia
Cristina Vega-García, Christian Ortiz Ruiz, Raquel Canet Castellà, Inés Sánchez Bosch, Daniel Queralt Creus

581 Technical and Economic Assessment of the Use of Aerial Resources in Fighting Forest Fires
J.C. Mérida, J.J. Gallar, E. García, E. Primo

591 A Fast Method for Calculating Emergency Response Times Using Travel Resistance Surfaces
David C. Hatfield, Marc R. Wiitala, Andrew E. Wilson, Eric J. Levy

597 Preliminary Development of a Probability-Based Fire Severity Modeling System for California Forests
John W. Benoit, Haiganoush K. Preisler

603 An Integrated System for Static and Dynamic Risk Evaluation at a National Level
Paolo Fiorucci, Francesco Gaetani, Riccardo Minciardi

621 Actions of the International Association for Mediterranean Forests to Prevent Forest Fires
International Association for Mediterranean Forests

627 The Economics of Interface Wildfires
John Handmer, Beth Proudley

639 Effects of Liability and Regulation on Prescribed Fire Risk in the United States
Jonathan Yoder

651 Tradeoffs Between Fire and Habitat Management in a Forest Reserve
S. Hummel, D. Calkin, R.J. Barbour

661 Managing Efforts to Prevent Forest Fires in South America
Guillermo Julio-Alvear

673 Remfiresat, Real Time Emergency Management for Forest Fire Services via Satellite
Jesús Gonzalo, Susana Martínez, Gonzalo Martin

683 Towards Developing a Global Wildland Fire Strategy
Johann G. Goldammer

697 Estimating the Impact of Proximity of Houses on Wildfire Suppression Costs in Oregon and Washington
Geoffrey H. Donovan, Peter Noordijk, Volker Radeloff

703 Wildfire Initial Response Assessment System: A Tool for Fire Preparedness Planning
Marc R. Wiitala, Andy E. Wilson

709 Forest Fires in Mexico and Central América
Roberto Martinez Domínquez, Dante Arturo Rodríguez Trejo

Findings and Conclusions of the Second International Symposium on Fire Economics, Planning, and Policy: A Global View [1]

Armando González-Cabán[2]

Introduction

During this symposium we had the opportunity to exchange ideas regarding the economics of fire management, and to share the latest in development and technologies available for optimizing fire management expenditures. We heard representatives from public fire management agencies in Chile, Mexico, Spain and the United States of America give us a regional and global vision of the forest fire problem in four major regions of the world: South America, Mexico and Central America, Europe and North America. Together with a presentation on global vegetation fire trends by the Global fire Monitoring Center these four presentations set the tone for the whole symposium and highlighted many of the common concerns with the problems of wildland fires throughout the world. Some of the most prominent reasons presented for the continuous and increasing wildland fire problem were related to social and economic factors such as poverty in rural areas, particularly in developing countries economies, and abandonment of the rural areas. A related problem is the population increase and higher concentrations along forested areas, creating the new coined problem of the wildland urban interface (WUI). This problem is mot prevalent in developed economies of the west, although not exclusive of developed countries. Another significant concern affecting negatively the problem of wildfires is changes in forestry policies. Other significant contributors to the problem are changes in global weather patterns, changes in land use patterns, and fire exclusion policies.

It was also evident from these regional presentations that the costs associated with the wildland fires problem and fire management programs are substantial ranging in the billion of dollars. For example, since 2000, the United States Department of Agriculture Forest Service (USDAFS) alone has spent more than $1 billion annually in forest fires suppression. Canada spends and average of $400 to $800 million annually. Neither of these figures includes timber, health, recreation or

[1] An abbreviated version of this paper was presented at the second international symposium on fire economics, planning, and policy: a global view, April 19-22, 2004, Córdoba, Spain.

[2] Economist with Fire Management in the Wildland/Urban Interface Research and Development Program at the Forest Fire Laboratory, Pacific Southwest Research Station, USDA Forest Service, 4955 Canyon Crest Drive, Riverside, CA 92507; Phone: 909.680.1525; email: agonzalezcabn@fs.fed.us.

personal property related expenditures. In the South American continent losses are estimated as high as $1.6 billion annually. Recent estimates of the impacts of the Indonesian fires of 1997-98 on the economies of Indonesia, Malaysia, and Singapore were as high as $10 billion. The long-term damage caused by net transfer of carbon to the global atmosphere as a consequence of excessive burning and reduced carbon sequestration capacity in the Russian Federation have recently been assessed to be in the magnitude of $5 billion per year.

The problem is not any simpler in terms of the land area affected. In the US an average of close to 2 million hectares of forest lands annually have been affected. In Canada the equivalent amount is 2.5 million hectares. During 1998, 2.3 million hectares were affected in Mexico and Central America. When added to the 5.3 million hectares of agricultural burns in the area the total jumps to 7.7 million hectares. In the South American continent more than 3 million hectares burned on average during the 1990s. On average Europe burns more than half million hectares of forest and non-forest land annually. During 2003, Portugal alone burned more than 450,000 hectares of forest lands; France's average annual area burned increased by more than 30% from the 90s decade; the Russian Federation burned 23.7 million hectares, and Australia lost more than 60 million hectares! Worldwide estimates are that more than 350 million hectares of forest lands are burned annually.

In response to the overwhelming evidence of the magnitude of the problem the presentations and discussion following the regional overview dealt with the topic of strategic fire management planning. Divided into three sessions authors presented different approaches used by several world organizations to best plan their forest fire protection programs. Presentations varied from developing a global wildland fire strategy to specific planning techniques for individual countries from Chile to the USA, and to Europe. Some had developed models for allocating fire fighting resources using Geographic Information Systems, other developed tools for strategic budget processes for initial attack response. Experiences and models from different parts of the world were presented and discussed.

The wildland fire program has been traditionally discussed in terms of fire ecology and fire management but by and large not from the perspective of its economic dimension. Two full sessions were devoted to the fire economics issues. Nonmarket valuation techniques were presented on how to include nonmarket values information into strategic fire planning. The economic implications of wildfire management were discussed and some "myths" about fire management presented. The cost and benefits of the application of prescribed burning as a tool for sediment reduction was presented among others.

Sustainability of fragile and non fire dependent ecosystems is threatened by catastrophic fires. These fires also affect large expanses of forest plantations. A session was devoted to discuss the relationship between forest fires and sustainable forest management. Examples from Spain and Chile highlighted the difficulties in trying to practice sustainable forestry while confronting wildland fire problems of the magnitude presented here.

The regional presentations made clear the importance of public policies in shaping government agencies response to the problem of wildland fires. At the same time these policies affect the manner in which society reacts to the established programs. The issue of wildland urban interface was discussed extensively as one

that is shaping the new approaches public agencies at the local, regional, and national level will use in establishing wildland fire management programs. The factors that affect the views of homeowners about wildfire hazard and fuels management were also discussed.

There is common held believe in the wildland fire community that increasing the level of forest fuels treated by prescribed burning activities would decrease fire suppression expenditures. A full session was devoted to this topic with mixed results. Results show that there are analytical problems in assessing treatment effectiveness and these may be compounded by deficiencies in the type of data typically collected by public agencies. Other problems are related to the relatively scant information available on treatments applied on a landscape scale.

Problems Identified

After three intense days of presentations the following list of problems where identified as having a significant impact on the wildland fire problem.

1. Socio-economic
    a. Poverty in rural areas
    b. Abandonment of rural areas
    c. Population increases and concentration in urban areas
    d. Shift in forestry policies
    e. Wildland urban interface
    f. Low forest land values
2. Programmatic
    a. Lack of clear, and sometimes conflictive policies
    b. Lack of continuous well financed prevention and education campaigns
    c. Lack of coordination (local, regional, national, and international levels)
    d. Lack of fire management programs funds
    e. Lack of good information databases
    f. Lack of fire insurance programs
3. Political
    a. Lack of political will to promote effective forest protection
    b. Lack of community involvement
    c. Agricultural policies resulting in agricultural burns being a major agent of forest fires.

Conclusions

From this list of problems the following conclusions were reached:

1. Increasing fire severity observed in many regions as a consequence of direct and indirect impacts of human interference and environmental change
2. Different regions experiencing the consequences of fire suppression or reduced fire use, with its impacts on biodiversity, carrying capacity, landscape patterns, etc.
3. Alarming trend of fire-induced carbon transfer from the terrestrial sphere to the atmosphere, especially from drained or climatically altered wetlands
4. Main cause of fire is agricultural burning
5. Globalisation of markets influences fire use and fuel loads
6. The wildland/urban interface problem is growing rapidly requiring a new paradigm for a workable solution
7. Larger and more expensive fire suppression organizations are not necessarily the answer.
8. Preventive silviculture programs & education programs in urban and rural areas may not be enough, without adequate funding
9. Community involvement programs are necessary (integrated fire management—social, ecological, economic and operational issues)
10. Economic analysis of forest fires protection programs is essential (including valuation of fire impacts)
11. Development of a wide-reaching system of personnel certification and qualification is needed
12. Establishment of cooperative agreements at the local, regional, national & international levels is necessary
13. New policies are needed to deal with:
    a. abandonment of rural areas
    b. poverty in rural areas
    c. wildland/urban interface issues
14. Development of national databases
    a. Fire history
    b. Intentional fires (arsonists profile)
    c. Fire costs (local, regional, national)
    d. WUI (definition of term, inventory by country, structures lost, economic impact)
15. Research needs
    a. Social, economic, and human behavior studies in fire awareness
    b. Home and safety research in WUI

c. Proportion of budget needed for fire education, prevention to achieve reduction in number of fires

d. Verification of global (country) remote sensing data (total area burned, fire history, etc)

e. Use of fuel treatments to reduce fire hazard and occurrence

f. Economic impacts of forest fires

In closing the general consensus of the audience was that this kind of international conference dealing with issues of fire economics, planning and policies should be continued on a regular schedule. It was recommended that the next symposium be scheduled for 2008.

Page left blank intentionally.

Approach to Reaching an Optimum Budget for Forest Fire Prevention, and its Application to the Forest Areas of Mediterranean Spain[1]

Esteban Castellano,[2] Carolina Alum,[3] Carolina Rodríguez[3]

Summary

By determining the optimum budget for forest fire prevention in a specific territory, an objective reference is provided of the financial cost, which tends to be high and is frequently the subject of much controversy. This paper proposes not only to establish a cost efficiency function for the fire fighting budget of a region on the basis of previous budgets, the number of fires and the average data on burnt surface area which permit marginal costs to be established; but also, the value of the natural active surface area affected, which may be assessed from two perspectives: that of the owner of the forest land – private value - and that of the public related to the forest land - private value plus public value-; this study proposes to focus on the latter. The final phase consists of comparing the marginal cost of the budget with the value per unit of surface area f the damage caused by the fires. This methodology is proposed for application to Mediterranean forest land in Spain where public values are a substantial part of the total value. As case studies we have used the forest lands of the Autonomous Community of Andalusia and the Community of Valencia.

Introduction

The frequency and intensity of forest fires, particularly in countries with marked periods of drought, have determined an intensive fire-fighting policy. In the case of Spain the situation has reached a catastrophic level, as in recent decades thousands of fires have led to a high toll of human life and incalculable losses, which in many cases are impossible to recover.

Bearing in mind that the recurrence of fires in forested areas has the effect of degrading the environment in terms of: destruction of soil, erosion, loss of native species, game … prevention of these disasters is of the utmost priority for the competent authorities involved.

The Council Regulation (EEC) no. 2158/92 on the prevention of forest fires in

---

[1] An abbreviated version of this paper was presented at the second international symposium on fire economics, policy, and planning: a global view, 19–22 April, 2004, Córdoba, Spain.

[2] Forestry Engineer. Rural Development, Subdirección de Planificación Ambiental. Tecnologías y Servicios Agrarios, S. A., c/ Conde de Peñalver, 84. 28006, Madrid, España.

[3] Forestry Engineer. Forest Services, Subdirección de Planificación Ambiental. Tecnologías y Servicios Agrarios, S. A., c/ Zurbano, 45. 28010, Madrid, España.

[3] Forestry Engineer. Rural Development Department, Subdirección de Planificación Ambiental. Tecnologías y Servicios Agrarios, S. A., c/ Conde de Peñalver, 84. 28006, Madrid, España.

Community forests established a Community programme for the prevention of forest fires, it has identified the causes of fires, the creation of protection systems, and the improvement of those already in existence, including vigilance. This programme has achieved positive results, such as the financing of specific causality studies which have improved knowledge on the causes of fire, which is essential to the basis of a prevention policy. Nevertheless, this scant provision clearly shows the limited scope preventive efforts have provided so far. This programme was in force until 2001. Since 2003, forest fire prevention has been encapsulated in the Parliament and Council Regulation (EEC) 2152/2003 on the monitoring of forests and environmental interaction in the Community (Forest Focus), which show the characteristics of forest land in its contribution to the development of rural areas – economic and social aspects - and nature conservation, – environmental aspect- .

The European Union Social Fund (EUSF) is also involved through rural development programmes and measures for prevention of forest fires.

The Spanish Forestry Plan proposes to coordinate the plans of the Autonomous Communities (regional governments) and the General State Administration through the Forest Fire Fighting Committee (CLIF). This coordination should be based on the distribution of risk and cost-efficiency criteria, as an essential step in achieving the objective of forest fire prevention and control. (Environment Ministry 2002) The aim is to promote fire prevention measures which reduce the number of fires and limit the impact they have on forested areas.

Society is become increasingly aware that forest lands, in addition to providing a source of raw materials, play an essential part in maintaining balance, particularly in respect of the soil, water systems, climate, fauna y flora; they also provide environmental services and direct amenities. The source function of raw materials refers to private assets – those for which there is rivalry for their consumption and over who shall exploit them : the proprietor : - The rest consist of public assets over which proprietors have no rights- they are made use of by any normal member of the public – and constitute what are known as externals. The value of the forest land is incomplete unless the externals are taken into account, particularly those forest lands with limited productive possibilities.

The cost –efficiency analysis is a useful tool in the field of environmental policy (Azqueta 2002). It involves the rationalisation of a commonplace practice: weighing up the advantages and disadvantages of the decision on how to achieve a goal in the best possible way, in this case it would be the optimum budget for fire-fighting. The novelty of the analysis lies in the incorporation of public assets in order to establish the social cost of the burnt surface area and the enablement of direct comparison with the optimum fire fighting budget.

Fire-fighting has been centred almost exclusively on fire suppression, where important advances have been made in rate of effectiveness. Conversely, prevention and adequate forest planning within the framework of efficient land management has largely been forgotten. Unfortunately, the global budget details available cover suppression and prevention, thus a joint marginal cost has been estimated. Given this fact, it is not possible in this study to make any inference regarding the proportion of these chapters in the budget.

The results merely provide an initial approach, due to the fact that we have only been able to obtain overall data, and because it must be assumed that the efficiency of budgets in respect of prevention and suppression are different, and the overall

optimum budget will be proportionally different for these parts.

Objectives

The main objective is to determine an ideal budget, required for prevention of forest fires in each of the Autonomous Communities mentioned in this study, from the point of view of society overall and not merely from the point of view of private assets.

Secondary objectives are as follows:

- Demarcation of the area of validity of the optimum in function of the other explanatory variables of the cost-efficiency function – analysis of sensitivity-.
- Establishment of the distance existing between the budgetary amounts awarded by the Autonomous Communities studied and the optimum budget established. It would also be interesting to see whether the situation is similar in both cases.
- To determine the social cost per hectare burnt, bearing in mind the natural regeneration occurring in the Mediterranean area.

Materials and methods

Basic data to estimate the cost-efficiency function

The period studied is from 1991–2002, in two autonomous communities: the Autonomous Community of Andalusia (ACA) and the Community of Valencia (CV). The data noted for each of the years within the period are contained in *table 1* : Autonomous Community, year, number of fires, total surface area burned, budget for the year updated to Euros 2003 and Birot's index.

The capacity of a fire prevention budget to reduce the surface area burned within a given period is influenced by the meteorological conditions of that period. Meteorology has been included in the cost-efficiency function using the Birot index calculated with yearly data according to the following formula:

$$IB = N \times Pa / Tm$$

With IB being the value of the index, N the number of days of annual rainfall Pa annual precipitation in millimetres and Tm average annual temperature. The number of fires was not used ultimately because the total surface area burnt was used to measure efficiency within the cost-efficiency functions, instead of average surface area per fire which initially had appeared more appropriate. The reason is that prevention measures include public awareness campaigns which have led to a declining trend in the number of fires.

Table 1—*Basic data for estimation of the cost-efficiency function*

Autonomous Community	Year	Number of fires	Burned Area (hectares)	Birot Index	Prevention budget (per thousand € 2003)
ACA[1]	1991	2.110	65.252,8	9,6	34.936,1
ACA	1993	1.288	17.342,3	11,2	52.554,1
ACA	1994	1.671	36.134,0	7,8	56.720,8
ACA	1995	1.389	12.971,5	9,8	52.438,5
ACA	1996	739	1.257,9	35,7	50.669,3
ACA	1997	750	2.951,2	24,5	36.725,3
ACA	1998	1.137	5.241,5	7,6	61.643,2
ACA	1999	892	6.627,2	9,8	69.193,4
ACA	2000	938	5.411,3	14,2	78.361,3
ACA	2001	961	7.351,4	16,3	56.276,2
ACA	2002	1.181	10.640,7	14,9	63.773,6
ACV[2]	1991	869	44.426,3	20,1	10.329,4
ACV	1992	769	26.188,5	13,8	29.307,7
ACV	1993	715	25.966,7	11,5	26.482,1
ACV[3]	1994	751	138.404,5	8,1	44.278,8
ACV	1995	467	2.220,4	6,8	57.106,8
ACV	1996	383	765,1	16,1	59.598,2
ACV	1997	348	898,2	14,9	59.139,0
ACV	1998	546	1.967,3	8,8	67.661,8
ACV	1999	579	6.356,5	5,7	65.075,8
ACV	2000	606	6.547,8	11,2	66.656,3
ACV	2001	442	4.792,8	13,6	70.175,5
ACV	2002	321	1.202,1	16,3	68.663,5

Source: Modified from the Junta de Andalucía, the Generalitat Valenciana (regional governments) and the National Meteorological Institute

[1] Autonomous Community of Andalusia

[2] Community of Valencia

[3] The figure for this year is considered to be atypical and was not taken into account in the regression model

The budgets in pesetas have been converted to Euros using the official exchange rate of 166,386 peseta/€, and every year up to 2003 they have been updated with coefficients and methods supplied by the National Institute of Statistics (INE 2003).

There was no budget data available for 1992 en Andalusia.

1994, was the worst year for forest fires in Spain in recent decades, 92 large-scale fires accounted for 76.63 % of the surface area burned that year in Spain. In ACV it was a particularly bad year with eight large fires of over 5,000 hectares which caused 115,986 hectares burned. This year was considered atypical and was not taken into account when making the regression.

Evaluation data

The ACA and the AVC evaluation data was obtained from land models created by the Junta de Andalucía and the Generalitat Valenciana, (regional governments) which take into account the public as well as private assets which generate forest eco-systems. The results for large areas are contained in *table 2*.

Table 2—*Total economic value by forest area in each of the regions*

Type	Autonomous Community of Andalusia			Autonomous Community of Valencia		
	Area (ha)	PV[1] (euros/ha)	TEV[2] (euros/ha)	Area (ha)	PV[1] (euros/ha)	TEV[2] (euros/ha)
Conifers	625.673	1.554	7.656	278.270	644	5.877
Broadleaved	933.718	2.050	5.979	21.680	674	7.950
Mixed stands	626.598	1.714	6.585	328.329	668	7.147
Shrubs	1.896.953	745	4.312	574.518	446	4.236
Pasture	322.173	892	4.420	12.280	909	5.351
Total	4.082.942	1.285	5.554	1.215.078	560	5.476

Source: Modified from the Junta de Andalucía and the Generalitat Valenciana
[1] Productive value, is the value of woodland as exclusive generator of private assets
[2] Total economic value is the value of woodland as generator of private and public assets

The dates of reference for the models are: 2000 for ACA and 2001 for the ACV. Consequently the values have been updated to 2003 with the same methods used for the budgets.

The evaluation of the ACA forest land takes into account the following private elements: wood, pine nuts, cork, chestnut, pasture, game, wind; and public elements: recreational areas, landscape, CO_2 fixing and non-use.

The ACV evaluation incorporates as private assets: wood, truffles, pasture, game, fishing and wind; as public: recreational areas, landscape, CO_2 fixing replenishment of water sources, flood protection and non-use.

The ACA model has been adjusted to incorporate environmental elements from the ACV and which were not included at the time due to lack of quantitative information; the following specific elements have been added: replenishment of water sources and flood protection.

Value lost through forest fires

Initially, the value of natural stock lost when a hectare of woodland is burned is the total economic value (TEV) of that hectare. If working with regional averages, the values should be for each forested area in each of the Autonomous Communities, those contained in the columns for TEV in *table 2*. Nevertheless, not all the value of the burned surface area is lost, since part of it will regenerate naturally.

In the case of small fires natural regeneration of 100 % is assumed; conversely regeneration in extensive fires is only partial.

In order to attempt to estimate the value recovered through natural regeneration in large-scale forest fires, firstly the concept of regeneration period must be defined (PRG). This is the period of time within which, with a high level of probability, the new mass growth substituting the burnt area may be considered as established; or to put it another way, the years an area will take before it produces viable seeds or re-growth (Bond and Wilgen 1996). From an economic point of view, the mass is not

considered completely recovered until it reaches the same fully functioning level it had prior to the fire, this second concept is known as the period of recovery (PRE); it may be affirmed that from this point on the ecosystem will once again generate an infinite flow – estimated with the hypothesis of a sustainable situation— of annual income equal to that lost prior to the fire. In the period between the PRG and PRE, it is assumed that the income grows in a linear manner with the passage of time. F*igure 1* illustrates this point

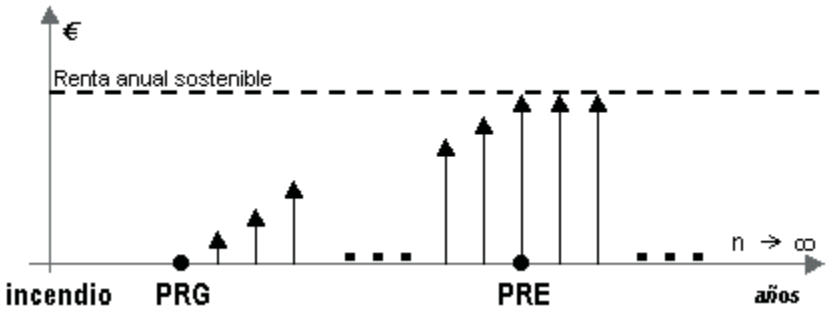


Figure 1—Flow of funds recovered by the regeneration of the mass following an extensive fire.

In large-scale fires —of more than 500 hectares— for each of the large forest areas, the percentage of regenerated surface (RGI) , the PRG and the PRE have been estimated, considering the data for each type of vegetation with the surface area of each dominant species pursuant to the Second Forest Inventory (Ministry of the Environment 1998).

With respect to conifers, *Pinus halepensis* presents the greatest level of regeneration following fire, due to its wide dissemination, aided by high temperatures and low germination requirements of the pine cone. Conversely, other species of the *Pinus* genus tend towards low germination, due undoubtedly to their early dissemination, pre-summer and the sensitivity of the cones at moderately elevated temperatures (Rey et al 2003). As an approximation, INFOMED (Mediterranean Forestry Institute) detected in the ACV that more than 78 % of the forest surface area of adult *Pinus halepensis* burned had regenerated in a natural manner. Nevertheless, in those other pine woods which had not reached maturity the results were very different, and only 2 % of the surface area was regenerated (Gómez 1998). Other studies have assigned a figure of 7% to the masses of *Pinus nigra* and *Pinus sylvestris* —which are typical of northern and Central European woods—since these practically disappear following a forest fire. (Habronk 2001).

For broad-leaved masses**,** the regenerated surface areas rises to 60 % as shown in simulations carried out in the great fire of 1994 in Bages and Berguedá in Cataluña (Habronk 2001) and that of 1995 in Mercadal in Illes Balears (Hugel 2001). *Quercus ilex* is capable of re-growth following felling and fire, which presupposes good adaptation to low intensity fires. Nevertheless, following high intensity fires its ability to grow from the stand disappears, due to destruction of the stumps. The percentage of regenerated undergrowth and brush rises to 80 % (Rey et al 2003). It is estimated that pasture areas may reach the same levels as the underbrush of up to 80%.

In an analysis of the recurrence of fires, the age at which areas of *Pinus* become established is that in which the trees are able to produce viable pine cones – between 7 and 15 years (Bond and Wilgen 1996)—. On the other hand in the case of oaks, the PRG rises to up to 25 years (Díaz–Delgado 2003). The PRG considered for other types of terrain such as brush wood and pasture is 4 to 2 years respectively. Finally, the PRE of the vegetation types was taken as the state of maturity, as defined by a panel of experts, which is the criterion used in the integral evaluation of forest lands of the Community of Madrid (Castellano et al 1999).

The capacity for the regeneration of flora may be modified by a series of factors which are extraneous to the nature of the plant species such as: size and recurrence of fire, type of terrain, height, gradient, exposure… (Bond 1996, Habronk 2001). Consequently the values shown in *table 3* are only general average figures estimated solely for the purpose of correcting the loss of value suffered by the natural stock**.**

Table 3—Regeneration data and total economic value lost in large-scale fires

Vegetation type	Conifers	Broadleaves	Mixed	Brush	Pasture	Total
RGI[1] (pct)	25	60	50	80	80	
PRG[2] (years)	12	20	15	4	2	
PRE[3] (years)	45	60	50	15	4	
Value lost CAA[4] (pct)	65,6	72,3	68,1	50,6	43,9	60,3
Value lost CAA (euros/ha)	5.019	4.325	4.485	2.182	1.942	3.348
Value lost CVA[5] (pct)	79,5	83,5	81,0	70,6	66,6	76,7
Value lost CVA (euros/ha)	4.670	6.640	5.788	2.989	3.563	4.201

Source: Modified, from the Junta de Andalucía and the Generalitat Valenciana (regional governments)
[1] Percentage considered by dominant specie, naturally regenerated surface area and the zone studied
[2] Regeneration period
[3] Recovery period
[4] Autonomous Community of Andalusia
[5] Community of Valencia

The lost value percentages in each of the areas are calculated differently for large-scale fires and others. In extensive fires all the value of surface area is lost as it does not regenerate, in the remainder income is depleted for a number of years until the forest land recovers; this reduction in value is calculated with the difference between Current Net Values of the permanent sustainable income and the flow of income shown in *figure 1*.

In small fires the value lost is calculated in the same way as with regenerated areas which have suffered large-scale fires since these recover naturally in their entirety. The total values lost per hectare for each of the Autonomous Communities studied, shown in the last column of *table 3*, have been calculated bearing in mind the lost values of each of the forested areas, considered with their respective territorial divisions.

The total value lost is greater in the ACV, because the proportion of extensive fires is much greater than in the ACA —86,52 % and 54,78 % respectively of the total surface area burned in the study period —.

Cost–efficiency function

The function which relates the efficiency of the preventive actions against forest fires measured by the surface area burned as a dependent variable, with the cost of that preventive action - the prevention plus suppression budget —, incorporates another independent variable — the Birot index—, which includes the meteorological conditions for the year with the following logarithmic formula:

$$LnSQ = A_1 + A_2 \times LnP + A_3 \times LnIB$$

SQ being the surface area burned, P the protection budget, and IB the Birot index; all of which refer to a specific year; and A_1, A_2, and A_3 the corresponding regression parameters, which are shown together with some statistics in *table 4*.

Table 4— Parameters of the cost-efficiency function

Concepts	Autonomous Community of Andalusia		Autonomous Community of Valencia	
	Value	T Student	Value	T Student
Independent Term. A_1	378.660	12,00	420.748	8,79
Budget Coefficient. A_2	0,9999624	-2,32	0,9999369	-4,17
Birot Index Coefficient.A_3	0,8935705	-4,63	0,9106788	-1,30
Correlation. Coefficient ^{2}	0,74		0,69	
Error of dependent variable. ey	0,6313135		0,8887510	
Snedecor's F. F	11,37		8,87	
Degrees of Freedom	8,00		8,00	

Source: The authors' own

The two regressions are significant with 95 % reliability except T of Student A_3 in the ACV, which only has an 85 % reliability. As expected, due to the numerous factors which affect the total burned surface area and the simplicity of the regression model, errors in the estimation are high, which causes extremely varied estimates. Nevertheless, the results may be considered sufficiently accurate to enable the determination of a range of budgets required for a given level of surface area burned.

The function determining the upper limit of distribution of errors for the surface area burned estimated with 95% reliability is:

$$LS = e^{(LnSQ+1,96\ ey)}$$

LS being the upper limit of distribution of errors of the estimate of the surface area burned SQ, and ey the error of estimation.

Marginal costs

The cost-efficiency function gradients and the upper limit of 95 % reliability of distribution of error means that he hectares saved from fire by each 1000 euro increase in the budget. The equations for the gradients of these functions are those

corresponding to their derivatives with respect to the variable Budget and, respectively are expressed:

$$SQ' = A_1 \times A_2^{P} \times A_3^{IB} \times LnA_2$$

$$LS' = e^{(LnSQ+1,96\ ey)} \times LnA_2$$

In reality the marginal cost being sought is the opposite of these gradients multiplied by 1,000, which is the sum of euros by which the budget should be increased to safeguard an additional hectare. The form of the functions determines that the marginal costs decrease when the budget is increased.

In this way an objective system is available —for a given meteorological situation— which permits a budget increase until the value of the surface area safeguarded is equal to the increase required to achieve it.

Discussion

The presence of meteorology in the cost-efficiency function implies that the optimum budget depends on the meteorological conditions, and, in addition, the distribution of error in the estimation of the surface area burned gives rise to a range of budgets to reach a specific surface area burned. These circumstances have been used to define the conditions surrounding the optimum budget, and those of the two e two Autonomous Communities studied are shown in *table 5*, by simply fixing three meteorological conditions :average Birot index for the period, index minus a typical deviation corresponding to an especially arid year and index plus a typical deviation to include the opposite situation; and the estimated cost efficiency function – minimum budget-and the upper limit of 95% reliability of distribution of errors – maximum budget- .

Table 5— *Conditions surrounding the optimum budget (financial figures in thousands of euros)*

Annual Drought	Autonomous Community of Andalusia			Autonomous Community of Valencia		
	Birot Index	Minimum budget	Maximum budget	Birot Index	Minimum budget	Maximum budget
High	6,04	84.711	117.636	7,91	63.012	90.636
Medium	14,27	60.083	93.008	12,24	56.592	84.216
Low	22,49	35.455	68.379	16,57	50.172	77.796

Source: Authors' own

Budgets for recent years have obtained an intermediate surface area burned between that which would be expected for the estimated cost-efficiency function and the upper limit of its distribution of errors with 95 % of reliability. As aridity is not completely foreseeable, a conservative hypothesis should be assumed. In this situation it is understood that the optimum budget would be the average of those corresponding to a high aridity in the cost –efficiency function- maximum budget – That is around 90 million Euros in the ACA and 75 million Euros in the ACV.

The average budgets of the last five years are approximately: 66 million Euros in the ACA and 68 million Euros in the ACV. Consequently, neither of the two

Autonomous Communities would be at the optimum budget level, ACA being 73 % and the ACV 91%..

The optimum budget is higher in the ACA because it covers a larger area and because the aridity is more heterogeneous and extreme.

The productive values represent 23 % in the ACA and 10 % in the ACV, thus under no circumstances can the level of budget adjudicated to forest fire prevention be justified which probably explains why the present budgets are perceived in some quarters as very high.

by increasing protection to the optimum level (Riera and Mogas 2003), which confirms that the optimum social budget is greater at current levels in the Mediterranean area.

References

Azqueta, D. 2002. **Introducción a la economía ambiental**. Aravaca (Madrid). Mcgraw–Hill Profesional; 236–268.

Bond, J.W.; van Wilgen, B.W. 1996. **Fire and Plants**. London: Chapman & Hall, p. 263.

Castellano, E.; González, S.; Rábade, J.M.; San Miguel, M.A 1999**. Integral economic valuation on forest ecosystems: a case study of mixed broad–leaved and pure coniferous forests in the community of Madrid**. En: Olsthoorn A.F.M y otros (Eds). Management of mixed–species forest: silviculture and economics.

Díaz–Delgado, R. 2003. **Efecto de la recurrencia de los incendios sobre la resiliencia post–incendio de las comunidades vegetales de Cataluña a partir de imágenes de satélite.** Revista Ecosistemas año XII 3: 30–39.

Gómez J. 1998. **Incendio Forestal y Regeneración**. Revista Las Provincias. Instituto Forestal Mediterráneo (INFOMED).

Habronk, A. 2001. **Regeneración natural y restauración de la zona afectada por el gran incendio del Bages y Berguedá de 1994**. Tesis Doctoral inédita, Universidad Autónoma de Barcelona. Facultad de Ciencias Biológicas.

Hugel, I. 2001. **Estudio de la Regeneración Natural de Pinus halepensis Mill. tras el incendio de agosto de 1995 en "Mercadal" (Menorca)**. Proyecto de Fin de Carrera, Universidad Politécnica de Madrid. Escuela Técnica superior de Ingenieros de Montes.

Instituto Nacional de Estadística, 2003. **Actualización de rentas.** Indice de Precios de Consumo. Ministerio de Economía.

Ministerio de Medio Ambiente, 2002. **Plan Forestal Español 2002–2032**. Madrid. Dirección General de Conservación de la Naturaleza: 145 p.

Rey, J.M.; Espigares, T.; Nicolau J.M. 2003. **Restauración de ecosistemas mediterráneos.** Colección Aula Abierta. Madrid: Universidad de Alcalá, p. 272.

Riera P.; Mogas J. 2003. **Valoración del riesgo de incendios forestales en España.** Revista Ciudad y Territorio 135: 119–126.

Servicio de Inventario Forestal del Área de Banco de Datos e Inventario Patrimonial, 1998. **Segundo Inventario Forestal Nacional (1986–1996)**. Ministerio de Medio Ambiente.

An Economic Assessment of Fuel Treatments at the Landscape Level[1]

Hayley Hesseln,[2] Don Helmbrecht,[3] Janet Sullivan,[3] Greg Jones,[3] Kevin Hyde[4]

Abstract

We examined the costs of fuels treatments at the landscape level from ecological and economic perspectives. We set up a model using MAGIS (Multiple-resource Analysis and Geographic Information System), to examine landscape changes in response to thinning and prescribed burning on forested lands including wildland-urban interface areas. Our objectives are to assess treatment types based on changing costs, budget levels, and tradeoffs between two objectives: ecosystem restoration and hazard reduction. Specifically, we wish to address the following questions: How do social costs affect accomplishments in the Wildland Urban Interface (WUI)? How do costs affect allocation of fuels management resources between wild lands and the WUI? Can we fully restore ecosystems, and at what cost? How do budget levels affect allocation of fuels management resources?

Introduction

Wildland fire plays an important role in many forested ecosystems by influencing vegetative composition and structure, landscape patterns, and ecological functions (Brown and Smith 2000). In the Northern Rocky Mountains of the United States, many of these ecosystems and their associated species are considered to be fire-adapted, meaning that they have the ability to survive and regenerate in a fire-prone environment. Historically, fire has maintained the characteristics that define these ecosystems. Land managers and researchers have begun to acknowledge that many land management policies and practices over the last century, especially fire exclusion; have resulted in major changes in how fire influences fire-adapted forest ecosystems.

In the absence of fire, forest succession leads to the replacement of fire-resistant tree species with less fire-resistant species and subsequent increases in stand density and fuel loading. These changes are most apparent within short-interval, fire-adapted systems, which historically experienced frequent, low intensity fire events, but have also occurred in ecosystems that historically experienced less frequent, high intensity events (Brown and Smith 2000). Over time, this transformation has directly affected natural fire regimes (Morgan et al. 1996, Barrett 2002, Hardy et al. 2001) resulting in uncharacteristic fire frequency, severity, and/or spatial extent.

---

[1] An abbreviated version of this paper was presented at the second international symposium on fire economics, policy, and planning: a global view, 19–22 April, Córdoba, Spain.

[2] Dept. of Ag Econ, 51 Campus Drive, University of Saskatchewan, Saskatoon, SK S7N 5A8.

[3] National Center for Landscape Fire Analysis, University of Montana, Missoula, MT 59812.

[4] Rocky Mountain Research Station, USDA Forest Service, Forest Sciences Lab, Missoula, MT 59807.

Fire regimes refer to "the nature of fire occurring over long periods and the prominent immediate effects of fire that generally characterize an ecosystem" (Brown and Smith 2000). The fire process, however, is uniform in neither time nor space. The frequency, intensity, seasonality, extent, and other characteristics of fire, which collectively make up the fire regime, vary considerably across the landscape (Agee 1993) thus making it difficult to evaluate the impacts of altered fire regimes.

Current wildland fire management acknowledges the importance of restoring the natural ecological role of fire. In fact, the 2001 Federal Wildland Fire Management Policy states as a guiding principle that "The role of wildland fire as an essential ecological process and natural change agent will be incorporated into the planning process." (U.S. Department of the Interior and U.S. Department of Agriculture 2001). Information on the effects of restoration-based fuel treatment strategies can aid in the success of future fuel management programs.

The objective of this research is to use a modeling approach to analyze the impacts of alternative fuels treatment strategies. We will combine financial, economic, and social information in a decision-making framework to evaluate the costs of alternative treatments for two objectives; (1) hazardous fuels reduction in the wildland-urban interface, and (2) restoration in fire-adapted ecosystems. These objectives are directly applicable to modeling and are consistent with the National Fire Plan. Two goals of the NFP are 1) hazardous fuels reduction and 2) restoration in fire-adapted ecosystems. Our objectives will be tied to mapping Communities at Risk (CAR) and Ecosystems at Risk (EAR).

We next provide our methodology and expectations followed by a discussion of potential findings.

Methodology

We use the optimization model MAGIS (*M*ulti-resource *A*nalysis and *G*eographic *I*nformation *S*ystem) to analyze the effectiveness of fuel treatments at the landscape scale (Jones et al. 1999, Chew et al. 2000) for the Bitterroot Mountains in western Montana. "MAGIS uses optimization to select the spatial arrangement and timing of treatments that fits user-determined objectives and constraints. MAGIS users can also specify the location and timing for specific treatments to test 'what-if' scenarios." (USDA Forest Service 2003). The model integrates ecological, social, and economic information which provides the basis from which to schedule treatments at the landscape level. MAGIS also provides as output the ecological effects and economic outcomes. Activities that can be modeled include a wide variety of silvicultural methods such as those geared toward mechanical fuels treatments and prescribed burning.

Our study site is located along the Montana/Idaho border and is approximately 96 km long. The Bitterroot Front was chosen as the study area because it is composed of approximately 105,208 hectares of forested land that represents a variety of forest types and includes a substantial wildland-urban interface component.

We are using the Northern Region Cohesive Strategy Team's risk assessments (i.e., communities at risk (CAR) and ecosystems at risk (EAR)) to define objective functions in MAGIS (USDA Forest Service 2003). Specifically, we will integrate the risk rule sets into MAGIS so that the risk attribute changes dynamically with changes in vegetation over time. Vegetative states are modeled using succession and are based

on the Region 1 west side zones, also used in SIMPPLLE (SIMulating Processes and Patterns at Landscape scaLEs[5]) Definitions for EAR and CAR are presented below as they are defined on the Internet.[6]

Ecosystems at Risk (EAR)

Estimating the relative risk of ecosystems from wildland fire requires an assessment of the likelihood of fire occurrence; and likely fire effects to an ecosystem should it catch fire. A spatial of ignition probability was derived from 20-years of fire data by interpolating between known fire locations and counting the of fires within a 4-km2 neighborhood. Ignitions were then classified [into]5 classes ranging from low to high.

Fire-regime condition class is an index of the of the current condition from the historical fire regime. Consequently it is derived from the historical fire regime and an estimate of the fire severity if a fire occurred. Fire-regime condition class is as a proxy for the probability of severe fire effects (e.g., the of key ecosystem components - soil, vegetation structure, species; alteration of key ecosystem processes - nutrient cycles, hydrologic regimes). Consequently, fire-regime condition class is an index of risk to the many components (e.g., water quality, fish status, wildlife habitats, etc.).

Ignition probability was integrated with fire-regime condition class to derive ecosystems-at-risk; the likelihood that components will be lost if a wildland fire occurred.

Communities at Risk (CAR)

The top priority of the National Fire Plan, FS-Cohesive Strategy and the Western Governors' 10-Year Comprehensive Strategy Plan is undoubtedly to reduce the threats of wildland fire to wildland-urban interface. The relative risk of communities to fire requires consideration of 3 factors: (1) the of fire occurrence; (2) the likely fire behavior should a fire occur; and (3) human settlement patterns. Therefore, the ignition probability, fire behavior, and population density spatial themes were to estimate the relative risk of the wildland-urban interface wildland fires.

We will use EAR and CAR as the basis for our models so that our assumptions and sensitivity analysis will be based on realistic fire management goals that are consistent with the National Fire Plan.

Research Goals

Our primary goal is to map a landscape in the Bitterroot Valley that can be manipulated for use by MAGIS to (i) minimize costs, or (ii) maximize acres treated for given sets of constraints including timing, budget levels, and acres treated. Holding other things equal we explore the following questions: How do targeted temporal goals affect allocation and cost? How does the budget affect accomplishments and allocation between two objectives? How do targeted acres affect costs and objectives?

[5] http://www.fs.fed.us/rm/missoula/4151/SIMPPLLE

[6] http://www.fs.fed.us/r1/cohesive_strategy/sitemapfr.htm.

To address our research questions, we will develop a series of scenarios and decision rules. Potential rules may include the following:

- Treat only WUI acres (or prioritize),
- Treat only non-WUI acres (or prioritize),
- Treat all acres without preference,
- Treat acres with varying budget levels,
- Change treatment costs for stated scenarios.

Treatment methods will be predicated on condition class. For example, mechanical treatment methods must first be used for ecosystems classed as fire-regime condition class three (CC3) prior to Prescribed burning. We will assess various fuels treatment methods including prescribed burning, mechanical fuels treatments and a combination of the two.

We provide an example of selected potential treatments available and treatment scenarios that may be used for the simulation. While these are not our final choices, they do give an indication of our assessment opportunities. Below is a table of potential treatment types.

Table 1— *Potential Treatment Types.*

Activity	Treatment Goals
Underburn	Reduce understory fuels
Pre-commercial thin and underburn	Mechanical thinning to remove ladder fuels, then burn to reduce fuels from slash and other understory vegetation
Commercial thin	Remove mostly smaller diameter material and reduce ladder fuels.
Improvement cut	Remove undesirable species (regardless of size) in addition to smaller size components
Shelterwood Seedcut	Regeneration cut removes 60% of the overstory, leaving a residual stand in large trees of desirable species. Understory removed.

Based on the treatment types presented above, we will develop scenarios with explicit rules. We will begin with a No Action alternative and take baseline measures. Our objective will be to minimize EAR adding successively more constraints. We will repeat these iterations to minimize CAR as well and combine information to develop a final solution for each scenario.

Table 2— *Potential Scenarios that minimize EAR*

Scenario	Activity	Comments
1. No Action	No activity	Develop baseline indicator using CAR, EAR, Condition Class, or combination.
2. WUI objective	Treat only WUI acres	Develop treatments based on budget restraints, acreage constraints, and treatment constraints.
3. No objective priority	Treat all acres	Develop treatments based on budget restraints, acreage constraints, and treatment constraints.
4. Ecosystem restoration objective	Treat non-WUI areas (excluding wilderness)	Develop treatments based on budget restraints, acreage constraints, and treatment constraints.

In each case, we will explore similar objectives based on maximizing present net value (PNV), minimizing cost, or treating a specified number of acres.

Discussion

This research will provide fire and forest managers with much needed information regarding the feasibility of fuels treatment methods over time. Using an array of treatment scenarios we will be able to assess changes in costs and accomplishments, and to identify the potential success of fire management programs aimed to reduce risk in the wildland-urban interface, or to restore ecosystems, or some combination. Our findings will also be useful to policy makers for guidelines to developing realistic fire management policy regarding annual accomplishments and outcomes.

References

Agee, J.K. 1993. Fire ecology of Pacific Northwest forests. Island Press: Washington, D.C. 493 pp.

Arno, S.F. 2000. Chapter five: Fire in Western forest ecosystems. In: Brown, J.K.; Smith J.K., eds. 2000. Wildland fire in ecosystems: effects of fire on flora. Gen. Tech. Rep. RMRS-GTR-42-vol. 2. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 97-120.

Arno, S.F.; Petersen, T.D. 1983. Variation in estimates of fire intervals: A closer look at fire history on the Bitterroot National Forest. Research Paper INT-301. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 8 p.

Arno, S.F.; Scott, J.H.; Hartwell, M.G. 1995. Age-class structure of old growth ponderosa pine/Douglas-fir stands and its relationship to fire history. Research paper INT-RP-481. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 25 p.

Baker, W.L. 1993. Spatially heterogeneous multi-scale response of landscapes to fire suppression. Oikos 66, 66-71.

Brown, J.K.; Arno, S.F.; Barrett S.W.; Menakis, J.P. 1994. Comparing the prescribed natural fire program with presettlement fires in the Selway-Bitterroot Wilderness. International Journal of Wildland Fire 4, 157-168.

Chew, J.D. 1995. Development of a system for simulating vegetative patterns and processes at landscape scales. Ph.D. dissertation. University of Montana, Missoula, MT. 182 p.

Chew, J.D.; Moeller, K.; Stalling C.; Bella; E.M.; Ahl, R.S. 2002. User's Guide for SIMPPLLE, version 2.2. Proposed Gen. Tech. Rep. RMRS-GTR-xxx. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 222 p.

ESRI Inc. 2001. ArcGIS, version 8.2. Environmental Systems Research Institute, Inc. Redlands, CA. USA.

Hartwell, M.G. 1997. Comparing historic and present conifer species compositions and structures on forested landscapes of the Bitterroot Front.

Jones, J. G.; Chew, J. D; Zuuring, H R. 1999. Applying simulation and optimization to plan fuel treatments at landscape scales. In: Gonzalez-Caban, Armando; Omi, Philip N., tech. coords. Gen. Tech. Rep. PSW-GTR-173. Proceedings of the Symposium on Fire Economics Planning, and Policy: Bottom Lines; 1999 April 5-9; San Diego, CA.

Albany, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station: 229-336.

Jones, J.L.; Barrett S.W.; Berglund, D. 2002. Modeling historical and current fire regimes for major vegetation types in northern Idaho and western Montana: A first approximation. Office report on file, Planning Division, USDA Forest Service, Flathead National Forest, Kalispell, MT. 27 p.

Keifer, M.; Caprio, A.C.; Lineback, P.; Folger, K. 2000. Incorporating a GIS model of ecological need into fire management planning. Pages 122-129 in Neuenschwander, L.G. and Ryan, K.C., technical eds. Proceedings of the Joint Fire Science Conference and Workshop, Volume 1, June 15-17 1999, Boise, ID.

Landres, P.B.; Morgan, P.; Swanson, F.J. 1999. Overview of the use of natural variability concepts in managing ecological systems. Ecological Applications 9(4), 1179-1188.

Long, D.G. 1998. Mapping historical fire regimes in northern Rocky Mountain landscapes. Thesis. University of Idaho, Moscow, Idaho. 63 p.

Miller, C.; Landres, P.B.; Alaback, P.B. 2000. Evaluating risks and benefits of wildland fire at landscape scales. Pages 78-87 in Neuenschwander, L.G. and Ryan, K.C., technical eds. Proceedings of the Joint Fire Science Conference and Workshop, Volume 1, June 15-17 1999, Boise, ID.

Sampson, N.; Atkinson, D.; Lewis, J. eds. 2000. Mapping wildfire hazards and risks. The Haworth Press, Inc.

Schmidt, K.M.; Menakis, J.P.; Hardy, C.C.; Hann, W.J.; Bunnell, D.L. 2002. Development of coarse-scale spatial data for wildland fire and fuel management. Gen. Tech. Rep. RMRS-GTR-87. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, 41 p. + CD.

U.S. Department of Agriculture, Forest Service, Northern Region Cohesive Strategy Team. 2003. Fire management plan. http://www.fs.fed.us/r1/cohesive_strategy/contactfr.htm. Flathead National Forest, 1935 3rd Ave. East. Kalispell, MT 59901.

U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory (2002, September). Fire Effects Information System, [Online]. Available: http://www.fs.fed.us/database/feis/ [Accessed September 2002].

U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 2003. Software and land management planning. http://www.fs.fed.us/rm/econ/magis/ accessed February 25, 2004.

U.S. Department of the Interior and U.S. Department of Agriculture. 2001. Review and update of the 1995 federal wildland fire management policy. Bureau of Land Management, Boise, ID.

WSAL. 2000. FireRisk: A fuels, fire, fire regime database. Version 1.0. Prepared for the USDA Forest Service, Northern Region by Wildlife Spatial Analysis Lab, Montana Cooperative Wildlife Research Unit, The University of Montana, Missoula, MT 59812.

Social Impact of Large-Scale Forest Fires[1]

José Mª Rábade,[2] Carmen Aragoneses[2]

Summary

Growing public alarm at the problem of large-scale forest fires, is evident from an assessment of their past and present repercussions on the population in general. Numerous and varied media reports indicate the extraordinary social and environmental impact of forest fires.

Emergency situations caused by evacuations, physical injury and at worst, loss of human life are extensively covered in the media which moreover lists environmental damage and figures for the numbers involved in the suppression operations, plaice firemen, volunteers, army air and land resources etc…

Blocked roads and railway lines, electricity, mobile and land telephone lines cut, destruction of homes and industries, and the way of life of many communities are annual news stories and the balance of the catastrophe caused by fire results in a wealth of articles, editorials and communications.

A search in the newspaper archives reveals shocking figures, which we offer here to illustrate the magnitude of a problem which is now unsustainable and to which the managers and politicians responsible have become accustomed.

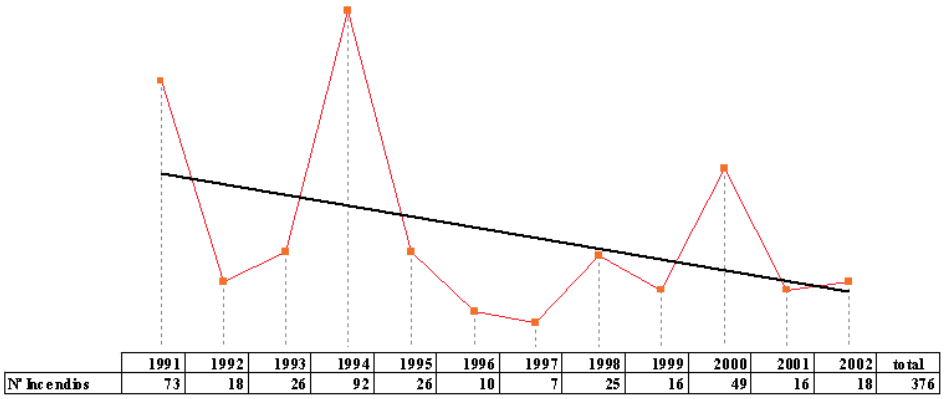
The figures

Spanish forest land covers more than 26 million hectares, 52 % of the country's surface area, of which approximately 14 million hectares are covered by fairly densely wooded forest ecosystems, which makes Spain the country with the second largest forest area in the EU and the fourth in terms of woodland.

---

[1] An abbreviated version of this paper was presented at the second international symposium on fire economics, policy, and planning: a global view, 19–22 April, Córdoba, Spain.

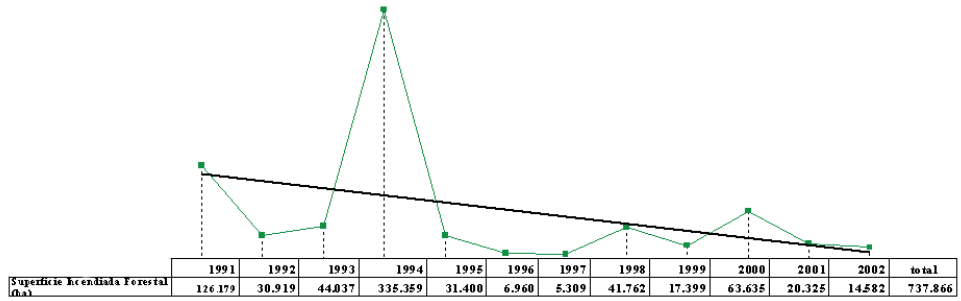
[2] Tecnologías y Servicios Agrarios, S.A. (TRAGSATEC). Julián Camarillo, 6. Madrid. CP 28037.



	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	total
Nº Incendios	73	18	26	92	26	10	7	25	16	49	16	18	376

Figure 1—Number of large-scale fires. 1991-2002. Source: B.D. EGIF.MIMAM

In the last twelve years (1991-2002) more than 232.000 fires spread over 1.800.000 hectares of woodland, scrubland and pasture, 7% of the forest surface area. Of these, 376 fires spread over more than 500 hectares (large fires) covering an extension of 738.000 hectares, 41% of the burned surface. 1991, 1994 and 2000 were particularly bad years with respectively 73, 92 49 large-scale fires which burned 550.000 hectares (fig. 1) (fig. 2).



	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	total
Superficie Incendiada Forestal (ha)	126.179	30.919	44.037	335.359	31.400	6.960	5.309	41.762	17.399	63.635	20.325	14.582	737.866

Figure 2—Surface covered by large-scale fires (hectares). 1991-2002. Source: B.D. EGIF. MIMAM.

In order to address this overwhelming number of fires–20.000 per annum– the Spanish state has had to mobilise more than 3.200.000 fire-fighters from the ranks of professional firemen, volunteers and the armed forces, which amounts to an average of almost 270.000 fire-fighters per year. This was implemented with the aid of 318.000 machinery units on land –automatic pumps, heavy and light tractors and other equipment– a total of 27.000 units per year, and 1.4 units per fire, to which 71.300 air fire fighting units should be added –'planes, helicopters and coordination planes–, an average of 6,000 units per year or 0.31 units per fire.

The impact

The social impact of fires, particularly large-scale fires, is plainly evident from numerous media reports.

Typing the term forest fires into the Google search engine in Spanish, English

and French resulted in around 236.500 references for the period between 1991-2003 with the development shown in *figures 3* and *4*, where it is evident that the number has tripled between the beginning and end of the period.

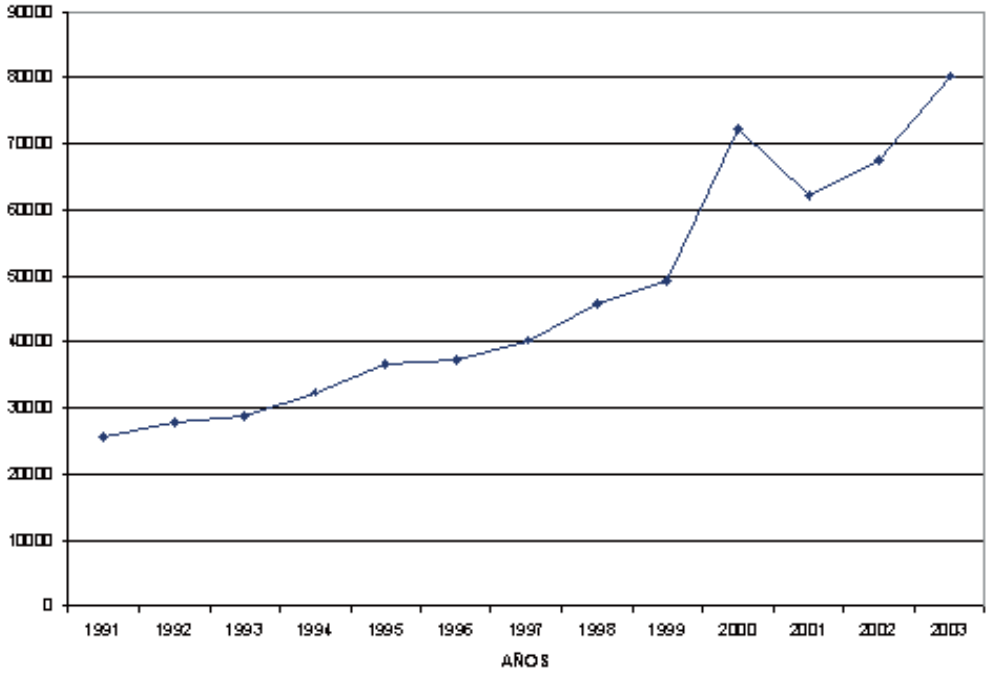


Figure 3—Number of references to forest fires taken from a Google search enquiry during the period 1991-2003. Source: Author's own.TRAGSATEC.

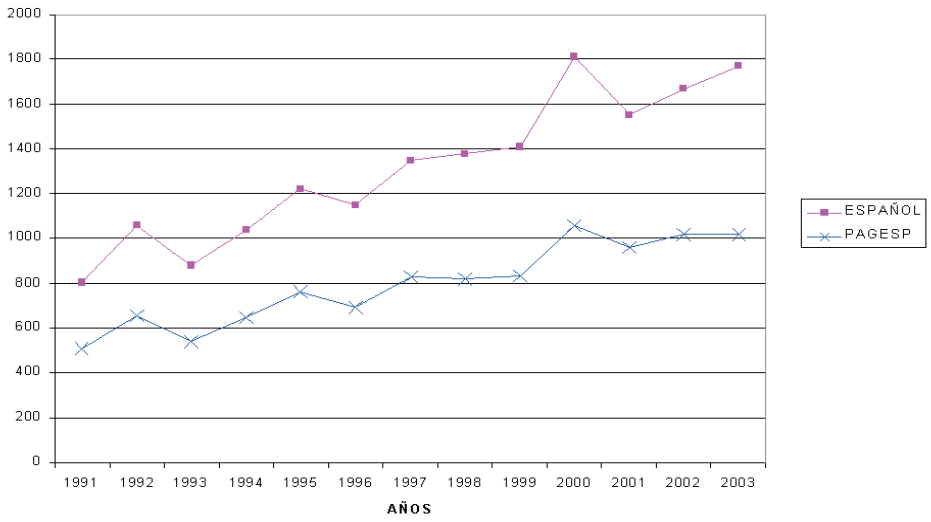


Figure 4— Number of references to forest fires taken from a Google search enquiry during the period 1991-2003. Source: Author's own.TRAGSATEC.

If we confine this search to Spain, to the national press (prensa_incendios.mdb, TRAGSATEC) and to the same period 1991-2003, we find 226 articles covering news references to 102 fires, of which 82 spread over more than 500 hectares. F*igure 5* shows their distribution throughout that period, with articles corresponding to the years 1994 and 2003 being specially significant, reporting on 57 fires, 43 of which were large-scale conflagrations.

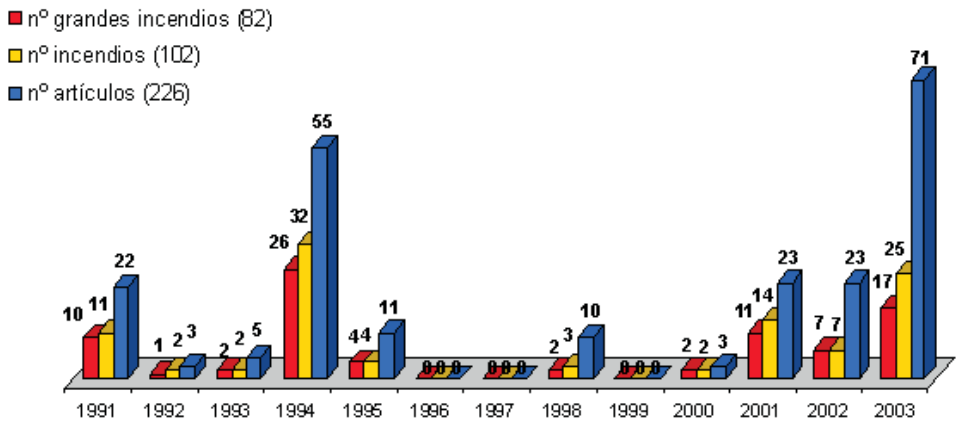


Figure 5—Number of fires, large-scale fires and press articles 1991-2003. Source: Database prensa_incendios.mdb. TRAGSATEC

Damage

Throughout the period analysed (1991-2003) forest fires caused serious damage to people, their properties and to the environment. As illustrated in *figure 6*, 59 people lost their lives, 30 of whom were professional fire fighters. 1994 was a particularly disastrous year with 41 mortal victims, 20 of whom died in a single fire (Millares, 25,930 hectares) and 15 in three fires (Montemayor, St. Mateu de Bages and Alicante, 45,000 hectares), followed by 2003 when seven people died. 118 people were injured, 64 in the 1994 fires and 27 last year in 2003 and 41,752 people had to be evacuated, 10,372 in the disasters of 1994 and 23.042 in the great fires of 2003. 169 homes were either partially or totally destroyed, 92 of these in the years 2000 and 2003. On 17 occasions there was long term collapse of electricity services and water supplies and national trunk roads were blocked 32 times.

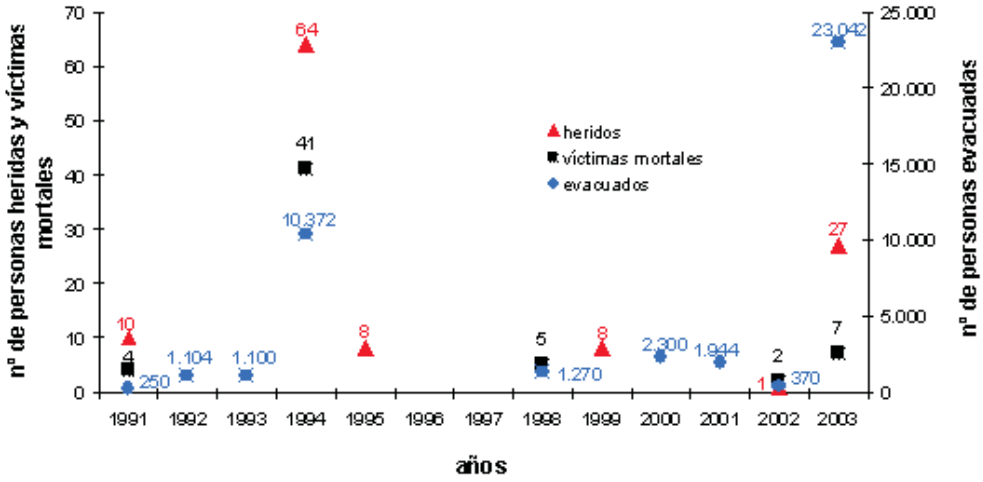


Figure 6—Number of deaths, people injured and evacuated. 1991-2003
Source: Database: prensa_incendios.mdb. TRAGSATEC

Environmental damage is yet another aspect of the impact of large-scale fires, which destroy the habitat of species, some of which are threatened, facilitating the spread of disease and pestilence, sterilising and eroding soils, modifying the quality of water and water courses, in general, making valuable forest space unsustainable.

A clear example of environmental damage to the soil and water courses is the case of Lújar in the Granada mountains. On 19, 20 and 21 August 2000, a fire spread over 1.207 hectares of forest ecosystem where water flows directly into the Rules dam, on the River Guadalfeo. *Tables 1, 2* and *3* show the considerable changes in maximum flow and return over 50 years, average loss of soil and average emission of sediment generated by the disappearance of part of the cover of the water basin.

Table 2—*Variation in average soil losses before and after fire. Source: Environmental Department Regional Government of Andalusia.*

Basin	Before the fire (tons/hec/year)	After the fire (tons/hec./year)	%
Bco. de las Piedras	29,11	33,61	15
Bco. del Algarrobo	15,72	120,78	668
Bco. de los Hornos	9,67	68,47	608
Bco. de Miranda	13,40	98,13	623
Bco. Cortijo los Romeros	19,24	47,69	148
Bco. del Olivo	111,11	206,28	86
Bco. del Muerto	15,55	55,93	260
TOTAL	21,01	87,67	317

With regard to impact on the annual average emission of sediment deposited in the Rules dam, in the River Guadalfeo, the figures show that the number of tons per year has multiplied by 18.

Table 3—*Variation of average annual emission of sediments before and after fire. Source: Environmental Department Regional Government of Andalusia.*

Basin	Surface area (hec)	Emission prior to fire (tons/year)	Emission following fire (ton/year	%
Bco. de las Piedras	395,81	1.966,98	2.887,50	47
Bco. del Algarrobo	559,65	1.329,50	67.595,33	4.984
Bco. de los Hornos	987,31	2.389,70	42.581,66	1.682
Bco. de Miranda	710,21	1.668,20	48.761,81	2.823
Bco. Cortijo los Romeros	110,46	188,69	578,08	206
Bco. del Olivo	190,89	2.998,40	39.377,08	1.213
Bco. del Muerto	121,19	239,94	1.306,34	444
TOTAL		10.781,41	203.087,80	1.784

Equally significant is the impact on our forest ecosystems' crop biomass. During the period 1991-2002, approximately 671.000 hectares of forest have been affected by fire, 22,000.000 of mature trees (∅ > 75mm) and at a bark volume of 27,000.000 m3 growing at a rate of 1,500.000 m3 per annum. The fire at Pedro Bernardo (Avila, 2000) which spread to 4,000 hectares of woodland with 1,322.000 mature trees and 192,000 m3 of timber was particularly damaging as was the fire at Valencia de

Alcántara (Cáceres, 2003) which spread to 19,300 hectares, of which 9,000 were forests of cork oak, chestnut, Pyrenean oak, holm oak and pine, affecting a bark volume of 167.500 m3 which incorporated 7,200 m3 of timber per year.

Fuel

The current situation of our forest lands, analysed from the perspective of reaction and resistance to fire leads to the conclusion that the negative impact on people, property and the environment will not decrease unless, and this is unequivocal, strenuous preventive measures are taken. This fact may be deduced from simple observation of the data shown below.

If we examine the annals of the Spanish National Forestry Inventory (IFN) throughout its three twelve-year cycles (IFN1, IFN2 and IFN3) (1964-2004), we note the sharply increasing densification occurring in our forests in terms of the number of trees, vegetation, undergrowth and dead vegetable matter in contact with the ground.

If we compare the number of mature trees ($\varnothing$ > 75mm) per hectare in the nineteen sixties (1st national forestry inventory, IFN1) with those of the eighties (2nd national forestry inventory, IFN2) and those of the nineties (3rd national forestry inventory, IFN3) we note a marked upward trend of the dasometric indicator. To give the figures for some relevant cases: in IFN1 the forests of Cáceres contained 52 trees per hectare and in IFN3 the figure is 148, three times as many. In Cantabria the *Pinus pinaster and Pinus radiata* ecosystems have risen from 692 trees per hectare (IFN2) to 918 trees per hectare (IFN3). The eucalyptus woods of Pontevedra have risen from 446 trees per hectare (IFN2) to 663 trees per hectare (IFN3). The density of pines in Asturias has doubled, from 411 trees per hectare (IFN2) to 825 trees hectare (IFN3). The *P.halepensis* pinewoods of Murcia, have also duplicated stocks, from 180 trees per hectare (IFN2) to 321 trees per hectare (IFN3).

If we turn our attention to undercover vegetation –undergrowth – and take as an example the woods of *Pinus halepensis* in the south of the Community of Madrid the area covered by the species *Quercus coccifera, Rosmarinus officinalis, Rhammus lyciodes, Helichrysum stoechas* and *Thymus spp*. which, at the beginning of the nineties (IFN2) covered 14 % of the ground, today cover 59 %. A similar situation exists in the undergrowth of the *Pinus sylvestris* ecosystems in Barcelona, comprising *Calluna vulgaris*, *Ligustrum vulgare*, *Quercus coccifera*, *Rosmarinus officinalis*, *Phillyrea sp* and *Thymus spp*. which in the mid-nineties (IFN2) covered 16 % of the forest floor, today cover 62 % of the pinewood area.

An indicator of ignition capacity could be the thickness of the dead vegetation covering the forest floor. Thickness of more than 4.5 cm which, according to IFN2 in Barcelona covered 12% of the forest surface and in IFN3 it had jumped to 22 %.

In Cáceres, the progression is similar, the thicknesses which in IFN2 reached 3% have doubled in 10 years (IFN3). The situation in Ourense is even more extreme where the percentage of cover greater than 4,5 cm in IFN2 were 45 % and are predicted in IFN3 at 98 %.

This high densification suffered by our forests may be explained both from the perspective of intense silviculture applied to our forest ecosystems. The samples taken by the IFN over a national network of 90,000 plots reveal that at a national level, cultivated forest in the nineteen-eighties accounted for one in every four hectares of woodland (25 %). IFN3, which started in the mid-nineties shows that this

is now one in every six hectares, (15%) The case of Galicia is particularly striking where there has been a 60% reduction between inventories (IFN2/IFN3), and the cases of Ourense and La Coruña are particularly alarming where cultivated forest accounts for one in ten hectares (10 %) (*table 4*).

Table 4—*Intensity of silviculture systems in the forests of 15 provinces. Source: National Forestry Inventory of Spain .DGCN. MIMAM*

	% of forest surface subject to treatment of canopy				
	IFN2	IFN3	(IFN3-IFN2)*100 /IFN2		
Province	**Treatment of canopy**	**Not noted**	**Treatment of canopy**	**Not noted**	**Treatment of canopy**
Ávila	28,0	72,0	23,4	76,6	-16,6
Badajoz	30,9	69,1	27,2	72,8	-11,8
Illes Balears	13,6	86,4	13,2	86,8	-2,9
Cáceres	18,3	81,7	16,5	83,5	-9,7
A Coruña	30,8	69,2	12,6	87,4	-59,0
Lugo	30,5	69,5	14,3	85,7	-53,2
Murcia	43,6	56,4	22,1	77,9	-49,4
Navarra	11,3	88,7	8,0	92,0	-29,3
Ourense	28,9	71,1	11,4	88,7	-60,8
Asturias	10,5	89,5	7,2	92,8	-31,8
Pontevedra	45,1	54,9	18,7	81,3	-58,4
Salamanca	47,9	52,1	34,5	65,5	-28,0
Sta.Cruz de Tenerife	9,1	91,0	4,5	95,5	-50,7
Cantabria	14,3	85,7	7,2	92,8	-49,5
Tarragona	6,2	93,8	3,6	96,4	-42,1
Weighted average	25,6	74,4	17,1	82,9	-31,4

The accumulation of fuel in our forests has reached an alarming level. The Map of Fuel Models in Spain is one way of visualising this situation, the map is on a scale of 1:50.000, and the general panorama is shown in *figure* 7.

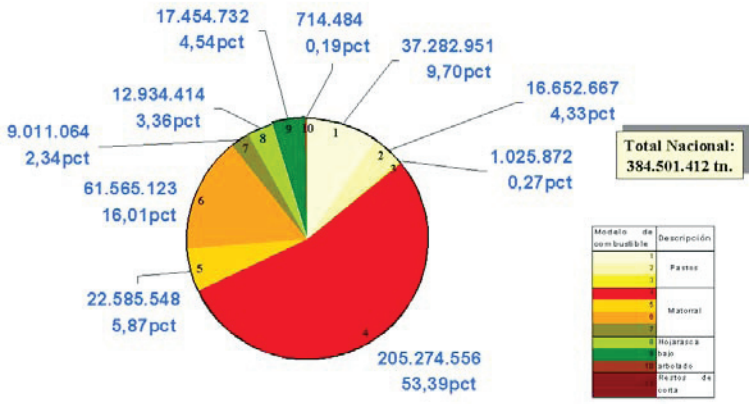


Figure 7—National distribution of fuel models in tons.
Source: Map of fuel models in Spain 1:50.000. DGCN.MIMAM

The total quantity of forest fuel – dry material- at a national level is over 384 million tons, corresponding to the undergrowth models el 77 % of the total, pasture 14% and leaf litter and brash the remaining 9 %.

Territorial distribution, *figure 8*, places five provinces at the head of the list, Cáceres, Badajoz, Cuenca, Ciudad Real and León, with the greatest extent of forest areas, and their forest ecosystems contain more than 12.5 million tons, followed by a group of ten provinces with more than 9.5 million tons of fuel each.

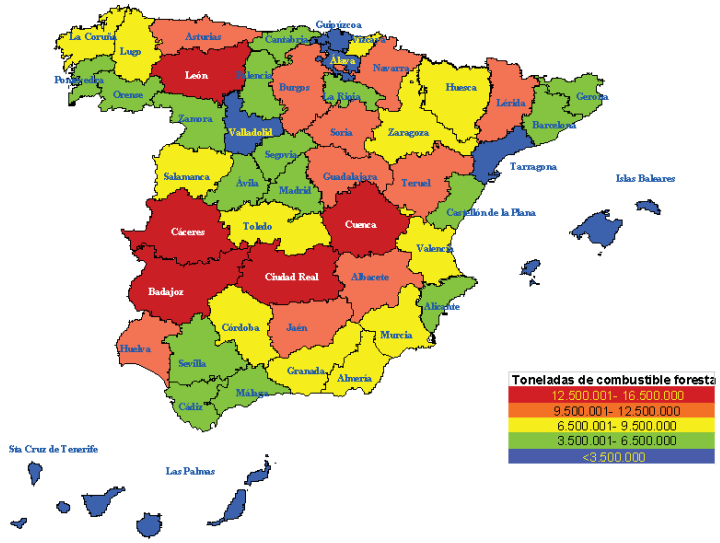


Figure 8— Territorial Forest Distribution, in tons. Source:. Tragsatec own figure

In terms of surface, the areas of undergrowth are particularly significant basically comprising dense thickets and shrubs over two metres high with an average fuel load - dry material- of approximately 30 tons per hectare and wooded shrubby areas less than 2 meters high with inflammable or highly flammable species and fuel loads of approximately 12 tons per hectare, which makes a total of 16 million hectares, or to put it another way, one in three hectares of the geographical area of Spain. (*fig 9* y *10*).

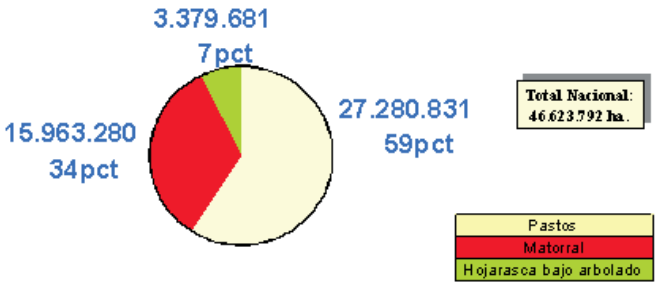


Figure 9— National Distribution of types of fuel in hectares . Source: Map of fuel types in Spain 1:50.000. DGCN. MIMAM

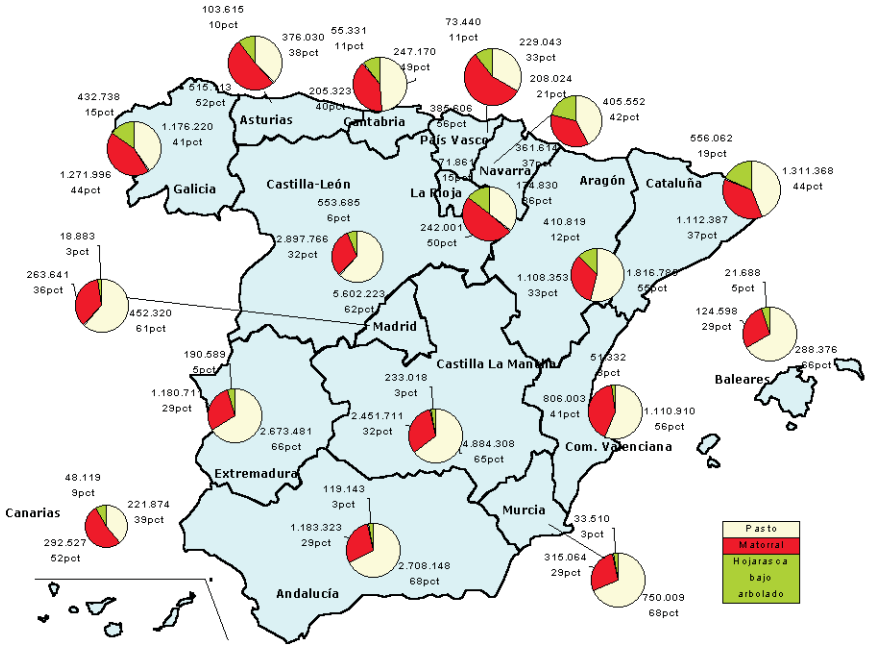


Figure 10—Distribution by Autonomous Community of different types of combustible in hectares. Source: Map of fuel models in Spain 1:50.000. DGCN. MIMAM

Solutions

How can we address a problem of this magnitude? Protection against forest fires basically requires two courses of action, suppression and prevention. In Spain fire suppression has reached considerable levels of professionalism and efficiency which is evident from the significant reduction in the average surface burned, despite, as we

have seen, the handicap of accumulated fuels, some of which are highly inflammable and their worrying effect on the safety of land fire-fighting units. The extraordinary resources required to reach this level of efficiency have already been described. Fire suppression has indeed been effectively dealt with.

The main concern which remains to be resolved is prevention. The hoped for mobilisation of activity has not occurred to a solid or concrete degree, only aspects such as fire detection have been addressed. The Autonomous Communities of Spain have not devised a Fire Management Strategy.

If the commitments contained in the newly promulgated National Forestry Law do actually materialise, there may be some hope. We recall some of these below:

- Sustainable forest management.

-Proprietors are responsible for technical and material management.

-Forestry planning within the framework of land management

-Promotion of commercial forestry and of related social and economic sectors

-Creation of employment and development of rural areas

-In addition the requirement of proprietors and institutions to comply with the obligations enforced by the Basic Civil Protection Directive on Forest Fires in respect of local plans and self –protection, presupposes a radical change in future trends regarding the social economic and environmental impact of forest fires.

Bibliography

Consejería de Medio Ambiente. Junta de Andalucía. España. **Plan de actuaciones urgentes en la zona afectada por el incendio forestal ocurrido los días 19 al 22 de agosto en la Sierra de Lújar. Provincia de Granada, 2000.**

Dirección General de Conservación de la Naturaleza. Ministerio de Medio Ambiente. España. **Inventario Forestal Nacional (IFN).**

Dirección General de Conservación de la Naturaleza. Ministerio de Medio Ambiente. España. **Mapa de combustibles de España, 1:50.000 (MFE-50).**

Dirección General de Conservación de la Naturaleza. Ministerio de Medio Ambiente. España. **Estadística General de Incendios Forestales.**

Tecnologías y Servicios Agrarios, S.A. **Base de datos prensa_incendios.mdb.**

Tecnologías y Servicios Agrarios, S.A. **Plan de protección contra incendios de los ecosistemas forestales en la isla de La Palma, 1999.**

Tecnologías y Servicios Agrarios, S.A. **Plan de protección contra incendios de los ecosistemas forestales de la C.A. de las Islas Baleares, 2000.**

Ministerio del Interior. **Directriz Básica de Planificación de Protección Civil de Emergencia por incendios forestales, 1993.**

Page left blank intentionally.

Mechanisms for the Internalization of the Environmental Benefits of Forests and Their Application to Forest Fire Prevention[1]

Ignacio Elorrieta,[2] Concepción Rey[3]

Abstract

Forests provide society with a series of environmental benefits which could nevertheless be lost through poor management or a lack of incentives to preserve them. These benefits include the protection of the soil and the hydrological cycle, the fixing of atmospheric carbon, biological diversity, landscape, recreation, etc. These benefits are rarely valued until harmful effects make their presence felt in the form of damage. Forest fires represent a direct physical manifestation of those effects. Steps taken as preventative measures assist in ensuring these environmental benefits are not lost. Regulatory mechanisms have been proved insufficient to channel the acts of individuals into patterns of behaviour which avoid forest fires. Such measures have proved difficult to implement and require a high, often excessive, rate of investment in surveillance and enforcement. Economic instruments such as subsidies, taxes and the creation of markets, in addition to voluntary agreements, complement regulatory efforts at fire prevention. This paper outlines appropriate fire prevention mechanisms and their consequences, thus providing sufficient incentives for society to have regard to the environmental benefits generated by forest areas when engaged in decision making processes.

Introduction

Forests provide numerous goods and services demanded by a society which is increasingly appreciative of their utility. More than half of Spain's total surface area is covered by forests, of which at least two-thirds are privately owned. The Forests Act 43/2003 acknowledges the social function of forests both as the source of natural resources and the supplier of a wide range of environmental services.

This recognition of the benefits to be obtained from forests and the externalities they produce, enjoyed by society as a whole, obliges the State to take active policies to promote preventative measures and the conservation, protection, replacement, improvement and use of forests. Empirical (Gobierno de Navarra 2001, Azqueta Oyarzun 2002) and theoretical (Elorrieta et al. 1998, Plana and Piqué 2003) studies have demonstrated the need, sometimes attended to, to take the benefits to be gained from forests into account in individual decisions and in State policies.

---

[1] An abbreviated version of this paper was presented at the second international symposium on fire economics, policy, and planning: a global view, 19–22 April, Córdoba, Spain.

[2] Doctor in biology. Director of the Environmental Integration Service of the Directorate-General for the Environment at the Environment Department, Town and Country Planning, the Government of Navarre. Avenida del ejército, 2. 31002, Navarra, Spain.

[3] Environmental economist. Rural Development Section, Environmental Planning Department, Tecnologías y Servicios Agrarios, S. A. c/ Conde de Peñalver, 84. 28006, Madrid, Spain.

Forest fires have historically represented a means of regulating our ecosystems. Nevertheless, the present day frequency and intensity of forest fires caused by specific social, economic and climatic conditions in the geographical area in question, has built up a degree of pressure on the environment which will be difficult to sustain. Any forestry policy, whether it involves long-term development or day-to-day planning, management or economic utilization, must take forest fires into account as a threat to sustainability.

State intervention aimed at minimising or mitigating the negative effects of forest fires on the positive externalities of forests is implemented by means of a series of mechanisms which internalise the environmental benefits of forests. This paper aims to identify the most appropriate mechanisms for the prevention of forest fires and their consequences, to ensure they provide sufficient incentives to encourage society to bear the environmental benefits of woodland in mind when taking decisions.

Environmental benefits of forests

From the classical perspective of linear economics, natural resources have been assigned the value of raw materials, which, following appropriate processing, are converted into goods which satisfy human needs - these are productive aspects. This approach holds that if something has no price it has no value, and the protection of the natural environment is pointless unless there are economic advantages in protecting it.

Linear economic models were superseded in the second half of the twentieth century by circular economic models, and it is now established that society also satisfies its needs by contemplating the landscape or by enjoying Nature in the countryside - these are recreational aspects. Furthermore, it is acknowledged that ecosystems are also capable of providing very important services free of charge – these being environmental aspects – such as carbon fixing by plants, which helps prevent the greenhouse effect, soil protection, which generates a proper layer of organic material, a positive impact on water quality in reservoirs, pollination by insects, etc. These new models will make it possible to put a monetary value on goods which have not, to date, been integrated into market mechanisms due to their lack of a price.



Figure 1 - The circular economic process (From left to right – Environmental aspect, Productive aspect, Recreational aspect).

In circular economics, the 'Environment' is defined as capital which provides surpluses in the form of goods and services of many kinds, both public and private. (*Fig. 1*). These produce three kinds of economic functions which help to satisfy human needs:

- The provision of productive goods.
- The provision of recreational goods and services.
- The provision of functions supplied by ecosystems which are necessary for life, and environmental services.

People do not always give these functions the importance they deserve. They seem to become aware of their value when the degradation of one of these elements requires them to 'open their wallets' to pay for the services which nature had previously provided free of charge. A clear example would be the additional cost of making water safe for drinking because the quality of the water at source has deteriorated through a failure to secure the appropriate natural filtration mechanisms at the site of precipitation in forests. (Elorrieta et al. 1998).

In order to calculate the total value of the forests, it would be necessary to take into account all its constituent elements, whether they have a market price or not, given that their absence from the marketplace does not imply they are valueless (*Table 1*). It is necessary to distinguish between private value - income from timber, firewood, fruit, etc. - and public value – recreational activities, enjoyment of the countryside, the capture and fixation of carbon etc. – and a non-use value - existence, options, bequests and gifts. Goods which have no price in the marketplace can be determined on the basis that to value something is to express its use and that positive preferences in our society are translated into a willingness to pay, for which money is the only measure.

Table 1—*Classification of forest values*

	TOTAL VALUE	
	USE VALUE	NON-USE VALUE
PUBLIC GOODS	Recreation Countryside / scenic beauty Carbon capture and fixation Erosion control Flood prevention	Existence Options Bequests Gifts
PRIVATE GOODS	Timber, firewood and cork Grazing Hunting and fishing Fruit and mushrooms Aromatic and medicinal plants Bee-derived products Wind	...

Great progress has been made in recent years in developing effective evaluation methods, and the economic valuation of forest ecosystems now represents an essential instrument in ensuring that public and private decision-making processes are well informed and directed. At the same time, the evaluation methods help forge a social conscience which is more in tune with environmental protection and make it possible to determine the value of the environment, whether it is well-preserved or degraded.

A series of techniques are available to evaluate environmental profit and loss in specific ecosystems. The aim is to identify the correct technique or methodology for each specific element, e.g. contingent valuation for non-use, hedonistic pricing for the landscape, the travel cost method for recreation, etc., while accepting that these are subjective values and are affected by the availability of information.

It is also necessary to bear in mind that our knowledge of the multifarious interrelationships and links between each of the natural elements is incomplete. This type of uncertainty cannot be eliminated and, as a result, the value thus obtained for a monetised environmental asset should always be taken to be a minimum.

The economic valuation of biodiversity and the resources of which it consists represents an important tool in creating well-directed and adjusted incentives. This is not an end in itself, but it can serve as a starting point for policy formation. Such valuation may prove insufficient to promote the effective conservation of the valued goods or service, and supplementary measures should also be drawn up.

Notwithstanding the environmental and social benefits provided by forests, it is a fact of life that both proprietors and the direct users of these goods and services focus on short-term objectives which produce higher returns, and completely forget the long-term benefits which require the sustainable use of resources.

Forest Fires

Over a large part of the Iberian Peninsula, forest fires are a natural part of the environment. Mountain and Mediterranean forest predominate, with a great many species being very well adapted to fire (*Pinus pinea, P. halepensis and P. pinaster*). As a result, forest fires do not necessarily imply an irreversible loss of vegetation, and sometimes even serve to reinforce certain forest areas (Vélez 2000).

However, most forest fires are currently anthropic, rather than natural in origin, and are the result of specific social and economic conditions (*Fig. 2*):

- The use of fire in agricultural practices, stubble burning, brush clearance and the disposal of agricultural waste.
- The use of fire to renew livestock grazing and to clear land for more grazing.
- The use of fire for hunting purposes, both to facilitate hunting and against the enclosure of land required to carry out hunting activities.
- The abandonment of silvicultural sites which leads to an accumulation of forest fuels.
- The abandonment of rural land as part of general migration to the cities.

– A fall in the profitability of land use with a view to changing the land use or due to conflicts arising from the limitation of use (Nature Reserves)

– Fires ignited by pyromaniacs and vandals, as an act of vengeance, etc.

Forest fires represent an extremely serious threat to forest conservation. They cause several kinds of loss: firstly, a drop in the economic output of the forest areas employed for productive purposes, which depends on the natural regenerative capacity of the forest to foster renewed economic activity; secondly, a deterioration in the recreational services provided by these areas, and in the beauty of the landscape, and finally, a reduction in the environmental functions of the stand, i.e., a decrease in the area's ability to capture carbon, an increase in erosion, a decline in standards of living, etc. (Bengoechea 2002).

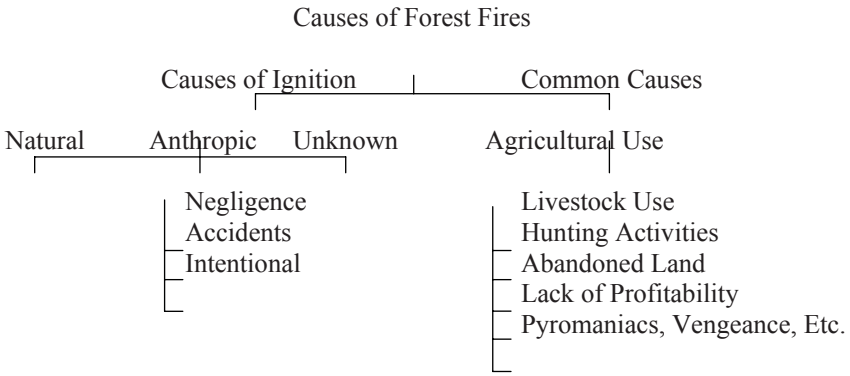


Figure 2—*Causes of forest fires*

The number of forest fires is currently rising significantly, and although a large number of these fires affect areas of less than one hectare, the sheer number of fires implies a continuous increase in resources dedicated to fire suppression activities. Given that the aims of prevention include a reduction in the number of fires, it may be observed that the ideal level of protection has not yet been achieved, which suggests that it might be necessary to reassess the prevention policy.

Fire prevention mechanisms

The planning and execution of the necessary measures to prevent forest fires in Spain are the responsibility of the forestry departments of the regional governments. These activities are carried out jointly with other government agencies and private bodies and individuals.

The forest fire strategy is implemented through prevention, detection and extinction programmes. The first of these activities should be considered the most important and fundamental element of forest fire activities, as prevention aims to avoid any fire incidents whatsoever. All use of forests should be informed by the need to prevent the ignition and spread of a forest fire.

Consequently, all forest fire prevention mechanisms should have two basic aims: to avoid ignition and, if ignition takes place, to prevent the fire spreading. The first of these objectives is clearly the most important and, unfortunately, the most

difficult to achieve, given that no-one is free from responsibility in this respect. The distinct governmental agencies have developed different mechanisms to achieve fire prevention goals. The mechanisms can be summarised as follows:

- Dissuasive vigilance. Through environmental awareness programmes, public information campaigns, the provision of statistical information and specialised training and support for groups interested in forest conservation and forest fire prevention.
- Forest planning. One of the primary objectives of such planning being to preserve forests through prevention and to regulate the uses and activities to which forest areas may be subject, by means of rules, limits and prohibitions.
- Investment in infrastructure: access roads and tracks, water supply points, protection for forest buildings, recreational facilities. The investments are overseen by a Forest Fire Priority Action Plan (FFPAP).
- Preventative silvicultural work: brush clearance, fuel removal, pruning, the creation of firebreaks, etc.

Everyone has to do what they can in the fight against forest fires, and the Forests Act provides that anyone who discovers a fire is obliged to report it and, where appropriate, to co-operate in suppressing it. Furthermore, the Act places a greater burden on those who benefit most from forests. As a result, the Act establishes the general principle that owners of forest lands are responsible for the management of the property, both in terms of organisation and work on the ground. However, who is to pay for maintaining and improving the forests, which benefit society as a whole? The State continues to be the principal body responsible for the prevention of forest fires, and it bears practically all the costs arising from preventative measures, given that preventative silvicultural treatments undertaken by private landowners might easily be more costly than the economic benefits to extracted from the forests.

The Forests Act provides for a levy on the owners of forest areas to raise revenue for spending on the conservation and enhancement of the forests. The Act establishes an improvements fund, using money raised from a 15 percent minimum levy on forestry products, although the rate has been increased by some regional governments, and is employed to partly finance spending on forest fire prevention. The charge may only be levied, however, on local corporations which are proprietors of forest areas officially declared to be of public utility. As a result, the funds generated are insufficient to cover the total cost of fire prevention activities.

The support provided by the State specifically in respect of fire prevention activities should be reciprocated by an obligation applicable to all citizens, and in particular the proprietors of the forests, to assist in maintaining the source of the benefits from which they directly benefit. A clear demonstration of this principle is the Forest Fires Extinction Tax in Andalusia, which is payable by the forest landowners and covers the costs of extinguishing forest fires, while obliging them to co-operation actively in the implementation of measures aimed at preventing and fighting forest fires. Furthermore, landowners can be exempted from the tax where they have taken part in fire prevention activities.

Forest Incentive Policy

There is no single step which will prevent forest fires, given that each geographical area has differences in climate, in the structure of property ownership and in the overall approach to forests, all of which can have a direct influence not only on the incidence of forest fires but also on the means of preventing them.

All efforts to prevent forest fires must improve forest management in a way which makes it possible to generate positive benefits and externalities which are perceived to be symbols of identity in a cultural landscape, and which ensure that the agricultural, livestock and silvicultural activities which manage the area are able to continue populating, nurturing and protecting it against all attacks.

An incentive policy allows the State to move the focus of its fire prevention efforts onto the users of the forest, i.e. the direct beneficiaries, in such a manner that they can contribute to fire prevention by modifying their behaviour. There are two classes of instruments which can be employed for this purpose (Azqueta 2002, Carvalho 2002):

- Normative instruments, which act coercively on the behaviour of private individuals.
- Economic instruments, which represent positive and/or negative incentives aimed at achieving voluntary changes in individual behaviour.

Normative instruments

These require the State to impose specific rules of behaviour which generally affect everyone equally. Such instruments may be divided into several types (Azqueta 2002):

- Rules governing forest use. These regulate access to natural forest resources and their extraction and use. They include the obligation to give notice of a fire if discovered and prohibitions, authorisation, penalties, etc.
- Rules covering the planning and management of forest areas. These govern the type of activities which take place in a specific area, e.g. areas of high fire risk, fire defence plans, building regulations, changes in land use, etc.

Economic instruments

These instruments lack coercive force and simply allow individuals to choose whether to act in one way or another, each choice having its own costs. This is defined by the Spanish Forest Strategy as a mechanism which acknowledges the positive externalities of the multifunctionality of forests. The aim is for individuals to decide themselves whether or not the action in question is worthwhile, depending on the costs they must pay for each action (Azqueta 2002). There are two key requirements for these instruments:

- They must ensure Ecological Coherence, given that the instruments are basically aimed at guaranteeing the environmental benefits generated by forests, and not exclusively at improving individual financial return.
- They must establish a Voluntary sense of Commitment, which combines productive activities with the strengthening of social bonds and the

production of environmental services which have not previously been remunerated by the marketplace.

The recent Forests Act reserves a whole chapter for dealing with forest fires and their prevention and extinction. It establishes high fire risk areas and a requirement to draw up detailed plans specifying the preventative tasks required in order to avert forest fires. The Act proposes several ways of accomplishing those tasks, including collective agreements, individual agreements, the temporary assignment of land to the State, grants and subsidies and, where appropriate, compulsory execution of the tasks by the State at the cost of the landowner.

The State has traditionally employed the above-mentioned mechanisms to provide forest owners with varying types of financial assistance intended to provide them with partial compensation for the limitations placed on the private enjoyment of their land by the public aspect of forest lands.

Although this financial support is considerable, it has never, on the whole, been sufficient, and Art. 65 of the Forests Act has, for the first time, made it possible to increase the funds available by paying for the positive externalities and incorporating them through the following mechanisms:

- Subsidies for sustainable forest management activities aimed at the forest land owners. The eligible activities include forest fire prevention, by means of investment in infrastructure, replanting, spending on maintenance and improving the forest stand, silvicultural treatments, etc.
- The establishment of contractual relations with the land owners, including the local corporations, as well as encouragement and support for associations and pressure groups in favour of the prevention of forest fires, all designed to channel the co-operation of the forest land owners and thereby to improve the ability to manage forests.
- Direct investment by the State. Given that the beneficiary of the environmental goods and services provided by forests is society as a whole, it is only natural that the State should be the principal, albeit not the only source of financing for efforts to provide incentives for externalities.
- Environmental insurance. The Act contemplates establishing a Forest Fire Insurance Policy, with the added attraction of priority access for policyholders to subsidies for sustainable forest management.
- Low-interest loans. The Act specifies that the State should make low-interest loans available to finance investment in forests, which includes the mechanisms for preventing forest fires.

The Act takes into account the possible effects of human activity, which makes it possible to draw up incentive policies which help to internalise the environmental benefits obtained from forests. These incentives can, in turn, be used, as least in part, to undertake work or implement measures aimed at preventing of forest fires.

It is essential to acknowledge society's role in the battle against forest fires, in which the guiding principal might appropriately be the phrase associated with the Barcelona Declaration, i.e. 'he who engages in conservation will be rewarded', where the conduct in question positively works towards securing the environmental benefits for society in general. The Act also has regard to this principle in establishing that the

following factors, amongst others, should be taken into account in regulating the incentives:

- The conservation, recovery and improvement of biodiversity and landscape depending on the measures specifically adopted to these ends.
- The fixation of carbon dioxide in forests as a means of mitigating climate change, depending on the quantity of carbon fixed in the forest biomass and acknowledgement of the energy in forest residues.
- The conservation of forest soil and hydrological systems as a means of counteracting desertification, depending on the degree to which the plant cover and silvicultural practices contribute to reducing the loss or degradation of the soil and of surface and ground water resources.

These incentives encouraging sustainable forest management are intended to guide conduct towards safeguarding the environmental benefits produced by forests, which, in turn, helps to improve forest fire prevention.

Conclusions

Not only do forest fires cause financial loss, they are also one of the principal causes of a decline in the social function of forests and in the goods and services generated by these ecosystems.

The mechanisms envisaged in Art. 65 of the Forests Act which regulate the incentives for environmental externalities must be put into practice so as to ensure that land owners are actively involved in the defence of their forest lands and in the prevention and extinction of forest fires.

In order to achieve this it is necessary to assign a monetary value to the environmental benefits created by forests. This makes it possible to determine which specific incentives, by changing the conduct of individuals, will facilitate use of the mechanisms which serve to prevent forest fires, e.g. direct subsidies, taxes and other levies, soft loans, insurance, etc. The aim is to achieve sustainable management of forests by extracting maximum economic, social and environmental value, which, in turn, ensures they are not abandoned, guarantees their survival as part of our natural heritage and internalises the full value of Nature.

References

Álvarez, M.; Field, D. 2001. **Beneficio social de la gestión de uso múltiple de los espacios forestales**. III Congreso Forestal Español. Granada. Mesas 4 y 5: 55-61.

Azqueta Oyarzun, D. 1994. **Valoración económica de la calidad ambiental**. Aravaca (Madrid). Mcgraw-Hill; 300 p.

Azqueta Oyarzun, D. 2002. **Introducción a la economía ambiental**. Aravaca (Madrid). Mcgraw-Hill Profesional; 236-268.

Bengoechea, A.; Fuertes, A.M. 2002. **Valoración monetaria de la reducción del riesgo de incendio en un espacio natural.** Oviedo. V Encuentro de Economía Aplicada; 1-19.

Carvalho Mendes, A. 2002. **Economic Instruments for National Forest Programmes**. En Cross-sectorial policy impacts on forest. Tikkamen, I; Glück, D; Pajouja, H. (eds.). EFI Proceedings 46: 119-140.

Elorrieta J.I. 2001. **El capital natural ¡Ya es hora de hacer cuentas!**. III Congreso Forestal Español. Granada. Ponencia Mesa 10: Política sociología y economía forestal.

Elorrieta J.I.; Castellano, E.; García, A. 1998. **Valoración Integral de la Biodiversidad de Navarra**. En Mapping 63: 12-18.

Gobierno de Navarra. 2001. **Estrategia Navarra para la conservación y el uso sostenible de la diversidad biológica y plan de acción 1999-2004**. Biosfera. Consejería de Medio Ambiente, Ordenación del Territorio y Vivienda: 102-103.

Martínez Alier, J.; Roca, J; Sánchez, J. 1998. **Valoración de externalidades y de bienes ambientales. Internalización de externalidades**. PNUMA. México. Serie de textos básicos para la formación ambiental 1: 35-69.

Plana Bach, E.; Piqué Nicolau, M. 2003. **Casuística y posibles soluciones a los grandes incendios forestales de la cuenca mediterránea. El caso de Cataluña**. Madrid. ETSI; 1-8.

Vélez Muñoz, R. et al. 2000. **La Defensa contra incendios forestales. Fundamentos y Experiencias**. Madrid. Mcgraw-Hill.

Page left blank intentionally.

An Approach to a System for Monitoring the Impact of Extensive Forest Fires in Spain[1]

Ricardo Vélez,[2] Balbina López[2]

Summary

Fire, as a natural element, has been a decisive factor in the composition of the forest landscape. Nevertheless, the recurrence of forest fires in certain areas and the extensive area they may cover can endanger the survival of forest systems.

Studies on the impact of fire have centred on establishing the development of the ecosystem following the fire and the evaluation of financial loss; however, less frequent is analysis of the landscape component of the impact produced by fire, and its permanence in the eco-system

From 1990, Spanish statistics for fires include this effect on the landscape although no analysis has been made from the results obtained, nor has the subsequent development of the affected landscapes been examined, which in some cases will have been restored whilst in others the eco-system has developed naturally.

A study of what happened in previously burned areas may be interesting as an instrument in forestry policy and should describe the zones under analysis, both before and after the fire and indicate the series of processes from the time of the fire to the present situation.

The Spanish Forestry Administration has undertaken the study of nine large-scale forest fires occurring in the last twelve years as a pilot scheme in which the permanent impact of the fire will be examined evaluating its state and analysing the causes which may or may not include human activity.

The study will establish normalised procedures for the systematic control of areas affected by large-scale fires in the future and will facilitate a system of periodic prospecting to evaluate impact.

Introduction

Forest fires cause a series of ecological disturbances which are often decisive in the subsequent regeneration of the burned ecosystem. The magnitude of the effects produced by fires depends to a large degree on aspects such as the fire regime: intensity, type of fire, recurrence of fires within a specific zone, the time of year when the fire occurs, in terms of the stage of development of the vegetation present, the type of vegetation, its ability to adapt to fire and its germination characteristics

[1] An abbreviated version of this paper was presented at the second international symposium on fire economics, planning, and policy: a global view, 19–22 April, 2004, Córdoba, Spain.

[2] General Directorate for the Conservation of Nature, Ministry of the Environment, Gran Vía de San Francisco, 4. Madrid. CP 28005.

[2] Tecnologías y Servicios Agrarios, S.A. (TRAGSATEC). Julián Camarillo, 6. Madrid. CP 28037.

post-fire, meteorology, or even the effect of the microclimate linked to different exposure or the exploitation following the fire.

Given the number and complexity of the factors which may arise in each case, the effects of a fire on the ecosystem are extremely variable, which can hinder forecasting, with any real guarantee, the possible re-growth of vegetation following a fire.

Monitoring of the development of forested areas affected by large-scale fires where in some cases restoration work will have been carried out, and in others left to nature, is a basic tool in assisting the assessor to establish the most appropriate strategies for recovering burned areas .

At the end of 2003, the Spanish Forestry Administration set up a study to develop a **System for Monitoring the Impact of Large-Scale Fires** which, through individualised, continuous and systematic monitoring of areas affected by large-scale fires occurring in the last twelve years, would help to define subsequent courses of action, establishing normalised procedures for the control of areas which have been burned.

The study intends to describe the zones included in the study both prior to and following the fire, and to explain the processes which led to the present situation from the onset of the fire, to ascertain the permanence of the fire's impact mid term, examining its present state and analysing the causes of that state, which may include human activity or the absence thereof.

Nine large-scale fires which occurred in the last decade have been selected from seven Autonomous Communities of Spain, considering that the eco-systems affected are sufficiently representative to extrapolate the results obtained to those of the remainder of Spanish territory *(table 1)(fig. 1)*.

Table 1—*Location of the nine large-scale fires selected for the study.*

Year	Community	Province	Municipal District	Surface area affected (ha)
1991	C. Valenciana	Valencia	Buñol	15.400
1994	Murcia	Murcia	Moratalla	24.817
1994	Castilla La Mancha	Cuenca	S. Martín Boniches	17.859
1994	C. Valenciana	Alicante	Montgó-Denia	820
1994	C. Valenciana	Castellón	Altura	5.000
1995	Canarias	S.C. Tenerife	Rosario	2.677
1995	Galicia	Pontevedra	Vilaboa	775
1998	Extremadura	Cáceres	Descargamaría	820
1998	Castilla and León	León	Castrocontrigo	2.763



Figure 1—Location of large-scale fires.

Method

The main objective of the study is to facilitate the periodic and systematic monitoring of land units affected by large-scale fires, developing an adequate methodology for the procedure, and identifying the normalised information for inclusion in the EGIF General Database. Defining an appropriate methodology for obtaining this objective would be based on the conclusions reached in different phases of the study. *(fig. 2)*.

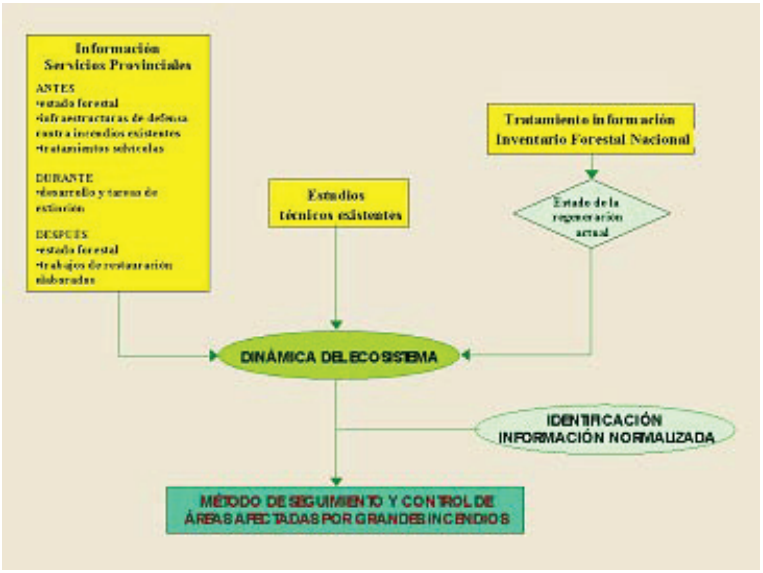


Figure 2—Content of the study.

Initially, it would be necessary to ascertain the forested state of the ecosystems

prior to the fires occurring: aspects such as specific composition of the ecosystem and the state of its development: pastures, scrub land and wooded areas, any forestry activity or exploitation, whether or not the land had an adequate infrastructure for fire fighting and fire prevention or the state of the communications network, road networks, water supply networks etc. in addition to conditions of the outbreak and spread of the fire, so it that would be easier to understand the processes which have led to the current situation following the fire.

The development of forests affected by large-scale fires depends to a large degree on the ecological conditions and the type of activity to be carried out but the structure and constitution of the existing young population constitutes one of the most determining factors.

It is therefore essential to ascertain the state of regeneration at the present time achieved by looking at the main indicators:

Type of regeneration: Provides information in respect of the origin of the woodland.

Development Category: Classifies regeneration on the basis of normal height and diameter, in order to ascertain the development stage of young trees.

Regeneration Density: Provides information on the degree of density of a specific species.

The main source of information for discovering these indicators is the National Forestry Inventory. The mapping and alphanumerical information of the plots of land provides the value of the variable density of regeneration for each sample area *(fig. 3)*.



Figure 3— Geographical location of the fire in Rosario 1995 (S.C.Tenerife, Canaries) and Map of the location of the plots of the National Forestry Inventory.

In order to define the spatial trend of the variable, spatial interpolation techniques may be used to estimate the value of the variable in specific points not taken as samples in the area covered by the existing plots. It is also necessary to create a buffer zone, namely an area between the limits of the surface area and a

fictitious limit towards the outside of the original border, since knowing the regeneration data for the plots included in the buffer zone and applying the method of spatial interpolation, it is possible to generate the model up to the very edge of the burned area, correcting any lack of values by using statistical techniques *(fig. 4)*.

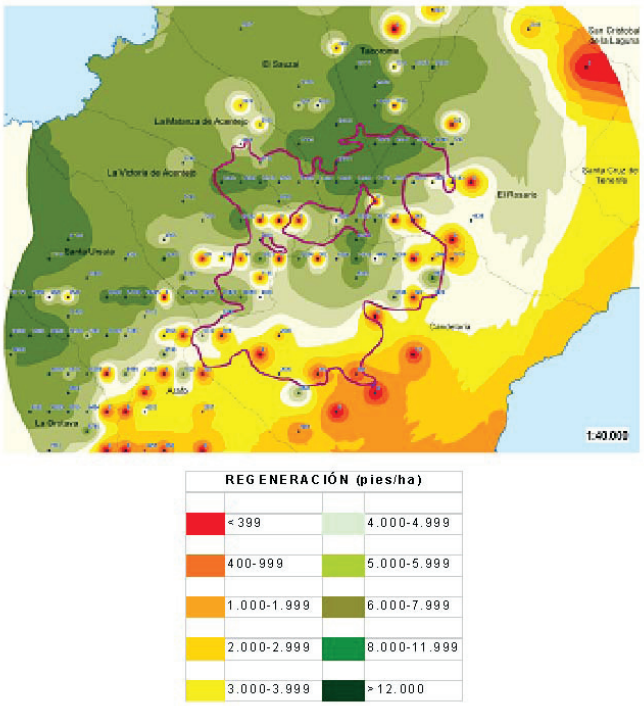


Figure 4—Map of forest regeneration Rosario forest fire 1995 (S.C.Tenerife, Canay Islands)

Working with such large-scale land dimensions does not permit a detailed control of the numerous variables which influence regeneration; however, the results permit the definition of each study zone in a general manner.

Finally, an interpretation will be made of the information contained in the studies and the restoration activities subsequent to the fire specifically carried out in affected sectors to increase knowledge of the factors and elements involved in the composition of the present landscape.

Bibliography

Ministerio de Medio Ambiente. **Segundo Inventario Forestal Nacional. Provincia de Alicante (Comunidad Autónoma Valenciana), 1995.**

Ministerio de Medio Ambiente. **Segundo Inventario Forestal Nacional. Provincia de Cáceres (Extremadura), 1994.**

Ministerio de Medio Ambiente. **Segundo Inventario Forestal Nacional. Provincia de Castellón (Comunidad Autónoma Valenciana), 1995.**

Ministerio de Medio Ambiente. **Segundo Inventario Forestal Nacional. Provincia de**

Cuenca (Castilla La Mancha), 1995.

Ministerio de Medio Ambiente. **Segundo Inventario Forestal Nacional. Provincia de León (Castilla y León), 1995.**

Ministerio de Medio Ambiente. **Segundo Inventario Forestal Nacional. Santa Cruz de Tenerife (Canarias), 1994.**

Ministerio de Medio Ambiente. **Segundo Inventario Forestal Nacional. Provincia de Valencia (Comunidad Autónoma Valenciana), 1995.**

Ministerio de Medio Ambiente. **Tercer Inventario Forestal Nacional. Región de Murcia, 2003.**

Ministerio de Medio Ambiente. **Tercer Inventario Forestal Nacional. Provincia de Pontevedra (Galicia), 2001.**

Vélez Muñoz, Ricardo. 2000. **La defensa contra incendios forestales. Fundamentos y experiencias.** ed. Mc Graw Hill. Efectos del fuego en los ecosistemas forestales; 4.1-4.102.

Forest Fire Prevention Plans in National Parks: Ordesa Nacional Park and Monte Perdido[1]

Basilio Rada,[2] Luis Marquina[3]

Summary

Protected natural spaces contribute to the well being of society in various ways such as maintaining biological diversity and quality of the landscape, regulation of water sources and nutrient cycles, production of soil, protection against natural catastrophes and the provision of recreation areas, education, science and culture, aspects which attain maximum relevance in the lands under the protection of the National Park.

The singular nature and the high degree of protection to a large extent limit management, since the principles of conservation and natural processes prevail in these areas. Nevertheless the inevitable responsibility to ensure now and in future, the ecological economic and social functions of these spaces goes on to assume a management model on the lines of compliance with the Pan European Criteria for Sustainable Forest Management.

In 2000 management of the Ordesa and Monte Perdido Park , in the Spanish Pyrenees which was declared a natural park in 1918, took the initiative to devise a Plan for the Prevention of Forest Fires in the park and its surroundings which may be a reference for the other parks comprising the network of Spanish National Parks.

The Plan analyses the effectiveness of current protection resources, supported by cartography which aids decision making, fuel maps, fire risk, visibility, territorial isochrones and areas which at the same time plan the necessary measures to guarantee the protection of this space, which in many areas is inaccessible due to the steep landscape.

The possibility of counting on this planning indubitably constitutes an important technical support tool, which will assist management, not only in terms of fire prevention, but in respect of the conservation of the park, since it provides a cartographic and alphanumerical base for consultation and analysis within the framework of GIS (Graphic Information System) –DINAORDESA-, with the possibility of extending or creating new information using the data contained therein.

Introduction

The various climatic and altitudinal conditions determine the great diversity of ecosystem in the Ordesa and Monte Perdido Natural Parks, which includes an enormous range of plant and animal communities and he entire area provides an astonishing landscape of tremendous contrasts which represents the systems linked to

[1] An abbreviated version of this paper was presented at the second international symposium on fire economics, policy, and planning: a global view, 19–22 April, Córdoba, Spain.

[2] Autonomous Organisation of Nacional Parks. Ministry of Environment, Gran Vía de San Francisco, 4. Madrid. CP 28005.

[3] Autonomous Organisation of Nacional Parks. Ministry of Environment, Ordesa and Monte Perdido Nacional Park. Paseo de las Autonomías, Pasaje Baleares, 3. Huesca. CP 22071.

erosion formations and sedimentary rocks. For this reason in 1918 the area was declared a National Park with a protected area of 2.100 ha. extended in 1982 to more than 15.000 ha. today.



Figure 1—Map indicating National Parks which belong to the Park Network

The network of National Parks is an integrated system for protecting and managing the most valuable and representative areas of Spanish natural heritage. The purpose is to ensure the conservation of National Parks and make them available to the public and also to improve scientific knowledge regarding their natural and cultural values in addition to promoting a conservationist social conscience interchange of knowledge and experience in terms of sustainable development, training and qualification professionals working in the sector and their incorporation participation in international networks and programmes. *(fig.1)*.

The Ordesa and Monte Perdido national park is in the province of Huesca, which belongs to the Autonomous Community of Aragón, and it is the ideal territory for maintaining various species of flora and fauna which due to their rarity and unusual nature give this open space a high biodiversity value.

The threat of forest fires on our forest areas is even more relevant in the case of Ordesa since the effect of a fire in this area would cause damage in environmental terms but also to people and assets which would be difficult to quantify. Given this fact, together with public use of the park, it would be advisable to have a Forest Fire Prevention and Protection Plan for the Ordesa and Monte Perdido National Park which would provide the park with sufficient means of self protection as well as measures which would be taken from other plans on a wider scale.

The Ordesa National Park was a pioneer in devising a Forest Fire prevention plan which covers not only the area defined as national park but also a surrounding area which has been determined Peripheral Prevention Zone which covers a total of approximately 35,000 ha.

The principal goal of the plan is to define and quantify the protection measures required to optimise and reinforce present prevention resources, vigilance and suppression which the park already has available and to establish guidelines which will guarantee coordination of the resources and organisation involved in the prevention and protection against fires.

Development of the Plan

Description of the territory

The Ordesa and Monte Perdido National park is in the district of Sobrarbe, in northern Huesca. It covers 15,687 ha., which belong to five municipal districts: Bielsa, Fanlo, Puértolas, Tella-Sin and Torla. The territorial area of the plan also extends to the Peripheral Protection Zone (ZPP), which covers a further 19,245 ha. which belong to the aforementioned townships and in addition the municipality of Broto *(fig.2)*.



Figure 2—Map of Ordesa and Monte Perdido National Park..

The complex geological and morphological history of this area together with extreme climate conditions have made this area a landscape of tremendous contrast comprising four valleys: the Cañón de Añisclo which runs north to south, the Valle de Ordesa running east to west , and running south-east to north-east the Garganta de Escuaín and the Valle de Pineta. In the Peripheral Zone three more valleys mark the boundaries of those mentioned above: Bujaruelo, Vió and Airés *(fig.3)*.



Figure 3—Valle de Ordesa.

Forest systems are amply represented with beech woods, firs and pines and box in chalky areas, in addition to high mountain pastures which were once used extensively for livestock.

There is also an abundant diversity of protected species of flora and fauna which led to the park being declared a Biosphere and Human Heritage site in 1977, Special Protection Zone for Birds in 1988 and Diploma from the Council of Europe in 1989, as well as being named Nature Reserve (Valle de Bujaruelo) and various protected landscapes *(fig.4)*.



Figure 4— Flora and Fauna of the Park.

Risk of fire and priorities for prevention

An analysis of the most characteristic elements of the area in which fire could break out and spread provides the required information for planning means of protection and prioritising the land so that there is a guaranteed protection of the valuable ecosystems in the Park itself and the surrounding area.

The plan analyses the risk of fire as shown in the following diagram *(fig.5)*.



Figure 5— Methodological diagram of fire risk analysis

The physical characteristics of the Park and its surroundings make fire propagation the most relevant aspect in the risk of fire. *(fig 6)*.

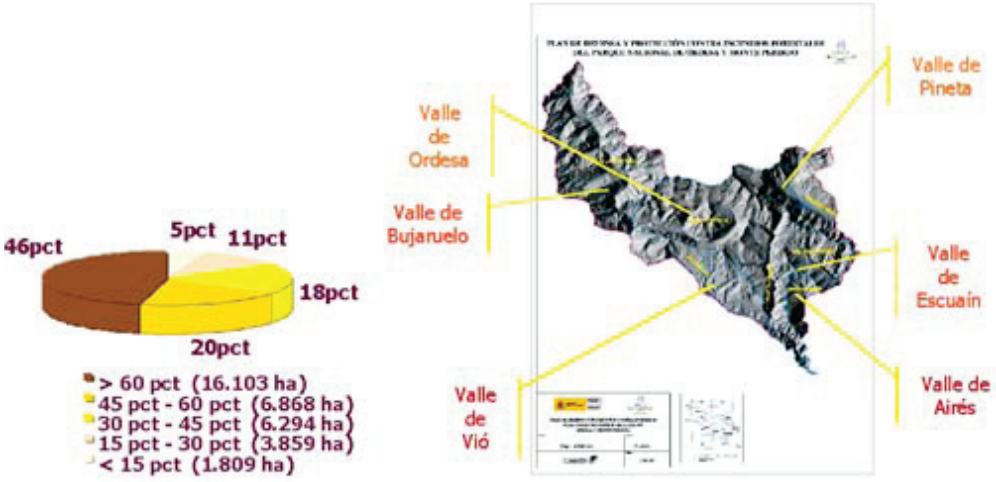


Figure 6—Map of digital model of the land with distribution through valleys and surface distribution of the gradient

Stratification of the territory in areas of homogeneous gradient shows the abrupt relief of the Park, where 66 % of the surface shows gradients of 45 % and 46 % is situated on gradients of more than 60 %. In these conditions propagation of fire would reach extremely high risk levels, if it were not for the fact that the combustibility of those zones is moderate since this is alpine pasture. *(fig. 7)*.

Nevertheless, in the sunny areas of Ordesa, Escuaín, Pineta and the valley of

Vió, the risk increases due to the reduced humidity caused by continuous sunshine on the fuels.

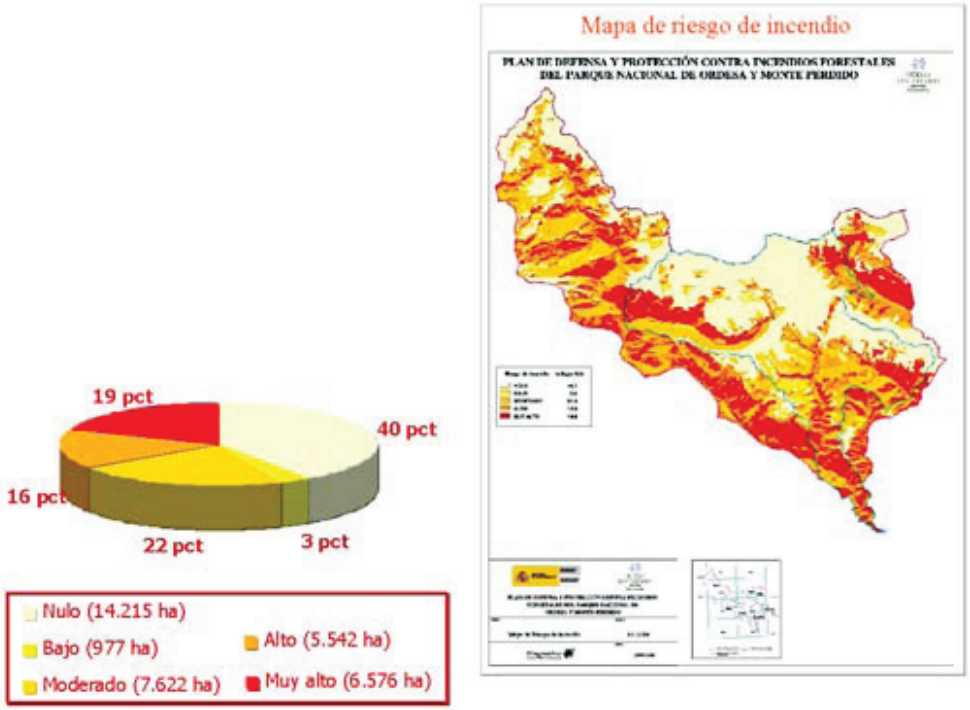


Figure 7— Spatial distribution of the risk of fire and map of fire risk

The Map of Fire Risk was the result of all the factors integrated which lead to the conclusion that Ordesa presents a very high fire risk in 19 % of its surface and priority should be given to these particular points of land *(fig. 8)*.

Protective Measures

Once fire hazard zones in the area have been analysed, in addition to statistical analysis to ascertain the periods of greatest danger, the Plan makes an inventory of the Park's protection resources in order to carry out an analysis and diagnosis of the situation to establish that the measures are adequate for the level of risk.

The Plan makes a detailed analysis of the effectiveness of the current resources using cartography as support which is particularly important, visibility maps which facilitate information regarding the visible surface from the location of lookout point, land and air isochrones, with which it is possible to discover the arrival times and the suppression resources in any point of the territory, given its locations and the ADP map in which each point of the territory is classified according to whether or not it is accessible, within reach and penetrable, depending on the series of conditions. *(fig. 9, fig. 10)*.

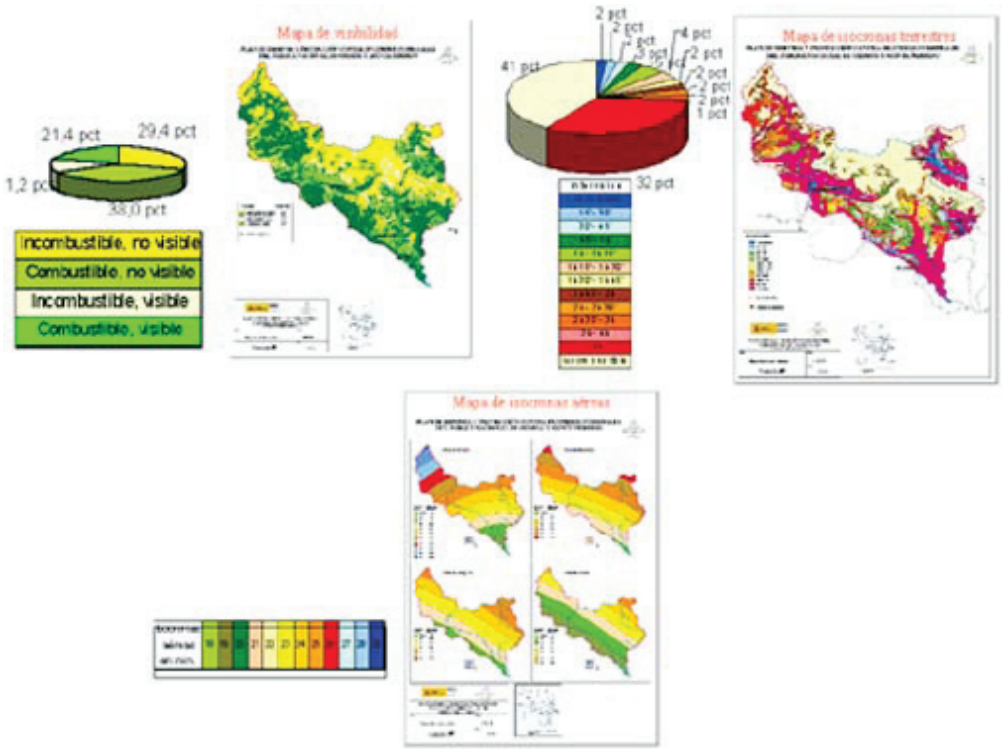


Figure 8—Map of current visibility, map of terrestrial isochrones, and map of aerial isochrones

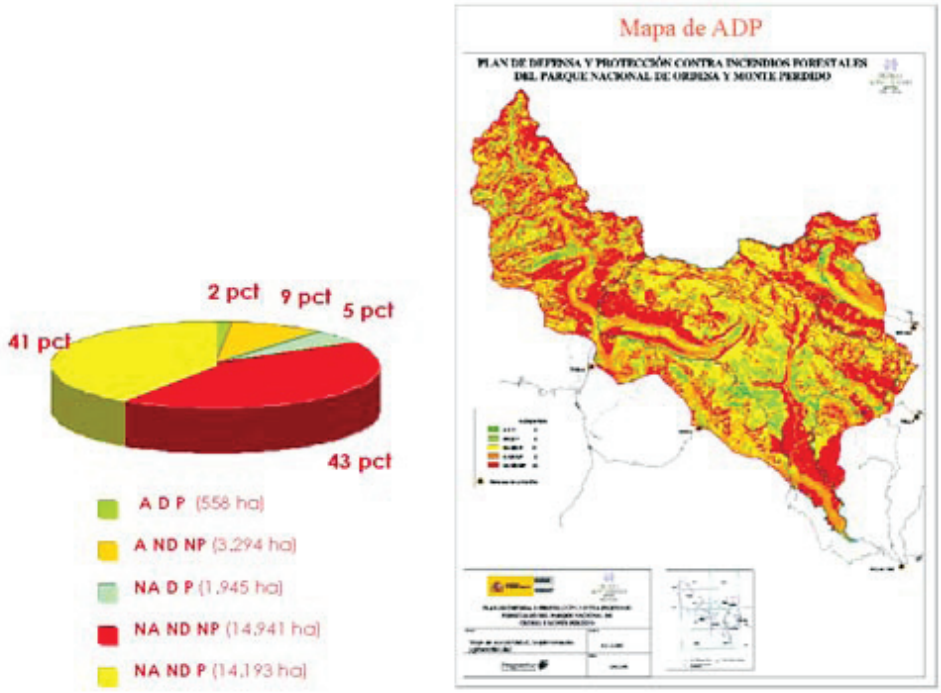


Figure 9—ADP Map (accessibility, displacement and penetrability)

The results of this analysis indicated the need to reinforce some aspects of the fire prevention measures in the park and its surroundings.

The protection measures proposed in the plan were structured in three main sectors: prevention, vigilance and suppression.

Nevertheless, it should be pointed out that the particular nature of this area and the high level of protection it enjoys, limits management of the area to the terms of the Plan Rector de Uso y Gestión (PRUG 1995 – Use and Management Plan-) guided by the Conservation Principle and has to respect natural processes, therefore **prevention** from the classic and most efficient perspective oriented towards dealing with large scale forest fuel, does not fit the model in Ordesa. However the Plan considers the need to develop preventive activities reinforcing the **water supply infrastructure** in those points of the area where the Plan has detected a shortage, maintaining the existing **road infrastructure** to facilitate use of suppression resources and by preventing the outbreak of fire through measures to increase **public awareness**.

Detection and suppression are of supreme importance in the prevention of fires in the Park and surrounding area, since a rapid alert considerably diminishes the extent of the effects of fire which is translated to a reduction in the normally elevated cost of putting out the fire.

El Plan was created within the framework of GSI (Geographic Information System) which facilitated incorporation of cartographic and alphanumerical information obtained from analyses carried out for integration in DINAORDESA, a system conceived to facilitate management of the Park by providing extremely detailed territorial information.

Bibliography

Balcells, E. 1988. **Monografía 37**. **Ordesa-Viñamala**. Ministerio de Agricultura Pesca y Alimentación. Instituto Nacional para la Conservación de la Naturaleza

Boletín Oficial de Aragón. **Decreto 226/1996, de 17 de agosto, por el que se aprueba el Plan Especial de Protección Civil de Emergencias por Incendios Forestales - PROCINFO.**

Boletín Oficial de las Cortes Generales. Ministerio del Interior, 8 de marzo de 1993. **Informe de la Ponencia designada en el seno de la Comisión de Agricultura y Pesca sobre Incendios Forestales.**

Boletín Oficial del Estado. **Ley 2/1985, de 21 de enero, sobre Protección Civil.**

Boletín Oficial del Estado. **Real Decreto 407/1992, de 24 de abril, por el que se aprueba la Norma Básica de Protección Civil.**

Boletín Oficial del Estado. **Orden de 2 de abril de 1993. Directriz Básica de Planificación de Protección Civil de Emergencia por Incendios Forestales**.

Boletín Oficial del Estado. **Real Decreto 409/199, de 17 de marzo, por el que se aprueba el Plan Rector de Uso y Gestión de Ordesa y Monte Perdido.**

Dirección General de Protección Civil. 1996. **Plan Estatal de Protección Civil para Emergencias por Incendios Forestales**. Ministerio del Interior.

Fab Consultores S.A. 1.993. **Resúmen del Estudio sobre motivaciones de incendios forestales intencionados. Instituto Nacional para la Conservación de la Naturaleza.**

Gobierno de Aragón. Departamento de Agricultura y Medio Ambiente. Dirección General del Medio Natural. Servicio de Protección del Medio Natural. 1995 **los incendios forestales en Aragón. Memoria 1.995. Plan de prevención y lucha para 1.996**

ICONA, 1981. **Técnicas para defensa contra incendios forestales. Monografia nº 24.** Varios autores.

ICONA, 1991. **IV Curso Superior de Incendios Forestales**. Varios autores. Ministerio de Agricultura, Pesca y Alimentación.

ICONA, 1993. **Manual de Operaciones contra Incendios Forestales**

ICONA, 1997. **Partes de incendios del periodo 1979-1997**. Área de Incendios Forestales.

Margalef, R. 1991. **Teoría de los sistemas ecológicos**. Universitat de Barcelona. Estudi General. Ciencies experimentals i matematiques.

Miguel, A. 1998. **Bases para la ordenación del pastoreo en el Parque Nacional de Ordesa y Monte Perdido (Huesca)**.Proyecto Fin de carrera. Escuela Técnica Superior de Ingenieros de Montes. Universidad Politécnica de Madrid.

Ministerio de Agricultura, Pesca y Alimentación. 1988. **Mapa de cultivos y aprovechamientos escala 1:50.000**. Hojas 1.083, 1.085 y 1.088.

Moreno, J. y Aragoneses, C., 1995. **La cartografía en la planificación de los Parques Nacionales**. Mapping: 23, 38-44.

Red de Parques Nacionales. Gorría, A.J., 1.992. **Los efectos de la declaración del P. N. de Ordesa y Monte Perdido en la población y el sistema socioeconómico de su entorno.** Documento de síntesis.

Rivas-Martínez, S. 1987. **Mapa de series de vegetación de España**. Ministerio de Agricultura, Pesca y Alimentación. I.C.O.N.A.

Rothermel, R. C. 1972. **A mathematical model for fire spread predictions in Wildland fuels**. USDA Forest Service. Int USA.

Rothermel, R. C. 1983. **How to predict the spread and intensity of forest and range forest fires**. USDA Forest Service. Int USA.

Ruiz de la Torre, J. 1990. **Distribución y características de las masas forestales españolas**. Ecología, Fuera de Serie, nº 1. ICONA.

Universidad de Santiago de Compostela. Escuela Politécnica Superior. Campus Universitario. Lugo. 1997. **Ponencias sobre el estado de la investigación y el desarrollo en protección contra incendios forestales en España.I Seminario Nacional.**

Velez, R y otros, 1982. **Manual de prevención de incendios mediante tratamiento del combustible forestal.** ICONA.

Page left blank intentionally.

Integral Plan for the Prevention of Forest Fires in Spain in the Case of the Community of Valencia[1]

Javier Gómez,[2] Ángel Guzmán[1]

Absract

The integral plan for forest fire prevention takes into account every aspect of the behaviour of the forest ecosystem in a forest fire, proposing adequate preventive measures for fuel management, considering the most important changes of forest use in recent decades so that fuel accumulation constitutes one of the main risk factors in the outbreak of large-scale fires. But also it includes the creation and maintenance of a road network and water supply infrastructure leading to rapid, safe and efficient fire extinction.

However, in order to ensure that the above infrastructures function successfully within the concept of sustainable forest management, direct action on each and every cause of forest fires is proposed. Therefore, in addition to acquiring detailed knowledge of each of those causes, conflicts are analysed and conciliation systems established alongside a system of active dynamic vigilance with a presence throughout the territory, able adapt to changing hazard conditions.

Introduction

The gradual reduction of the number and the extent of forest fires is a basic aim of the Conselleria de Territorio y Vivienda del Gobierno Valenciano, (regional planning department) and one which, despite its achievements so far, is not an easy task and which is, of necessity, an ongoing endeavour, incorporating new measures, resources, technologies, and moreover, constantly dependant on the maximum cooperation of public sectors.

Prevention is the key in the battle against forest fires. Data shows time and again the obvious correlation between the number of fires over the years and the surface area affected, thus any action towards reducing the number of fires is fundamental in an overall fire-fighting strategy.

A reduction in the number of fires is therefore essential in the search for a definitive solution to the problem, and the *Generalitat Valenciana* (the Valencia Government) has in recent years dedicated a considerable part of its budget to achieving this end, in educational and awareness programmes, the conciliation of interests with those who make use of the woods and surrounding areas, research into the causes of forest fires, forestry and environmental volunteers, and preventive vigilance.

---

[1] An abbreviated version of this paper was presented at the second international symposium on fire economics, policy, and planning: a global view, 19–22 April, Córdoba, Spain.

[2] Consellería de Territori i Habitatge. Generalitat Valenciana. C/Francisco Cubells 7. 46011 Valencia (España).

Programmes implemented both through direct investment and grants, with the latter being an increasingly used measure, there are help lines in progress for assistance with voluntary environmental activities, dissemination of forest fire prevention measures in the agricultural sector, the promotion of controlled grazing biomass control and elimination of agricultural waste without the use of fire (pilot scheme).

However the prevention of forest fires does not end once the aim of reducing the number of fires has been achieved, the second objective is to reduce the area affected by fire.

Actions to reduce the number of fires are complemented by others, no less important, which facilitate rapid fire detection followed by swift, efficient and safe extinction of the fire through, for example, the implementation of a network of forest firebreak zones, the extensive reintroduction of livestock in forest areas as a natural undergrowth eliminator, the expansion and improvement of the Forest Security Plan, both in terms of forest look-out points and the mobile security with the incorporation of more modernised vigilance units

All this is the key to the success of the forest fire prevention policy currently being implemented by the Valencia Government.

Knowledge of the causes

Knowledge of the causes and motives for forest fires is fundamental when designing various prevention policies, and essential to this is the work carried out by the Research Operation Group for the Causes of Forest fires.

This team, which has been in operation since 1995, is a key player in prevention strategy, and in recent years its work has discovered over 90% known causes of fires in the state sector over the years.

Conciliation of interests

The concept of the conciliation of interests is complex and includes various activities such as the ordering of recreational use, promotion of alternatives systems, to use of fire in agricultural procedures, promotion of controlled grazing, as a tool of biomass control etc.

The aim is not so much to act directly on the direct cause of the forest fire but rather on the problematic structure which determines the creation of hazardous situations or negligent attitudes which could give rise to a forest fire.

The promotion of biomass control by means of controlled grazing, for example, has been one of the most successful projects which, in addition, re-establishes a traditional practice beneficial to fire prevention.

This technique of extensive controlled grazing is carried out with the cooperation of farmers and the Valencia government, which provides the extra costs this activity generates.

Controlled grazing is implemented on the basis of a plan of exploitation, involving the number of livestock owned and the area of hectares available. The plan

establishes both the number of hectares to be grazed daily, based on the numbers of livestock owned, and the number of hectares of grazing over a specific period.

The plan establishes rotational grazing with periodic appraisals to determine the response of the vegetation and to check that rational use is being made of resources so that the environmental benefits are optimised to the highest degree.

At the same time measures are being taken to provide the forested areas with an agricultural support infrastructure with the construction of sheep folds and drinking troughs for livestock.

Also important in respect of conciliation of interests, is making the elimination of agricultural waste and forest fire prevention compatible, and to this end projects such as the Local Burning Plans in the municipal sector or subsidising of agricultural waste burners have been put into practice.

However, there is a clear desire to promote new technologies for the disposal of agricultural waste which would obviate the need for burning, and pilot schemes for the disposal of agricultural and vegetable waste without the use of fire should be mentioned.

Vigilance

A continuous growth plan

The Vigilance Plan is a prime objective in the Valencia Government's forest fire prevention policy, and there has been a constant rise in financial, material, human and technological resources with a budget of 10,154,677.99 € allocated in 2003.

A dynamic plan

Several collectives and administrative departments carry out the functions of patrolling and controlling the woods and forests of the Community of Valencia *(Table 1),* and it is therefore important that they act in a coordinated way. The Vigilance Plan therefore, is not simply the sum of its parts but effectively a strategy which defines the guidelines and criteria for implementing those means in an effective and dynamic manner.

The plan is designed to adapt to hazardous conditions; in order to plan the activities of the prevention units, studies determine in each local area and operative zone, the period and moments of greatest risk, thus enabling service to be available to coincide with these conflictive periods. In order for this response to be effective the plan needs to operate 365 days a year. This objective is achieved through a progressive system of incorporation which ensures the presence of vigilance services all year round.



Figure 1— Mounted and land vehicle fire prevention unit

Table 1— Among the various prevention units included in the Vigilance Plan those managed by the Town and Country Planning Dept. are particularly noteworthy

Units	Alicante	Castellón	Valencia	Region	Total
Ordinary prevention units	18	20	34	-	72
Horseback units (fig. 1)	1	3	1	-	5
Motorbike prevention units	3	3	5	-	11
Multi-purpose prevention units	4	4	6	-	14
Helicopter transport units	-	-	-	1	1
Technical unit	-	-	-	1	1
Forest lookout points	13	25	33	-	71
Environmental agents	53	65	109	-	227
Cause investigation group	3	2	3	1	9
Technical personnel units	13	11	16	3	43
Communications Centre	1	1	1	-	3
Total	**109**	**134**	**208**	**6**	**457**

This, together with participants in the voluntary environmental and forestry programmes, and the resources provided by the regional Justice and Administration Department, local government bodies, Local Police, Ministry of Environment and the Forces of State Security amounting to the participation of more than 5,000 people in 2003.

Forest look-out posts

Another basic element in the setup is the network of forest look-out posts, since in addition to the vigilance work they carry out, they are also important for the coordination of both the Community of Valencia's Vigilance Plan for the Prevention of Forest Fires and for forest management.

The maintenance and improvement of this network is a permanent goal, and various work projects are being undertaken which will result in more efficient services and improvements in safe working conditions for all personnel. Within this framework of improvements in the efficient service of the forest look-out points since 2002, a remote controlled camera system has been introduced in the area of the forest look-out point of Font Roja.

Similarly, the network is currently being extended, with 4 new look-out points which will benefit from the latest architectural techniques as part of a pilot scheme.

Volunteer force

The volunteer force is a force for public change characterised by its disinterested, supportive in nature and participation; it does not in any way substitute or relieve anyone of their responsibilities but is nevertheless a process which affects the conception, attitudes and values both of the person who carries out voluntary work and the society to which that person belongs.

Of all the fields in which voluntary action can be developed, defence of the environment and specifically the prevention of forest fires is one of the most important and one of those in which the Valencia public have shown considerable interest, and as a result, the Valencia Government has assumed the task of promoting and acknowledging this by means of aid and through direct action.

Improvement of infrastructures

Correct forest management requires an adequate infrastructure with a network of units, some of which attempt to prevent fire spreading and such as firebreak areas or water tanks, and others in addition to being useful and fundamental to halting the spread of fire are also extremely useful for vigilance and management of forest systems such as roads and look-out points.

The forest road network

Of all these measures the improvement and maintenance of the forest road network is extremely important, since in ensures correct management of the forest terrain, both in terms of improvement of forest quality, vigilance and when the need arises,

providing immediate and safe access for fire-fighting teams in the event of forest fires.

To this end a series of continuous investments are being made in an effort to improve this road network with a series of projects designed ultimately to create a hierarchical network which, irrespective of meteorological conditions, will always be roadworthy for the modes of transport of the management, vigilance and extinction departments.

Water tanks

The water supply network has been designed with a practical approach, the purpose of which is to provide the forest areas with an open deposit for every 2,000 hectares, with a minimum capacity of 200.000 litres *(fig 2*), thus ensuring a rate of to 6 minutes between loads for fire extinction helicopters.



Figure 2—Example of a water deposit for fire extinguishing services

In recent years the number of facilities has considerably improved, thus fulfilling one of the prevention policy goals, namely to reduce the number of fires and to ensure that when fires break out, the infrastructure permits rapid, safe and efficient implementation of fire-fighting methods, and an important aid in achieving this end is the integration of all the information available in the Integrated Management System

Firebreak areas

The present situation of forest fuel, social and economic changes which have taken place in recent decades (abandonment of traditional agricultural foresting practices,

such as timber use; end of agricultural activities, reduction of grazing) together with the natural vegetation system of the Mediterranean area, have led to a situation in which the risk of a "catastrophic" forest fire is real one.

It is therefore necessary to propose policies for fuel management of forest land, which would be considered useful not so much in an ordinary fire but in the Great Fires which tend to recur in Mediterranean areas.

The previous proposals, in conjunction with the reality of forest fires which have occurred during the last decade in the Community Valencia, have been instrumental in the Valencia Government's assumption that essential to its policy of forest fire prevention and extinction, is the development and implementation of a Preventive Forestry Plan drafted with strict adherence to technical guidelines and in line with the international scientific community which supports fuel management as a basic strategy in the campaign against forest fires.

The plan has been devised to include the total forested area of the Valencia Community, irrespective of whether the property is public or privately owned. In order to ensure that the plan is also executed on private land a process is underway to declare Urgent Action Zones, by means of Regional Government Decree.

Another fundamental characteristic of the Plan is its commitment over time which requires the maintenance of 2 to 4 year periods. This maintenance is currently in progress in the initial areas where the plan has already been implemented, and for which, apart from the traditional systems, other compatible methods are being developed such as biomass management using controlled grazing and truffle cultivation forestry.

As mentioned, the Plan has been designed to cover the total forested territory of the Valencia Community, for which it has 68 areas of activity which form part of the corresponding work projects, which include activity both in public and private forest land, and therefore, prior to carrying out projects in privately owned woodlands, a declaration of Urgent Action Zone is implemented in every area.

New management systems

To date, various forest fire prevention schemes have been developed, the creation of which required the response to a series of basic questions such as Where can a fire occur? How can it occur? When can it happen? The reply to these questions is obtained from knowledge of situations of risk in time and in space.

Knowledge of such situations permits "mobilisation" of prevention resources which are able to prevent the outbreak of fire, or, if this is impossible, at least the effects may be minimised.

Nevertheless, it should be borne in mind that given the nature of a region as varied as Community of Valencia in which risk factors are changeable and in many cases due to a complex interrelation of multiple factors. It is therefore necessary for those in management when making decisions to have at their disposal support tools which should be reliable and appropriate to the social and climatic characteristics and to the physical terrain to which they will be applied.

The Integrated Management System (IGS), implemented at the end of 2002 con as an experiment is a dynamic tool which though based on a Geographical

Information system is much broader in scope as it can process and generate varied information, since it serves and is served by various forest fire prevention programmes already implemented by the Valencia government and which have such positive results in reducing the effects of forest fires in the Valencia Community.

Dissemination of preventive messages

Despite the importance of all the activities described, it is nevertheless necessary to maintain and carry out campaigns disseminating the messages of prevention at all levels of society either through general campaigns such as those using communications media, via radio, television or newspapers. Also, and very importantly, through specific campaigns which focus for example on the agricultural sector and are publicised through agricultural unions and associations or through specific activities such as environmental education.

Implementation

These activities are implemented in two ways, through direct investment and by means of grants either to the proprietors of forestry land both public and private or to specific bodies, the financial breakdown of which is indicated in table 2.

Table 2— *The table shows the various budgets allotted in 2003 to various forest fire prevention programmes carried out in the Community of Valencia*

Programmes	**Euro**
Information and awareness	167.980,00
Forestry Education and dissemination	Not quantifiable
Conciliation of interests	4.277.386,00
Management	130.230,48
Forest vigilance and volunteer plan	10.154.677,99
Forest fuel management. Preventive forestry	3.636.362,00
Environmental volunteers	778.015,20
Other infrastructures. Material and human resources	4.270.158,00
Total	**23.414.809,67**

Program for Postfire Monitoring and Control in the Forest Ecosystems of Moratalla (Murcia, Spain)[1]

Juan de Dios Cabezas,[2] Remigio Masia [2]

Abstract

The complexity of factors involved in a forest fire, such as the fire regime, the time of year in which the fire occurs in relation to the phase of the yearly development of the existing vegetation, the type of vegetation, its ability to adapt to fire conditions, its germinative characteristics, the post-fire weather conditions and even the microclimatic effects resulting from differences in aspect, makes it impossible to predict with absolute certainty the response ability of vegetation after a fire has occurred.

Monitoring the post-fire evolution of forest systems affected by large fires helps fire management specialists to establish the most appropriate action for restoring the burned areas.

The Forest Fires Monitoring Program for the Murcia Region, presented herein, has implemented the study of the effects of two large fires on the region's forest ecosystems, namely Calasparra in 1991, which affected 800 ha, and Moratella in 1994, where 24,000 ha were affected, 65% of which were wooded area.

Although the evolution of forest systems depends a great deal on the ecological conditions and the type of management implemented, the structure and constitution of the existing new population—that is, the regeneration—is one of the most decisive aspects. Using territorial information regarding land use, vegetation, relief, edaphology, etc., and basing data primarily on the 1999 National Forestry Inventory conducted in the Region of Murcia, the Program divides the territory into zones according to their current state of regeneration and examines the main indicators of the state of these areas.

With the results obtained, the process can be characterized appropriately and used to plan measures aimed at restoration, conservation, and improvement of the vegetation cover, as well as other important measures to diminish erosion, such as stabilizing slopes and correcting torrential flow through hydraulic engineering, and protective measures against the risk of forest fires and the phytosanitary damages that inevitably result from a fire.

Introduction

In the Region of Murcia, forest fires do not occur with the same frequency as in other areas of the Mediterranean Basin. During the period 1992 – 2001, although 1,393 fires affected almost 28,000 ha, 24,817 ha corresponded to the Moratella fire of 1994.

Nevertheless, the weather conditions of scarce precipitation and high temperatures, and more importantly, certain structural conditions such as the desertion of the rural environment and the lack of forest management in the majority

[1] An abbreviated version of this paper was presented at the second international symposium on fire economics, planning, and policy: a global view, 19-22 April, 2004, Córdoba, Spain.

[2] Consejería de Agricultura, Agua y Medio Ambiente. Dirección General de Medio Natural. Catedrático Eugenio Úbeda, 3. Murcia. CP 30008 (Ministry for Agriculture, Water and the Environment. General Direction for the Natural Environment).

of private forest areas, which leads to the accumulation of forest fuels, all create the ideal setting for forest fires.

The gravity of the situation calls for the implementation of an integrated forest policy that recognizes the permanent risk of fires and provides for a series of measures aimed at mitigating the problem. This idea is established in the Spanish Forest Strategy and in the Spanish National Forestry Plan, which considers the defence and protection against fires to be a priority for future actions.

Along the same lines, the Region of Murcia Forest Strategy expresses the need to develop Fire Protection Management in order to counter the high degree of damage caused by fires. Such management would involve different levels of planning according to the marked objectives.

Among other protective measures, the Region of Murcia Forest Strategy incorporates fire prevention, alertness and suppression, and the promotion of research and training to improve knowledge of the problem. Special importance and priority is given to the need to develop a Post Forest Fire Monitoring Plan, which through individualized, continual and systematic study of fires would make it possible to define a post-fire action plan establishing regulated procedures for control and restoration of burned areas.

Analysing and reviewing the diverse factors influencing the state of the vegetation cover after fire damage and verifying the efficiency of the measures taken for the restoration thereof will provide data as to how an ecosystem responds to the effects of a fire. This will in turn help to identify the necessary measures to guarantee a complete restoration of the damaged vegetation cover.

Development of the Plan

The area of study is located in northwestern Murcia, mainly in the Northwest Region and the Cieza municipality (*figure 1*).



Figure 1—*Geographic location of the area of study*.

The geographic area in question measures 28,137 ha, of which 91% is forest land where tree systems in regeneration clearly dominate the prevailing brush formations. The most extensive tree formations are the *Pinus halepensis* forests in

regenerated state, as oak trees are scarcer and not in pure form, but rather mixed together with pine trees *(figure 2)*.



Figure 2—*Pinus halepensis in regenerated state.*

It is important to note the valuable natural wealth of the area of study, which is home to diverse ecosystems of important species of flora and fauna. Many of these ecosystems have been granted special protection, such as the Special Protection Areas (S.P.A.) under the Bird Directive: Sierra de Moratalla and Sierra del Molino, Quipar Reservoir, and Cagitán Plains; the Sites of Community Importance (S.C.I.): Sierra de la Muela, Sierras and Vega Alta del Segura and Benamor River, and a Protected Natural Area: Sotos y Bosques de Ribera de Cañaverosa Natural Reserve.

After the fires, the vegetation cover was restored with aleppo pine in specific areas and silviculture treatments were carried out on smaller areas, namely earthing-up (ridging), felling and thinning.

Roads were also improved and woodland hydrological structures were restored. This latter measure mainly involved constructing dykes to prevent the possible negative effects of soil loss, erosion, desertification, etc., which are foreseeable in the short and medium terms *(figure 3*). In addition, treatments to combat the pine processionary caterpillar were carried out in the Moratalla Municipality.



Figure 3—*Hydrological works and road improvement in the area of study.*

Using territorial information regarding land use, vegetation, geomorphology, edaphology, etc., and basing data primarily on the Third National Forestry Inventory

conducted in Murcia in 1999, the territory was divided into zones according to current state of regeneration. This was done with the objective of establishing the measures for restoration of the area *(figure 4*).

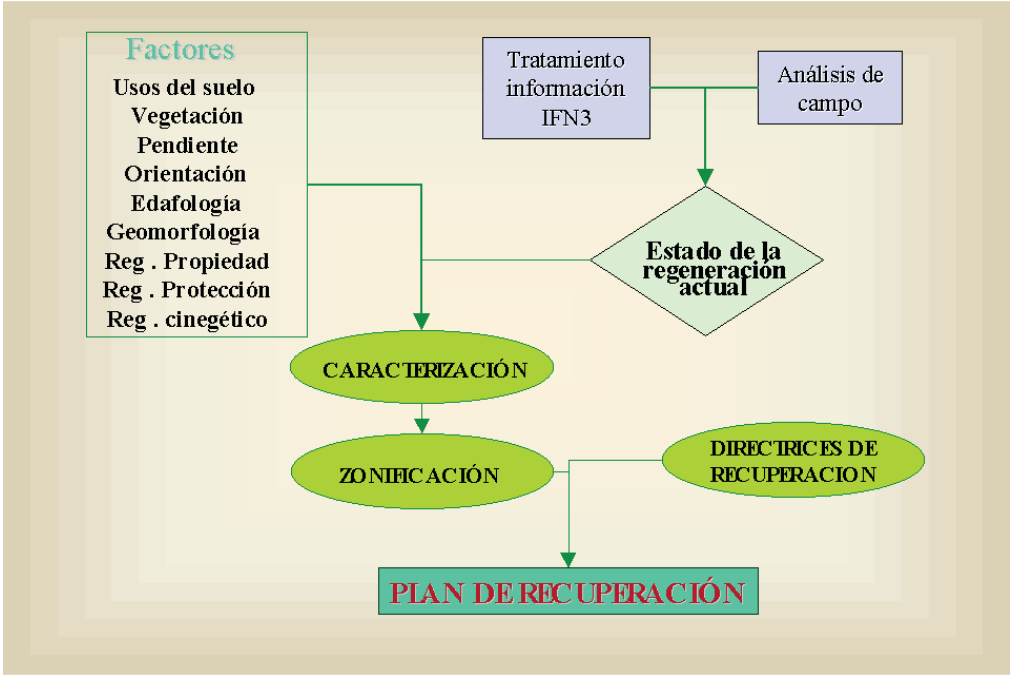


Figure 4—*Program content.*

Such an extensive territorial scale makes it impossible to control in detail the numerous variables affecting regeneration. Nevertheless, the results obtained were sufficient to adequately characterize, in general terms, the process to be used in forest planning for the area studied.

Current state of regeneration

The evolution of forest systems depends heavily on the ecological conditions and the type of management implemented. However, the structure and the constitution of the existing regeneration constitute one of the most determining factors.

In order to know the current state of regeneration, the principal indicators were analysed, namely regeneration density and the development stage of the regeneration.

The study was conducted in the framework of a geographic information system, with which **the field plots charted in the National Forestry Inventory** coinciding with the area of study **were identified**. The process of cartographic and alphanumeric information regarding the plots contained in the data base—specifically in terms of type of regeneration and density or number of plants per category of development, which is shown by the height and normal diameter—made it possible to calculate the value of the regeneration density variable in each sampling point.

Following that, a regeneration model was created using statistical techniques such as spatial interpolation in order to estimate the value of the variable in the non-sampled points in the area covered by the existing plots. In order to apply this method a buffer zone was created; that is, the area included between the limit of the surface area with a fictitious limit, formed by the succession of points 5 kilometres from the exterior of the original boundary. Having data on the regeneration of the plots included in the buffer zone, and applying the spatial interpolation method, a model was created to the boundary of the burned area, thus remedying the lack of values. The result obtained is the value of the indicator **regeneration density of all the species (feet/ha) and in all stages of development** (*figure 5*).

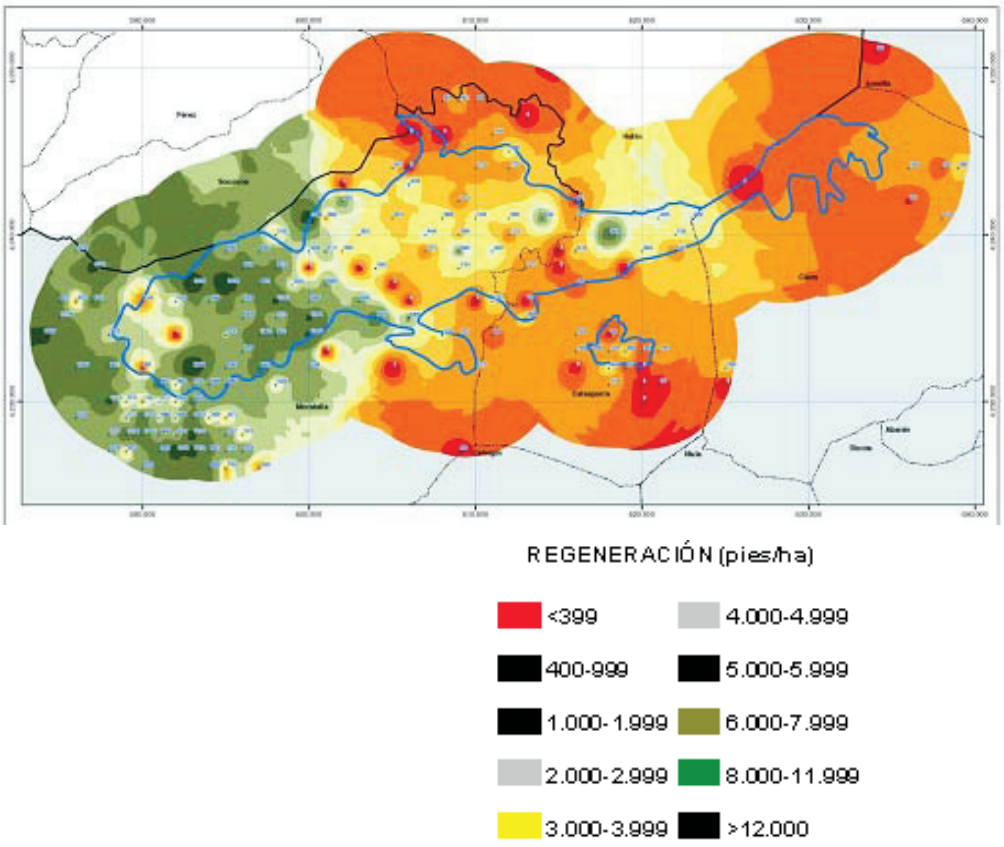


Figure 5—*Regeneration map.*

After the current state of regeneration in the area of study was obtained by spatial interpolation, the area was divided into homogenous units. The measures taken in each unit would then correspond exactly to the needs of the unit.

Firstly, by using orthophotography and with the support of DINAMAP GIS, the different areas were digitalized by photo-interpretation, with special attention placed on the criteria of land use and the degree of vegetation cover (*figure 6*).

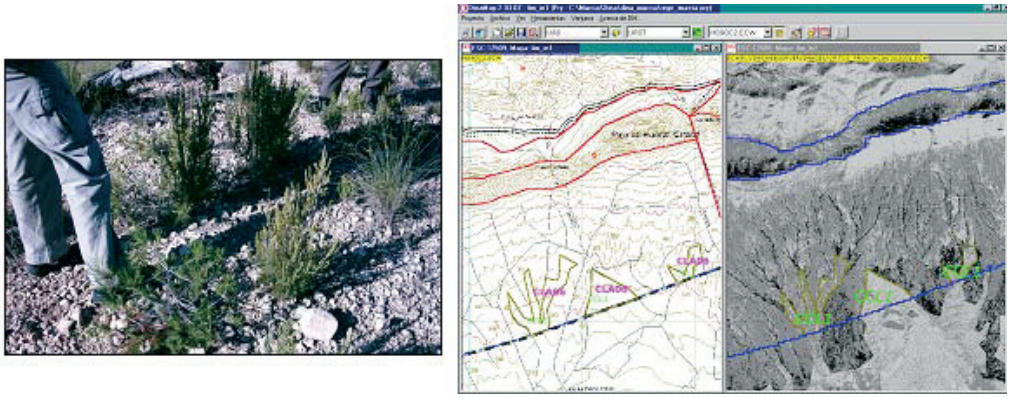


Figure 6—*Field work: Division of the territory in homogenous units of regeneration (DINAMAP GIS).*

Subsequently, in the field work stage, visits were made to the different units in order to verify their homogeneity in terms of existing regeneration density. In cases where the density was not homogenous in the unit, new units were identified and zoned in the field. The regeneration density of the dominant species (*Pinus halepensis*) was estimated, and a nine-level classification was established according to the following values (*table 1*).

Table 1—*Regeneration density. Field data.*

Levels	Number of ft/ha
1	<400
2	400-1,000
3	1,000-2,000
4	2,000-4,000
5	4,000-6,000
6	6,000-8,000
7	8,000-10,000
8	10,000-12,000
9	>12,000

The results obtained made it possible to identify 92 territorial units that were homogeneous in terms of regeneration, as reflected in the following diagram *(figure 7*):

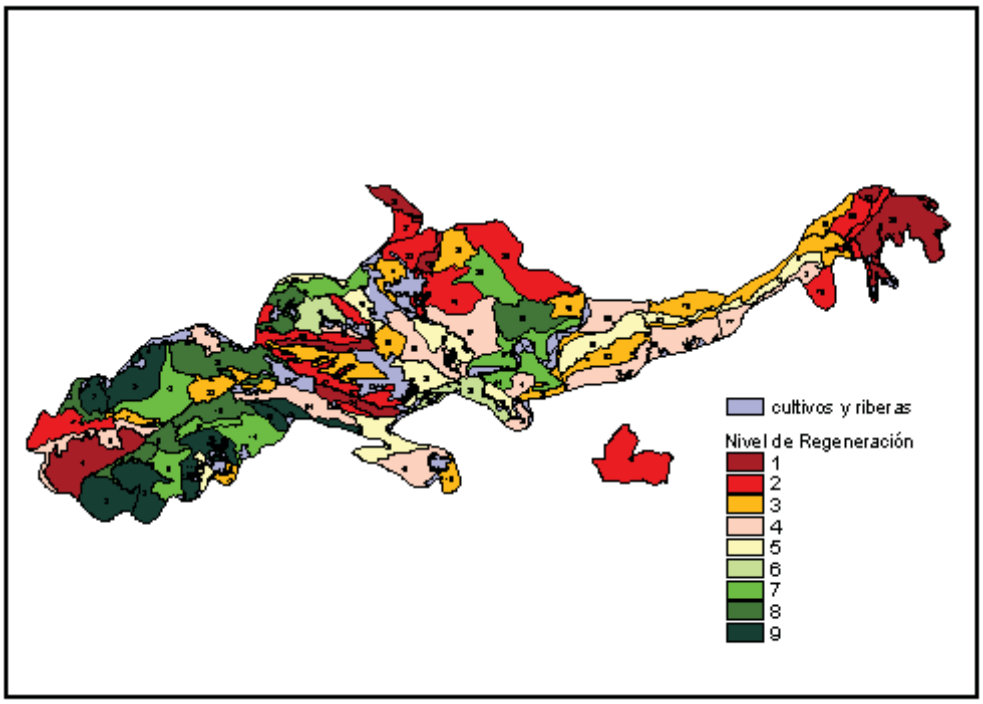


Figure 7—*Zoning of the area according to regeneration level.*

Once the units of homogenous regeneration were established, the specific characteristics of each were examined in order to facilitate the structuring of the measurements to be taken.

Foundations and guidelines for recovery

The recovery of the vegetation cover sometimes occurs naturally with no human intervention, at least when the intensity of the fire is moderate or low or when the existing vegetation species have fire adaptation mechanisms. This is the case for *Pinus halepensis*, with a high percentage of serotinus seeds whose dormancy is broken by the high temperatures of a fire.

When the natural regeneration process is underway and no measures have been taken immediately following the fire, the best solution is to take no action whatsoever, given that movement of machinery could damage budding vegetation.

Nevertheless, human intervention is indeed necessary in the majority of cases, either to promote regeneration through silvicultural measures improving the crop, or through restoration measures when situations of soil loss, erosion, etc., are foreseeable in the short or medium-term.

Once the units were categorized as per their regeneration state, the measures necessary for restoring the forest dynamism were planned.

The actions proposed for the area of study were aimed at restoration, conservation and improvement of the vegetation cover. In addition, other important steps were planned to reduce the effects of erosion, such as stabilization of slopes and correction of torrential flows through hydraulic engineering.

Protecting the head of basins, mainly in areas of high erosion potential, is a priority when a fire has wiped out the vegetation cover of an area.

Likewise, as laid out in the regional Forestry Strategy, special attention must be paid to the restoration and conservation of riverside systems due to their important role in preventing erosion, their natural regulation of flood flows, their contribution to water quality improvement, and the diversity and wealth contained in their ecotones.

Finally, a series of measures were carried out to help the woodland overcome effects of the forest fires and the phytosanitary damages that are inevitably produced after a fire.

Restoration was planned bearing in mind the aim of achieving a stable and permanent tree population in balance with the environmental conditions. This general objective does not exclude the maintenance of less mature vegetation when the ecological or floral value of this vegetation is worth conserving, or when the tree and shrub population is incompatible with the natural site conditions, as is the case with esparto grass areas.

In light of the protective character of these repopulations, they were planned in line with fire protection criteria. In that regard, the density of the repopulation was conceived in such as way as to be coherent with the design of firebreaks in areas near infrastructures such as trails, roads, etc.

The **measures proposed** for restoration of the area were structured in two separate categories: firstly, **biological measures**, which integrate all the actions aimed at restoration, conservation, and improvement of the vegetation cover, as well as actions to control the phytosanitary damages produced by the fire. Secondly, a series of **supplementary measures** were developed to prevent erosion and the risk caused by forest fires.

In order to define the biological measures for the area of study, the units zoned during the fieldwork stage were grouped in a preliminary classification, eliminating those **areas where no measures were to be taken** (such as crop areas, non-productive lands, and esparto grass areas). The rest of the land was considered **possible areas for implementing measures**. For these latter areas, a study was made of the influence of ecological factors such as current state of regeneration, slope, aspect, altitude, edaphology, rainfall, etc.

In order to establish the units for the different measures to be taken, the most determining factors are considered: **the current state of regeneration, altitude and slope of the land**, given that as was observed in the field, the regeneration model reflects the influence of aspect (shaded areas had higher regenerated density) and water availability (more intense regeneration occurs in areas with higher precipitation and water flow accumulation). In addition, in the event the introduction of species is a possibility, the altitude determines the species that can be introduced. Lastly, slope is a determining factor when deciding whether or not mechanized labour will be used for preparing the land. With respect to edaphology, it was demonstrated through the field work that, in general, soils are not determining factors in the regeneration level, except for those with special characteristics and highly localized distribution.

Once it was determined which measures would be carried out on which plots of land, and in order to determine **the surface area marked for restoration**, the land was organized according to regeneration development and density. Specifically, the

superficial distribution of the regenerated density was considered in each plot of land for each of the categories (*table 2*).

The measures proposed are as follows:

Table 2– *Measures according to the category and density of the regeneration.*

Measures	Number of ft/ha
1	Restoration of the vegetation cover in areas with density of 0-400 feet/ha and regeneration category 1
2	Restoration of the vegetation cover and earthing-up (ridging) in areas with density of 0-400 feet/ha and regeneration categories 2, 3 and 4
3	Restoration of the vegetation cover and earthing-up (ridging) in areas with density of 400-1,000 ft/ha and regeneration category 1
4	Restoration of the vegetation cover and earthing-up (ridging) in areas with density of 400-1,000 ft/ha and regeneration categories 2, 3, and 4
5	Support for regeneration in areas with density of 1,000-2,000 ft/ha and regeneration category 1
6	Earthing-up (ridging) in the regeneration of aleppo pine in areas with density of 1,000-2,000 ft/ha and regeneration category 2
7	Clearance and earthing-up (ridging) in areas of 1,000-2,000 ft/ha and regeneration category 3
8	Clearance and earthing-up (ridging) in areas of 1,000-2,000 ft/ha and regeneration category 4
9	Silvicultural treatments such as thinning and felling, as well as clearing in areas with density greater than 2,000 ft/ha and regeneration categories 3 and 4
10	Phytosanitary treatments: defoliators
11	Phytosanitary treatments: wood borers

For those areas with scarce regeneration, biological measures were planned, such as efforts to restore the vegetation cover along with earthing-up, clearing and support for regeneration. The total surface area for such measures was 16,545 ha, 23% of which is public woodland.

In those areas with excessive regeneration density, certain silvicultural treatments such as thinning and felling were proposed to encourage the development of the existing regeneration. This was planned for an area greater than 3,200 ha.

In addition, to counteract the weakening of the forest system that occurs after a fire, short and medium-term treatments were planned both for defoliators and wood borers over a total area of 24,512 ha.

In order to guarantee the complete restoration of the ecosystems affected, an investment of 25,883,956 € was deemed necessary. The majority of this figure (25,130,055 €) was earmarked for biological measures, with the remaining portion allocated for the instrumental measures planned, specifically the preparation of forest hydrological restoration plans and the planning of forest fire protection measures.

Bibliography

Brugarolas Molina, Carlos. 2002. **Repoblación forestal. Comunidad Autónoma de la Región de Murcia.** Revista Montes nº69; 78-82.

Martínez Fernández, Faustino. 2002. **Repoblación forestal. Nuevas experiencias.** Revista Montes nº69; 83-85.

Ministerio de Medio Ambiente. **Segundo Inventario Forestal Nacional. Región de Murcia. 1991.**

Ministerio de Medio Ambiente. **Tercer Inventario Forestal Nacional. Región de Murcia. 2003.**

Páez Blázquez, Manuel; Cabezas Cerezo, Juan de Dios; González Rincón, Alfredo. 1999. **Selvicultura preventiva contra incendios forestales.** Revista Foresta, Asociación y Colegio Oficial de Ingenieros Técnicos Forestales; 114-119.

Vélez Muñoz, Ricardo. 2000. **La defensa contra incendios forestales. Fundamentos y experiencias.** Capítulo 4: Efectos del fuego en los ecosistemas forestales. Mc Graw Hill.

Development of Measures for Self-Protection Against Forest Fires: Application in Highly Vulnerable Installations[1]

Francisco Sanz de Julián,[2] Balbina López García [3]

Abstract

The National Institute of Aerospace Technology (INTA), a public research agency founded in 1942 and reporting directly to the State Secretary of Defence, is dedicated to aerospace research and technological development in other industrial areas.

INTA carries out a wide range of research and development activities in different aeronautic disciplines, communication and navigation systems, remote sensing, etc. Development in these fields requires sophisticated and technologically advanced facilities. Should a forest fire occur, these installations would be placed at a great risk.

The threat of forest fires forms part of Civil Protection planning, and is thus contained in the Basic Civil Protection Regulation, which determines the need to prepare Special Fire Protection Plans in corresponding areas of need.

The pertinent regulation for the Community of Madrid is the Civil Protection Plan for Forest Fire Emergencies (INFOMA), which is integrated in the Community of Madrid Civil Protection Plan (PLATERCAM). The Plan lays out the organization of and the procedures for using the resources and services owned by the Autonomous Community of Madrid and any other resources and services that the National Administration or other public or private entities might assign to the Community. The purpose of the plan is to effectively respond to forest fire emergencies within the Madrid boundaries. Accordingly, Appendix 5 establishes the need for Self-Protection Plans for forest fires with measures "involving all the resources (existing human and material resources of a company, isolated centre of population, housing developments, or camp grounds, etc. located in or near a forest area), as well as the regulations for taking action for prevention, initiation of fire suppression, and protection of the population until the time external Action Groups arrive on the scene and intervene".

This framework was used to develop INTA's Forest Fire Protection Plan, which includes a series of preventative measures to effectively and appropriately respond to the possible event of forest fire.

---

[1] An abbreviated version of this paper was presented at the second international symposium on fire economics, policy, and planning: a global view, 19–22 April, 2004, Córdoba, Spain.

[2] Instituto Nacional de Técnica Aeroespacial "Esteban Terradas". Secretaría de Estado de Defensa. Ministerio de Defensa. Carretera de Ajalvir, km 4. Madrid. CP 28850. (The National Institute of Aerospace Technology "Esteban Terradas". Secretary of State for Defence. Ministry of Defence).

[3] Área de Servicios Forestales. Subdirección de Planificación Ambiental. Tecnologías y Servicios Agrarios, S.A. (TRAGSATEC). Julián Camarillo, 6. Madrid. CP 28037. (Forest Services Area. Environmental Planning Sub-Direction).

Introduction

The main aim of the Plan is to equip INTA with a series of self-protection measures, with preventative aspects such as control of forest fuel and water availability, in order to guarantee protection against possible woodland fires which, given the proximity, could affect the Institute's facilities.

The first step in turning this abstract objective into a concrete plan was to divide the area in question into zones and to prioritise the defence measures. This was done by identifying the present forest systems and their flammability, quantifying the fire risk and locating the elements that would be vulnerable in the event of a fire (*figure 1*).

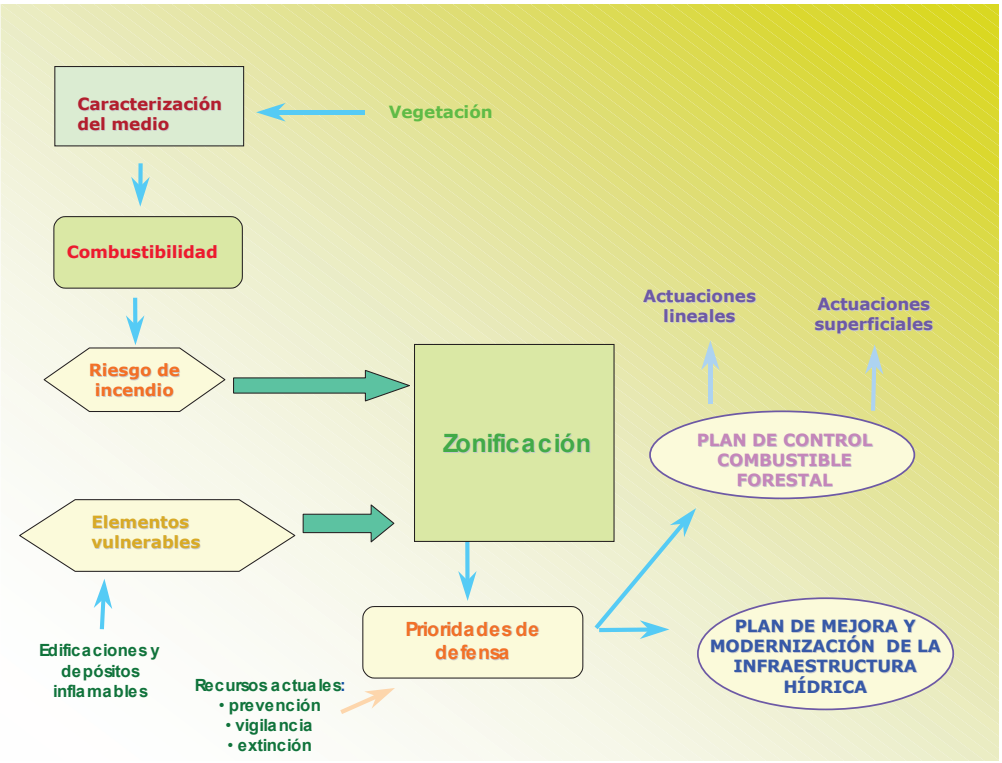


Figure 1—Organization of the Plan.

Description of the Situation

INTA has facilities throughout Spain; however, the main facilities for which the Plan has been developed are located in the municipality of Torrejón de Ardoz and cover more than 363 ha.

The Plan corresponds to two clearly differentiated zones: an essentially woodland area with only a few facilities that covers 306 ha (84% of the total area) and a predominately developed area, where almost all of the Institute's infrastructures and facilities are located.

The area in question was classified according to use and the forest systems were identified by using georeferenced orthophotography supplied by INTA's Remote Sensing Laboratory and taken during a flight with an AMDC (Airborne Multiespectral Digital Camera) in early 2002. The classification was also done with

the support of TRAGSATEC's Dinamap SIG software for the development of projects with three basic components: cartography, databases and images.

Development of the Plan

Zoning

In the **woodland** zone, the most relevant factor is the **risk of spread**, interpreted in the Plan through flammability. The relief factor is not taken into account since the change in level in the area is less than 50 meters and therefore irrelevant when considering spread.

Within the **urban** area, practically all the buildings are occupied during the week, and thus the occupants of the buildings are at risk. Evacuation plans are therefore required.

In addition, factors such as the presence of inflammable materials or the nature of activities that could take place in certain facilities are especially important and were taken into account when prioritising the preventative measures.

Accordingly, the territory was zoned bearing in mind the aspects of risk of spread and the classification of vulnerable elements (*figure 2*).



Figure 2—Map of protection and defence priorities (Very high priority: Sector 1, Moderate Priority: Sector 2, High Priority: Sector 3)

From this zoning, priorities for protecting and defending the installations were established in the form of two Plans: Improvement and Modernization of the Water Infrastructure and Forest Fuel Control.

Improvement and Modernization of the Water Infrastructure

INTA's facilities house a complex network of well-water pipes that provide water to 40 hydrants—all of which are type 100 except two type 80—through a 20 KW pump supplying between 3.5 and 4.5 kg/cm^2 pressure. The pump takes water from an 800m^3 reservoir that is refilled with water extracted from the well by an underwater

pump. In addition, the fire suppression system includes a series of hydrants serving certain buildings not connected to the mentioned well-water mains but rather to auxiliary deposits or directly to the Canal de Isabel II water network.

Overall, INTA has a total of 53 exterior hydrants, 83 valves and 15,700 m of piping, mainly high-density polyethylene and fibre cement pipes.

In order to calculate the needs of the facilities, existing regulations[4] were taken into account. Software[5] specially designed for calculating supply and irrigation mains was used for the sizing of the facilities, assigning of the materials, diameters and registered pressure of the piping, and determining the necessary pumping groups. With this software it is possible to simulate the most unfavourable supply conditions.

Once the calculations were made for the current INTA water main, it was apparent that some stretches of piping had to be substituted to satisfy the calculations made of the most unfavourable conditions. It was also necessary to incorporate another pump and another generator, so that the well-water network would have two impulse pumps and two generators, situated on parallel lines so that both pumps could function with electric supply and, in case of a power failure, with the generator.

Likewise, the Plan provides for the incorporation of 35 new type-100 hydrants, 15 of which will be placed consecutively every 200 meters along the test circuit. The remaining 20 hydrants will be placed in different points of the well-water main that surrounds the constructed area.

Forest Fuel Control Plan

The regulation of fuel, or preventative silviculture, is the ideal tool for creating horizontal and vertical fuel discontinuity. Of the methods for modifying or eliminating fuel, the main measures are mechanical clearing, application of herbicides and prescribed burning. In view of the special characteristics of the land on which INTA's installations are found, the following actions are most appropriate:

- **Lineal measures** such as creating and continually maintaining fuel break strips, as both a barrier to advancing fire and as support for fire suppression teams and resources. More than 16 km would be affected by these measures.
- **Superficial measures** that include silvicultural treatments and chemical clearing. The treatments involve thinning or felling, which contribute to the modification of the fuel models by attempting to break horizontal fuel continuity. These treatments would be effected in more than 23 ha. **Chemical clearing** is the best alternative for protecting areas that lie near buildings. The selected herbicide was glyphosate, which is a non-selective, systematic broad-spectrum herbicide. In addition, it biodegrades rapidly.

[4] Norma Básica de la Edificación NBE-CPI/96: Condiciones de protección contra incendios en los edificios y Reglamento de prevención de incendios de la Comunidad Autónoma de Madrid. (Basic Construction Regulation NBE-CPI/95: Conditions for Fire Protection in Buildings and Regulation of Fire Prevention in the Autonomous Community of Madrid.)

[5] GESTAR, diseñado conjuntamente por el Departamento de Agricultura y Medio Ambiente del Gobierno de Aragón, por la Escuela Universitaria Politécnica de Huesca perteneciente a la Universidad de Zaragoza, y por la Comisión Interministerial de Ciencia y Tecnología (GESTAR, co designed by the Department of Agriculture and the Environment of the Regional Government of Aragón, the Polytechnic University of Huesca (part of the University of Zaragoza), and the Inter-Ministerial Commission for Science and Technology)

The herbicide is to be applied to a 25 m strip around the buildings (44 ha to be treated).

Bibliography

Boletín Oficial de las Cortes Generales. Ministerio del Interior, 8 de marzo de 1993. **Informe de la Ponencia designada en el seno de la Comisión de Agricultura y Pesca sobre Incendios Forestales.**

Boletín Oficial del Estado. **Ley 2/1985, de 21 de enero, sobre Protección Civil**.

Boletín Oficial del Estado. **Real Decreto 407/1992, de 24 de abril, por el que se aprueba la Norma Básica de Protección Civil.**

Boletín Oficial del Estado. Orden de 2 de abril de 1993. **Directriz Básica de Planificación de Protección Civil de Emergencia por Incendios Forestales.**

CEMAGREF, 1988. Division Techniques Forestières Mèditerranèennes Jean de Montgolfier. **Guide technique du forestier méditerranéen français. Protection des forets contre l'incendie**

Dirección General de Protección Civil. 1996. **Plan Estatal de Protección Civil para Emergencias por Incendios Forestales. Ministerio del Interior.**

Departamento de Agricultura y Medio Ambiente del Gobierno de Aragón, Escuela Universitaria Politécnica de Huesca perteneciente a la Universidad de Zaragoza, y Comisión Interministerial de Ciencia y Tecnología. **Gestar, guía del usuario, versión 1 (Win 95)**

ICONA, 1981. **Técnicas para defensa contra incendios forestales**. Monografía nº 24. Varios autores.

ICONA, 1987. **Manual de Prevención de Incendios mediante tratamiento del combustible forestal**

ICONA, 1991. **IV Curso Superior de Incendios Forestales.** Varios autores. Ministerio de Agricultura, Pesca y Alimentación.

ICONA, 1993. **Manual de Operaciones contra Incendios Forestales**

Rothermel, R. C. 1972. **A mathematical model for fire spread predictions in Wildland fuels**. USDA Forest Service. Int USA.

Rothermel, R. C. 1983. **How to predict the spread and intensity of forest and range forest fires**. USDA Forest Service. Int USA.

Universidad de Santiago de Compostela. Escuela Politécnica Superior. Campus universitario. Lugo. 1997. **Ponencias sobre el estado de la investigación y el desarrollo en protección contra incendios forestales en España.I Seminario Nacional.**

Vélez, R., et al. 2000. **La defensa contra incendios forestales. Fundamentos y experiencias**. Mc Graw Hill.

Page left blank intentionally.

Macroeconomic Analysis of Investment in Fire Protection Using Social Accounting Matrixes: Application to the Navarre Region[1]

Marcelino Pellitero,[2] Patricia Suárez[3]

Summary

This work carries out an analysis which evaluates the effects of investments in fire protection on the regional economy from a macroeconomic point of view. The new feature of the methodology used is that it has integrate the sum of these investments within a general economic circulation model which consists of a Social Accounts Matrix (SAM) for the Navarre region (Comunidad Foral de Navarra), drafted from its Input-Output Tables (IOT) . The objective was to thus identify the direct, indirect and induced effects of these investments by applying the theory of Leontief multipliers. The analysis justifies the economic and financial backing of this type of forestry management policy, not only from the environmental angle, the protection of the ecological functions of the forestland, but also from a macroeconomic point of view by highlighting that these investments stimulate the regional economy by obtaining an increase in the regional GDP which exceeds the sum of investments made and which is accompanied by job creation.

Introduction

Fire is the main threat to the survival of the woodland and the rest of the forest areas on the Iberian Peninsula. In contrast to other parts of the world, where the majority of fires are due to natural causes (lightning), on the Iberian Peninsula there is a prevalence of forest fires due to anthropic causes. Paradoxically, the main cause of these forest fires is linked to the economic and social progress its population has undergone.

This improvement in living conditions is responsible for the migration of the rural population towards urban areas, the drop in the rate of demographic growth, the abandonment of cultivated land, and the growing lack of interest in the use of forestry resources as a source of energy.

---

[1] An abbreviated version of this paper was presented at the second international symposium on fire economics, policy, and planning: a global view, 19–22 April, 2004, Córdoba, Spain.

[2] Degree in Economics. Area of Rural Development. Sub-directorate for Environmental Planning, Technologies and Agricultural Services. Conde Peñalver. 84. 28006 Madrid. Spain.

[3] Degree in Law. Area of Rural Development. Sub-directorate for Environmental Planning, Technologies and Agricultural Services. Conde Peñalver. 84. 28006 Madrid. Spain.

As a direct consequence of the above. there has been a growth in forestry surface area, abandonment of the rural environment, and what is more important, an accumulation of fuel due to the excess of biomass, contributing significantly to an increase in fire risk and also giving rise to a new type of forest fire characterized by its voracity and speed of propagation and which affects increasingly large surface areas.

Investment in forest fire protection is currently the only way of reducing economic, environmental and personal damage produced by these fires. This study calculates the macroeconomic effects of forestry management polices in the Navarre region from the total of economic programmes directed at forest fire prevention during 1996.

In order to link up investment in fire protection with the regional economy, it is necessary to bear in mind the interrelationship between the different sectors of production. The quantification of this impact is tackled using Input–Output (I-O) analysis, specifically using the Social Accounting Matrixes by means of the multipliers obtained from these.

Unfortunately the information contained in a conventional I-O table may be incomplete for the purposes of evaluating regional macroeconomic impacts, when the relationships which define the use of the resources are not exclusively industrial. The I-O models do not include information on the external effects of the economy's production processes. i.e. on the distribution and circulation of income between economic partners (Thorbecke 1985). For this reason the approach of authors such as Pyatt and Round (1985) or Atkinson (1996) has been used. These authors began to develop a more complete approach based on the SAMs. From this, Khan et al (1990) or Martínez de Anguita (1999), amongst others, have begun to use SAM multipliers which broaden the impact of a change in the use of resources, including direct. indirect and induced effects on the income resulting from this change, and which at the same time bring the environment within the economy – a necessary integration process.

In order to determine the global impact of this forestry management policy, the analysis is extended using SAM, thus fully including the entire cyclical process of the economy (Field 1997), (Pearce y Turner 1989) and enabling us to estimate more precisely not only the direct and indirect effects but also effects induced or caused by the measures taken - stimuli and knock-on effects produced on the regional economy.

Methodology

The Social Accounting Matrixes

The SAMs are very useful analysis tools which, from a quantitative viewpoint, study the economic structure of a specific organisation, regardless of its size. The SAM also enables us to evaluate the effects on this structure of several different exogenous changes, such as those related to reforms in economic policy.

Based on the logic of the Input-Output analysis, the SAMs attempt to correct and overcome some of the most obvious limitations of conventional data bases used for economic analysis: to include all the economic transactions which occur between all the parties in a specific economy and, more specifically, to show the interrelationship between the production structure and the distribution of income and

consumption patterns. It also models the effect of a change in exogenous variables on the production structure and the different economic institutions.

A SAM is the accounting record of all flows in an economic system during a specific period (generally one year). This is equivalent to a snapshot of the links existing between the production sectors of a country, a region, a community or a group of these. The SAM is an extension of Leontief's (1996) Input-Output Table (IOT) and also includes the production structure, data on the distribution of income and institutions' demand structure.

Multiplier Effect of Investment in Fire Protection. Application to the Navarre Region.

The economic impact on the regional economy may be estimated using the multipliers and analysing the Input-Output tables, or the SAM models. The latter are more complete. Multipliers are analysed to estimate the regional economic impact resulting from changes in the final demand for a good or service, or a group of these (Alward et al. 1993). They may also be used to estimate the economic reduction resulting from a tax or rate, applying the multipliers theory inversely (Miller and Blair. 1985).

To find the multiplier effect of investment in forest fire protection. we took the IOTs for the Navarre economy for 1996. In order to facilitate the analysis of these, a modification was made in the sectors making up the original IOTs. More specifically, the 24 sectors of the Navarre IOTs were grouped into 11 as follows: agriculture, livestock, forestry, agrifood industry, chemical-textile, mining, metallurgy, transport elements and spare parts, public administration. services and others. The first three were separated while the remaining areas were grouped together. Once the IOTs had been established with the new sector-based distribution, the Navarre SAM was constructed.

The SAM Backward[2] multipliers were then calculated. producing the following results *(table 1)*.

Table 1— *Backward multipliers for the different production sectors.*

Sectors	Backward Multiplier (type I)	Backward Multiplier (type III)
Agriculture	1.16906	1.20403
Livestock	1.39510	1.44131
Forestry	1.00236	1.00888
Agrifood Indus	1.37107	1.46005
Chemical–Textile	1.11671	1.20137
Mining	1.23193	1.38256
Metallurgy	1.19615	1.29002
Transport Elem.	1.19416	1.26466
Others	1.22416	1.33972
Public Admin	1.32507	1.85286
Services	1.29772	1.50697

[1]The Backward multipliers in the Leontief matrix come from the SAM of the technical coefficients for production. The type I multipliers only include the inter-industrial effect, whereas the type III multipliers include the regional effect, including the whole cycle of the economy. i.e. they consider a broader based effect. **Source**: Own develop.

The relevance and suitability of using the SAM Backward multipliers is shown in how the weighting of the rest of the sectors varies with regard to the

distribution obtained in the IOT multipliers. i.e. the SAM analysis estimates more thoroughly the relationships between the production sectors, but taking in the entire economic cycle. Below details this reassigning of weightings between the production sectors for the case of the Backward multiplier for Forestry, the sector which receives investment in forest fire protection. *(table 2)*.

Table 2—*Distribution of weightings by type of multiplier used (as a percentage).*

Sectors	Weighting in the Backward Multiplier (type I)	Weighting in the Backward Multiplier (type III)
Agriculture	0.00 %	0.01 %
Livestock	0.00 %	0.00 %
Forestry	99.77 %	99.12 %
Agrifood Ind.	0.00 %	0.02 %
Chemical–Textile	0.01 %	0.01 %
Mining	0.00 %	0.01 %
Metallurgy	0.01 %	0.02 %
Transport Elem.	0.00 %	0.00 %
Others	0.11 %	0.25 %
Public admin.	0.00 %	0.04 %
Services	0.10 %	0.52 %

Source: Own develop.

In the case of the SAM multiplier it is observed that the weight of the rest of the sectors increases to 0.88 per cent compared with 0.23 obtained by the IOT analysis. This means that the effect identified by the SAM multiplier is 282.61 percent greater than the figure obtained using the IOT multiplier.

Results and Discussion

Given the difficulty of obtaining budget data on fire prevention in the Navarre region in 1996, and as the figure allotted to fire prevention in 1998 which appears in the Navarre Forestry Plan (Navarre Government 1998) is based on real data from previous years, we consider that this is fairly approximate and is taken as valid for 1996.

Using the Backward multiplier of the SAM model, we obtain the overall effect which investment in fire protection has had during 1996 on the Navarre economy. Thus, these funds, amounting to €1.827 million are obtained. This produced an increase in regional GDP of €1.843 million, €0.016 million corresponding to indirect and induced effects caused by Forestry on the regional economy, mainly resulting in repercussions on the service sector: 59.56 per cent and on other areas: 28.15 per cent.

The modest value achieved by the Navarre forestry sector multiplier fits with the value obtained at national level and highlights its scarce development, due mainly to the fact that this sector has not traditionally been considered as a key or strategic one in economic development at regional or national level.

To calculate the effects of these investments on regional employment, the relationship between production and jobs was identified for each economic sector *(table 3)*.

Table 3—*Proportion between production and jobs by sectors (millions of euros/job)*

Sectors	Multiplier	Sectors	Multiplier
Agriculture	0.03278	Metallurgy	0.13550
Livestock	0.03278	Transport Elem.	0.20880
Forestry	0.03278	Others	0.12993
Agrifood Indus.	0.13277	Public admin.	0.04907
Chemical–Textile	0.10980	Services	0.05732
Mining	0.09678		

Source: Own develop.

Thus we obtain the figure of €1.827 million invested, producing 56 direct jobs (in the forestry sector). Similarly, in order to create indirect and induced employment in other sectors, investments of over €10 million would be necessary.

Conclusions

Using the SAM model multipliers we obtained the overall effect of investments in fire protection on the Navarre economy. This analysis unequivocally justifies economic and financial backing for this type of forestry management policy, by highlighting that these investments dynamise the regional economy, increasing the regional GDP beyond the level of the investments made.

Investments directed at fire prevention produced an increase in regional GDP of €1.843 million, €0.016 million corresponding to indirect and induced effects caused by the forestry sector in other areas of the regional economy.

Investments in forest fire protection have been responsible for the creation of approximately 50 percent of direct jobs in the primary forestry sector, with the production of 56 jobs (Ministry of Labour and Social Affairs).

Although the forestry sector does not contribute to the GDP very significantly, its productive aspect should be considered as fundamental, given the strategic importance it has on mountain or depressed areas in rooting the rural population to the region.

Due to the essential role of the forests, both from the economic point of view (timber production) and the ecological viewpoint (maintaining biodiversity, CO2 sink, water and soil conservation, etc.), investments in forest fire prevention, and therefore the forestry sector, must be considered as strategic, since apart from providing an impulse for the regional economy, they guarantee future quality of life for the public and constitute one of the main pillars of sustainable rural development.

References

ALWARD. G.. SIVERTS. E.. CAROL TAYLOR and WINTER. S. 1993. **Micro INPLAN User's guide**. Colorado. United Department of Agriculture. Fort Collins.

ATKINSON. G. 1996. **Sustainable Development. Theory. Measurement and Policy**. Madrid. Translated in Recursos. Ambiente y Sociedad: Información Comercial Española. 751p.

FIELD. BARRY C. 1997. **Environmental Economics: An introduction**. New York. 2nd Edition. McGraw Hill Companies.

NAVARRE GOVERNMENT. 1997. **Regional Accounts of Navarre. 1995. Input-Output Tables**. Pamplona. Araldi S.L. and Statistics Unit of the Navarre Govt.

NAVARRE GOVERNMENT. 1998. **Forestry Plan for Navarre.** Government of Navarre Department of the Environment, Land Planning and Housing..

KHAN. H.. C. F. SENG y W. K. CHEONG. 1990. **Tourism Multiplier Effects on Singapore**. Annals of Tourism Research. 17. 408-418.

LEONTIEF. W. 1966. **Input-output economics**. New York. Oxford University Press.

LEONTIEF. W. 1970. **Environmental repercussions and the economic structure: An input-output approach**. The Review of Economics and Statistics 52: 3.

MARTÍNEZ DE ANGUITA. P. 1999. **Introducing the environment into a Social Accounting Matrix**. Syracuse. New York. Masther Thesis. SUNY- ESF.

MILLER. R.E.. y P.D. BLAIR. 1985. **Input-Output analysis: Foundation and Extensions**. NJ .Englewood Cliffs. Prentice Hall.

SPANISH MINISTRY OF LABOUR AND SOCIAL AFFAIRS 2000. **Información sobre mercado de trabajo. Resumen anual de datos del Observatorio Ocupacional 1999**. Madrid. National Institute of Employement.

PEARCE. DAVID W. and R. KERRY TURNER. 1990. **Economics of Natural Resource and the Environment**. Johns Hopkins Press.

PYATT. G. y J. J. ROUND eds. 1985. **Social Accounting Matrix: A basis for planning. Washington**. The World Bank.

THORBECKE. E. 1985. **The Social Accounting Matrix and Consistency - Type Planning Models. In Social Accounting Matrices: A basis for planning**. Washington. World Bank Symposium.

Integrated Management System for Forest Fire Prevention: Its Application in the Valencia Region (Spain)[1]

Luis Velasco,[2] Jorge Suárez[2]

Summary

Forest fire prevention requires the ability to answer a number of questions such as: Where could a fire occur? When could it occur? What form will it take? In order to obtain answers, we need correct knowledge of hazardous situations in terms of time and space. We need to be aware of these situations in order to "mobilize" prevention suppression resources to avoid a fire breaking out or, if this occurs, to limit its effects to the minimum

The characteristics of the environment in which these fires can occur are very varied, particularly in a Mediterranean setting such as the Valencia region (Autonomous Community of Valencia) where risk factors are changeable and, in many cases, are due to a complex interrelation of multiple, and diverse factors. Managers, when taking decisions, must have at their disposal support tools which must be reliable and adequate to suit the social and climatic features of the physical environment in the area they are to be used.

The Integrated Management System, set up in the Valencia region, has been designed as a dynamic tool, backed by a Geographical Information System but rather more broad-based, as it is equipped to manage and produce a wide range of information, providing a service to and obtaining feedback from the forest fire prevention programmes implemented by the Valencia region.

Introduction

Forest fire prevention demands knowledge of both available resources and possible hazardous situations. The Valencia region is a region with markedly Mediterranean conditions, where weather conditions change constantly, conditions which are moreover particularly relevant to daily levels of forest fire risk. These considerations, linked to other factors concerning the surroundings, provide us with a very high number of variables which affect the decision-making process, and make it necessary to have support tools at our disposal.

Knowing the scenario where a possible fire may break out is essential in order to programme all necessary action to avoid this occurring (Vélez 2002). This knowledge of the many different risk factors and their evolution in time and space enables prevention resources to be "mobilized". These resources, although perhaps insufficient to prevent fires breaking out, will indeed be able to minimize their number and intensity.

The system described was designed from 2002 onwards, following guidelines and directions fixed by the Valencian government's environment department and implemented by the forestry department of the publicly owned company, VAERSA. It has never been considered as a closed system and is therefore continually adapted to suit the real needs of its

[1] An abbreviated version of this paper was presented at the second international symposium on fire economics, planning, and policy: a global view, 19–22 April, 2004, Córdoba, Spain.

[2] Conselleria de Territori i Habitatge. Generalitat Valenciana (Valencian Regional Govt.). C/Francisco Cubells 7.46011 Valencia España. velasco_lui@gva.es y suarez_jor@gva.es.

users who, in principle, are those responsible for prevention. In a second phase it will be extended to other organizations and agencies also involved in fire fighting.

General characteristics of the system

At the time of approaching the guidelines for design of the system, it was considered, firstly, that this should be a dynamic tool, supported by a Geographical Information System able to manage and produce wide ranging information, either cartographic, documentary or statistical. The use of maps in emergency situations makes it necessary that these should be easy to understand, comparable, significant and quickly accessible (Nicolás, J.M, 2001). One of the basic requisites was therefore that it should be user-friendly for any type of user with a basic computing knowledge.

The need for the system to function by a module system was also considered, so that even though it is a joint tool, each one of the modules may work independently. Lastly, the whole application was developed in order that it be accessible and operational through Internet. Although this condition was not initially envisaged, its adoption brings a number of associated advantages which increase the operating capacity of the system. However, the system has a hierarchical access protocol with different degrees and capabilities in the sphere of both queries and updating capacity.

The previous guidelines laid down the basic principles to be followed in its design. The contents were stipulated in a first phase by the Surveillance Plan on forest fire hazards in the Valencia region. The second phase introduced other general applications for forest fire prevention, depending on the real demands of users. The first modules developed were those of weather and risk analysis, a map server, the support module for locating fire hotspots and a lightning early warning system. Other implementations have been added to these modules, such as data base managers or the analysis of individual anthropic hazards.

Hazard module and meteorological analysis

Introduction

The objective of this module is to supply a zoning plan of the area which meets the priorities of forest fire defence. To achieve this, the different variables which come into play in the probability of a fires braking out, the potential danger level of the fire, and the forestry type in the area have all been incorporated within simple maps. The application was developed on a geographical information system, applying a grid of 95,000 polygons in the Valencia region. Each variable calculated is interpolated in this grid. The result is a series of maps giving probability rates and danger indexes for forest fire prevention. The information they provide, using ecological and climatic parameters, enable us to view the level of fire hazard and danger, as well as the causes of the outbreak; distinguishing whether this was physical or due to continuing pressure which has been exerted upon a specific area over time.

To sum up, the Priorities Map for defence indicates the areas with greatest forest fire protection requirements; i.e. it is assessed which areas have the most unfavourable combinations of factors and greatest forest quality, these being the top priorities for surveillance. As a general rule, Protected Natural Areas and forestland with an fcc>25 % will always be within the highest defence priority thresholds. The information the map supplies is a support tool for daily decisions in planning surveillance and prevention resources. In the final decision in order to prioritise available resources it is fundamental to superimpose this information with the information from the early warning modules in the case of lightning and anthropic risks.

Methodology

The methodology is based on a multi-criterion analysis of different variables used, according to the weightings and formulations used in the Autonomous Community of Valencia Prevention Plan on Forestry (Generalitat Valenciana 1995) *(fig 1)*, the final result being a zoning of the area by fire risk, potential danger level, and forest quality or priority for defence.

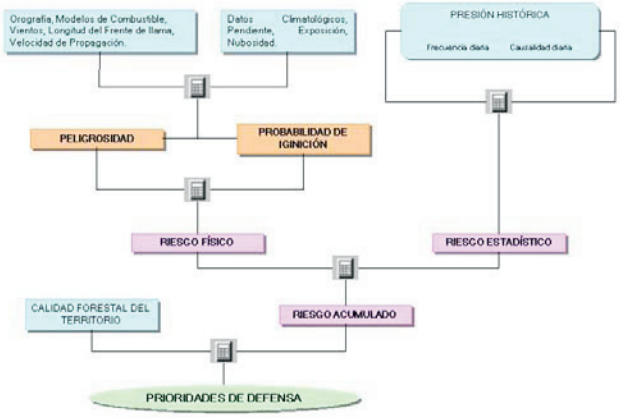


Figure 1—General methodology applied in the calculation process

This methodology was designed for a static application, so that in order to use it in a dynamic system in which the different formulations are calculated on a daily basis, it has been necessary to vary the weighting and thresholds to a certain extent.

Cartographic server

For daily calculation of the different indices, a significant amount of cartographic information has been required on digital support. The system has not been designed as a substitute to the decision-making process which must be undertaken by the Manager. For this reason it combines complex indexes, along with the basic information, in this case cartographic, which enables individual decisions to be taken. The server has also proved to be especially useful in solving another problem: the difficulty of introducing the use of the GISs generally to technical personnel with forest fire prevention responsibilities and forest management in general, apart from facilitating the use of a unified mapping system by the surveillance, prevention and fire-fighting services. The system has a cartographic server developed on ArcIms ®, which covers the basic needs in a user friendly environment. Amongst the operations which may be undertaken is included the production of individualised subject-based cartography, location of infrastructures, access to individualised alphanumeric information, and surface area planning, etc..

Prevention resources manager

The Valencia region has a major number of resources whose key and almost exclusive function is to undertake surveillance work and provide information on forest fire prevention. It is a dual purpose system: firstly the resources themselves have to be managed i.e. location, operability, routes, etc., and secondly the information they produce: meteorological data, operating incidents, individual hazards, etc..

As regards mobile resources, the system includes an area-based database which lists available resources for each municipality in the Valencia region, their characteristics, route and period available. The permanent resources (forestry observatories) are itemised in an area-based data base which includes complete information on the characteristics of the facility, along with an interface which enables meteorological data to be entered in real time.

Fire-fighting support infrastructure

The System is accessible to a wide number of organisations with a role in both fire prevention and extinction, as well as, in line with the current set up for public resources in the Valencia region, the bodies responsible for maintaining the firewall areas network, water tanks and forest road network, and the fire-fighting authorities. These are based in different departments of the Valencian regional government. For this reason it has been considered a priority to have a permanent inventory of all these infrastructures. In the case of the firewall area networks and forest road network, this is only accessible as cartographic information through the server, however in the case of the water tanks and other water supplies, there is a fiche with periodic updates which include the complete characteristics of this infrastructure, including their water levels in the summer season.

Fire Location Support Module

One function of the permanent surveillance network is the detection of any sign of possible fire and immediate transmission of this by radio or mobile telephone to the Emergency Call Centre for verification and, if applicable, immediate mobilisation of fire-fighting systems. The objective of this module is to facilitate this task. The module obtains a panoramic photo from each observatory, simulating the observer's vantage point. The photo is corrected, georeferencing the film produced, so that each pixel of the photograph has a number of coordinates on the plan.

Results

During the course of 2003 the system received 13,000 queries, an average of 35 per day, with 209 users registered. Within these users there is a broad range of professionals, shared between the different local government departments in the Valencia area. In spite of their different computing knowledge, these professionals have adapted very well to the System, getting actively involved right from the start in the maintenance of information and in its structure, through suggestions, e-mails, or personally at the different briefing meetings which have taken place to date.

It is early days to present conclusions which could be extrapolated to other situations. We consider that having a multidisciplinary team made up of forestry and computing professionals, in close contact with the real users, and the fact that from the start they have been able to use the system as easily as they make a query in the network, has been the key to this acceptance.

Thanks

The work undertaken by the VAERSA Forestry Dept. should be underlined, and particularly that of Javier De Vicente, whose work has been fundamental in the results obtained to date.

References

Nicolas, J.M. 2001. **Mapa de demanda de defensa territorial frente a los incendios forestales.** Dept. of the Environment. Autonomous Community of Madrid. Madrid (Spain)

Vélez, Ricardo. 2002. **Nuevas tecnologías para un viejo enemigo, el fuego forestal.** I Jornada técnica sobre prevención de incendios forestales. El desarrollo tecnológico y la prevención de incendios forestales, Valencia (Spain)

Generalitat Valenciana. 1995. **Plan de Selvicultura Preventiva de la Comunidad Valenciana.** Valencia (Spain).

Page left blank intentionally.

Fire and Economics: Understanding the Amazonia's Fire Arch[1]

Tatiana Schor,[2] Arnaldo Carneiro Filho,[3] Carlos de Almeida Toledo[4]

Abstract

Looking down at the Amazonian region using satellite images a "fire arch" that approaches the Amazon River can be seen. Due to this visual effect the pattern of deforestation of Amazonia is usually considered a "fire arch" that approximates the Amazon River through the southwest of Brazil. The arch has been monitored since 1988, and estimates of deforestation areas have been an important instrument for fire prevention policies and national and international public opinion. The verified deforested areas in the years of 2000-2001 have been 1,4 times bigger than the original estimates. What has caused such a big increase in the fire and consequently in deforested areas in the Amazonia is not only a national Brazilian preoccupation but also a worldwide concern. Environmental scientists' and policy makers are concerned in understanding why the actual deforested area is bigger than the estimate, why there was a fire increase in some areas and if the fire arch pattern can be still considered as a dominant fire structure in the Amazonian Region.

Fire in the Amazon Region used by traditional population and also related to economic activities such as opening of pastures, logging and cereal plantations. In fact, fire is usually considered the cheapest technology for cleaning a forest area for further economic activity. But, *can the fire registered in the satellite images be correlated with economic factors registered in the macroeconomic indicators?*

This paper is interested in approaching this question by means of analytically relating the different deforestation indices and the fire images with the local, regional and national macroeconomic indicators.

Making use of the satellite images of the fires in the Amazon Region, areas that had an important fire increase will be chosen as case studies. The period of study chosen will be during the Brazilian Real Economic Plan, 1994-2002, due to the fact that during the initial and final years of this economic plan a great increase in fire areas in the Amazonian Region was registered.

The case studies chosen will be analyzed by means of local (the municipalities which most caught fire), regional and national economic indicators searching for possible explanations of the fire patterns which caused the important deforestation increase during the years of 2000-2001 and discuss the possible future changes in the Amazonian "fire arch".

---

[1] An abbreviated version of this paper was presented at the second international symposium on fire economics, planning and policy: a global view, 19–22 April, 2004, Cordoba, Spain.

[2] Economist, Teacher of Environmental Economics and Scientific Methodology, Environmental Education, SENAC-São Paulo and doctorate student in the postgraduate program in Environmental Science, University of São Paulo, Brazil.

[3] Coordenator of the Geoprocessing Laboratory at the Instituto Nacional de Pesquisa Amazônica, Manaus, Brazil.

[4] Economist, Teacher of the History of Economic Thought at Santanna University and doctorate student in the Geography Department of the University of São Paulo, Brazil.

Introduction

Fire management involves a large scope of analytical and methodological tools. Economic theory has not been influenced by the complicated debate aroused by the contemporary necessity to protect wildland remnant from fire. Fire management agencies have long looked at economic indicators and observed many relationships between economic activities and fire. These relationships vary enormously due not only to the different economic activities but also due to the historical processes involved in the occupation of the wildland. This paper analyses the commonly called Amazonia's Fire Arch by means of integrating the economic theory with the local historical processes of fire in Brazil and more specifically in the Amazonian frontier. This exploratory analysis hopes to contribute not only to the understanding of the fire in the Amazon but also to the discussion of wildland fire in economic theory and environmental management.

The Amazonian Fire Arch

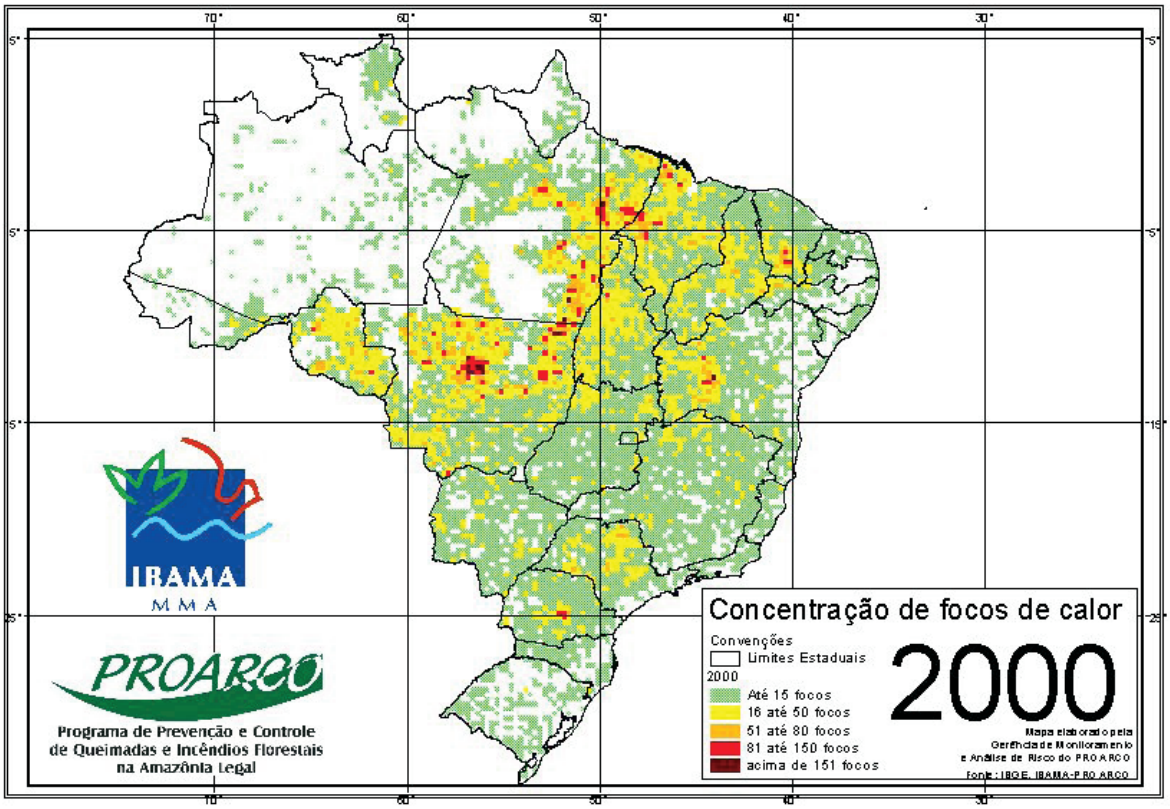
Looking down at the Amazonian region using satellite images a *fire arch* that approaches the Amazon River can be seen. Due to this visual effect the pattern of deforestation of Amazonia is usually considered a *deforestation arch* that approximates the Amazon River *along the eastern and southern edges of the forest* (Cochrane, M. A. and others. 2002:288). This *deforestation arch* has a visual effect when seen through satellite images of a concentration of heat focuses delineating a *heat arch* or more specific terms: a *fire arch*. This *fire arch* approaches the Amazon River from the southeast and in spite all efforts of controlling and monitoring the fire done by the Brazilian governmental agencies (IBAMA and more specifically PROARCO) has increased in the past years, such as can be seen in *figure 1*.

The arch has been monitored since 1988, and estimates of deforestation areas have been an important instrument for fire prevention policies and national and international public opinion. The verified deforested areas in the years of 2000-2001 has been 1,4 times bigger than the original estimates. As can be seen in *figure 1* above the concentration of heat focuses has increased considerably in 2002 in comparison with 2000.

What has caused such a big increase in the fire and consequently in deforested areas in the Amazonia is not only a national Brazilian preoccupation but also a worldwide concern. Environmental scientists' and policy makers are concerned in understanding why the actual deforested area is bigger than the estimate, why there was a fire increase in some areas and if the *fire arch* pattern can be still considered as a dominant fire structure in the Amazonian Region due to the fact that there has been an increase in important fire focuses out of the arch territory (such as the big forest fires in Roraima, north of the Amazon River).

Fire in the Amazon region is used by traditional population and also related to economic activities such as opening of pastures, logging and cereal

plantations. In fact, fire is usually considered the cheapest technology for cleaning a forest area for further economic activity. In order to approach the fire arch debate in an analytical perspective it is necessary to understand the position occupied by the Amazon region in the Brazilian economic activity.



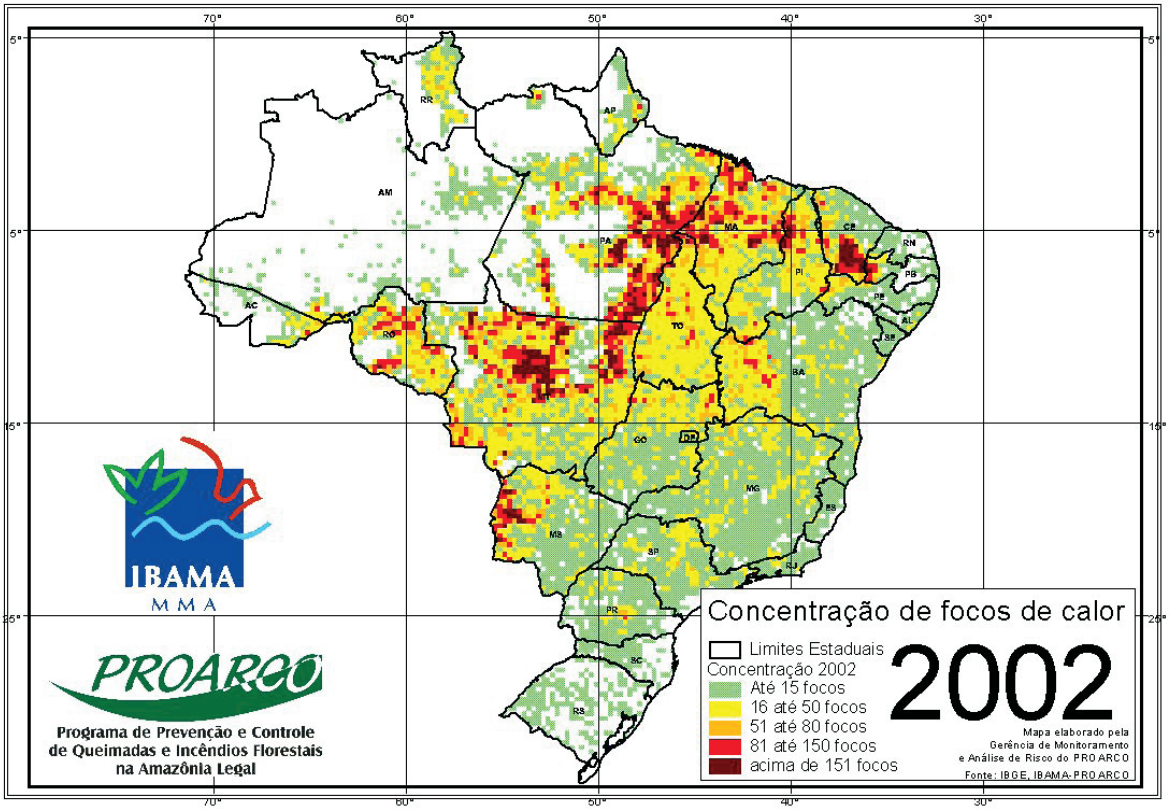


Figure 1—Concentration of Heat Focuses in Brazil 2000 and 2002

The Legal Amazon: the history of territorial occupation.

To better understand the Amazonian Fire Arch it is necessary to define what is meant by Amazonia. The Amazon River has an estimated drainage basin of 6,600,000 Km2 (Wood, C.H. and Skole, D.1998:72) occupying an area that includes land in Brazil, Bolivia, Columbia, Equador, Peru and Venezuela. Brazil is divided politically into five geographical regions: south, southeast, northeast, central and north. All the states of northern Brazil – Roraima, Amazonas, Pará, Acre, Rondonia - occupy what is usually referred to as *Classical Amazonia* (Moreira, I.A.G. 1989; Vesentini, J.W.V.1996). These states do not take into account the watershed of the Amazon River Basin. In order to congregate all states that are related physically to the Amazon River Basin with the perspective of regional planning the Brazilian Federal Government created a law (a first version in 1953) that configured a region designated *Legal Amazon* which consists of all the Northern States plus Mato Grosso, Tocantins and Maranhão west of the 44th Meridian.

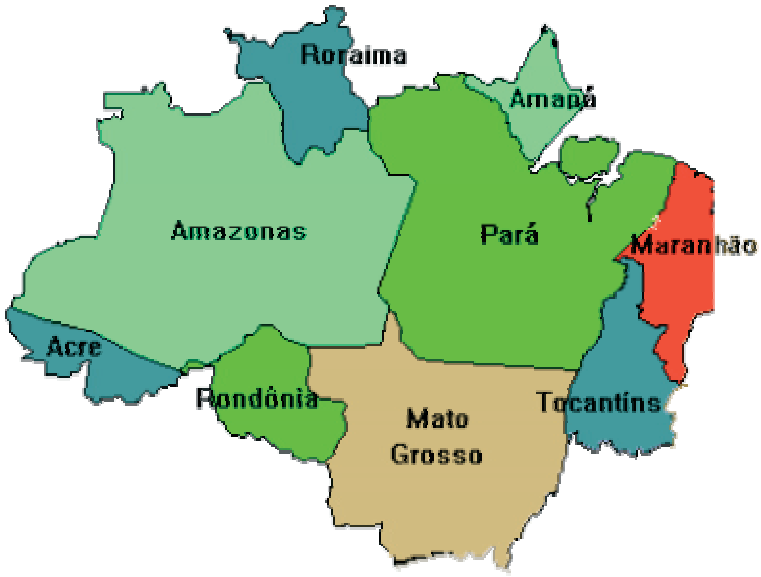


Figure 2— The North of Brazil: Legal Amazonia

The occupation of this region began in the XVIII century through the now called State of Pará mainly for the extraction of forest products such as timber, cocoa, vanilla and aromatic resins with Indian slave labor force (Prado, C. 1965:71). In the context of a Portuguese colonial system this region was considered peripherical thus the Indian slavery and not African originated like most of the country. Since this period the concern about the geopolitical importance of the river system has kept the region under constant military supervision. In the XIX Century an important economic activity started: the *Rubber Cycle* – 1870-1910. During this period land ownership was extended right through Acre State. The activities related to the rubber extraction were an important demographic attraction. Many rubber farms were established changing completely the forest format especially in the States of Pará, Amazonas and Acre. The rubber crisis, due to the plantation of rubber trees in Malaysia at the beggining of the XX century, generated an economic crisis which left behind abandoned rubber-tree plantations and many rubber collectors who had migrated from the northeastern Brazil to work in this economic cycle (Fausto, B. 1999). These rubber collectors continued cultivating the rubber-trees but increased subsistence farming activity (*roça*). This type of traditional agricultural activity usually is based in cleaning a small area with fire and then planting different types of manioc and other family consumed products. An activity long learned with the Indians. The family economy after the rubber-crisis was strongly based on the cultivation of the *roça*, some rubber extraction and the collection of forest products. This is still the case in many places in the Legal Amazon, especially in Acre and Amazonia.

During the Second World War the Brazilian government promoted a migratory politics trying to re-activate the rubber production. Many workers coming from the northeastern states were convoked as rubber-soldiers. During this period many old rubber-tree farms were re-established and some new ones set up. Again in a short period of time due to an important demographic and economic pressure the forest was transformed. The forest was transformed not only in its ecosystem, but mainly in its demographic and land property structure. The region started to live a crescent social tension associated with many people without land and large plots of unproductive land. The social tension was strongly due to the concentration of land in the hands of few.

The geopolitical question concerning the Amazon region is strongly related with the conception that the region, although occupied by small families' landholders, *suffers* of a demographic emptiness and a lack of productive investments that could occupy the region productively. So during the period of 1964-1970 important investments in infrastructure, such as the Transamazonian Highway, were made using World Bank and the Interamerican Bank credits. These investments were also directed to large land property (400.000 to 700.000Ha) with emphasis in cattle raising (Gremaud, A.P. and others, 1997). In this context, the social conflicts already existing were accentuated. During the period 1970-1974 the construction of highways continued motivating the occupation of the wildlands around these infrastructures. These highways configured a new pattern of territory occupation: the fish-bone structure (Moran E. and others. 2002). This new territorial occupation is so called due to the images seen from above: the deforestation occurs around the main highway and the secondary roads that give access to the farms that surround the main road. These farms were government colonization projects of small farmers on 100-hectare plots along both sides of the Transamazonian Highway (Wood, C. H. and Skole, D. 1998:73). During this period these colonization projects were responsible for most of the fire and subsequent deforestation in the Amazon, especially in the oriental part of the Amazon in the so called *deforestation arch*. The role played by the small farmers in the process of deforestation in the Amazon is well know and extremely complicated to resolve:

Although much, if not most, of the deforestation that took place in the Amazon was carried out by medium- and large-scale ranchers, small farmers were also implicated in the process, as evidenced by the typical cycle of land use. Small farmers commonly clear 2 to 3 hectares of land, which they cultivate for as long as fertility remains high. In most areas soil fertility is depleted in 2 to 3 years, necessitating the clearing of more land. Since there are approximately 500,000 small farmers in the region, these figures imply a demand for additional 500,000 hectares of cleared land per year (Homma and others 1992:9). Crude as these estimates may be, they nonetheless point to the magnitude of existing internal demand for land clearing, even if the migration of small farmers to the Amazon were to stop altogether. (Wood, C. H. and Skole, D. 1998:74)

During the 70´s this pattern was accentuated with privileged credit for large properties, governmental colonization projects and the construction of the highways that were never completed. This pattern is largely based in extensive cattle raising, until 1995 land for cattle raising with relation to the total of agricultural land in the Amazon was 81,5 percent (IBAMA, 2003). The typical cycle of land use perpetuated.

The government stopped financing these projects and the large cattle raising farms during the 1990´s but the occupation of the Legal Amazon became

autonomous and the extensive cattle raising activity became economically viable without subsidies of the government (Margulis, S. 2003). The interruption of the fiscal and financial subsidies that where predominant in the 70´s and 80´s, considered the main causes of the deforestation of the Legal Amazon did not generate the expected results. The fire and deforestation monitoring by the National Institute of Spatial Research (INPE – Instituto Nacional de Pesquisas Espaciais) did not permit the formulation of public policies which would prevent fire and subsequent deforestation. In this sense, the causes of occupation and deforestation in the Legal Amazon during the 1990´s need a better understanding. Margulis (2003) in a report to the World Bank entitled *Causes of deforestation in the Brazilian Amazon* suggests that the real process of occupation and deforestation has to do with the following elements: (1) The agents of the deforestation have short planning horizon and base their activities in the mining of forest nutrients (2) cattle raising in the Amazon has small revenue and its persistence can only be explained by the subsidies or credits from the government that sustain speculative gains (3) small producers are important agents in the deforestation process (4) logging is one of the main causes of deforestation (5) roads are also causes of deforestations and not the consequence of the high potential of the agriculture in the region (6) soybean plantation has expanded rapidly in the barren lands (*cerrado*) putting pressure on the expansion of the agriculture frontier towards new areas. The elements presented do in fact congregate the heritage of the frontier expansion and economic activities in the Amazon making clear that the land use pattern, strongly molded by the economic activities, are the main causes for the persistence of the *deforestation arc* and impressive *fire arch*.

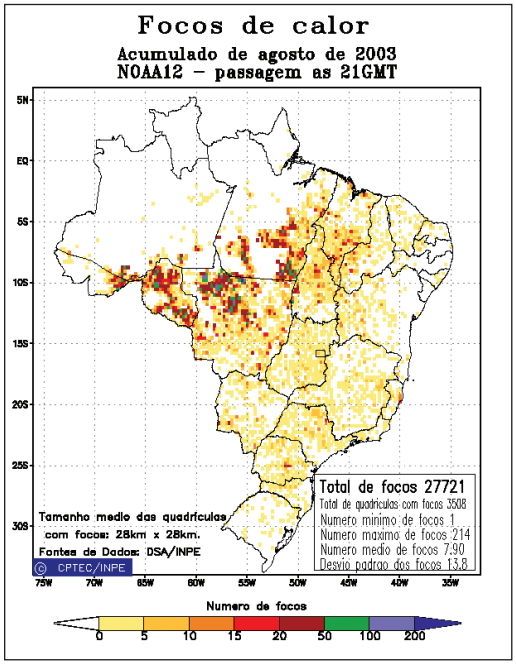


Figure 3— The Amazonian Arch of Deforestation

The persistence of the fire arch

So that the fire in the Legal Amazon can be adequately discussed it is necessary to turn explicit the uses of the burnt areas. It can be assumed, in accordant to the

arguments expressed above, that the use of fire represents the advance of the agricultural frontier, in other words, the augmentation in quantitative terms of land used in the country. The expansion of the economic usage of agricultural land has as a classical explanation in economic theory as David Ricardo's land rent theory (Ricardo, D. 1996:Chap.2). Even though the ricardian theory of rent seems to fit perfectly into the argument it is necessary to weave some commentaries about this concept and the critiques to which it was been subjected. Not doing so would make Ricardo's argument rather naïve two centuries latter.

David Ricardo comprehends rent as *that portion of the produce of the earth which is paid to the landlord for the use of the original and indestructible powers of the soil* (1996:45). Due to the unquestionable experience of environmental degradation in the begging of this century (XXI´s) the use of the term *indestructible* must be rethought. Alternatively to Ricardo's conceptualization of rent we can consider an interesting formulation of Karl Marx. Marx when criticizing Ricardo comments that when the material standpoint is considered, as use value, and not as social form, land is a *means of production not produced* (1981:964). This formulation is interesting for understanding wildland fire and forest deforestation in two aspects.

Firstly, it considers that these *means of production not produced* are not replaced by the revenue received by the landowner. In the same way as the market which the existence (that is not a result of planning) precedes the formulations of the economic science (its theoretical understanding) the use of the natural resources (here identified as land) also precedes its theoretical understanding. The consequence of this incomplete understanding is the possibility that the destruction of the (natural) resources, necessary for the reproduction of society, happens without the possibility to control it. There is no doubt that in terms of agriculture the substitution of the *means of production not produced* by means of production *produced* has made a quick advance: the conversion of forest into agricultural land by means of the use of artificial resources such as pesticides and fertilizers. In this sense, there is a problem. It is not known exactly all the necessary things for the reproduction of the non-produced resources used by society. This problem gains an important dimension specifically when dealing with the role played by the tropical forests in the maintenance of the climatic patterns, biodiversity and other environmental aspects. This problem must be considered seriously.

This takes us to the second interest point of the formulation made by Marx: the social form. Marx's standpoint, know as radical, puts into question the historically determined possibilities of economic organization of the reproduction of society. Without having to take over the normative part of the author's argument, society should reflect about the character of the economic organization, and, in this sense, its territorial dynamic expansion.

In his elaboration of the theory of absolute rent, amplifying Ricardo's land rent theory (restricted to rent that he denominates as differential), Marx (returning to Adam Smith) discusses the role of land monopoly for society. His emphasis, that possesses a clear political character (revolutionary), is about the consequences of this monopoly on the value of the reproduction of the working force, associated to the creation of a structural surplus of workers - relative surplus population (Chapters 25 and 33 of Capital, Book 1).

In relation to the argument constructed in this paper it is interesting to note how this dynamic interacts with the existence of the tropical forest inside of an

underdeveloped country marked by a strong colonial heritage. The dynamics described in the item *The Legal Amazon* of this paper contradicts, *relatively,* the thesis defended by Marx in the 33th. Chapter of **The Capital** *The Modern Theory of Colonization*. In this chapter, the author argues that the existence of available land for subsistence farming makes unviable the use of employment on salary basis. When the expression *relatively* is used the intention is not only to remember the slavery past, but is above all to remember that until today it is possible to encounter slaves in the Legal Amazon (Martins, J. S. 1997).

It is impossible to comprehend the expansion of the occupation of the Amazon without taking into consideration the role played by land property. It was presented above the land use cycle; this same cycle can be seen in a much tenser and violent expression. The social conflicts due to illegal properties and the expropriation of small farmers due to the existence of these false documents plays an important role in the deforestation and the use of fire in the region. This process of expropriation is surely one of the factors of the expansion of the deforestation arch in the Amazon. Strengthen with these property titles and usually with armed militias the *grileiros* (land-grabbers) expulse the small farmers. These in order to survive penetrate into the forest occupying wildland by means, initially, of fire. This is one important way, not only in terms of natural resources but especially in terms of social conflict, that the fire and deforestation arch approximates the Amazon River. This is the image seen by the satellites: the *heat* of the Amazon on fire.

Conclusion

It seems that the predominant tendency in the Legal Amazon, as has been discussed above, is the expansion of the cattle raising and soybean plantation. The advance of these economic activities in Amazonia, and in Brazil, responds to strong internal and external demands, specially since the *crazy cow* crisis.

It is important to remember, as has been discussed above, of the role played by the government by means of subsidies and credits for the large farms directed to extensive cattle raising. If this command is now being carried out by the private initiative, such as suggested by Margulis, it means that the command is now the market allocation. If this is the case, the logic of the expansion of the agricultural frontier must be analyzed in this perspective.

Presented these considerations we can now turn back to the propositions of Ricardo's land rent. Land rent would be, for the author, the surplus proportioned by differentials in costs, due to the advantage of fertility and localization of the land used in relation to those land plots that the agricultural production provides only normal profits. What defines the occupation of a new stripe of land is an increase in price due to an increase in demand that makes viable these stripes that were deficitary.

In this sense, the occupation of wildland would be determined by the surplus provided by its use. In case this surplus stays beyond the normal profit, the land plot would be abandoned. The consequence is that the occupation of an additional stripe of land would depend in the surplus provided by the use of a determined area. Ricardo affirms that the increase in the land rent is always due to the increase in richness of a country and of the difficulty to produce food for the increasing population, generating revenues in the most productive stripes. In the period of

increase of heat focuses such as shown in *figure 1* (during the years 2000-2002) there was a regional increase in the price of land due not only to the *crazy cow crisis*, which augmented the demand for cattle raising activities, but also due to an increase of soybean plantations. It can also be asked if the increase of the fire arch is a direct consequence of the high capital investments in the soybean and cattle productive network or if it was an *indirect* effect of this process such as suggested by Margulis. The expression *indirect* suggests the perpetuation of the land cycle use. This land cycle use, as an expropriation dynamics, means that the people who lived in the area that now is incorporated to this productive network have been pushed forward, occupying the wildland by means of fire. Anyway, Ricardo's argument provides a good explanation for the problem treated above.

The existence of the fire arch that corresponds with the deforestation arch, even after the state stimulus for the occupation of the Amazon has ceased, seems a function of demand. Such stimulus, due to the nature of the market economy, is difficult to be controlled, especially in a situation that regional studies about the area are limited. And nothing can be said about the existence of coherent policies towards the region. Even the creation of an effective fire monitoring structure such as the PROARCO, which monitors daily the fire arch in the Legal Amazon, in such extensive region of difficult access has the tendency to function merely as a palliative. The solution of the problem of preservation of wildland and its unknown resources needs to be related to the social problem hidden behind the heat focuses seen in the satellite images.

By means of this exploratory analysis alternatives for the problem of fire monitoring and planning can be thought. The necessity of a theoretical approach does not restrict itself to the normative answers suggested by the authors cited above. It also shows the necessity to re-elaborate the economic theory in order to incorporate new problems such as the fire dynamics. The theoretical answers given by Ricardo and used to understand contemporary problems can not be totally sufficient because the reality analyzed is not totally clear. Anyway, it provides a good insight to an insipient debate that can take theory to new normative proposals.

In this sense, the analysis of the Amazonian fire arch by means of incorporating the classical economic theory provides a different standpoint not only for the theory and regional territorial understanding but also provides new elements in the fire monitoring, planning and environmental management debate.

References

Cochrane, Mark A. and others. 2002. *Investigating positive feedbacks in the fire dynamic of closed canopy tropical forests.* In WOOD, Charles H. and PORRO, R. (eds) **Deforestations and Land use in the Amazon.** University Press of Florida, Florida, USA.

Fausto, Boris. 1999. **História do Brasil**. 7 edition. EDUSP, São Paulo, Brazil.

Gremaud, A. P. and others. 1997. **Formação econômica do Brasil.** Editora Atlas. São Paulo, Brazil.

Prado Junior, Caio. 1965. **História econômica do Brasil**. Editora Brasiliense, 9 edition, São Paulo, Brazil.

Margulis, Sergio. 2003. **Causas do desmatamento da Amazônia Brasileira.** Relatório ao Banco Mundial, Brasília, Brazil.

MartinS, José de Souza. 1997. **Fronteira. A degradação do Outro nos confins do humano.** Editora Hucitec, São Paulo, Brazil.

Marx, Karl. **Capital. A critique of political economy.** Penguin Classics, London, England.

Moran, Emilio F. and others. 2002. *Trajectories of Land Use. Soils, succession, and crop choice.* In WOOD, Charles H. and PORRO, R. (eds) **Deforestations and Land use in the Amazon.** University Press of Florida, Florida, USA.

Moreira, Igor A. G. 1989. **O espaço geográfico. Geografia geral e do Brasil**. Editora Ática, São Paulo, Brazil.

Ricardo, David. 1996 (1817). **Principles of political economy and taxation.** Prometheus Books, New York, USA.

Vesentini, José W. 1996. **Brasil sociedade e espaço**. Editora Ática, São Paulo, Brazil.

Wood, Charles H.; David, Skole. 1998. *Linking satellite, census, and survey data to study deforestation in the Brazilian Amazon*. In LIVERMAN, Diana and others. 1998 **People and Pixels. Linking remote sensing and social science**. National Academy Press, Washington, USA.

Page left blank intentionally.

The Influence of Ethnicity and Language on Economic Benefits of Forest Fire Prevention From Prescribed Burning and Mechanical Fuel Reduction Methods[1]

John Loomis,[2] Lindsey Ellingson,[2] Armando González-Cabán,[3] Hayley Hesseln[4]

Abstract

This paper compares the non-market benefits received by several ethnic groups from prescribed burning and mechanical fuel reduction programs in California. A mail booklet with follow-up phone interview was used to elicit responses. Whites, African Americans and half the Hispanics received the survey in English, while the other half of the Hispanic sample received the survey in Spanish. Univariate test statistics on ethnicity and language indicated there were significant differences in interview response rates of Whites, African Americans and Hispanics (using both English and Spanish language versions). There is no statistical differences in willingness to pay logistic regression coefficients of Hispanics, Whites and African Americans for the prescribed burning program, but there were significant differences across groups for the mechanical fuel reduction program. Mean willingness to pay for prescribed burning was the $100 lower per year for Whites ($400) than African Americans ($505), but these differences are not significantly different. Willingness to pay of Whites ($437) for the mechanical fuel reduction program was half that of Hispanic's taking the survey in Spanish ($863), but the large confidence intervals suggest these differences are not statistically significant. The bid coefficient for African American's was insignificant for the mechanical fuel reduction program, while for Hispanics it was insignificant for the prescribed burning program. It is interesting that different ethnic groups respond differently to the two fuel treatment programs. Nonetheless, there is a substantial support and willingness to pay by Whites and African Americans for prescribed burning and for Whites and Hispanics for mechanical fuel reduction in California.

Introduction

Increasing numbers of wildfires each summer has brought forward legislative and administrative proposals for expanding prescribed burning and mechanical fuel reduction programs. A policy of accelerating the amount of land to be mechanically

---

[1] An abbreviated version of this paper was presented at the second symposium on fire economics, planning and policy: a global view. 19–22 April 2004, Cordoba, Spain.

[2] Professor and Research Assistant, Department of Agricultural and Resource Economics, Colorado State University, Fort Collins, CO 80523.

[3] Economist, Forest Fire Lab, Pacific Southwest Research Station, USDA Forest Service, Riverside, CA 92507.

[4] Professor, Department of Agricultural Economics, 51 Campus Drive, University of Saskatchewan, Saskatoon, Canada, SK S7K 5A8.

thinned or prescribed burned is not without opposition. Prescribed burning can generate significant quantities of smoke that affects visibility and creates health problems for people with respiratory conditions. Prior initiatives to increase prescribed burning in states such as Florida and Washington have often been limited by citizen opposition due to smoke and health effects. The prescribed burning program is also expensive and costs as much as $250 per acre. Thus a policy relevant issue is whether this time there will be sufficient public support for an active prescribed burning program to occur. This paper extends our previous work in Florida (Loomis and others 2002) on the performance of contingent valuation method (CVM) in representing the views of Spanish speaking Hispanics and English speaking residents of Florida towards prescribed burning and mechanical fuel reduction in two directions. First, we add a targeted sample of a third minority group (African Americans). Secondly, we inquire whether there are differences in CVM responses of Hispanics asked to take the survey in English (as is commonly done) versus in Spanish, typically a more native language for Hispanics. This allows us to better isolate the effect of language (Spanish versus English) from ethnicity (Hispanics, Whites and African Americans). The results provide the most comprehensive evaluation of the performance of CVM in a multi-racial and multi-lingual society such as California.

The importance of understanding ethnic and language differences when making public policy decisions is growing. Collectively, minority groups are close to becoming the majority in many states of the United States. Many of these minority groups speak languages other than English. U.S. Bureau of Census data indicates that 32 million adults in the U.S. speak a language other than English in their home. Census data from 1990 to 1999 showed that on average, the Hispanic population grew by 39% in the U.S, with states such as Arizona, California, Florida, New Mexico and Texas, having an even more rapidly increasing Hispanic population. In our study area in California, nearly one-third of the population (11 million people) are of Hispanic or Latino origin. Another important racial or ethnic group in California are Blacks or African Americans, representing 7.5% of the California population or 2.5 million people.

A "guiding assumption" of survey methodology has been that similarity between interviewers and respondents has some influence on survey responses (Reese and others 1986), and this similarity may increase the validity of survey responses (Hurtado 1994). However, there has been little testing of racial/ethnic interviewer effects in phone interviews (Cotter and others 1982). We suspect there would also be response rate differences to mail and phone surveys due to race and ethnicity. Besides any obvious language difficulties, many minority cultures often feel marginalized by the dominant public institutions such as government agencies and universities. As such they tend to have low voter participation. It is plausible that the same disinterest may carry over to answering referendum contingent valuation surveys, particularly if sponsored by the dominant culture’s institutions like government or universities.

Whether explicit omission of non-English speakers in the sample or implicitly through language selection effects, either potentially leads to unrepresentative samples that limits the generalizability of empirical results or yields an underestimate of benefits by omitting benefits received by non-English speaking households. To date, no studies have specifically compared CVM responses of Whites, African American, and Hispanic households.

The objective of this study is to determine if differences exist in survey response rates, overall WTP question protest responses, and differences in WTP estimates for White households, African American households, and Hispanics households (half of which took the survey in English, as is typical, and half took the survey in their native Spanish language). The two wildfire fuel reduction programs under study are quite relevant to people living in California due to the state's frequent wildfires. The unique feature of this experimental design of having half the Hispanics take the survey in English and half in Spanish will aid in understanding how a respondent's native language may shape their participation and response in CVM surveys. If cultural differences are found, it may suggest the need to tailor material in the CVM survey so as to better communicate with each culture. This research will also allow us to evaluate how well traditional non-market valuation methods such as CVM work with different ethnic groups. The methodological approach demonstrated here has broad applicability to other fire prone states with large Hispanic populations such as Arizona and New Mexico.

Hypotheses Tested

Response Rate and Refusals to Pay

Our survey modes involve an initial random digit dialing phone call with a short (5 minutes) initial interview. We then request their name and address to mail a survey booklet and schedule a time for an in-depth (20 minute) interview. Thus, the first basis of comparison is whether African Americans, Hispanics and Whites respond equally to the initial phone call and follow through on the in-depth interview. Since the interviewers identified themselves as being with a California university, it is hypothesized that these three groups might react differently to a request from a university. Therefore they may not be equally responsive to the request for an initial interview, and a follow-up in-depth interview. Such a differential response rate would make it more difficult to generalize resulting economic values from the survey sample to the population. The null hypothesis is that the overall survey response rate (R) to the CVM survey is independent of language and ethnicity:

$$\text{Ho: } R_{\text{AfricanAmericans}} = R_{\text{Hispanic-Spanish}} = R_{\text{Hispanic-English}} = R_{\text{White}}$$

This will be tested using separate four by two contingency tables and a χ^2 test for both the first and second interviews.

Responses to the WTP questions elicited during the in-depth interview are the main focus of our analysis. First, we compare the four groups reasons for refusing to pay anything. Some refusals are valid expressions of zero WTP since they reflect lack of value for the good or low income (i.e., inability to pay). Other respondents that give a zero valuation or refuse to pay because they reject the scenario or rationale that citizens should have to pay for this program, are often termed protest responses (Mitchell and Carson; Halstead and others). These respondents often do not "buy into" the premise that they are responsible for paying for the solution, or are unconvinced the solution will actually work, or feel government will not spend the money collected on the specific program. Here too, cultural differences between the majority culture and a minority culture may result in systematically different responses, with higher protest responses from a more distrusting minority culture.

To determine what might potentially be a protest response the following strategy was used in the voter referendum CVM question sequence. First, if a respondent

indicated he or she would vote against the program at their initial bid amount, they were asked whether they would pay $1. If they said they would not pay $1, they were asked an open-ended question "Why did you vote this way?". The interviewer was instructed to type in exactly what the respondent said. After all interviews were completed, the reasons were analyzed for content to classify answers by similar reasons given by the respondent. This open-ended response approach avoids having respondents fit themselves into pre-set protest categories or having the interviewer place them into pre-set categories.

Comparing the overall protest reasons given, we will test the null hypothesis of no difference between the four groups in terms of acceptance of the premise and credibility of the CVM survey. The null hypothesis is that the distribution of refusals to pay and protest responses to the CVM survey are independent of ethnicity and language:

$$\text{Ho: Protest}_{\text{AfricanAmericans}} = \text{Protest}_{\text{Hispanic-english}} = \text{Protest}_{\text{Hispanic-spanish}} = \text{Protest}_{\text{White}}$$

This will be tested using a four by two contingency table. Significance tests will be performed using a χ^2 test.

WTP Model and Related Hypotheses Tests

As suggested by the NOAA panel on contingent valuation, a voter referendum willingness to pay question format was used (Arrow and others 1993). Hanemann (1984) suggests how a respondent may answer a dichotomous choice CVM question. He views the respondent as evaluating the utility difference associated with the status quo versus paying some amount ($X) to have the program. If the utility difference is positive for the program, the individual would respond "Yes". If the utility difference is distributed logistically, a logit model can be used to estimate the parameters and allow for calculation of WTP. The effect of language and ethnicity will be tested for using a logit model in two primary ways. First, we can test whether ethnicity and language simply shifts the logit function up or down by an intercept shifter (e.g., B2, B4, B6) or affects the bid slope of the logit function (e.g., B3, B5, B7) in equation

(1): ln(Pi/1-Pi)=B0+B1Bid+B2 AfricanAmericans

+B3 Bid*(AfricanAmericans) + B4 Hispanic-Spanish

+ B5 Bid*(Hispanic-Spanish) + B6 Hispanic-English

+ B7 Bid*(Hispanic-English) +..BnXn

where: Bid is the dollar amount the respondent is asked to pay

AfricanAmericans is one for African Americans, and zero for Whites and Hispanics

Hispanic-Spanish is one for Hispanics taking the survey in Spanish

Hispanic-English is one for Hispanics taking the survey in English

The null hypotheses are:

Ho: B2 = 0; Ho: B3 = 0; Ho: B4 = 0; Ho: B5 = 0; Ho: B6 = 0; Ho: B7 = 0

The hypotheses are tested through evaluation of the t-statistic on the respective coefficients.

A more general test is to evaluate whether all the coefficients in the logit equation would vary with ethnicity and language. Thus, four separate logit equations are estimated, one each for Whites (W), African Americans (AA), Hispanic-Spanish (HS) and Hispanic-English (HE) of the form:

(2a) $\ln(Pi/1-Pi) = W0 + W1\ Bid + W2\ X2 + W3\ X3 + ... + WnXn$

(2b) $\ln(Pi/1-Pi) = AA0 + AA1\ Bid + AA2\ X2 + AA3\ X3 + ... + AAnXn$

(2c) $\ln(Pi/1-Pi) = HS0 + HS1Bid + HS2X2 + HS3X3 + ... + HSnXn$

(2d) $\ln(Pi/1-Pi) = HE0 + HE1Bid + HE2X2 + HE3X3 + ... + HEnXn$

The null hypothesis is of coefficient equality across all four groups:

Ho:W0=AA0 =HS0=HE0; W1=AA1=HS1=HE1;...Wn=AAn= HSn = HEn

The null hypothesis is tested using a likelihood ratio test comparing the separate logit equations to a pooled logit equation of all four groups. The significance test is conducted by evaluating the chi-square statistic. If this null hypothesis is rejected, then it is sensible to investigate which ethnicity and language treatments are the ones that are statistically different from each other, and which, if any, are not statistically different from each other. Thus, we will conduct a series of pairwise tests if needed.

Comparisons of mean WTP estimates across ethnicity and language groups will be used to establish if differences exist in the benefits of the public program to each group. The null hypothesis tests whether the WTP estimate by ethnicity and language are equal:

Ho:WTPWhite=WTPHispanic-English=WTPHispanic-Spanish= WTPAfricanAmericans

The results are determined by whether the confidence intervals overlap or not.

Survey Design

The survey booklet was developed in conjunction with forestry professionals in California. It described the acreage that is burned by wildfires in an average year as well as the typical number of houses lost to wildfire each year. Next, a program increasing the use of prescribed fire or controlled burning in California was described. Specifically, respondents were told that the prescribed burning fuel reduction program would reduce potential wildfire fuels through periodic controlled burning. It was acknowledged that prescribed burning does create some smoke, although far less than a wildfire. Then the survey booklet provided additional information and drawings contrasting wildfire and prescribed fire. The cost of financing this program of prescribed burning was described as a cost-share program between the State of California and the county the individual lived in.

The WTP elicitation wording was:

California is considering using some state revenue as matching funds to help counties finance fire prevention programs. If a majority of residents vote to pay the county share of this program, the Expanded California Prescribed Burning program would be implemented in your county on federal, state, and private forest and rangelands. Funding the Program would require that all users of California's forest and rangelands pay the additional costs of this program. ...If the Program was

undertaken it is expected to reduce the number of acres of wildfires from the current average of 362,000 acres each year to about 272,500 acres, for a 25% reduction. The number of houses destroyed by wildfires is expected to be reduced from an average of 30 a year to about 12. Your share of the Expanded California Prescribed Burning program would cost your household $__ a year. If the Expanded Prescribed Burning Program were on the next ballot would you vote

__In favor ___Against? "

The mechanical fire fuel reduction program was defined in the booklet as the following: *Another approach to reducing the buildup of fuels in the forest is to "mow" or mechanically chip the low- and medium-height trees and bushes into mulch. This is especially effective at lowering the height of the vegetation, which reduces the ability of fire to climb from the ground to the top or crown of the tress. In addition, mechanical "mowing" slows the growth of new vegetation with the layer of mulch acting as a barrier.*

The mechanical fire fuel reduction program was stated as not producing any smoke, unlike the prescribed burning method, so as not to deteriorate the air quality. The survey booklet explained the number of acres and houses that are destroyed each year in California due to wildfires and it stated that only one of the two programs would be implemented. The mechanical fire fuel reduction dichotomous choice willingness to pay question was stated as follows:

If the Mechanical Fire Fuel Reduction Program was undertaken instead of the Expanded Prescribed Burning Program, it is expected to reduce the number of acres of wildfires from the current average of approximately 362,000 acres each year to about 272,500 acres, for a 25% reduction. The number of houses destroyed by wildfires is expected to be reduced from 30 a year to about 12. Your share of this Mechanical Fire Fuel Reduction Program would cost your household $X a year. If the Mechanical Fire Fuel Reduction program were the ONLY program on the next ballot would you vote? ____ In favor____ Against

The funding of both of these fuel treatment programs was explained as being on a county-by-county basis, where if a majority of the county residents voted for the program, the state of California would match funds for the approved counties and everyone in the county would be required to pay the additional stated amount for their county. The bid amount, denoted by $X, varied across respondents and had the following values: $15, $25, $45, $65, $95, $125, $175, $260, $360, and $480.

Data Collection and Survey Mode

The survey was conducted through a phone-mail-phone process. To obtain a representative sample of households, random digit dialing of the households living in a sample of California counties was performed. The counties were selected so there was a mix of counties that frequently experience wildfires, counties that occasionally experience wildfires, and counties that almost never experience wildfires. Once initial contact was established, language was verified along with elicitation of initial attitude and knowledge of wild and prescribed fire, followed by the scheduling of appointments with individuals for detailed follow-up interviews. During the interim time period, a color survey booklet was mailed to the household. These interviews were conducted with the aid of this color booklet. The booklet was sent in English to Whites, African Americans and approximately one half of the Hispanic households.

The other half of the Hispanic households were sent the survey booklet in Spanish. The individuals were asked to read the survey booklet prior to the phone interview. Phone interviews were conducted in either English or Spanish depending on the language of the booklet received.

Results

Comparison of Survey Response Rates

Because the survey was conducted in two waves, ethnic groups are compared on response rates from the initial random digit dial phone survey and the follow-up in-depth interviews separately in Table 1. While, the response rates to the initial phone calls were all over 40%, there is a statistically significant difference between the four groups in response to the initial phone call. The highest response rate (75.5%) is by Hispanics phoned by a Spanish-speaking interviewer. The extra effort to contact people in their native language was definitely worthwhile in the initial interview. Specifically, a significantly higher response rate was obtained (based on the chi-square statistic of 9.98) by conducting the initial interview with Hispanics in Spanish as compared to English.

Table 1—*Comparison of Response Rates by Ethnicity and Language*

First Wave - Screener	Caucasian	African American	Hispanic English	Hispanic Spanish	Total
Total Initial Sample Contacted	794	708	733	620	2855
Completed Initial	328	308	421	468	1525
1st Wave Response Rate	41.3%	43.5%	57.4%	75.5%	53.4%
Chi-Square Total					**58.61****
Chi-Square (AA vs C)					0.298
Chi-Square (HE vs HS)					**9.98****
Second Wave - In-Depth Interview					
Refused to give address	4	4	9	1	18
Phone disconnected, moved, not available	16	25	37	47	125
Not called by end	51	3	0	0	54
Net sample for 2nd wave	257	276	375	420	1328
Total surveys completed	187	126	170	139	622
2nd Wave Response Rate	72.8%	45.7%	45.3%	33.1%	46.8%
Chi-Square Total					**34.25****
Chi-Square (AA vs C)					**10.51****
Chi-Square (HE vs HS)					**5.48***

*Significant at the 5% level

**Significant at the 1% level

Unfortunately, the opposite effect occurs in the in-depth interviews. After mailing a Spanish language booklet to Hispanic households, a relatively low response rate of 33% was obtained in this phase, significantly lower than obtained from Hispanics who were sent the survey booklet in English. This initially appeared somewhat counter-intuitive since one would have expected that the prospect of being called back by a Spanish language interviewer would have resulted in a higher response rate on the in-depth interview phase. However, the use of Spanish language on the initial call resulted in such a high response rate (75%), that we might have recruited some people who typically would not answer surveys. When they received the survey booklet and saw it was substantial (7 pages), they declined to participate in the in-depth interview. Whereas in the initial calls to Hispanics in English, we obtained a lower initial response rate (57%) but it may have been people who were serious about completing the entire survey process. On the flip side, the response rate of Whites was the highest in the in-depth interviews. Overall, the chi-square statistic suggests there is a statistically significant difference in response rates to the initial phone interview across the four samples (chi-square = 58.61) and the in-depth phone interview (chi-square 34.25). However, in the in-depth interviews, Whites have a statistically higher response rate than African Americans, while in the initial interviews they were not different.

Reasons Why Households Would Not Pay for the Program

Table 2 presents the categorization of refusals to pay, i.e., individuals that indicated they were in favor of the prescribed burning or mechanical fuel reduction program at no cost, but then would neither pay their initial bid amount nor pay $1 in the follow-up willingness to pay question. These individuals appear to favor the program but essentially have a zero WTP. Table 2 lists the reasons why a person would not pay the $1 for the prescribed burning program. The first three reasons listed in Table 2 are not considered protest responses because having no value for the program or receiving no benefits from the program, as well as not being able to afford to pay, are valid reasons for zero WTP. However, the other three categories of responses are considered protests because they were frequently prefaced with, "I am in favor of program" or "I'm all for it, but I think the program should be paid for by those living in the forests or with existing taxes."

Table 2—Reasons why respondents would not pay $1 for prescribed burning

Reason	African Americans	Hispanics-English	Hispanics-Spanish	Whites	Total
Non Protest Responses					
No Value/No Benefits	0	3	0	1	4
Cannot Afford	1	1	0	3	5
Taxes Already too High	0	0	0	2	2
Non Protest Total	**1**	**4**	**0**	**6**	**11**
Protest Responses					
Should be Paid for with Existing Taxes	2	0	0	4	6
Those that Live in Forest Should Pay	1	0	0	0	1
Other	1	3	0	1	5
Protest Total	**4**	**3**	**0**	**5**	**12**

Because of the frequency of zero cell entries for some ethnic groups for specific protest responses, only an overall chi-square of protest responses versus non-protest responses can be computed. The calculated chi-square of 1.994 indicates no statistically significant difference among the ethnic groups in the pattern of protest and non-protest reasons for refusing to pay. Nonetheless, it is noteworthy that no refusals to pay were received from Hispanic households being interviewed in Spanish. Across all four groups there is substantial overall support for prescribed burning as a means to reduce wildfire. Specifically, there were only 23 households out of 622 households (3.7%) that would not pay $1, and only 12 of these were considered protest responses. There were 116 people who said NO to their initial bid, but of these, 92 said YES to the $1.

Table 3—*Reasons Why Respondent Would Not Pay $1 for the Mechanical Fire Fuel Reduction Program*

Reason	Whites	African-American	Hispanic-English	Hispanic-Spanish	Total
Non-Protest Responses					
No Value/Benefits Where I Live	1	2	2	1	6
Cannot Afford	1	2	0	0	3
Reduces Food/ Vegetation For Wildlife	4	7	4	1	16
Method is Unnatural/ Leave Nature Alone	3	6	2	0	11
Dislike Mechanical Fuel Program	3	4	3	1	11
Non-Protest Total	**12**	**21**	**11**	**3**	**47**
Protest Responses					
Prefer Prescribed Burning Method	5	2	2	0	9
Others Should Pay For It	1	3	1	0	5
Does Not Need Additional Funding	2	2	0	0	4
Wants More Information About Program	1	1	0	0	2
Does Not Trust the State	0	1	0	0	1
Harms Their Business	0	1	0	0	1
Other	1	4	1	1	7
Protest Total	**10**	**14**	**4**	**1**	**29**
Total	**22**	**35**	**15**	**4**	**76**

Table 3 presents the result of the mechanical fuel reduction refusals to pay. The upper half of the table reflects non-protest refusals to pay while the lower half reflects protests or rejections of the premise of the CVM constructed market. Hispanics had the least amount of protest responses (5), while African Americans protested the most with 14 responses. A chi-square test was used to determine if there are differences in reasons for refusals to pay across ethnicities. With three degrees of freedom, the calculated chi-square was 1.68 and the critical chi-square value was 7.815. Since the calculated chi-square was less than the critical chi-square, we accept our null hypothesis that there was no statistical difference among ethnicities for protest and non-protest reasons for not paying at least $1 for the mechanical fuel reduction program.

Results of Logit Regressions

Table 4 presents the results of the "full" logit model that includes not only the ethnicity and language variables, but also other demographic variables (Age, Education, Home Value, Gender, Income, number of people in the household, and whether they owned their own home), attitudes (prescribed burning causes health problems-Health Problems from Prescribed Burning), as well as whether they have witnessed a forest fire (Witnessed Fire) and observed their neighbors house burning (NeighborHouseBurn). In the prescribed burning analysis, we also included a variable (FireTown) which reflects whether the household lives in a town that has either had a fire in the recent past (e.g., Oakland) or lives adjacent to forests that repeatedly burn. These other non-ethnicity variables were included to attempt to control for as many of these factors as possible to guard against our hypothesis tests of ethnicity and language being influenced by omitted variable bias.

Overall, the coefficient on the bid amount (Bid) is negative and statistically significant for both the prescribed burning and mechanical fuel reduction program. Education level and whether respondents view prescribed burning to cause health problems from smoke were both significant at the 0.05 level for the prescribed burning program. In terms of our hypotheses regarding ethnicity and language, Table 4 indicates that none of the ethnicity or language logit intercept shift variables or logit bid slope interaction terms are statistically significant at conventional levels for the prescribed burning program. However, for the mechanical fuel reduction program the Hispanic-English (HE Bid) bid slope interaction term and the Hispanic-Spanish (HS) intercept shifter were significantly different from zero at the 10% and 2% level, respectively. This suggests a less price sensitive demand for the mechanical fuel reduction program among Hispanics given the survey in English, and a higher overall support for Hispanics given the survey in Spanish.

Taken as a whole, the results in Table 4 suggest if there are other differences in ethnicity and language, they may not be adequately accounted for solely by a simple intercept shifter and bid slope interaction terms. Thus, the differences might be more pervasive, involving differences in all the coefficients. Using a specification focusing on just the variables in Table 4 with t-statistics greater than one, we estimated a reduced model for each of the four groups individually, without, of course, the ethnicity and language variables. To conserve space these are not reported here (see Ellingson, 2003 for details on the mechanical fuel reduction logit models).

Table 4—*Logit Function with Ethnicity Intercept and Bid Slope Interactions*

	Prescribed Burning			Mechanical Fuel Reduction		
Variable	Coefficient	t-Statistic	Prob.	Coefficient	t- Statistic	Prob.
Constant	2.5123	3.030	0.002	1.0525	1.24	0.212
Bid	-0.0052	-3.523	0.000	-0.0024	-1.93	0.052
African American (AA)	-0.0489	-0.089	0.928	-0.0984	-0.251	0.801
AA Bid	0.0010	0.464	0.642	0.0015	0.808	0.418
Hispanic-English (HE)	-0.0995	-0.186	0.852	-0.1124	-0.291	0.771
HE Bid	0.0029	1.387	0.165	0.0027	1.641	0.100
Hispanic-Spanish (HS)	0.4861	0.717	0.473	1.1234	2.272	0.023
HS Bid	0.0029	1.154	0.248	-0.0008	-0.424	0.671
Gender	-0.3114	-1.211	0.225	-0.3284	-1.694	0.090
Home Value	4.17E-07	0.767	0.442			
Health Problems from Prescribed Burning	-0.8459	-2.572	0.010	-0.2540	-1.038	0.299
Witnessed Fire	0.1649	0.585	0.558			
Neighbor House Burn	0.5292	1.057	0.290			
Income	-5.08E-06	-1.383	0.166	-1.50E-05	-1.571	0.116
$Income^2$				1.07E-10	1.943	0.052
Age	-0.0022	-0.245	0.806	0.0099	1.361	0.173
Number in Household	0.1115	1.262	0.206	0.0447	0.687	0.491
Education	-0.0982	-2.033	0.042	-0.0329	-0.712	0.475
Experience Smoke				-0.0296	-0.147	0.883
Own Home				-0.1228	-0.537	0.591
FireTown	0.2375	0.690	0.489			
Mean dependent variable	0.79					.63
McFadden R^2	0.096					.060
LR statistic (17 df)	45.787					42.14
Probability (LR stat)	0.0001					0.0004
Sample Size	474					536

Prior to reporting the results of the likelihood ratio test for coefficient equality we summarize the results of the individual logit equations. For the prescribed burning program the bid slope coefficients are statistically different from zero at the 1% for Whites and African Americans but not for either Hispanic group. It is encouraging that the sign is negative on bid in both Hispanic regressions, but it is unusual for the bid coefficient to be insignificant in dichotomous choice CVM responses. This is contrary to what Loomis and others (2002) found for Hispanics living in Florida for a

prescribed burning program there. One difference may be that Hispanics in Florida are predominantly from the Caribbean area, while Hispanics in California are from Mexico and Central America. For the mechanical fuel reduction program the bid amount is statistically significant at the 5% level for Whites and Hispanics given the survey in Spanish, but not for Hispanics given the survey in English or for African Americans.

To test whether the logit willingness to pay coefficients are different between all the four treatments, likelihood ratio tests were conducted, and are reported in Table 5. For the prescribed burning program, there appears to be no statistical difference in the sets of coefficients between the four models (calculated chi-square =33.34 while the critical was 36.15 at the .05 level). These results are consistent with what Loomis, and others (2002) found in Florida when comparing English and Spanish samples logit models as well. However, for the mechanical fuel reduction models, this same test indicates there is a statistically significant difference at the 5% level between the four groups logit willingness to pay coefficients. In the conclusion we hypothesize why the results are different for the two programs.

Table 5—*Likelihood Ratio Tests of Coefficient Equality Across Ethnic Groups.*

	Prescribed Burning	**Mechanical Fuel Reduction**
Groups	Log Likelihood	Log Likelihood
White	-70.91	-103.95
African Americans	-46.35	-71.70
Hispanic-English	-62.19	-101.51
Hispanic-Spanish	-33.48	-54.79
Sum of Unrestricted	-212.93	-331.95
Pooled-Restricted	-229.61	-349.13
Calculated Chi-Sq	33.34	34.36
Critical Chi Sq @5%	36.15	28.87
Significantly Different?	No	Yes

Willingness to Pay Results

Table 6 displays the mean willingness to pay for Whites, African Americans, and Hispanics given the survey in Spanish and the respective confidence intervals. We used the following formulae (Hanneman 1989) to calculate mean willingness to pay:

$$\text{Mean WTP} = (\ln (1 + \exp (\alpha))) / \beta$$

The product of the coefficient and mean values for all independent variables excluding the bid coefficient is denoted by α and β is the absolute value of the bid coefficient (Park and others1991).

Mean willingness to pay for prescribed burning was $100 lower per year for Whites ($400) than for African Americans ($505), but these differences are not significantly different. Interestingly, using the African American logit coefficients with demographics of Whites, cuts the difference in WTP in half, suggesting that demographic differences play a large role in the difference in WTP. For the mechanical fuel reduction program, willingness to pay of Whites ($437) is half that of Hispanics taking the survey in Spanish ($863), but the large confidence intervals suggest these differences are not statistically significant. The bid coefficient for African American's was insignificant for the mechanical fuel reduction program, while for Hispanics it was insignificant for the prescribed burning program, thus precluding calculation of statistically significant estimates of mean WTP. It is interesting that different ethnic groups respond differently to prescribed burning and mechanical fuel reduction. Nonetheless, there is a substantial support and willingness to pay by Whites and African Americans for using prescribed burning, and for Whites and Hispanics for mechanical fuel reduction in California. Whites mean WTP is similar for the prescribed burning and mechanical fuel reduction program.

Table 6—*Mean WTP and 90% Confidence Intervals for Prescribed Burning and Mechanical Fuel Reduction Program in California.*

	Mean	90% Confidence Interval
Prescribed Burning		
Whites	$400	$312-$608
African Americans	$505	$363-$1,126
Mechanical Fuel Reduction		
Whites	$437	$278-$1,813
Hispanic-Spanish	$863	$494-$2,124

Conclusions

This paper investigated if there were ethnicity and language differences in survey response rates, reasons for refusing to pay, and willingness to pay for forest fire management policies. Using a univariate test (chi-square), we found a statistical difference in survey response rates between African Americans, Whites and Hispanics for both the initial random digit dialed interviews and the scheduled follow-up CVM phone interviews. Using Hispanics' native language (Spanish) did improve the response rate to the initial interviews, but this did not carry over to the follow-up CVM interviews involving the survey booklet. Reasons for not being willing to pay even one dollar for the prescribed burning and mechanical fuel reduction programs were similar among African Americans, Whites, and Hispanics taking the survey in English and Spanish. A logit regression that pooled all four groups responses to the prescribed burning program, and simply controlled for ethnicity and language using an intercept shifter variable and bid slope interaction term did not indicate any statistical differences between the four groups. A likelihood ratio tests on the four separate ethnicity and language logit models confirmed that the coefficients in the logit equations are not statistically different for the prescribed burning program.

Hispanics had an insignificant coefficient on the prescribed burning program

bid, a finding robust to whether the survey was administered in English or Spanish. In contrast, Whites and African Americans had a negative and statistically significant coefficient on the bid amount for prescribed burning, allowing us to calculate their mean willingness to pay for this program. Whites' willingness to pay was $400 while African Americans was $505 for the prescribed burning program, but these differences are not significantly different. Using the African American logit coefficients with demographics of Whites, cuts the difference in WTP in half; suggesting that demographics differences play a large role in the difference in WTP.

For the mechanical fuel reduction program, there were significant differences in the bid slope coefficient for Hispanics given the survey in English, with this group being less price sensitive to the cost of the program than Whites and African Americans. Hispanics given the survey in Spanish also voted in favor of the mechanical fuel reduction program at a higher rate, than any of the other three groups. Hispanics given the survey in Spanish had an annual willingness to pay per household of $863, twice that of Whites at $437. One possible reason for statistically significant differences in logit willingness to pay coefficients for Hispanics and higher willingness to pay of Hispanics may be that the mechanical fuel reduction program is quite labor intensive compared to prescribed burning. As such, Hispanics may believe the mechanical fuel reduction program will provide them with job opportunities, resulting in greater support for this program.

Overall, our results suggest substantial willingness to pay of California households for a prescribed burning or mechanical fuel reduction program that would decrease the number of acres burned by wildfires in California by 25% and reduce the number of houses burned in a typical year by 18. African Americans appear to prefer prescribed burning, and Hispanics appear to prefer mechanical fuel reduction. Whites have equivalent willingness to pay for either program.

With average willingness to pay of at least $400, and more than 12 million households in California, the willingness to pay for either of these programs is about $5 billion. Note, the survey explicitly indicated that only one of the programs would be implemented, so that it would be incorrect to add the values of these two fuel reduction programs together. Finally, this survey was conducted before the major wildfires swept through Southern California during the fall of 2003. We would expect that these willingness to pay value would have increased substantially had we conducted the survey after these wildfires. A comparison of the post fall 2003 values and these pre 2003 values might yield interesting insights as to whether willingness to pay is sensitive to these recent fire events in Southern California.

References

Arrow, K., Solow, R., Portney, P., Leamer, E., Radner, R. and Schuman, H. 1993. Report of the NOAA Panel on Contingent Valuation. U.S. Department of Commerce, Federal Register 58(10): 4602-4614.

Cotter, P., Cohen, J. and Coulter, P. 1982. **Race-of-Interviewer effects in telephone interviews**. Public Opinion Quarterly, 46(2): 278-284.

Ellingson, Lindsey. 2003. **The Role of Ethnicity and Language in Contingent Valuation Analysis.** Fort Collins: Colorado State University. 58p. M.S. Thesis.

Halstead, J., Luloff, A., and Stevens, T. 1992. **Protest bidders in contingent valuation.** Northeastern Journal of Agricultural and Resource Economics 21:160-169.

Hanemann, M. 1984. **Welfare evaluations in contingent valuation experiments with discrete responses**. American Journal of Agricultural Economics 67(3): 332-341

Hurtado, A. 1994. **Does similarity breed respect: interviewer evaluations of Mexican-Descent respondents in a bilingual survey**. Public Opinion Quarterly 58(1): 77-95.

Lenski, G. and, Leggett, J. 1960. **Caste, class, and deference in the research interview**. American Journal of Sociology 65(5): 463-467.

Loomis, John, Bair, Lucas, and González-Cabán, Armando. 2002. **Language related differences in a contingent valuation study: English versus Spanish**. American Journal of Agricultural Economics. 84(4): 1091-1102.

Mitchell, R., and Carson, R. 1989. **Using surveys to value public goods: the contingent valuation method**. Washington D.C.: Resources for the Future. 463 p.

Park, T., Loomis, J., and Creel, M. 1991. **Confidence intervals for evaluating benefit estimates from dichotomous choice contingent valuation studies.** Land Economics 67(1): 64-73.

Reese, S., Danielson, W., Shoemaker, P., Chang, T., Hsu, H. 1986. **Ethnicity of interviewer effects among Mexican-Americans and Anglos**. Public Opinion Quarterly 50(4): 563-572.

Tindigarukayao, J. 2001. **Challenges in Conducting Sample Surveys in the Caribbean.** Social and Economics Studies 50(2): 167-178.

Weeks, M. and Moore, P. 1981. **Ethnicity-of-interviewer effects on ethnic respondents.** Public Opinion Quarterly 45(2): 245-249.

Legal Frameworks for Forest Fire Management: International Agreements and National Legislation[1]

Mike Jurvélius[2]

Abstract

This presentation focuses on some legal aspects of forest fire management, namely international agreements and national legislation dealing with forest fires and is based on the updating work of Frédéric St-Martin, Legal Consultant; carried out in March 2004.

The main objectives of the up-dating was to: (i) identify newly developed national and sub-national legislation on forest fire management; (ii) update the inventory of international agreements on forest fires maintained by FAO; and (iii) prepare a standard template for developing Global Agreements based on the Template agreed upon by the International Wildland Fire Summit in Sydney in October 2003.

Updating of national legislation dealing with forest fires was carried out through a systematic search in FAOLEX, the FAO legislative database.

The international agreements and the national legislation identified in this update, were clustered into two categories of forest fire legal documents: (i) international agreements, including emergency response agreements and other agreements; and (ii) national legislation consisting of texts which either deal specifically and more or less fully with forest fires, or partly deal with some aspects of forest fire management among other forestry aspects.

The legal documents on forest fires that were identified in the course of this work included: (i) 20 emergency response international agreements; (ii) 9 international agreements not dealing with emergency response but covering other aspects of co-operation on forest fires; and (iii) 204 documents on national legislation, of which 95 are specific to forest fires, and the others deal with forestry generally and cover forest fires to some extent.

[1] An abbreviated version of this paper was presented at the second international symposium on fire economics, planning, policy: a global view, 19–22 April, 2004, Córdoba, Spain.

[2] Mike Jurvélius, Forestry Officer (Forest Fire Management), Forest Resources Development Services, Forest Resources Division, Forestry Department, FAO Viale Delle Terme di Caracalla, 00100, Rome Italy, mike.jurvelius@fao.org.

Introduction

Following on from a previous report by Bob Mutch and Maresa Bors, entitled *Follow-up Report to FAO/ITTO International Expert Meeting on Forest Fire Management, March 2001* (Rome, October 2001), this report focuses on some legal aspects of forest fire management, namely international agreements and national legislation dealing with forest fires.

In July 2001, the FAO Representatives in member countries were requested to locate international agreements on forest fires with a view to updating the list of those already available within FAO. In January 2002, a second request was made to the FAO Representatives for assistance in locating new agreements that might have been signed or drafted since the previous request, as well as any in-country fire agreements that may exist.

In-country agreements are those signed within a country either between states, provinces or other local government entities, or between institutions and/or departments in the national government.

By 2002, more than 30 responses were received from the following countries: Bolivia, Brazil, Burkina Faso, Burundi, Chile, Colombia, Cyprus, El Salvador, Ecuador, Eritrea, Ethiopia, Haiti, Honduras, Indonesia, Laos, Lebanon, Lesotho, Mauritius, Morocco, Peru, Rwanda, Seychelles, Sierra Leona, Sri Lanka, Syria, Thailand, Togo, Tunisia, Uruguay and Venezuela (Annex 2). Most answers given by the FAO Representatives were negative (i.e., no agreements in place). However, a number of cooperation agreements existed. It was recommended that this list be regularly updated as replies are sent by FAO Representatives and new information becomes available.

The full texts of the above legal documents, together with summaries for the international agreements, have been entered into a database and are available online in FAO's website.

In 2001, four recommendations were made for future action by FAO in relation to the legal aspects of forest fire management: (i) regularly update the information on international agreements and national legislation; (ii) further elaborate the outline for developing international agreements (Model Agreement Annex 1.), and develop new outlines for related operational guidelines and operating plans; including fire logistics; (iii) further review and assess the national legislation on forest fires; and (iv) develop guidelines for the formulation of national legislations on forest fires.

The international agreements and the national legislation identified were clustered into two categories of forest fire legal documents:

(i) international agreements, consisting of:
  (a) emergency response agreements;
  (b) other agreements; and,

(ii) national legislation consisting of legal instruments which:
  (a) either deal specifically and more or less fully with forest fires;
  (b) deal in part with some aspects of forest fire management.

This presentation focuses on some of the legal aspects in forest fire management, namely international agreements and national legislation dealing with forest fires and is based on the updating work of Frédéric St-Martin, Legal Consultant; carried out in March 2004.

Altogether, the legal documents on forest fires that were identified in the course of this updating work included:

(i) 20 emergency response international agreements (plus one which is still under negotiation);

(ii) 9 international agreements on other matters; and,

(iii) 204 documents referring to national legislation, of which 95 are specific to forest fires, and the others deal with forestry generally and cover forest fires to some extent.

1. International Agreements

1.1 Emergency Response Agreements

To date FAO has received copies of emergency response international agreements. The agreements are listed below, with an indication of: the parties to the agreement, the name and date of the agreement, and a brief outline of the purpose of the agreement. Their full text is accessible at the FAO Forestry Department's website

(http://www.fao.org/forestry/foris/index.jsp?start_id=5288).

Some of these international agreements on forest fires have annual Operational Guidelines or Operating Plans, which contain procedural details for the implementation of the agreements. These documents are regularly reviewed, in general every year, to adjust the implementation modalities of the agreements to the specific circumstances of the parties involved. Examples of operational guidelines, such as those developed under the agreements Mexico / USA or Canada / USA can be accessed through FAOLEX (http://www.fao.org/Legal/default.htm).

Examples of Emergency Response International Agreements

Parties to the agreement	Name and date of the agreement	Purpose of the agreement
Spain / Portugal	Protocol between the Kingdom of Spain and the Republic of Portugal regarding technical co-operation and mutual assistance on civil protection, 1993	Preparation and execution of projects on scientific and technical co-operation regarding civil protection (Article 1)
France / Spain	Agreement on mutual assistance between the French and Spanish fire fighting and assistance services, 1960	Facilitate mutual aid and prompt sending of assistance in case of emergencies occurring in border areas
Morocco / Spain	Agreement on technical co-operation and mutual assistance in civil protection, 28 December 1992	To improve scientific and technical research, and to provide mutual aid in case of catastrophes or emergencies
Argentina / Chile	Agreement between the Republic of Argentina and the Republic of Chile on co-operation in cases of catastrophes, 1997	Co-operation between the Parties shall be in the following areas: 1. Exchange of information in order to prevent catastrophes and their effects 2. Exchange of information and experiences regarding actions in cases of emergencies 3. Exchange of technological information to apply in cases of emergencies 4. Elaboration and development of programmes, projects and joint plans for emergencies 5. Development of plans for mitigation and operative

		coordination to face common risks 6. Collaboration in cases of emergencies through: a) Provision of personnel and means of assistance b) Use of means of technical assistance and logistics c) Supply of medical care and food at the request to mitigate the effects of emergencies (Article 2)
Argentina / Chile	Agreement on the protection of border forests against fires, 1967	Establish an effective system of co-operation for the protection of the common forests of the border area covered by the Agreement, including a mechanism to prevent, verify and extinguish fires (Article 1)
Finland / Russian Federation	Agreement by and between the Government of the Finnish Republic and the Government of the Russian Federation about Co-operation to avert disasters and to prevent their consequences, 1994	To foster co-operation in the following areas: 1. development of actions and methods that increase the contracting parties' possibilities of averting disasters, to notifying them and to prevent their consequences; 2. notification of disasters that have adverse effects across state borders; 3. mutual assistance to prevent the consequences of disasters (Article 2)
Mexico / United States of America	Wildfire protection agreement between the Department of the Interior and the Department of Agriculture of the United States of America and the Secretariat of Environment, Natural Resources, and Fisheries of the United Mexican States for the common border, 1999	The purpose of this Agreement is to: 1. enable wildfire protection resources originating in the territory of one country to cross the US/Mexico border in order to suppress wildfires on the other side of the border within the zone of mutual assistance in appropriate circumstances; 2. give authority for Parties to co-operate on other fire management activities outside the zone of mutual assistance (Article I)
New Zealand / United States of America	Wildfire Arrangement between the Department of the Interior and the Department of Agriculture of the United States of America and the National Rural Fire Authority of New Zealand, 2001	To provide a framework within which one Participant may request and receive wildfire suppression resources from the other Participant and to encourage co-operation on other fire management activities (Article I.1)
China / Russia	Agreement on Joint Control of Forest Fire between the Government of the People's	To improve forest fire control in border areas, to share experience in forest fire control, and to help each

	Republic of China and the Government of Russian Federation, 1995	other to prevent forest fires and to reduce losses there from
United States of America / Australia-New Zealand	International Agreement between the US Department of the Interior, Bureau of Land Management, US Department of Agriculture, Forest Service for the National Multi-agency coordination group for and on behalf of the Government of the United States of America, and the Secretariat of the Department of Natural Resources and Environment for itself and as agent of the Crown in the right of each Australian State and Territory and the Crown in the right of New Zealand, 2000	To facilitate mutual assistance in wildland firefighting between Australia, New Zealand and the United States of America (Article I)
Canada / United States of America	Northwest Wildland Fire Protection Agreement, 1998	To promote effective prevention, presuppression and control of forest fires in the Northwest wildland region of the United States and adjacent areas of Canada, by providing mutual aid in prevention, presuppression and control of wildland fires, and by establishing procedures in operating plans that will facilitate such aid (Article I)
Canada / United States of America	The North-eastern Interstate Forest Fire Protection Compact Public Law #129 – 81st Congress.	Promotion of effective prevention and control of forest fires in the north-eastern region of the United States and adjacent areas in Canada by the maintenance of the adequate forest fire fighting services, and by providing mutual aid in fighting forest fires among the states or provinces of the region (Article 1).
Mongolia / Russia	Draft Agreement on Co-operation for Forest and Steppe Fire Protection between Russian Federation and Mongolia	Improve fire protection in the forest and steppe regions along the Russian and Mongolia border (20 km on either side) by sharing firefighting means, preventing fires, and reducing fire losses.
Bulgaria/Greece	Protocol for cooperation between the National Service of Fire Protection of the Republic of Bulgaria and the National Service of Fire Protection of the Republic of Greece, 1993.	Both parties will render mutual assistance for the liquidation of the originated fires and accidents and for the minimization of their dangerous consequences.
France/Italy	Agreement regarding the intervention by water bombers in case of mutual assistance for forest fires.	This agreement delimitates when mutual assistance is needed, the procedure to ask for assistance and the period of time for which it is applicable.
Italy/Switzerland	Agreement between the Italian Republic and the Swiss Confederation on the cooperation in the field of fire risk prevention and on mutual assistance in case of	This agreement defines the conditions in which one party will lend, in the limits of their possibilities, assistance in case of the occurrence of a natural

	natural catastrophes or human activities, 1995.	catastrophe or due to human activities which will threaten life, goods or the environment.
Greece/Malta	Agreement between the Government of Hellenic Republic and the Government of Malta in the field of Civil Protection, 2001.	This Agreement favours the cooperation between these states regarding sharing of scientific and technical cooperation in the management of emergencies, regarding cooperation in the enactment of policies in the field of prevention and protection of natural disasters, and regarding collaboration in the fight of emergencies which extend beyond the state borders or that cannot be eliminated by one country's own means.
Greece/Cyprus	Agreement between the Ministry of Public Order of the Hellenic Republic and the Ministry of Justice and Public Order of the Republic of Cyprus on co-operation of the national Fire Departments within their competency.	No translation from Greek was available at the time of the update of this report in August 2003.
Finland/Estonia	Operational Agreement between the Rescue Board of the Republic of Estonia and the Ministry of the Interior of the Republic of Finland, 1995.	Agreement providing a framework for the exchange of information, request for assistance and giving mutual assistance.
Spain/Portugal	Additional Protocol on Mutual Assistance in case of Forest Fires in Border Zones, adopted within the terms of the Protocol between the Queen of Spain and the Republic of Portugal on Technical Cooperation and Mutual Assistance in Civil Protection Matters, made in Evora on March 9th 1992, Figueira da Foz, 2003.	This Protocol facilitates the intervention of both parties in case of forest fires occurring within a strip of 5 kilometres from the common border. It aims to reduce the period of time between the occurrence of the fire and the response from the fire-fighting bodies.

1.2 Other Agreements

Nine international agreements plus four European Community documents not dealing with emergency response matters but covering other aspects of co-operation on forest fires were also received. These are as follows:

- Ghana / Province of British Columbia (Canada). Memorandum of Understanding between the Government of the Republic of Ghana and the Government of the Province of British Columbia, 1999 (on training and consultation around fire suppression).
- Finland / Burkina Faso. Agreement between the Government of the Republic of Finland and the Government of Burkina Faso regarding Finnish support to the management of bush fires, 1998.
- Indonesia and Malaysia. Standard procedures of the Memorandum of Understanding on Natural Disasters between Indonesia and Malaysia. This is the document establishing the procedures to implement the Memorandum of Understanding.

- Brazil / United States of America. *Acordo de cooperação entre o Serviço Florestal do Departamento de Agricultura dos Estados Unidos da América e o Instituto Brasileiro do Meio Ambiente e Recursos Naturais Renováveis do Ministério do Meio Ambiente para cooperação em fogo e mudanças ambientais nos ecossistemas tropicais*.
- Greece – China, Agreement Between the Ministry of Agriculture of the Hellenic Republic and the State Administration of the People's Republic of China on Forestry Cooperation, June 2002.
- Turkey – Uzbekistan, Protocol Related to Forestry Between the Ministry of Forestry of the Republic of Turkey and the Ministry of Forestry of the Republic of Uzbekistan, 1997.
- Nicaragua – Costa Rica, International Agreement for Collaboration in the Field of Forest Fires, 1996.
- Cyprus – Lebannon – Morroco – Syria – Tunisia, Draft of the International Cooperation Agreement in the Field of Information Sharing on Forest Fires and Their Prevention in the Mediterranean Area, 1996.
- Lebannon – France, Draft Agreement for the Protection of Forests Against Forest Fires within the Framework of the Cooperation with France, 1997.
- The Council of the European Union Decision of 2 October 2001 establishing a community mechanism to facilitate reinforced co-operation in civil protection.
- The Council of the European Union Regulation No. 2158/92 of 23 July 1992 on protection of the Community's forests against fire.
- Commission Regulation No. 804/94 of 11 April 1994 laying down certain detailed rules for the application of Council Regulation No. 2158/92 as regards forest-fire information systems.
- Commission Regulation No. 1727/1999 of 28 July 1999 laying down certain detailed rules for the application of Council Regulation No. 2157/92 on protection of the Community's forests against fire.
- European Parliament and Council Regulation (EC) No 2152/2003 of 17 November 2003 concerning monitoring of forests and environmental interactions in the Community (Fortest Focus).

These agreements are available through FAOLEX, the FAO legislative database.

1.3 National Legislation

Through a systematic search in FAOLEX, 204 documents on national legislation were identified. These were clustered into two categories:

- legislation specific to forest fires; and
- forestry related legislation covering forest fires.

1.3.1 Legislation Specific to Forest Fires

The category "legislation specific to forest fires" addresses distinctively, and more or less fully, forest fires. Ninety-eight legal instruments of this type were found and listed in Annex 5.

Thirty eight countries were identified as having this type of legislation, namely: Albania, Antigua and Barbuda, Argentina, Belize, Bolivia, Brazil, Canada, Central African Republic, China, Colombia, Comoros, Costa Rica, Croatia, Dominica, Fiji, France, Grenada, Hungary, Indonesia, Israel, Italy, Madagascar, Mali, Mexico, Morocco, Namibia, New Zealand, Nicaragua, Niger,

Philippines, Portugal, Russian Federation, South Africa, Spain, Syria, Tanzania, Togo, Uruguay and Viet Nam.

1.3.2 Forestry Related Legislation Covering Forest Fires

Under the category "forestry related legislation covering forest fires", 109 documents with provisions dealing with some aspects of forest fire management were found. They are listed in Annex 6, with an indication of the provisions addressing forest fire matters.

All the legislation mentioned above can be accessed through the FAO Forestry Department website (http://www.fao.org/forestry/foris/index.jsp?start_id=5288) or through FAOLEX (http://www.fao.org/Legal/default.htm).

2. Recommendations

In light of the findings of this report, the following recommendations are made for future action by FAO in relation to the legal aspects of forest fire management:

2.1 Updating legal information: the information available to FAO on international agreements and national legislation on forest fire management should be regularly updated with a view to maintaining a complete and reliable database of legal frameworks on forest fire.

2.2 Developing guidelines for international agreements: (i) the outline for developing international agreements contained in this report should be further elaborated in the form of detailed guidelines; (ii) outlines for developing operational guidelines and operating plans, which periodically detail the procedure for implementing such agreements, should also be prepared.

2.3 Assessing national legislation: the national legislation dealing with forest fires that was identified in this report should be further reviewed and assessed with a view to evaluating its effectiveness to better advice member countries on the revision or formulation of national legislation on forest fires.

2.4 Developing benchmarks for the formulation of national legislation on forest fires: the countries which have not formulated strategies, laws and regulations when having recurrent problems with forest fires are encouraged to do so. Some benchmarks that have been used in other countries are provided to support the enactment of such tools that will help to have a better control over forest fires.

3. Follow-up activities

Based on the recommendations made in 2001 on developing international agreements the Government of Spain organized a "Workshop on Multilateral Assistance against Forest Fires in the Mediterranean Basin" in Zaragoza Spain in 2003 to further this cause.

The International Wildland Fire Summit held in Sydney, Australia in October 2003; wherein the Summit participants discussed and agreed either in principle or in substance to a series of strategies such as:

- They agreed that an ***international agreement template*** presented in (Annex 1.) can be used by agencies wishing to form cooperative or mutual aid arrangements with one or more other countries for.
- They agreed that an ***Incident Command System (ICS*** should become the international standard for all wildland incident management participating in international or interagency agreements and exchanges.

Specific Actions requested by Summit participants:

1. Agreement to a series of regional conferences, summits, or roundtables to be held in the next four years.
2. Agreement to secure resources and funding for hosting the regional sessions and implementing other Summit outputs.
3. Agreement that the Summit outcomes will be transmitted to appropriate international organisations.
4. Agreement to request the assistance from the UN to lead the implementation of the outcomes of this strategy.

Annex 1.



Forestry Department

Food and Agriculture Organization of the United Nations

Forest Protection Working Papers

International Wildland Fire Management Agreements Template

Prepared by the International Liaison Committee
For
The International Wildland Fire Summit in 2003

Tom Frey & Ricardo Velez-Munoz

December 2003

USDA Forest Service Gen. Tech. Rep. PSW-GTR-xxx. xxxx.

Forest Resources Development Service
FFM/4/E
Forest Resources Division
Forestry Department

Working Paper

FAO, Rome,
Italy

Disclaimer

The Forest Protection Working Papers report on issues addressed in the work programme of FAO. These working papers do not reflect any official position of FAO. Please refer to the FAO website (www.fao.org/forestry) for official information.

The purpose of these papers is to provide early information on on-going activities and programmes, and to stimulate discussion.

Comments and feedback are welcome.

For further information please contact:
Mr. Mike Jurvélius, Forestry Officer (Forest Fire Management)
Mr. Peter Holmgren, Chief
Forest Resources Development Service
Forest Resources Division, Forestry Department
FAO
Viale delle Terme di Caracalla
I-00100 Rome, Italy
e-mail: mike.jurvelius@fao.org
peter.holmgren@fao.org

or: FAO Publications and Information Coordinator:
andrea.perlis@fao.org

For quotation:

ILC (2003). Legal International Wildland Fire Management Agreements Template. The Template was prepared for the International Wildland Fire Summit held in Sydney, Australia in October 2003 by the International Liaison Committee. This Document will be published under FAOs Forest Protection Working Papers, Working Paper FFM/4/E. Forest Resources Development Service, Forest Resources Division, FAO, Rome (*unpublished*).

© FAO 2003

International Wildland Fire Management Agreements Template

(Prepared by the International Liaison Committee for the 2003 International Wildland Fire Summit)

AUTHORS:
Tom Frey, International Program Coordinator, Bureau of Land Management, Department of Interior, USA
Ricardo Velez-Munoz, Jefe Del Área De Defensa Contra Incendios Forestales, Dirección General De Conservación De La Naturaleza, Ministerio De Medio Ambiente, España.

Introduction

The 3rd International Wildland Fire Conference held in Sydney, Australia 4-6 October 2003 and the subsequent Summit on 8 October 2003 provides important forums for discussions of how to manage the future of international wildland fire management and share solutions to global problems. This paper offers a template and information on cooperation in wildland fire management to countries interested in entering into formal relationships and agreements with other countries facing similar issues.

This paper is intended to enhance current international coordination and cooperation by providing information on the following:

- A Template outlining areas to consider when developing international cooperative agreements;
- Listing of the types of cooperation and assistance that may occur between countries;
- The responsibilities of countries sending assistance and of those receiving assistance;
- Websites containing information and examples of existing cooperative agreements and arrangements.

Template for International Cooperative Agreements

The following is an outline for a template of areas that need to be considered when countries are developing international cooperative agreements. There may be other areas that need definition and consideration besides those listed below. This template is drawn from an annex of a UN Food and Agriculture Organization (FAO) document *Legal Frameworks for Forest Fire Management: International Agreements and National Legislation*. This FAO document provides excellent reference materials, which should be reviewed prior to entering into international agreements.
Developing countries will require special consideration because they may not be able to reciprocate in a partnership as fully as a developed country can.
The important role of Non-Government Organisations (NGOs) should be considered as part of any bilateral or regional assistance arrangement.

It is strongly recommended that the parties to a mutual assistance agreement should exercise the agreement through exchanges, field exercises and low-level assistance prior to it being activated at a time of crisis.

Outline for International Cooperative Agreements

1. Parties to the Agreement
   - Includes governmental and non-governmental agencies and organizations at a variety of levels.

2. Purpose
   - Defines areas and forms of cooperation.
   - Define the scope of the cooperation.

3. Definition of Terms
   - Defines terms used in the agreement to insure there is no confusion or misinterpretation as to the meaning of the content of the agreement.

5. Expenses and Costs
   - Personnel- Defines how personnel costs will be set such as per person, per crew, per day or per assignment.
   - Equipment - Defines how equipment cost use will be set such as per day or per assignment.
   - Reimbursement of costs – Sets the procedures, amount, and criteria for reimbursement. Some agreements call for

reimbursement only after a certain threshold of time or level of support has been reached.
- Non-reimbursable – Under certain agreements all parties may agree to assist each other on a mutual aid, non-reimbursable basis.

6. Information and Coordination
   - Communication channels – Defines the protocols and methods to coordinate and exchange information.
   - Information exchange – Defines the types, amount and timing of information exchange.
   - Notifications – Sets the notification procedures for emergencies or for other significant events.
   - Coordination of work – Defines how and under what organizational structure the coordination of work will take place.

7. Liabilities, Claims and Compensations
   - Cross-wavier of claims/exemption from liability – Lists and defines how and when the cross-waivers and exemptions are in force for personnel that are being exchanged.
   - Exemptions to cross-wavier of claims – Lists and defines those areas or circumstances where the exemptions do not pertain to personnel that are being exchanged.
   - Damage to a third party – Outlines remediation methods and limitations for third party damage.
   - Medical assistance for injured personnel – Defines the protocols and procedures for assisting and possibly evacuating injured personnel.
   - Compensation in case of injury or death – Defines the timing, levels and limitations of compensation for injury or death. This may also be addressed above in the cross waivers and exemptions.
   - Privileges and immunities for the assisting personnel – Describes and defines the levels and limitations of privileges and immunities that the receiving country will provide to assisting country personnel.

8. Operating Plans / Operational Guidelines
   - Provision for operating plans/operational guidelines – Operating plans/operational guidelines are a critical component of all cooperative agreements. They should be carefully crafted and reviewed by all parties to the agreement. The plans and guidelines outline and define specific operational areas to insure that the agreement can implemented in a timely and efficient manner. They include

items such as points of contact, procedures for requesting resources, entry procedures, annual updates of costs, reimbursements, and cross waivers, and updated standards, qualifications or training requirements Also identifies how often and by whom the plans and guidelines will be reviewed, updated and the method for revalidating the contents of the plans and guidelines.

9. Border Crossings
   - Sets protocols and procedures for simplifying of border crossing taking into account sovereignty issues, including the following:
     - Opening of alternative border-crossing points to facilitate the assistance
     - Customs provisions:
       - Concerning personnel
       - Concerning equipment and materials
       - Concerning officer responsible for equipment
       - Concerning aircraft

   Portions of this information will also be included in the operational plans and guidelines.

10. Link to Disaster Management Plan for the receiving country.
    - Explains how the fire assistance plan sits within the wider disaster management plan for the receiving country, including legislation giving the necessary powers.

11 General Provisions
   - Entry of force of the agreement - Defines when agreement is activated.
   - Duration – Specifies how long the agreement will remain in force
   - Withdrawal – Defines how countries or organizations can withdraw from the agreement.
   - Termination – Defines under what circumstances the agreement will terminate.
   - Interpretation – Provides understandings and interpretations for countries and organizations concerning under what circumstances and limitations each party is entering into the agreement.
   - Settlement of disputes – Defines the method of dispute resolution.
   - Amendments – Defines when and how amendments to the agreement may be submitted, reviewed, and acted upon.

11. Standard Operation Procedures

- These procedures describe in detail the methodology to be followed when the agreement is activated, especially in relation to command and control, fire suppression procedures to be followed, communications systems and safety procedures to be used.
- The SOPs should be tested and refined using tabletop exercises, dry field exercises and low scale operations before being deployed in a full scale emergency.

12. Other Provisions
    - Provides the opportunity for any country, agency or organization signing this agreement to define other areas of cooperation that they want to include in the agreement such as:
        - Shared training activities, including materials
        - Study tours, technical exchanges, and joint exercises
        - Relationship of this agreement to other agreements
        - Standards for personnel
        - Safety equipment
        - Limitations on the type and use of telecommunications equipment
        - Method of recall of firefighting resources

12. Participating Countries/Agencies/Organizations Signature Page
    - It is important that all potential participants review and confirm their authorities to sign such an agreement.

Types of Cooperation and Assistance

International cooperation and assistance occurs in a variety of ways. Some agreements are non-reimbursable while others call for reimbursement. Some assistance is offered on a technical non-reimbursable basis and other assistance is offered or solicited during periods of disaster. When countries develop international cooperative agreements the purpose and method of cooperation and assistance need to be clearly identified and understood between all parties. The following describes several types of cooperation and assistance that currently exist.

Mutual Assistance:

Mutual Assistance agreements often deal with fire management issues along shared borders. Assistance by one country to another is usually

non-reimbursable with the understanding that both countries may benefit at different times from assistance along mutual borders

Cooperative Assistance:

These agreements are for assistance and cooperation throughout the countries or states that have signed the agreement, not just for the border areas. These agreements are usually set up on a reimbursable basis.

They may also include non-reimbursable exchanges of experts. These exchanges may include areas such as fire prevention and mitigation, prescribed fire, personnel exchanges, and broad based study tours of fire management programs.

Technical Exchanges:

Activities carried out under technical exchanges are similar to cooperative assistance agreements but are much more informal and exchanges are not always tied directly to an ongoing agreement. These are usually self-funded, non-reimbursable activities that occur on an as needed or as desired basis. They remain at technical and informational exchange level and do not include exchanges of resources to help with direct fire suppression activities.

Technical Assistance:

An offer of or a request for technical assistance may or may not be a part of a formal agreement. Technical assistance provides experts from one country to another country in need of technical assistance, to improve and strengthen the receiving country's abilities and capacity to deal with wildland fire management issues. The goal of technical assistance should be to reduce the need for outside assistance in the future. This type of assistance is usually non-reimbursable and is paid for by the country offering the assistance.

Disaster Assistance:

When wildland fires involve trans-border issues from a humanitarian, ecological, medical, economic, or diplomatic standpoint, some countries will offer immediate disaster assistance to affected countries on a non-reimbursable basis. Disaster assistance is meant to assist the affected country during a critical time period and may or may not be based on existing cooperative agreements. Disaster assistance

may be the genesis for future cooperative agreements or technical assistance programs.

Responsibilities of Sending Country and Receiving Countries

Countries sending or receiving assistance through the methods and agreements identified above need to understand that certain responsibilities are inherent in these relationships. The following paragraphs identify the responsibilities of all countries, agencies, or organizations involved. There are certainly more issues than those listed below that should be discussed prior to sending or receiving assistance but the information below attempts to identify some of the key elements of the responsibilities involved in these types of arrangements.

Sending Countries:

It is important to note that as countries enter into formal cooperation agreements with other countries, the success or failure of those agreements rests just as much on the personal conduct of the sending country's representatives as it does on the effectiveness of their fire management capabilities. It is critical to always send the country's most appropriate and qualified personnel, as the receiving country will quickly detect whether they are receiving the help they need or individuals who were selected on rank or seniority and not on skills and capabilities. This is especially critical with reimbursable agreements. Of particular importance is cultural sensitivity towards the people of the receiving country. Personnel being sent will be seen as ambassadors for their country and qualities appropriate to such a role should be included in the selection criteria.

Teams and individuals must also be made aware of local issues dealing with laws, customs, language, dress, food, etc. They must also be briefed on the command and control arrangements and their role and responsibilities within the fire management system of the receiving country.

Sending countries should prepare lists of resources, funding, materials and manpower that may be made available to receiving countries. It is essential that this information is kept accurate and current.

Both sending and receiving countries should maintain and exchange data on the nature, extent and frequency of fires so that the level of assistance sought and made available can be anticipated in any particular season.

Receiving Countries:

Just as sending countries have certain responsibilities, receiving countries must also accept the responsibilities involved in hosting personnel from other countries. Receiving countries must be prepared to brief sending country teams and representatives on the issues mentioned above as well as fire issues such as fuels, weather, topography, safety, management structure on the fires, fire fighting techniques and equipment, types and lengths of assignments, etc. Of particular importance is briefing on communications and legal issues within fire management as well as political and social sensitivities within the wider community. Receiving countries must also be prepared to provide logistical and operational support including welfare support as required.

Websites with Examples of Cooperative Agreements and Arrangements

National authorities are encouraged to contribute brief case studies, based on their own national experiences, to illustrate the different types of cooperation/assistance agreements that are currently in place or being prepared. Case studies can be forwarded to the Forestry Officer; Forest Fire Management at FAO HQ in Rome Italy mike.jurvelius@fao.org.

Websites:

The following websites provide a great deal of background and information on existing cooperative agreements and arrangements.

http://www.fao.org
http://www.fire.uni-freiburg.de/emergency/int_agree.htm

Conclusion

The fire management issues identified and discussed at the 3rd International Wildland Fire Conference highlight the connections and common concerns of the global community about wildland fire. This Summit represents an extension of the work accomplished at the Conference and provides a mechanism to identify ways to continue that progress. This paper has identified issues and provided a template to encourage countries to cooperate in dealing with wildland fire.

Page left blank intentionally.

Methodological Proposal for Analyzing the Vulnerability and Potential Gravity of Forest Fires Within the Framework of Civil Protection[1]

Carmen Aragoneses,[2] José Mª Rábade[2]

Summary

The circumstances which concur when a fire occurs cause situations of serious risk, catastrophe or public calamity, making fire a risk in general which should be covered under civil protection planning. It is considered as such under the Spanish Civil Protection Basic Regulations which establish that the risk of forest fires should be dealt with through special plans in regional areas which so require them. Considering the terms under which the basic directive defines the basic elements for planning, a proposal for methodology is presented which firstly assesses the vulnerability - or what amounts to the same thing -the degree of loss or damage which may be suffered as the result of a forest fire by the population, property and the environment and secondly assigns the level of potential gravity of a fire for each area of the region, depending on the intrinsic and extrinsic elements of the forest ecosystem, concerning available fire prevention resources. The analysis of regional distribution of vulnerability, the level of potential gravity of fires, and the elements which make these up will make possible adequate prevention measures – feasibility, fuel handling, and handling of other infrastructures and equipment – in order to be able to bring areas with a high potential for the gravity of forest fires down to lower levels of potential gravity.

Introduction

Forest fires constitute one of the main threats to our woodland, due both to the annual loss of forest surface area and the consequent loss of environmental, recreational and productive wealth which go hand in hand, as well as the harm and damage these fires cause immediately to both people and property.

The circumstances which concur in forest fires, as factors producing situations of serious risk, catastrophe or public calamity, as referred to in the Spanish Law 2/1985 on Civil Protection, qualify forest fires as a whole as a risk which should come under civil protection planning. This is indeed so in the Civil Protection Basic Regulation which in Section II, art. Six, determines that forest fire risk shall be the subject of special plans in regional areas which require these. These special plans should be drawn up in accordance with Civil Protection's Basic Directive on Forest

[1] An abbreviated version of this paper was presented at the second international symposium on fire economics, policy, and planning: a global view, 19–22 April, Córdoba, Spain.

[2] Forestry Services Area. Sub-directorate for Environmental Planning, Technologies and Agricultural Services (Subdirección de Planificación Ambiental. Tecnologías y Servicios Agrarios, S.A. (TRAGSATEC). Julián Camarillo, 6. Madrid. CP 28037.

Fire Emergencies, approved by Agreement of the Council of Ministers of 18th March, 1993 (BOE -Official State Bulletin of 15th April, 1993).

The Plans drafted as a result of this directive will refer to Civil Protection measures to reduce situations of catastrophic risk to people and property, since the basic principle of this Directive is that the protection of the life and safety of persons must prevail over any other value.

Vulnerability and potential gravity as basic elements in planning civil protection of forest fire emergencies

The Basic Directive indicates **the risk of fire**, **vulnerability**, the **periods of danger,** and the classification of forest fires by **level of potential gravity** as all being elements which are **basic to Civil Protection planning** on forest fire emergencies.

Although fire risk and periods of danger are aspects which were regularly included in fire protection planning and are determined using criteria defined in different methodologies, **vulnerability and level of potential gravity** are concepts which required be including in planning from the point of view of Civil Protection, and in the terms defining in the Basic Directive. Consequently, in 1993 the **methodology to be applied** was worked out to obtain these elements, bearing in mind all the factors determining them.

The knowledge of the **factors** which define **vulnerability and potential gravity,** and their interpretation through the different **indicators** enable us to put these elements into the geographical information systems (GISs) by integrating the data which characterize the subject and area studied and the knowledge of the subject's internal and external relations using rules and models.

The analysis of **regional distribution** of **vulnerability** and the **level of potential gravity of fires** will enable us to take **suitable measures on prevention** in order to reduce areas with high level gravity to **lower levels of potential forest fire gravity.**

Vulnerability

From the perspective of Civil Protection, the consequences of fires require quantitative analysis of vulnerable elements exposed to this phenomenon: **persons, goods** and **environment**.

The Basic Directive defines **vulnerability** as the **degree of loss or damage which may be suffered as the result of a forest fire by the population, property and the environment,** and in this regard Fire Protection Planning on forestry systems must include this focus as additional to that of the intrinsic value of the woodland.

The **life and safety of persons, infrastructures and inhabited areas,** the **overall economic value of the forest systems** and the **historical and artistic heritage** are the generic categories of wealth to be protected.

When planning within a geographically based information system, the GIS, the information on the different elements must refer to a grid square so that each of these

may be evaluated independently, later grouping them through a decision matrix, in order to achieve **overall vulnerability.**

Population

The vulnerability of the population can be interpreted from the three following indicators: ***Occupancy***, ***Interface*** and ***Dispersal*** which, taken together, determine the **vulnerability of the population.**

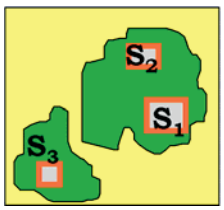
In order to establish the intervals into which to group the values obtained from these indicators, we analysed the range of values determined, i.e. the difference between the maximum and minimum value. The mean value is constituted by the second benchmark statistical parameter, since the value which leaves, below or above, 50% of the values indicates the intermediate value of this range. Taking these two parameters - range and median - three classification intervals are established in such a way that they contain a homogenous number of values.

Occupancy

The population within the forest system determines the greater or lesser degree of vulnerability of a specific territory.

$$\textbf{Occupancy} = \sum \text{Area of buildings in the forest surface area.}$$

Interprets the extension of the settlements in the forest systems: the greater the occupancy, the greater the presence of man-made buildings. (*fig.1) (table 1)*.



$$S_{ocupación} = S_1 + S_2 + S_3$$

Figure 1—Occupancy.

Table 1—*Assignation of the occupancy rate.*

Occupancy	Value (m^2)	Index
Low occupancy	0-25,000	1
Average occupancy	25,001-50,000	2
High occupancy	50,001-205,000	3

Interface

From the Civil Protection perspective it is important to locate developed areas which border on (interface with) forest areas. The planning interprets this proximity through interface or common perimeter between forest and urban systems. The GIS enables

this analysis to be done using the map on land use, backed up by the layer of information on the buildings.

$$\textbf{Interface} = \sum \text{common forest/urban perimeter}$$

Interprets the proximity or contact between urban areas and woodland systems: the greater the proximity (interface), the greater the vulnerability. *(table 2)*.

Table 2—*Assignation of the rate of interface.*

Interface	Value (Km)	Index
Little interface	< 5	1
Average interface	5.1-25	2
High interface	25.1-115	3

In order to fix the guidelines and priorities for protection, the GIS can locate, analyse and classify settlements depending on the percentage of its interface perimeter with forestland surface area. This forestland-urban interface provides very useful information for establishing the priorities of prevention action and will basically back up the nature and urgency of lower level plans – district, local and self-protection.

The GIS can classify interfaces in the following way:

Type 1 or length of the perimeter corresponding to urban surface area which is completely surrounded (75-100 percent) by forestland

Type 2 or length of the perimeter corresponding to urban surface area which is surrounded between 50-75 percent by forestland

Type 3 or length of the perimeter corresponding to urban surface area which is surrounded less than 50 percent by forestland

Dispersal

The proximity or distance – dispersal - between the different settlements in the forest systems also has an influence over vulnerability and will dictate the degree of concentration of preventive measures.

The GIS will make it possible to determine the distance between the centres of gravity of the different polygons which correspond to the buildings located on forestland (*fig.2)*.

$$\textbf{Dispersal} = \frac{\sum \text{distance between centres of gravity on forestland}}{\text{Number of polygons}}$$



Figure 2—Dispersal.

Interprets the degree of proximity or distance from the settlement on forestland: the greater the dispersal the greater the separation between the population *(table 3)*.

Table 3—*Assignation of dispersal rate.*

Dispersal	Value (km/number of estates)	Rate
Low dispersal	0-50	1
Average dispersal	501-500	2
High dispersal	500.1-2,100	3

The **vulnerability of the population** is established by a decision matrix which considers three factors, classifying this as **High, Medium and Low**.

Infrastructures and amenities

The impact that a forest fire may have on infrastructures and installations such as **roads, power lines, mobile telephony antenna, railway lines, airports, heliports, leisure parks,** and **camping sites** among others, makes it advisable to include them in fire protection planning.

The presence or otherwise of these elements shall determine the **vulnerability of infrastructures and installations** which shall be classified as **High, Medium, Low.**

The GIS allows us to intersect the infrastructure corresponding to the forestland and assign the highest vulnerability rate to each grid square. This is obtained by classifying each infrastructure category by damage or loss caused if affected by a fire.

Thus, for example, for roads, the following indexes are assigned: 3 : motorways and dual carriageways, 2: district or local roads and 1: tracks.

In the case of camping sites, recreational areas, hospitals and schools located in the area, the grid squares with high vulnerability of infrastructures and facilities will always be considered.

Vulnerability of infrastructures and facilities is defined through a decision matrix, bearing in mind for each square all the infrastructure present and its vulnerability index.

Overall Economic Value of Forest Systems

The Protection Plan interprets the vulnerability of the integral value of forest systems using the following three indicators: productive value, replenishment value, and

environmental value which by integration determine the **vulnerability of the overall economic value,** classifying this as **High, Medium and Low.**

The *productive value* is an estimate of the price of the forestland. This corresponds to what is calculated in the "technical fire report".

The *replenishment value* estimates the cost for society of having to replace the burned forestry system – the value of the final cost of repopulation, along with probability and survival.

The *environmental value* is made up of the ecological and recreational value. It is the value which society assigns to its ecosystems – the contingent value of these, distributed superficially by an index based on expert opinion.

In order to determine the vulnerability of the values: production, replenishment, and environmental - which correspond to each of the grid squares, this average value and its forestland is taken into consideration.

Historical and Artistic Heritage

The historical and artistic heritage in specific regions constitutes a major generic type of value to be protected.

The GIS interprets this heritage as the presence or absence of monuments and archaeological remains. This gives us the **vulnerability of the Historic and Artistic Heritage** and is classified as **High or Low.**

Overall vulnerability

Overall vulnerability is defined by bringing together four indicators we defined earlier, classifying the forestland as **Extremely vulnerable**, **Very vulnerable**, **Averagely vulnerable** and **Not very vulnerable**.

Classification of forest fires by their level of potential gravity

The assessment of human and material resources for fire extinction and, obviously, the protection of persons and property in relation to available resources, gives us a forecast of the gravity of the situation and a fire classification which corresponds to their **potential gravity level**.

Taking this valuation as a basis, a forecast is made of the gravity of the situation using the following scale:

Level 0: Refers to fires which may be controlled with planned fire fighting resources and which, even in the most unfavourable conditions, do not represent danger to persons unrelated to fire-fighting tasks, or to property other than that of the forest itself.

Level 1: Refers to fires which may be controlled with the Plan's fire-fighting resources at local level but which, due to possible spread, the need to apply measures to protect persons and property which may be threatened by the fire is anticipated.

Level 2: Refers to fires which will require State-level resources not assigned to the local Plan for their extinction, and at the request of the local authorities

responsible for this, or fires which may involve emergency situations which affect national interests.

Level 3: Refers to fires which are declared by the central government as endangering national interests.

It is important to emphasize that fires are classified considering the elements involved in the **behaviour of forest systems in a fire, their reaction and resistance** in a static manner, i.e. at a specific time and as they figure in the data base, after inventory.

From the **Civil Protection** perspective, the assessment of necessary human and material resources is obtained from the **topographical conditions** of the area where the fire or simultaneous fires occur; the **extension and characteristics of the forestall systems** which are under threat; the **conditions of the infrastructures** – firewall areas, road network, water reserves and access points – as well as **prevailing weather conditions** and the **possible dangers or vulnerability of persons unrelated to fire-fighting tasks.**

When planning within a SIG, the information on the different elements refers to a grid square so that each of these is evaluated independently, later grouping these in order to establish the **level of potential gravity** for each one.

Topographic conditions

The topographic conditions have a direct bearing on the behaviour of forest systems in a fire so slopes therefore have an effect on the potential level of gravity a fire may reach.

The Planning interprets topographic conditions using the **forestland slope.** To do so, four groups of slopes are established from the digital model of the land, coded as follows *(table 4)*:

Table 4—*Assignation of gravity by slope group.*

Slope Group	Gravity by slope
0-3 %	1
3-12 %	2
12-35 %	3
>35 %	4

Each grid square is assigned the maximum slope found on forestland.

Extension and Characteristics of forest systems

The extension and characteristics of the forest systems are interpreted through the following indicators: **fuel models, inflammability, continuous forestland and presence of firewall areas.**

Fuel Models

The fuel model determines the greater or lesser ease of forest fire propagation. Each of the squares is assigned the most dangerous model present there, with the

corresponding associated gravity, establishing models of high and thick scrubland as the most dangerous ones.

Flammability

Flammability or the speed with which plant species ignite in contact with a source of heat will affect the potential gravity of a forest fire. From the forest map each square of vegetation is assigned the flammability classification of the most inflammable species and to each grid square its corresponding gravity due to associated flammability.

Continuous forestland

Continuous forestland interprets the extension of the forest systems, an important factor to be borne in mind, since the greater the continuous forestland, the greater the potential gravity of the fire.

The GIS is able to determine forestland continuity and surface area using the forest map *(fig.3)*.



Figure 3—Continuous forestland.

Establishing a number of continuous surface area ranges, each grid square is assigned gravity by continuous forestland surface area, depending on the value reached.

Existence of firewall areas

The scale of firewall areas is another factor to be borne in mind, since the greater the discontinuity of fuel, the less the gravity of the forest fire.

This factor is interpreted by analysing the kilometres of firewall which appear for each square kilometre of forestland, it being possible to establish a number of ranges from the result, to which a specific gravity level is assigned *(fig.4)*.



Figure 4—Existence of firewall areas.

Each grid square is assigned a gravity rate depending on the presence of firewall areas.

Conditions of the physical environment and infrastructures

The conditions of the physical environment and infrastructures which have an effect on the gravity level of forest fires are interpreted through the ***road network, water access points, foreseeable fire sites, land and air isochrones, visibility*** and ***access areas.***

Road Network

The road network is interpreted through the **road density** indicator: kilometres of roads which appear per square kilometre of forestland. The lower the road density the greater the potential gravity.

Each grid square is assigned a rate of gravity per road density, obtained from the road infrastructure in its particular forestland surface area.

Water access points

The water available for extinction, interpreted as available volume, or at access points classified according to type of water source, makes it possible to assign a lower potential gravity rating, since this is an element which affects fire resistance.

Each square is assigned a potential gravity rating according to available water. The greater the amount of available water, the lower the potential gravity of forest fires.

Foreseeable fire sites

Planning must consider all points which are potential fire sites: sanitary landfills, industries with inflammable material, assigning each square a **very high gravity rating** if at least one of these fire sites is present.

Land and air isochrones

From the viewpoint of the potential gravity of forest fires, a major parameter to be borne in mind is the **attack time.** The land and air isochrone maps which give the attack time for each point in the area, assign each grid square a gravity rating by attack time *(fig.5)*.



Figure 5—Land and air isochrones.

Visibility

Another very important parameter related to the gravity of fires is the detection time. The visibility map classifies the forestland as visible and not visible, at least from a

fixed point in the surveillance network, so that to establish the potential gravity of this indicator the non-visible forestland surface area may be used.

For each one of the grid squares the non-visible forestland surface area is obtained, thus establishing intervals to which the potential gravity due to non-visibility can be applied.

Accessibility

We define the *accessible forest area* as the area which may be reached by water. Using GIS, a width of 300 metres may be obtained on each side of the road and from the constructed perimeter – 300 metres is the length the hose stretches *(fig.6)*.

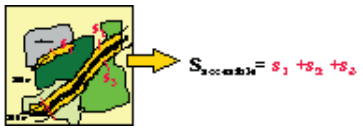


Figure 6—Accessible Forestland area.

Each grid square is assigned a potential gravity rate, depending on its available surface area.

Weather conditions

Weather conditions directly affect the level of potential gravity a forest fire may reach. These conditions are interpreted through weather risk, assigning the greatest weather risk present for each grid square.

Possible dangers for persons unrelated to fire extinction

From the point of view of potential forest fire gravity, Civil Protection pays great attention to the possible dangers for persons unrelated to fire fighting tasks. For this reason the Plan interprets this factor through indicators such as: **occupancy rate**, **buildings difficult to evacuate, presence of recreational areas and camping sites, and their difficulty of evacuation**

Occupancy

In the same way as for vulnerability, each grid square is assigned a gravity rating per occupancy rate, depending on the area occupied by buildings in the forestland.

Buildings, recreational areas and camping sites, which are difficult to evacuate.

The population requires special attention in cases of fire. Buildings must be absolutely accurately located, whether isolated houses or housing estates. In the case of fire there are major problems for their evacuation, as happens in recreational areas and camping sites. In these areas **self-protection schemes** must be developed.

The **difficulty of evacuation** is interpreted from the indicator: *number of buildings surrounded 100 percent by forestland, with difficulty of evacuation,* considering as such:

- Isolated houses in the hills in which there is supposedly an access road but which does not figure on maps.
- Houses with only one exit route.
- Houses with one exit route and one or more roads which terminate in the hills.
- Housing estates with only one exit route.

Recreational areas and camping sites are classified by difficulty of evacuation as *dangerous*, which have only one exit route or several which terminate in the hills, or *not dangerous* which have more than one exit route and are close to a centre of population or an agricultural area *(fig.7)*.



Figure 7—Inhabited areas difficult to evacuate.

Obtaining the Potential Gravity Level for Forest Fires

From a **parametric model** which includes all the above analysed variables, the **potential gravity level** is obtained. This may become a forest fire in each one of the grid squares.

$$\text{POTENTIAL GRAVITY} = \sum_{i=1}^{i=18} k_i \times V_i$$

Each variable is affected by a coefficient which varies depending on its importance in the area considered and adds or subtracts gravity depending on whether it relates to the element which contributes reaction or resistance to the fire.

The analysis of the regional distribution of the level of potential forest fire gravity will make it possible to take suitable **prevention** measures to reduce areas of **potentially high level forest fire gravity** to **lower level gravity potential.**

References

Boletín Oficial del Estado (Oficial State Bulletin). **Law 2/1985, of 21st January, on Civil Protection.**

Boletín Oficial del Estado. **Royal Decree 407/1992, 24th April, approving the Norma Básica de Protección Civil (Basic Regulation on Civil Protection).**

Boletín Oficial del Estado. **Order of 2nd April 1993. Directriz Básica de Planificación de Protección Civil de Emergencia por Incendios Forestales (Basic Directive on Civil Protection Emergency Planning for Forest Fires)**.

CEMAGREF, Aix-en-Provence, 1989. **Guide technique du forestier méditerranéen français**. CEMAGREF-DICOVA

Moldes, F.J. 1995. **Tecnología de los sistemas de información geográfica**. RA-MA editorial. Madrid.

Trabaud, Louis, 1992. Les **feux de forêts. Mécanismes, comportament et environnement**. Éditions France-Selection.

TRAGSATEC, 1993. **Plan de protección contra incendios de los ecosistemas forestales de la Comunidad de Madrid**.

TRAGSATEC, 1996. **Plan de protección contra incendios de los ecosistemas forestales de la Región de Murcia**.

TRAGSATEC, 1998. **Plan de protección contra incendios de los ecosistemas forestales de la Comunidad Autónoma de las Islas Baleares**.

TRAGSATEC, 1998. **Plan General de Defensa contra Incendios Forestales de la Isla de Tenerife**. Cabildo Insular de Tenerife.

TRAGSATEC, 1999. **Plan de protección contra incendios de los ecosistemas forestales de la Isla de la Palma**. Cabildo Insular de la Palma.

Vélez, R. 1982. Manual de prevención de incendios mediante tratamiento de combustible forestal. ICONA. Madrid.

Economic Analysis in the Control of Fuel Loading in Mediterranean Forest Ecosystems: Prescribed Burning, an Alternative to Mechanical Methods[1]

Francisco Rodríguez y Silva[2]

Abstract

The management of fuel loading is a vitally important activity in fire prevention programmes in Mediterranean forest ecosystems. The study and analysis of the issue, and the relevant planning and operational management activities have been established as a permanent requirement, both in time and space. The control of fuel loading makes it possible to obtain a spatialized reduction in the energetic intensity of potential fires where control and maintenance operations have been undertaken, and allows fire suppression resources to be moved around in a safe and efficient manner.

Control methods based on the mechanical removal and subsequent disposal of the residue have traditionally been, and continue to be the most common means of forest management. The progressive introduction of results based management drawing on scientific investigation in subjects such as fire behavior and the effects on the natural environment, opens up the possibility of gradually introducing the use of fire in Mediterranean areas in the form of prescribed burning as an extremely efficient tool in programmes aimed at controlling fuel loading. Expertise in forestry models of prescribed burning management provide for the safe, ecological, efficient and effective use of fire as a very useful tool in preparing forest ecosystems to prevent fire.

Data is currently data available from a management and experimental project co-financed by the European Union and the Junta de Andalucía (1997-2000) which studied methods of applying prescribed burning in Mediterranean ecosystems. Efforts should subsequently be aimed at progressively introducing the methods developed in the management programmes funded out of annual budgets by the government agencies responsible for the prevention of forest fires. An analytical study providing comparative cost data for mechanical systems and prescribed burning, with special emphasis on describing the properties of the distinct kinds of management based on fuel modeling criteria, will facilitate the incorporation, and therefore the applicability of fire as a tool in the removal of excess fuel loading. This paper considers the costs of both systems and presents a decision matrix to be consulted when activities are planned with the aim of dealing with fuel loading in Mediterranean ecosystems.

Before turning to the above-mentioned focus on the costs of the two systems of fuel loading control, it is necessary to set out the methodology employed in designing the fundamental technical requirements to be taken into account when faced with the task of drawing up a region-wide plan with a view to long-term permanency. Such a plan involves setting up a system directed at specific units in the area drawing on support from the

---

[1] An abbreviated version of this paper was presented at the second international symposium on fire economics, policy, and planning: a global view, 19–22 April, Córdoba, Spain.

[2] Professor, Fire Sciences, University of Córdoba, Avda. Menendez Pidal, s/n Apdo 3048 14080 Córdoba, España; email: ir1rosif@uco.es.

governmental procedures and funding required to ensure the ordered management of yearly burning programmes. The shift within the regional burning plan to the use of prescribed burning, guided by the requirement that it be ecologically acceptable and involve spatial-temporal distribution, represents a transfer of the studies and experience accumulated through investigation to their practical implementation in real world forest management situations as a preventative and frequent tool in the fight against forest fires.

Introduction, Materials, Methods

Background and basic premises

The project aims to define the activities, procedures and operative stages required in order to execute and experiment with prescribed burning. A regional plan can be drawn up within a framework made up of five separate sections.

- **The first section** covers the gathering of data, measurements and reconnaissance of the land with a view to selecting the forest areas in which it is appropriate to establish prescribed burning as a tool for controlling fuel loading. Representative plots are then identified within those areas to be used for experimenting with the prescription and subsequent burning. All the information from the selected forestry areas and plots are registered and referenced by means of geographical information systems. This first section ends with a methodological design for planning, and subsequently evaluating the burning.
- **A second section** covers the development of procedures to be adopted in carrying out burning, depending fundamentally on local conditions such as topography, vegetation types, spatial distribution and the load of fuel models, activities and land use by the inhabitants, meteorology and soil conditions. Different procedures are drawn up to ensure the burning is carried out in a safe and ecologically compatible manner, depending on the characterization of each forest area and the individual peculiarities of each selected plot. This section therefore covers the burning of the selected plots and testing of the existing methods for igniting, spreading and controlling the fire.
- **A third section** covers the drawing up and publication of the technical documentation and manuals required to implement the Regional Prescribed Burning Plan. The documentation includes the correct procedures and the technical forms to be filled in before undertaking each separate step in the burning, from preventive planning (evaluating and inspecting the areas to be burnt, planning the burning, prescribing the burning) to the burning itself and subsequent evaluation.

Once the management and experimental project aimed at defining a Regional Prescribed Burning Plan has been concluded, a regional map must be drawn up identifying appropriate areas for use of the prescribed burning system as a low-cost tool for removing excess fuel. The identification of the procedures to be followed when carrying out burning will also allow these techniques to be extended to the management of controlled burning (brush land burning and the burning of slash and waste from forestry activity and treatments), thus providing the best, safest and most effective techniques for burning in the ideal area at the right time in meteorological conditions which guarantee that the burning is under permanent control.

Survey and evaluation of the area. Taking data, measurements, selecting areas and plots, burning plans and evaluation.

The opportunities to carry out prescribed burning in forest areas and natural parks are determined by means of "Prescribed Burning Management Areas"(PBMA) in each individual area. The analysis and examination of these areas must take into account two separate criteria. Firstly, there are natural criteria, where a study is made of the general existing conditions created by the topography, the spatial distribution of forest vegetation, the spatial distribution of the modeling of forest fuels, the effects of local weather conditions, the presence of natural barriers, the level of floor cover and hydrology. Secondly, there are anthropic criteria, where human influence on the fire regimes is analyzed, i.e., the historic risk defined by the frequency and causation of recorded fires, as well as land uses and the ground cover. This information is obtained from the forest fire statistics database. The PBMAs are defined as areas which are found to be appropriate for the implementation of spatial-temporal programmes for the control of forest fuel by means of the structured and planned use of prescribed burning, following an inspection of the land and an analysis of parameters affecting the spread of fire, while ensuring ecological compatibility, preventive rate of return and safety, as well as control of the energy and dynamic force of the fire. Once the natural and anthropic criteria have been applied, the following objectives should be borne in mind when specifying appropriate areas for the use of prescribed burning:

- A decrease in the energy and dynamic force of any fires which may arise.
- Optimized effects of soils and water on the productivity and profitability in the balance sheet for natural processes.
- The protection of intrinsic natural values, both in terms of flora and fauna.
- A reduction in forest fires caused by uncontrolled brush burning.
- A reduction in forest fires caused by uncontrolled burning of grazing land**.**
- The maintenance of existing fire prevention infrastructure at a local level.
- A reduction in the risk of forest fires originating in areas used by the public.
- The protection of items of interest.
- The protection of areas bordering on sites of logging activity.
- The protection of areas bordering on estates containing plantations.
- The protection of forest areas bordering on farmland crops.
- The protection of forest areas bordering on waste disposal sites.
- Ordered management of competing vegetation.
- An improved habitat for wildlife.
- Improved silvopastoral activity.
- Renewal of the vegetation.

Within the selected Prescribed Burning Management Areas (PBMA), certain areas are defined as ‘Prescribed Burning Management Units’ (PBMU). These are given priority in the burning program and contain the individual ‘Prescribed Burning Blocks’ (PBB), which are identified in accordance with the plan implementing the proposed objectives. The Units should not be any larger than 500 ha. The proposed aims of prescribed burning in each individual block can respond to differing

objectives. The factors taken into account in identifying Units are the frequency of forest fires and the potential hazard associated with the combustibility of the forest vegetation, which is determined according to the ignition rates and the dynamic and energetic behavior of the fires (Rodríguez and Silva, 1995)

The individual Prescribed Burning Blocks (PBB) are identified once an assessment has been made of the forest system's ecological suitability and compatibility in respect of fires characterized by medium intensity energy values. To that effect, each of the PBMAs must have a complete fire behavior study in order to establish the prescriptions to be borne in mind when planning the burns, depending on the ecological conditions in the forest system. Burning must only be carried out where specific and tabulated conditions are met for each 'Forestry Model for Prescribed Burning' (FMPB), these being determined by the project. The FMPB is created by defining, classifying and standardizing the plant cover found in the PBMUs, from the perspective of the specific conditions required to proceed safely, efficiently and in an ecologically compatible way with ordered burning. Each model must include a description of the structure and combustibility of the existing plant cover**,** the local meteorological conditions under which it is feasible to carry out prescribed burning, the rate of dynamic propagation with which the burning process should develop spatially, the appropriate time of year in which to undertake burning, the size of the burn, the frequency of the burns, the methods to be used in igniting and controlling the burn, the necessary manpower and equipment and other specific recommendations.

The technical and planning procedures outlined above have been drawn up for application in each and every one of the existing priority action areas. The results determine the location of each of the zoned categories where the annual prescribed burning programmes will operate. Regional planning will cover all the Prescribed Burning Management Areas which require this tool as a procedure to control fuel loading and reduce the risk of forest fires. Based on the knowledge obtained from the experimental burns carried out throughout the project, each of these areas will be provided with the set of rules and protocols contained in Forestry Models for Prescribed Burning for the appropriate and effective application of prescribed burning.

Results and discussion

The results presented in this paper consist of forestry models specifically drawn up for the management of prescribed burning in Andalusia. The Forestry Models for Prescribed Burning have been obtained from a breakdown of the Behave fuel models. The models which have been drawn up have taken the following factors into consideration: the existence of a timber canopy, the horizontal continuity of the fuel, the diameter of the fuel and the vertical continuity between the distinct vegetation strata. The final classifications thus obtained for the identification of forestry models for prescribed burning are set out below.

A. No timber canopy to be protected.

FMPB	Description
1	Non-wooded or very sparsely wooded grassland, with little or no horizontal fuel continuity.
5	Non-wooded high brush (1.5-2m) with horizontal continuity.
7	Medium-sized brush (1-1.5m), horizontally discontinuous.
8	Medium-sized brush (1-1.5m) with horizontal continuity
14	Debris, together with herbaceous plants or brush of differing sizes.

B. Under a timber canopy which must be protected.

FMPB	Description
2	Herbaceous fuel (<60cm) with low brush content.
3	Herbaceous fuel (<60cm) with low brush content and vertical continuity with the tree crowns.
4	Taller herbaceous fuel (>60cm) with vertical continuity with the tree crowns.
6	Large-sized brush (1.5-2m), vertically discontinuous. The feasibility of burning is determined by the difference in height between the two strata.
9	Brush capable of incorporation in model 5 of the Behave system.
10	Brush capable of incorporation in model 6 of the Behave system.
11	Brush of the model 5 kind with a certain degree of vertical continuity with the tree crown.
12	Brush of the model 6 kind with a certain degree of vertical continuity
13	Litter
15	Debris

An information file has been prepared for each of the 15 Forestry Models for Prescribed Burning (FMPB) to provide guidance on executing the burn. The file contains the following information: the general characteristics of vegetation, times of the year for burning, environmental conditions for burning, physiographical conditions, ignition methods, cost, and photographic classification. As an example, the file for type 10 FMPB is provided below.

FORESTRY MODEL FOR PRESCRIBED BURNING TYPE 10:

Description of the model:

Brush consistent with Behave model 7, under a timber stratum. There is distinct discontinuity between the brush and timber strata, and therefore the possibility of damaging the timber crown is low, although greater than in type 9 FMPB. These are the ideal conditions for prescribed burning due to its ease of execution and low cost. The surface fuel consists of:

- Medium height brush (1 to 1.5m), covering 50 to 75% of the surface area.
- Herbaceous plants covering a surface area that can be over 50%.
- Pine needles or litter from trees, adding fine and dead elements to the fuel mix.

Total floor coverage is over 75%.

The fuel loading in this model varies between 15 and 20 Ton/Ha of dry material.

The roundwood diameter of the fuel loading in the experimental plots for the type 10 FMPB is:

Fuel Moisture	% of the total load
1-h	50
10-h	5 – 10
100-h	0 - 5
1000-h	0 - 5
Live	40

Specific composition:

The specific composition in areas where this particular model has been located is: **Tree stratum**: Pinus pinaster. **Shrub stratum**: Ulex Baeticus, Erica arborea, Phlomix purpurea, Cistus sp. **Herbaceous stratum**: Brachypodium officinalis

Burning seasons:

Burning under this model is feasible either in Autumn or Spring. All burns undertaken in the experimental plots took place in March and April with acceptable results, although autumn burns would probably have obtained improved results with respect to the amount of fuel removed. The average reduction in the quantity of fuel as a percentage of the original amount was 50% in Spring. Cistaceous plants in almost all the plots had a negative influence on the level of fuel eliminated.

Fire environment:

The ideal burning conditions for type 10 FMPB is:

Temperature	15 –25ºC
Relative humidity	50-75%
Fine Dead Fuel Moisture	8-14%
Wind speed	0-10 Km/h
Live fuel humidity	75 -125%

Ignition methods:

The ignition method in this model is determined by environmental or physiographical factors. It is advisable to use backing fire on slopes of over 15% in order to reduce flame length.

Cost:

Drawing on the data obtained in the experimental plots for this model, it is recommended that this particular type of burning is organised into plots of at least 0.65 Ha. This ensures that the burns will be more cost efficient than any other type of silvicultural treatment for fuel reduction.

Employing the structure of the file for the type 10 FMPB, the whole information file puts together the documents for the remaining fourteen models, thereby

providing a working document which makes it easier to locate the data required to draw up an operational burning plan. A comparative analysis between the costs of the prescribed burning technique and traditional methods is a vital strategy in disseminating an operational procedure which has not been considered in the past as a preventative silvicultural treatment. The so-called traditional methods for eliminating excess fuel loading consist of at least three stages; clearance (either manual or mechanical), removal and piling and, finally, the elimination of the waste product (by burning or shredding). In contrast to this sequence of operations, prescribed burning provides considerable savings in both money and the time needed to carry out the work. The savings are generated by the fact that prescribed burning achieves in one single step what the traditional methods took three to achieve.

A cost analysis comparing prescribed burning and traditional procedures.

Having presented the analytical procedure for obtaining the forestry models for prescribed burning, it is now necessary to employ tables of comparative data to analyze the cost per hectare for each method of removing forest fuels with the aim of reducing the potential hazard of forest fires and their spatial development with extreme characteristics. The traditional methods of forest fire prevention through measures dealing with forest fuel are based on eliminating the loading (kg/m^2) of surplus plant material, either through manual (tools or brush cutters) or mechanical means (tractors), its subsequent removal and piling, and then a final stage where the waste generated by these processes is either burnt or shredded. The forest fire prevention method offered by prescribed burning unifies all three of the stages required by the traditional methods, whether manual or mechanical, into one single operation. This obviously creates significant savings in time and money.

Drawing up the necessary financial estimates before undertaking clearance work aimed at preventing forest fires must be based on sound knowledge of the conditions on the ground where the work is intended to take place. The lack of a database detailing price per hectare, which includes important factors such as the density of forest fuels, the slope of the land and the diameters of the base of the shrubs, leads to important mistakes when preparing projects either due to an under or overestimation of the work units required.

In order to avoid these miscalculations, the financial costs of all necessary steps should be realistically measured and evaluated in order to ensure there is no need to review costs upon carrying out the fire prevention treatments. The costs for the traditional methods must therefore be calculated based on the following criteria:

A. ***Brush clearance***. (Manual, by brush cutter, either mechanized or employing a tractor). Costs vary depending on:

1 The roundwood diameter at the base of the brush stems, <3cm, 3-6cm and >6cm.

2. Slopes. Furthermore, depending on their physical position, the three measures cited above for stem diameters are divided up according to the steepness of the slope (s): s >50% and s <50%.

3. In addition, there are differences in cost on each slope depending on the percentage of the area covered by forest vegetation.

B. ***Combined silvicultural treatments***, (clearance, pruning and selective felling). This type of operation is considered to be subject to differences in cost depending on the density of vegetation, classified as low density, medium density and high density.

C. ***Gathering and piling forest waste following cutting and removal activities.*** As above, differences in cost for this operation are established according to the amount of material to be removed: <8t/ha., from 8 to 15t/ha., from 15 to 25 t/ha., from 25 to 35 t/ha., from 35 to 45t/ha. and >45t/ha. Within each of these classes, there are several costs depending on the slope: <30%, 30-50% and >50%.

D. ***Waste burning***. This final stage of the tasks which make up the silvicultural treatment for forest fire prevention is subject to cost variations which are calculated on the basis of the same measures given above for material removed in gathering and piling operations.

The experimental burns made it possible to determine the size of workforce which can undertake the task safely and efficiently, providing initial data in order to ascertain the 'cost-effective burn area'. This variable is considered to depend on the type of 'Forestry Model for the Management of Prescribed Burning', and therefore on the characteristics which identify it.

The workforce which made it possible not only to develop the FMPBs, but also to gather the data on cost and to determine the cost-efficient burn area for each of the models, consisted of seven workers and one foreman, a forestry technician, two drivers-mechanics for a vehicle with a 3,500 litre tank, fire suppression equipment and, finally, a driver-mechanic assigned to a vehicle designed for capturing meteorological data.

A. No timber canopy to be protected.

FMPB	Description	Cost-efficient burn area
1	Non-wooded or very sparsely wooded grassland, with little or no horizontal fuel continuity.	> **or** =1.7 ha.
5	Non-wooded high brush (1.5-2m) with horizontal continuity.	> **or** =0.45 ha.
7	Medium-sized brush (1-1.5m), horizontally discontinuous.	> **or** =1.8 ha.
8	Medium-sized brush (1-1.5m) with horizontal continuity	> **or** =1.8 ha.
14	Debris, together with herbaceous plants or brush of differing sizes.	> **or** =1.5 ha.

B. Under a timber canopy which must be protected.

FMPB	Description	Cost-efficient burn area
2	Herbaceous fuel (<60cm) with low brush content.	> **or** =0.93 ha.
3	Herbaceous fuel (<60cm) with low brush content and vertical continuity with the tree crowns.	> **or** =1 ha.
4	Taller herbaceous fuel (>60cm) with vertical continuity with the tree crowns.	> **or** =0.9 ha.
6	Large-sized brush (1.5-2m), vertically discontinuous. The feasibility of burning is determined by the difference in height between the two strata.	> **or** =0.4 ha.
9	Brush capable of incorporation in model 5 of the Behave system.	> **or** =0.6 ha.
10	Brush capable of incorporation in model 6 of the Behave system.	> **or** =0.65 ha.
11	Brush of the model 5 kind with a certain degree of vertical continuity with the tree crown.	> **or** =0.5 ha.
12	Brush of the model 6 kind with a certain degree of vertical continuity	> **or** =0.65 ha.
13	Litter	> **or** =1.75 ha.
15	Debris	> **or** =1.5 ha.

A cost comparison per hectare in average slope and density conditions between prescribed burning and traditional methods (manual and mechanised clearance and waste disposal) highlights the competitive advantage of prescribed burning (where the ecological conditions of the forest area are appropriate) over traditional methods.

Forestry Model of Prescribed Burning	Cost of prescribed burning. Euros/ha.	Cost of traditional methods. Euros/ha.	Cost differential between traditional systems and prescribed burning.
1	412.5	724.52	1.75
2	228.45	575.46	2.51
3	678.4	930.24	1.37
4	783.6	1.053.69	1.34
5	1,356.96	1,891.53	1.39
6	1,624.1	2,194.59	1.35
7	816.5	1,221.64	1.49
8	1,154.2	1,527.05	1.32
9	928.5	1,383.31	1.48
10	1,289.4	1,713.75	1.33
11	1,045.36	1,563.71	1.495
12	1,591.5	1,834.70	1.15
13	376.8	636.74	1.68
14	846.34	1,116.31	1.32
15	1,975.6	2,468.17	1.25

Conclusions

The proposed methodology makes it easier to identify the ideal forest areas for the use of prescribed burning, the level of ecological response of each of the forestry models for prescribed burning, the technical procedures and the cost data which, converted into prices, make it possible to draw up annual proposals for prescribed

burning as part of a region-wide plan. This would enable the use of prescribed burning on a regular basis as a preventative tool for the control of fuel loading in forest fire prevention programmes.

Acknowledgment

The author wishes to thank the Consejería de Medio Ambiente de la Junta de Andalucía and Eimfor (contractor for this project) and its team of technicians who were responsible for managing project no. 9761ES0050, entitled "Prescribed burning techniques for controlling fuel loading", presented by the Consejería de Medio Ambiente under the aegis of Council Regulation (EEC) No. 2158/92 of 23 July 1992 on the protection of the Community's forests against fire.

Bibliography

Anon., 1998. **Libro Rojo de la Prevención de Incendios Forestales**. Comité de Lucha contra los Incendios Forestales. Dirección General de Conservación de la Naturaleza. Ministerio de Medio Ambiente.

Anon. **Informes estadísticos de incendios forestales**. Consejería de Medio Ambiente. Junta de Andalucía.

Anon. **Prescribed burn manual**. 1994. Alberta Forest Service.

Anon. 1989.**A Guide for Precribed Fire in Southern Forest**. USDA Forest Service, Southern Region, february 1989, technical publication R8-TP11.

Lisle R. Gree, 1981. **Prescribed Burning in the California Mediterranean Ecosystem**. Symposium on Dynamics and Management of Mediterranean-type Ecosystems, June 22-26, 1981, San Diego, California.

Lisle R. Gree. **Burning by Prescription in Chaparral**. G.T.R. Pacific Southwest Forest and Range Experiment Station, PSW-51. USDA Forest Service.

Rodríguez and Silva, Fco, 1997. **Bases técnicas para la elaboración de un plan regional de quemas prescritas, aplicación a la Comunidad Autónoma de Andalucía**. Sociedad Española de Ciencias Forestales. Taller Internacional sobre la aplicación de Quemas Prescritas. Lourizán, Pontevedra.

Rodríguez and Silva, Fco. 1995. **Modelos de Comportamiento del Fuego Aplicados a la Ordenación de Áreas Forestales**. Taller Internacional sobre Prognosis y Gestión en Control de Incendios Forestales. Fondef, Universidad de Chile, Intec-Chile e Instituto Forestal. November 1995, Santiago de Chile.

Rodríguez and Silva, Fco. 2001**. Gestión y experimentación de quemas prescritas en Andalucía, recomendaciones técnicas para su empleo en la defensa contra los incendios forestales**. Actas del III Congreso Forestal Español. Sociedad Española de Ciencias Forestales. Junta de Andalucía.

Raybould S., Roberts T. **A Matrix Approach to Fire Prescription Writing**. Fire Management Notes, vol.44, number 4.

A Model for the Financial Assessment of Forest Fire Prevention Plans in Mediterranean Forest Ecosystems[1]

Francisco Rodríguez y Silva[2]

Summary

Current developments in the organisation and management of the prevention of forest fires addresses a line of work which will enable an in-depth insight into the interrelation between budgets invested and the results of those investments. Historically, budget management has never been subjected to an objective, scientific and justifiable procedure, but rather the process has been governed by expansive growth of costs and by demand, and in the majority of cases there has been no mid-term investment planning.

When circumstances change and the availability of funds is restricted there is a under valuation in forest management which impedes the maintenance and availability of budgets on previous levels, and when this happens it is necessary to document and justify the request for public funds to deal with genuinely necessary costs. In this phase and with a view to finding an efficient and planned response to the problem, there is a need for a work tool which is able to integrate, not only factors associated with the variables of financial analysis but also the consideration of factors and parameters involved in the presence of forest fires in areas needing protection. This has motivated the instigation of a research programme to develop a model able to create a cohesive interest and relation of all the variables regarding relations and activities associated with the management of forest fire prevention schemes. The philosophy of development behind the model was to devise a solid and yet polyvalent basis for exportation of the model results so that although a specific area of land was taken to develop the models in its design, definition and experimental stages as well as for its application, the material obtained should permit its application to other zones, bearing in mind the necessary adaptations.

The importance of obtaining an initial model in Mediterranean areas which includes the results of the means of suppression and particularities of the suppression procedures used, such as the abilities of different forest systems to recover following the impact of fire, focuses on obtaining a model based on economic criteria of the procedure, or a work tool which aids assessment and planning in the application and monitoring of defence plans.

Execution of the project will include an investigation to determine objectively the relations between the options proposed by forest fire prevention programmes and the consequences reached in terms of cost and foreseeable loss in the quantity and the quality of resources which may be affected after the impact of fires. Therefore, it should be understood that the focus of the methodological process of the investigation will be the cost –benefit analysis applied to defence and protection programmes.

In order to establish the basic conditions it is necessary to make an in-depth analysis and to acknowledge the statistical basis for forest fires and to make the requisite connection of real fire data (conditions and particularities of the first attack and extended attack) originating in the specific zone chosen for the experiment.

The identifying features of the evaluation models, since they were first devised, have

[1] An abbreviated version of this paper was presented at the second international symposium on fire economics, policy, and planning: a global view, 19–22 April, Córdoba, Spain.

[2] Forestry Engineer. University of Córdoba. Department of Forestry Engineering A/Menéndez Pidal s/n. 14080 Córdoba (España), email: ir1rosif@uco.es.

been conceived as management tools, thus the concepts and basics of pure investigation have been relegated to the phase of definition of instruments and requirements of economic nature. The development model will be presented in computerised format to facilitate calculation and so that operability is guaranteed and providing generalised application for users with direct responsibility in the organisation and management of fire-fighting programmes.

General Description of the project stages

The work involved in obtaining the model comprises the following stages:

1. Documentary stage, collating bibliography.
2. Knowledge stage, breakdown of the structure and operational basics of the NFMAS model
3. Bibliography review.
4. Historical compilation of real applicable cases and results obtained from the NFMAS model in USA.
5. Selection of functions, relations, loops and commands which are genuinely exportable from the NFMAS model for use in creating the model to be developed for application to Mediterranean areas.
6. Territorial recognition state and selection of work areas, for which management of prevention and fire-fighting programmes will be analysed.
7. Creation of the databases required to implement the model.
8. Development of the model.
9. Computer programming of the model and link with GIS tools (Geographic information systems).
10. Calibration and verification of the model in the field. Operation in actual fire-fighting conditions.
11. Compilation of user manuals and application of the model.
12. Presentation of material produced.
13. Training for system users.

Factors to be taken into account.

The model has basically been developed in relation to the principles and tools of economic nature based on:

1. The theory of marginal analysis
2. The inclusion of criteria for economic efficiency expressed in terms of “cost+net change in the value of resources”,
3. Estimation of the magnitude of change in production as a result of specific changes in the quantity of one or more of the inputs taken into account in the evaluation process
4. An analytical, formal and objective process.

From the perspective of model capacity the following operative and calculating possibilities were considered:

1. The assessment and comparison of efficiency and effectiveness of a protection programme and its options.
2. The measurement of burned areas and the number of fires classified by size and intensity which will result in analysis time and for a proposal for a specific programme of prevention and protection.
3. Evaluation by means of a specific simulated model able to examine the protection options against specific types of fires proposed and the strategies for dispatch of resources according to the specific conditions of these. The following variables were considered with this in mind:
    - The occurrence of historical risk
    - Cartography of fires occurring within the historical period under analysis and the areas of analysis of fire prevention management programmes
    - Potential risk of fire occurring
    - Differentiated incorporation in the map of potential hazards in areas of analysis of forest fire prevention management
    - Mobilisation time and access to resources
    - Land conditions
    - Difficulty in executing fire suppression work
    - Fire behaviour
    - Productivity of active resources
    - Specific size of control and time required
    - Evaluation of potential for escaped fires
    - Forest fuels
    - Seasonality and frequency of dominant meteorological phenomena
4. Capitalisation of the experience gained from the procedures followed in fighting forest fires. In addition to the detailed analysis of results obtained in suppression work, through research in the last ten years in the national database of fires, data has also been compiled on the real time (direct monitoring of fires in the field) results, effectiveness and costs of suppression of fires occurring in 2002 and 2003.
5. Determination of the Superficial Contraction Factor (SCF). This factor permits the integration of the effectiveness of suppression resources and is based on the reduction of surface area covered by fire when action is taken to control and finally suppress it, the numerical value is obtained by making a comparison with the theoretical surface obtained by freely developed simulation (without taking into account fire-fighting elements).

Input Parameters of the model

In order to economically assess the fire-fighting and protection scheme the following parameters have been considered as entrance values:

- **Fire behaviour, defining as work tools:**

1. level of linear intensity of the fire front
2. speed of propagation
3. speed of fire propagation in crowns
4. generation of secondary fires
5. transition from surface fire to canopy fire
6. flame length
7. classification of intervals of flame length in order to obtain types of intensity level of forest fires

- **Derivatives of behaviour and productivity of fire-fighting resources**

1. Surface and perimeter control for each intensity level of forest fires
2. time to reach the control perimeter
3. team forces

- **Organisation and procedures for suppression**
- **Methods for expediting human and material resources. Incorporation of the table for selection of options with specification of :**

1. individual resources
2. attack teams
3. team forces

- **Recognition and inventory of linear systems of prevention (firebreak lines , firebreak areas) and other infrastructures for prevention of forest fires already in existence.**
- **Economic evaluation in analysis zones of management resources for forest fires, taking into account the following:**

1. timber
2. pasture
3. underbrush
4. fruit
5. water resources
6. fish resources
7. fauna resources
8. leisure and recreation
9. hunting resources

10. landscape resources

- **Determination and evaluation of fixed annual maintenance costs for the prevention and control programme.**
- **Determination and evaluation of suppression costs taking into account the following:**

1. Unit costs per mission/fire-fighting operation
2. Average cost per hectare relative to the initial attack
3. Average cost per hectare relative to the extended attack
4. Average cost per hectare relative to the suppression of large-scale fire
5. Obtaining the net change in the value of resources for each of the previous situations

- **Economic evaluation of post fire recovery operations in affected areas, with prior determination of resilience of the system.**

1. Recognition of the effect of fires on resources
2. Spatial identification of these effects
3. Quantification of the effects and development of economic measure
4. Determination if annual production in the absence of fires.
5. Determination of total production for the planning period in absence of forest fires
6. Determination of total production for the planning period in the presence of forest fires

Minimum components considered for carrying out analysis and calculation using the SINAMI model computer programme.

In developing the model, the strategy of simultaneous creation of computerised structure of the programme was employed to permit calculation in accordance with the following components and applications:

- Control commands for management of programme utilities
- Printing options of documents produced by the model
- Management of files produced by the document, storage, recovery and indexing
- Identification of the work unit, protected space, forest land, local area.
- Information on the zones of analysis of management of prevention and control programmes also known as zone of analysis of fire management (ZAFM)) (figure nº 1)

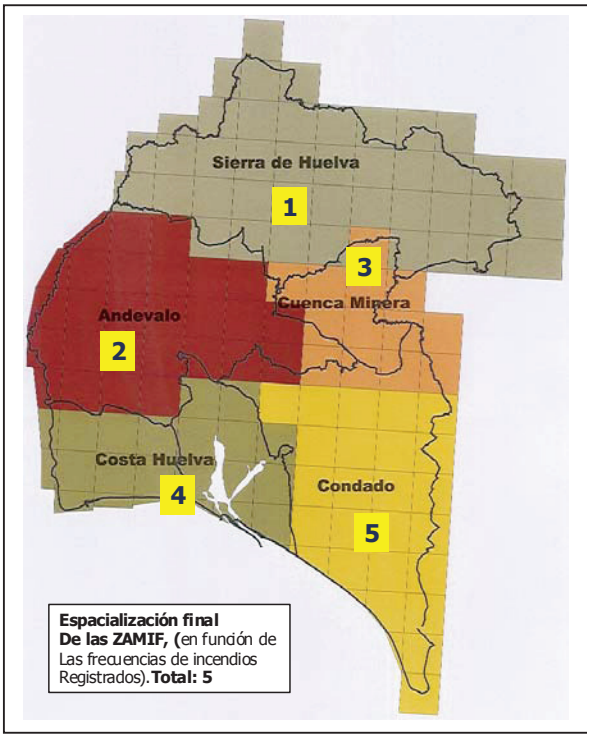


Figura nº: 1

- Limits for escaped fires
- Thematic cartography models of fuels and forest cover
- Presentation of fires per year and per level of intensity
- Speed of propagation to 50 and 90 percentile
- Dimensions of surfaces affected to detection
- Obtaining history of fire occurrence referenced geographically using national statistical database of forest fires.
- Determination by zone of most frequent meteorological conditions using historical data (ASCII format) from the National Meteorology Institute (NMI) and the incorporation of methods of interpolation for determination of meteorological parameters (figure nº: 2)

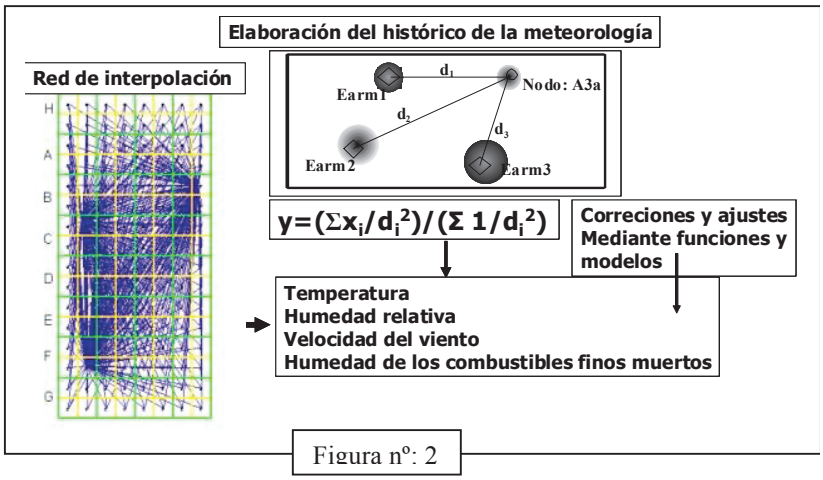


Figura nº: 2

- Determination of the potential evaluation of damages tool for application in economic evaluation. This application serves for evaluation land areas (including zones of analysis and management of forest fires) both prior to a fire and for real measurement and estimation in the case of fire.

General flow line considered in the execution of the model

- **Base model obtained in accordance with:**
  1. Analysis of historical antecedents of forest fires
  2. Analysis of programme of interrelation of entrance parameters
     - Individual means of fire suppression
     - Fire suppression attack teams
     - Fire suppression teams
     - Models of fuel stocks
     - Difficulty of suppression determined by means of calculation of Suppression Technical Difficulty Index (Rodríguez and Silva, 2000)
     - Potential hazard determined by means of calculation of the Potential Hazard Index (PHI), (Rodríguez and Silva, 2000)
     - Meteorological history
     - Historical analysis. In order to integrate historical antecedents calculus and analysis models were used proposed by the NFMAS system (González-Cabán, 2000) developed by the USDA Forest Service, which include models which qualify specific characteristics of the analysis zone and management of fires with greater intensity. The models serve to incorporate, by establishing typical relations "entrance values- exit values"

the required data for the model in order to carry out an economic analysis of the forest fire prevention programme under study. The modules considered are as follows: available suppression means, (types results, and costs) fuel models, topographical aspects, historic occurrence in relation to the fires , detection procedures and times, technical difficulty in suppression, dispatch procedure, arrival times, potential hazard in each zone of analysis and management of forest fires, speed and frequency of fires classified by each level of fire intensity, size at the start of suppression work and final analysis of the programme based on establishing comparisons between the results of suppression resources and the perimeter developed by fire behaviour, the costs and resources and the net change in evaluation of natural resources (figure nº: 3).

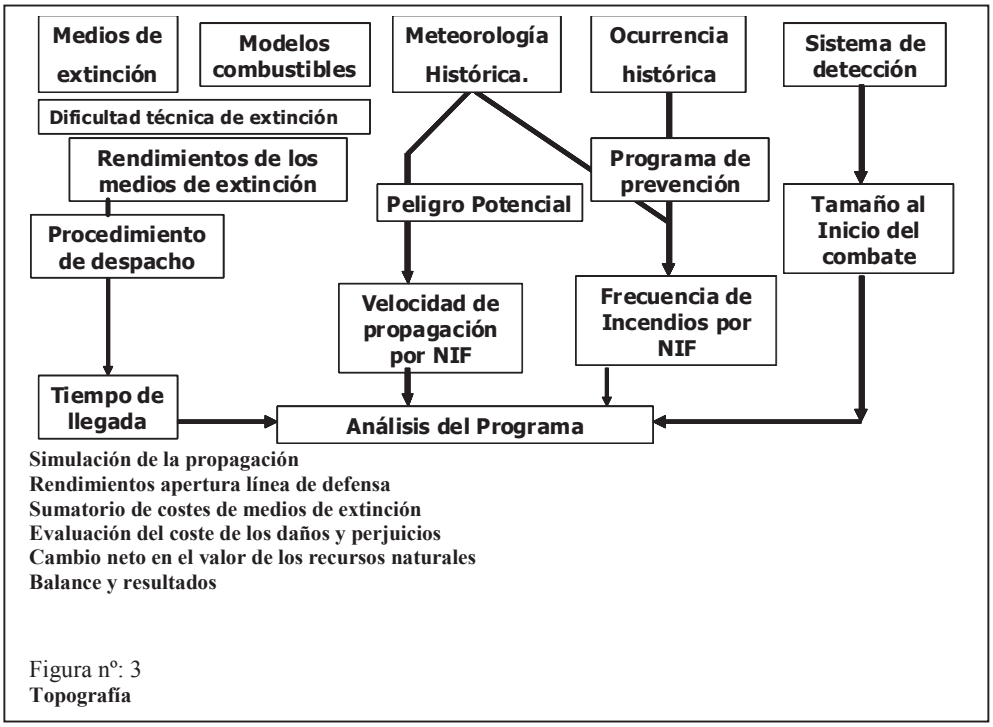


Figura nº: 3
Topografía

- Results of suppression means determined by incorporation of result curves of opening of lines of defence according to fuel models (Porrero M., Chico F., 2000)
- Detection system
- Prevention programme
- Dispatch system of fire-fighting resources
- Arrival times

- Detection size
- Speed of propagation by intensity level of fire
- Frequency of fires by level of intensity of forest fire
- Determination compared between the speed of development of the line of defence (in the establishment of the line of control) and the speed of growth of the fire perimeter. For the development of this phase the forest fire simulator "Visual-Cardin" (Rodríguez and Silva, F. 2002) was included in the model as a calculus tool (figure nº: 4)

3. Initial calculation using registered historical information
4. Calibration and link up with the planning process

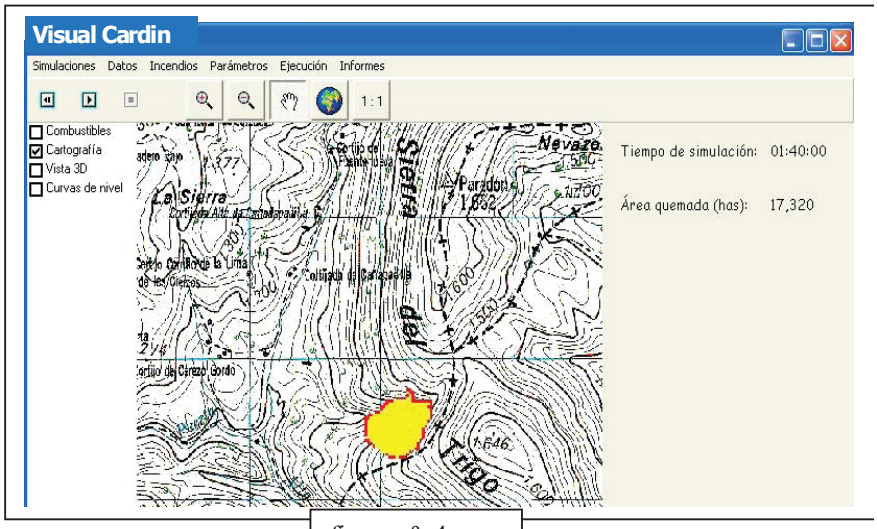


figura nº: 4

- **Evaluation of initial attack taking into account:**

1. Options from the control programme and budget for each zone of analysis making consultations with the tables compiled from historical information according to:
    - Control language of work
    - Mobilised resources
    - Selection of options
    - Average cost per hectare
    - Escaped fires from expected control
    - Unit cost per mission

2. Contained fires including calculation of affected area.
3. Escaped fires including calculation of pre-affected area
4. Number of fires per size and level of intensity
5. Area affected per size and level of intensity
6. Means used and number of dispatches per annum and per level of fire intensity
7. Forest fire suppression costs
8. Estimation of effects of fire and evaluation of resources
9. Total costs plus net change in value of resources
10. Identification of most efficient defence programme
11. Determination of annual budget
12. Monitoring and evaluation

This application has been defined to enable its methodological extension to evaluation of both extended attack and large-scale fire attacks. This extension of analysis and calculation although determined in its flow line has been postponed for incorporation in the second version of the model.

Selection of zone for development and experimentation of the model

The territory proposed for this study for development and experimentation of the model is the Autonomous Community of Andalusia (region in the south of Spain) and within this area the province of Huelva was chosen. This choice was made on the basis of forest surface, the history of registered forest fires, information on available thematic land cover, information o n preventive infrastructures and existing prevention and control programmes. In general the chose of Andalusia for investigation was considered on the basis of its professional organisation and an experienced system of prevention and suppression of forest fires , as well as the fact hat it has a concentrated database of registers, compiled from information obtained on past forest fires.

Acknowledgements

The author wishes to thank the Department of Forest Fire Prevention of the Board of Nature Conservation (Ministry of Environment) for technical material and documentation facilitated as well as financing provided through the research convention for development of a model for economic evaluation of forest fire prevention programmes (SINAMI), and the University of de Cordoba.

Bibliography

Anonymous. **Informes estadísticos de incendios forestales. Ministerio de Medio Ambiente**. Dirección General de Conservación de la Naturaleza. Área de Defensa contra Incendios Forestales.

González-Cabán A. 2000. **Planificación y análisis para la defensa contra incendios**

forestales. La defensa contra Incendios Forestales, Fundamentos y Experiencias. Coordinador Ricardo Vélez. Editorial McGraw Hill.

González-Cabán A. 2000. **Sistema de análisis general para el manejo de incendios forestales en Estados Unidos**. La defensa contra Incendios Forestales, Fundamentos y Experiencias. Coordinador Ricardo Vélez. Editorial McGraw Hill.

Porrero M., Chico F. 2000. **Rendimientos del personal de extinción**. La defensa contra Incendios Forestales, Fundamentos y Experiencias. Coordinador Ricardo Vélez. Editorial McGraw Hill.

Rodríguez y Silva, F. 2000. **Modelos de organización de la extinción**. La defensa contra Incendios Forestales, Fundamentos y Experiencias. Coordinador Ricardo Vélez. Editorial McGraw Hill.

Rodríguez y Silva, F. 2000. **Planes de defensa**. La defensa contra Incendios Forestales, Fundamentos y Experiencias. Coordinador Ricardo Vélez. Editorial McGraw Hill.

Rodríguez y Silva, F. 2003. **Aplicaciones de la predicción y simulación del comportamiento del fuego en la extinción de incendios forestales**. Revista Incendios Forestales número 8. Editorial Forres C.B. ISSN: 1575-572X.

Page left blank intentionally.

United States Forest Service (USFS) NRIS-INFORMS-Fire/Fuels Analysis Tool [1]

David S. Martinez [2]

Introduction

INFORMS is a decision support framework currently designed specifically for the Forest Service IBM platform. The acronym comes from "Integrated Forest Resource Management System." INFORMS was engineered to support planning tasks associated with watershed and project-level planning, and is used to assist forest- and district-level users in resource project management for the purpose of decision-making following the National Environmental Protection Act (NEPA) process.

The INFORMS interface is built primarily upon ArcView, with additional Oracle Forms as needed to support essential functions. Some custom (i.e., non-Oracle Forms and non-ArcView) windows within INFORMS are used when neither Oracle nor ArcView could support the needed functionality.

The underlying Oracle data structure behind INFORMS supports numerous planning functions, including the ability to:

- Support the entire NEPA process and improve decision quality and quantity
- Capture and isolated project or decision support data sets from corporate spatial and attribute databases
- Define project team members and define their access to INFORMS functions
- Access and run a range of analytical tools such as models, scripted queries, Arc Macro Language routines, and rule bases (a knowledge base component)
- Build and retain project alternatives via ArcView themes and Oracle datasets
- Track progress on projects on decisions via access to an event log or analysis record

Analytical tools used in INFORMS will vary from site to site since users at each site determine the suite of tools they wish to integrate within INFORMS. This can include information needed to make analysis accurate and site specific.

Vegetative Mapping

Because INFORMS is designed for National Environmental Protection Act (NEPA) analysis in the Forest Service, one of the problems to date has been the ability to look at future conditions of vegetation with and without treatment. This was easily done for single stands using the Forest Vegetation Simulator (FVS), but unless there stand

[1] An abbreviated version of this paper was presented at the second international symposium on fire economics, policy, and planning: a global view, 19–22 April, Córdoba, Spain.

[2] Regional Fire Ecologist, Fire & Aviation Management, Southwestern Region, Forest Service, U.S. Department of Agriculture, 333 Broadway S.W., Albuquerque, NM 87102.

exams are performed on each stand, this goal could not be achieved for the landscape of vegetation data for the entire analysis area.

The solution to this problem is the use of the Most Similar Neighbor Analysis (MSN) technology. The INFORMS application team has found that by the use of these two technologies (FVS & MSN) integrated with landsat imagery data, it is possible to create high quality vegetative maps for current and future conditions.

Additionally, this application set has been shown to create excellent landscape vegetation maps for forested lands. The requirements necessary to support this mapping are:

- Forest stand vegetation polygon GIS layer
- Recent spring landsat scene
- Stand exams well-distributed on all vegetation types on ten percent or more of the polygons
- Stand exam data loaded into FSVeg database to standardize the data source
- Digital Elevation Model buffered for the MSN Analysis Area

These are commonly available types of data. With this data set, tools within the INFORMS application will simulate the growth of the stands to the date of the landsat scene to calibrate them more accurately to the reflectance values represented. These stand exams then become what is known as reference stands. Based on the landsat and DEM data, the MSN application will find the most similar stand to use to represent each stand that does not have current data. Subsequently, a "for/use" table is populated. This is simply a pointer table that is used when an application in INFORMS needs data for a stand that has not been examined.

This process also creates very high-quality current vegetation GIS coverage data with accurate attributes for all stands. The current output is used to produce actuate fuels vegetation maps for use in public meetings, fuels analysis, and for planning fire suppression activities with FARSITE .

Efforts are currently underway to produce more attributes that are useful to all types of resource analysis. These attributes include:

- Basal area of tree species
- Tree species of the first 3 species in descending dominant order
- Average stands height
- Quadratic mean diameter
- Tree species crown cover

These are attributes that traditional image processing methods usually cannot supply. These results can be produced to a high degree of accuracy that can be improved with more stand exam sampling if needed, representing a systematic method of producing the desired quality of coverage.

Another advantage of this approach is that by simply maintaining the stand polygon layer, obtaining a new land satellite scene annually, and maintaining a minimal stand exam program for data collection, this high-quality current vegetation layer can be maintained quickly and inexpensively from year to year.

Fire and Fuels Analysis Packages

INFORMS currently is used primarily to support the NEPA process, particularly for Fuels Reduction applications. The application uses data from the FSVeg database projected forward using the Forest Vegetation Simulator, including the Fire and Fuels Extension (FVS/FFE) for the current condition and each decade into the future up to 40 years for no treatment alternatives. It is also possible to create as many treatment alternatives as desired. These can also be portrayed for the same growth periods to compare difference between treatment and no treatment and between alternative treatments.

Tools within INFORMS produce several valuable products:

- Product 1 generates a map for each time period. Known as the "burn model", this is a matrix of torching index (the wind speed that will be required to cause a ground fire to torch trees in the stand) and the crowning index (the wind speed that will be required to sustain a crown fire). The matrix of these two values generated by FVS/FFE is displayed as five classes of burn intensity. This creates a map for each forested stand polygon, which displayed in light to dark shades of red (darker shades representing greater intensity). This map is useful for several purposes in fuels reduction project planning. These include the ability to visualize the areas of greatest concern for possible treatment and their relationship to other areas of concern. The maps give us the ability to compare analysis areas such as watersheds to determine which is the highest priority for treatment. These maps are also quite useful in communicating to the public about the condition of areas they may live near or have concerns about.
- Product 2 is the creation of FARSITE ready data. FARSITE is a fire simulation application that models fire spread and intensity under user-defined conditions. These layers are created for current and future conditions. The primary use of FARSITE in project planning is to run a simulated fire through an analysis area with and without treatment to evaluate the effects of proposed treatments. FARSITE can be used to optimize various treatments; this data also comprises a very helpful tool for communicating with the public.
- Product 3 is the Stand Visualization System (SVS). INFORMS creates files that show how a stand will burn with or without treatment. This is useful for the identification team and public discussion of effects. The establishment of an automated method to accomplish this objective is currently under development.

Conclusions

The INFORMS application has provided land managers within the Southwestern Region of United States Forest Service (USFS) with a state-of-the-art modeling system. The system has allowed for the assessment of current and future wildfire risk conditions within forested areas with and without wildfire hazard reduction efforts. Various vegetative prescriptions have been modeled to assess their potential effects on current and future wildfire risk. These inputs are processed and wildfire risk maps are produced and displayed for further assessment by various Fire/Fuel Management Specialists. All of these capabilities have aided in directing current and future fuel mitigation and maintenance efforts and the development and modification of environmental analysis and planning within the Southwestern Region.

In addition, the modeling application has allowed for high-level multi-criterion decision making capabilities. This has been accomplished through the GIS interface and has been used to assess decision pathways and parameters through analysis of spatial and geospatial data. Analysis has involved the effects of thinning regimes on real world parameters involving many varied real world issues related to National Environmental Protection Act (NEPA), wildland fire suppression activities, and many other applications.

Inventory, monitoring and analysis efforts within the Southwestern Region have enabled land managers to monitor the effects of landscape disturbances and adjust prescriptions for future land management plans. Recording negative and positive responses to mechanical and prescribed burn treatments both validates current fuels mitigation strategies and provides the agency with more complete, current data sets with which to measure the effects of current land management practices. This enables land managers to adjust prescriptions based on scientific data collected using standardized protocols and the most up-to-date sampling techniques. Moreover, it helps ensure that we maintain a healthy, vibrant, and resilient forest ecosystem for now and into the future.

Fire History in the Mixed Pine-Oak Forest on the National Park Chipinque, in Monterrey, Nuevo Leon, Mexico[1]

Marco Aurelio González Tagle,[2] Javier Jiménez Pérez,[3] Klaus von Gadow[4]

Abstract

Forest ecosystems throughout the world have evolved over millions of years with fire as a common disturbance process. The assessment of the historical disturbance effects across landscapes can provide an important foundation for land management decisions, aimed at ecosystem restoration and maintenance. There are not many investigations in Mexico regarding the historic disturbance patterns, until now. Little research has been concluded locally in the Sierra Madre Oriental, the main research has been in 1998. But, these research has provided just general information about disturbance patterns, the ecological impact and succession.

The different effects forest fires have on biodiversity and successional patterns are considered by using examples from the Sierra Madre Oriental mixed forest, Parque Ecológico Chipinque in northeast Mexico. This is a synthesize paper on forest fire history in Chipinque Park. The Park Chipinque has a territorial extension of 1624 ha in the municipality of San Pedro Garza Garcia, Nuevo Leon. Forest fires have been determined from 1860 and onwards, by dating fire scars on living individuals of *Pinus pseudostrobus* and *Pinus teocote*.

Introduction

Historical disturbance in plant communities is an important subject for study as it provides necessary information for creating goals in the management and handling of ecosystems (Agee, 1993, Jiménez 1998). Forest fires occur in forest ecosystems all over the world and also, controversially, occur in areas of biological management and conservation (Pyne 1996). In the case of Mexico, forest fires are an extremely common phenomenon in protected areas such as national parks, biosphere reserve. (Jardel 2003).

In Mexico an average of de 8,903 fires are registered every year with a surface area of 324,865 hec. burned (CONAFOR, 2003). There has been scant research into the historical pattern for this disturbance. Until now research projects have been carried out in the Eastern Sierra Madre, in 1998 but they only provide general information on the patterns of disturbance and succession (Jiménez, 1998). There are also few studies on the frequency and history of fires.

---

[1] An abbreviated version of this paper was presented at the second international symposium on fire economics, policy, and planning: a global view, 19–22 April, Córdoba, Spain.

[2] Ph.D. Student at the Georg-August University, Göttingen, Germany email marco.gonzalez@web.de

[3] Professor at Faculty of Forestry Sciences, University of Nuevo Leon, Mexico.

[4] Professor at Faculty of Forestry Sciences, University, Göttingen, Germany.

The initial attempts at explaining ecological effects of fires lacked ecological data and a description of the fire regime in ecosystems. Research into the frequency and the period when fires occurred go back to 1940.

Terminology used in the history of fires has been standardised over time. Some of the definitions used in this investigation are *fire frequency,* which refers to the recurrence of a fire in a specific area over time. *Mean fire return interval* is the arithmetical average of all the intervals of fires in a specific area and within a given period of time.

The *Fire Regime* describes the patterns of fires and the effect on the ecosystem . These may also be described through their physical characteristics such as for example f*ire frequency, mean fire return interval ,* and their ecological effects such as the influence on the composition of species. There are several methods of determining the frequency of fires and for our study we used the method known as MFI *(Mean Fire Interval)*. The abstract concept of the method is as follows: determine how many years on average occur between fires in a specific point of the study area.

Objective

The main objectives of this study are: a) reconstruction of the history of fire frequency in the region of the Eastern Sierra Madre, b) to document the patterns of appearance of fires in the park, and c) to determine by using fire frequency the arithmetical average in the region and within a specific period (*Mean Fire Interval)*.

Methodology

Study area

The area studied is located in the Parque Ecológico Chipinque in the state of Nuevo León situated 25^0 33´ and 25^0 35´ North Latitude 100^0 18´ and 100^0 24´ Latitude East, bordering the Sierra Madre Oriental.

Sample

A dendrochronological analysis determined the dates of fires. A database was then compiled for the fire history. *Cross dating* (Bergeron, 1989, 1998; Everett, 1998; Stickney 2000) was used to determine the annual growth rings. In order to determine the date of previous fires, a sample was taken of individual trees of the *species Pinus pseudostrobus* and *Pinus teocote* which showed fire scarring. Various parameters were assessed to quantify the changes of vegetation occurring over time in different burned areas (diameter, height, azimuth angle length and width of the crown).

Results and Discussion

A natural chronological sequence was established of over 140 years. Which was

reconstructed for the mixed woodland community of the Parque Ecológico Chipinque. The chronological sequence comes from different burned areas, five fire dates were established from 1860 to 1998. From these events it was possible to establish and reconstruct the history of fire frequency. In accordance with the registered events the interval of fires was calculated, resulting in the equation $MFI = \sum^{n} I_i$ (Mean Fire Interval) for the region, which was 34.5 years. The WMPI (Weibull Median Probability Interval) was calculated. Table 1

Table 1— *Parameters for interpretation of MFIM. (Method for defining mean fire interval).Weibull Median Probability Interval.*

Parameters		Value
MFI		34.5
WMPI		37.06

In the light of the value 34.5, the region is classified within the range of severe Frequent Fires (an average interval of 25-50 years.)

With details of Weibull distribution factor by means of $\lambda(t) = c * t^{c-1} / b^{c}$ the probability of a new fire in a specific stand was obtained. Graph 1 shows the probability according to the Weibull function for Parque Chipinque 1860 -1998.

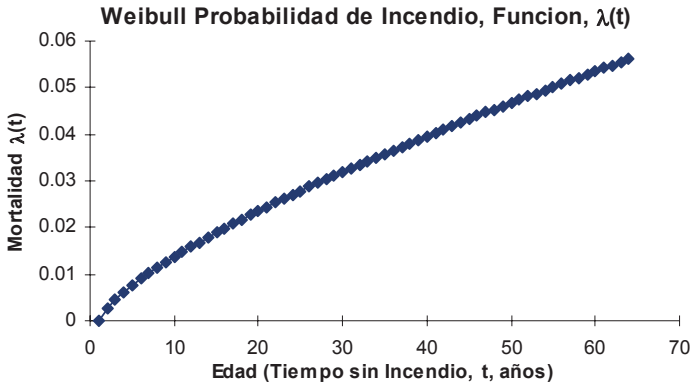


Figure 1— *Probability of fire according to the Weibull distribution factor obtained for the period 1860 -1998*

Finally it is important to understand the ecological processes involved in forest fires for the management and conservation of our forests particularly those designated as protected areas.

Bibliography

Agee, J. 1993, Fire Ecology of Pacific Northwest forest, Island Press. 53:75

Bergeron, Y. et. al.; 1998. Variability in Fire Frequency and Forest Composition in Canada's Southeastern Boreal Forest: A challenge for sustainable forest Management

Bergeron, Y. and M. Dubuc. 1989 Succession in the southern part of the Canadian boreal forest, Vegetation 79: 51:63

CONAFOR (Comisión Nacional Forestal, 2003. Reporte semanal de resultados estadísticos y acciones realizadas (1. enero- 31 Jul. 2003)

Everett, 1999, Fire history in the ponderosa pine/Douglas-fir forests on the east slope of the Washington Cascades, Forest Ecology and Management 129(2000) 207-225.

Fall, J. 1998; Reconstructing the historical frequency of Fire: A modeling approach to developing and test methods.

Jiménez, J.; O. Aguirre, 1998. Evaluación de daño de los incendios ocurridos en 1998 en el Parque Ecológico Chipinque, FCF-Parque Chipinque

Stickney, P. and Campbell, 2000, Data Base for early postfire succession in Northern Rocky mountain forest. General technical report RMRS-GTR-61CD

Who Should Be Responsible for Forest Fires? Lessons From the Greek Experience[1]

Gavriil Xanthopoulos [2]

Abstract

The organizations responsible for the functions of forest fire management are not the same in all countries. A variety of historical, political, social, environmental and financial reasons have resulted in a wide spectrum of forest fire management organization schemes. As fire problems, in the form of very bad fire seasons, are becoming all the time more pronounced and visible, there is often pressure for changes in the fire management structure in the affected countries, in one direction or another. Sometimes the demand for such changes is extreme, especially after major wildfire disasters. Obviously, this can lead to serious mistakes. In this paper the change in the organization of forest fire management that took place in 1998 in Greece is described in brief. The example is used to demonstrate the pitfalls and the problems and to document the need for objective criteria on how fire management should be organized in a country, given its own unique conditions.

Introduction

The organizations responsible for the functions of forest fire management, namely prevention, presuppression planning, suppression and post-fire rehabilitation, are not the same in all countries. A variety of historical, political, social, environmental and financial reasons have resulted in a wide spectrum of forest fire management organization schemes. As fire problems, in the form of very bad fire seasons, are becoming all the time more pronounced and visible, there is often pressure for changes in the fire management structure of the affected countries, in one direction or another. Sometimes the demand for such changes is extreme, especially after major wildfire disasters. Obviously, this can lead to serious mistakes, especially when new policies, legislation and regulations are prepared in a hurry, by partially informed politicians feeling the pressure of an outraged public and less-than perfectly informed mass media.

The objective of this paper is to provide an insight into this problem that will be useful when such decisions are being made. In order to do that, the paper draws from theoretical knowledge, personal experience, and real world examples. More specifically, the change in the organization of forest fire management that took place in 1998 in Greece is described in brief. The example is used to demonstrate the

[1] An abbreviated version of this paper was presented at the second international symposium on fire economics, policy, and planning: a global view, 19–22 April, Córdoba, Spain.

[2] Research Forest Fire Scientist, National Agricultural Research Foundation, Institute of Mediterranean Forest Ecosystems and Forest Products Technology, Terma Alkmanos, 11528, Athens, Greece.

pitfalls and the problems and to document the need for objective criteria on how fire management should be organized in a country, given its own unique conditions.

Theoretical background

At a global scale, the prevailing perception when considering forest fires is that they represent a natural disaster: A threat to the people and the environment, a destructive force that must be subdued. At least, this is the picture drawn by the mass media, the "truth" in the minds of people who live in the cities, the people who have property and interests that may be destroyed by a forest fire. However, this is not the case in the minds of the shepherd who starts a fire to stimulate new vegetation growth for his animals or the farmer who burns the stubble in his field to clean it up and start a new crop. Also, this has not been so in the traditional use of fire by the American Indians or by many other cultures around the world that persisted for many centuries without damaging the environment.

The negative perception, the fear about forest fires, was built to a large extent with the development and maturing of Forestry as a scientific field: A development that started in European countries, like Germany, where forests are timber rich, wood production is very important, and fires have a small natural role.

It took many years of fire suppression in the USA, where absolute fire control in the form of the "10 AM policy" was established shortly after the development of forestry there, until problems such as fuel accumulation, steep increase in fire potential, and forest succession pathway distortion, became evident. US forestry, patterned after its European predecessor, considered fire a menace and tried to suppress it at all costs. However, starting from the most fire prone ecosystems, such as California, scientists soon started voicing their concern about the problems that were developing. In the late 1960s and 1970s the voices became stronger and the total fire exclusion policies were gradually revised. This was supported by numerous studies on fire history and fire ecology, which demonstrated the natural role of fire in many types of forest ecosystems. Prescribed burning gradually became a management tool aiming among others to reduce fuel loads where they had accumulated and to provide management solutions, such as better animal grazing conditions, where needed.

The message soon spread around the world where scientists started being more critical of total fire exclusion. It became common understanding that in those forest ecosystems where the rate of live biomass accumulation through photosynthesis and dead material build-up exceeds the rate of biomass breakdown by the slow "oxidation" processes (molds, insects, bacteria) due to the environmental characteristics, fire, which is a rapid oxidation process, is necessary to complete the circle of life, release the nutrients and the growing space and reset the ecosystem to a new start. Also, to many scientists it became evident that only if the excess biomass production is removed by people through forest stand management or fuel management, or by animals through grazing, the occurrence of fire can be reduced or controlled in such fire dependent ecosystems.

In the 1980s and 1990s fire ecology in many ecosystems around the world was studied in depth. Knowing the role of fire allows for better decisions in regard to fire management policies. In theory, then, the knowledge and the tools were in place by the 1990s for new fire management policies that would not be oblivious to the importance of sound, fire-aware, forest management, and would include tools such as prescribed burning.

The current situation

Unfortunately, the idea of fire exclusion is established too deeply in the beliefs of people around the world. Other than the scientists and probably many people who live and work in the forest and in the agricultural fields, fire remains a source of fear, a menace, for the mainstream of city dwellers, including most politicians. The practice of prescribed burning has seen significant application in the US, but very little in Southern Europe. Forest management has not been given the attention and funding it needs, and in the last decade it has experienced shifts between ministries (environment, agriculture, economy) and organizational scheme changes (from top-down structures to regional or local breakdown of structures). Furthermore, when fire disasters hit, as has been the case in many countries in the late 1990s and early 2000s, the reflexes for blind suppression of the fear causing element (fire) are all too often stimulated and societies seek "security". In a world that is turning all the time more towards strong (and costly) security forces, heavily armed and with high technology in their support, the "solution" to stop the scare of forest fires is obvious to laymen's minds: more effective fire suppression. However, this one-dimensional approach is far from complete or sound. The example of what happened in Greece in the last few years, in regard to forest fires, is worth considering, to understand the issues involved and the potential pitfalls.

The Greek example

Greece is a European country occupying an area of 130,875 km^2 in the southern tip of the Balkan Peninsula. About 60% of this area (7.9 million ha) is characterized as forest land. Tall forests constitute 2.5 million ha, of this land, the rest being evergreen shrublands and partially forested areas (3.2 million ha) or degraded lands with low vegetation of mostly thorny spiny shrubs (phrygana) (1.9 million ha). These shrublands and grasslands are mainly used for grazing. Less than half of the tall forests are timber producing forests, mainly growing at high elevations. The rest consists of "low" or coppice forests that produce mostly fuelwood and of low elevation pine forests (mainly *Pinus halepensis* and *Pinus brutia*) with little timber producing but high aesthetic value. The climate over most of Greece is typically Mediterranean, with relatively mild winters and a hot and dry summer period (Xanthopoulos 2000a).

About 2/3 of all forest lands are state owned and are managed by the Greek Forest Service (GFS) which is a state organization with a long history and very important work in the past, especially in the post second world war era, when it helped develop infrastructures such as roads and dams in the country, providing jobs and resources to rural populations. Forest management and through that timber production, was an important task of the GFS through the second half of the 20th century. However, it was mostly centered in the mountainous areas, mainly of northern Greece, were productive forests of true-fir (*Abies sp*.), spruce (*Picea abies*), high-elevation pines (*Pinus nigra* and Pinus sylvestris), beech (*Fagus sp*.) and deciduous oaks (*Quercus sp*.) grow. Low elevation pine forests were for the most part out of scientific management as the funds needed for the task were never available. In practice, there was a management scheme applied by resin collectors who cultivated these forests, securing regeneration and protecting them.

The growth of tourism that started in the 1970s, a strong economic growth and the improvement of living standards gradually drove young people away from villages and from hard work in the forests. In the 1980s the country joined the European Union. Subsidies to the resin producers were not among the policies of the EU. The low elevation pine forests were practically abandoned.

In the same period, the demand for secondary homes in coastal areas for summer vacations started growing. This trend continues today, and the same is true for the development of urban-wildland interface zones in Attica (the region around Athens) and certain other areas as people try to avoid crowded city centers. Planning for this growth was very poor. Lack of a complete land cadastre was and still is a problem contributing in this direction.

As low elevation forests were gradually left unmanaged and villages were abandoned by young people, the number of forest fires and the yearly burned area started growing steeply by the end of the 1970s. The GFS which had the task of forest protection, started acquiring firefighting means in order to control forest fires. The first specialized firetrucks were purchased around 1971 and the first Canadair CL-215 amphibian waterbombers started operating in 1974. Forest protection from fires and illegal land occupation gradually became the focus of most GFS offices in southern Greece where these problems were more pronounced, while forest management continued to be the main task in most offices of northern Greece.

In the 1980s the yearly burned area kept increasing, exceeding the 100,000 ha mark twice (1985 and 1988) (*Fig. 1*). The need to improve the firefighting

mechanism was obvious but actions in the 1980s were quite slow and funding was limited. However, starting around 1993, the GFS started getting better organized for fire suppression with only marginally higher funding, except for the addition of 200 four-wheel drive semitrucks for initial attack in its fleet. The local offices developed presuppression plans, the coordination center in Athens was improved, helicopters were introduced in fire suppression for the first time, and handcrews were trained and transported by helicopters for initial attack. Soon there were marked signs of improvement in fire statistics. Then, came the year 1998.

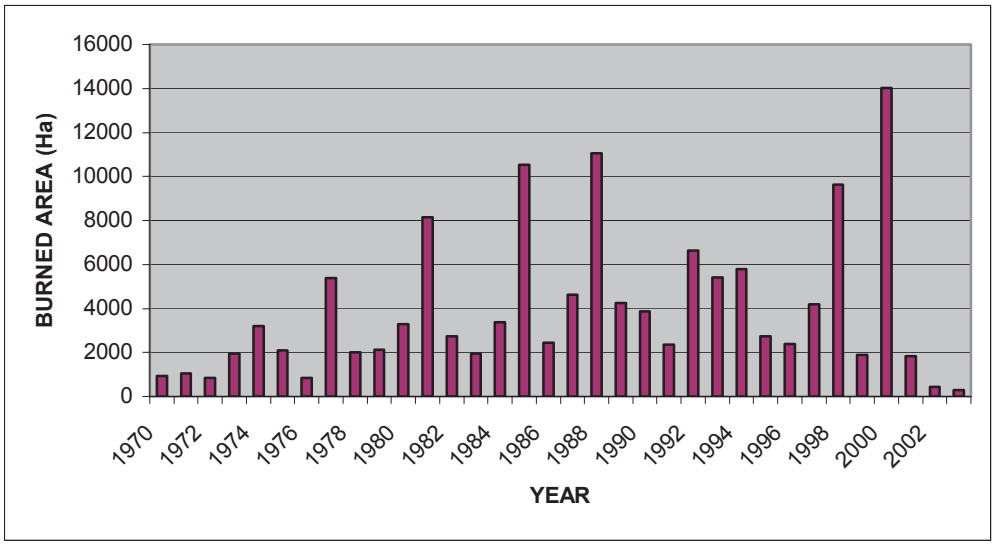


Figure 1—Evolution of yearly burned area in Greece in the 1970-2003 period.

The transfer of responsibility of forest fire suppression

The 1998 forest fire season in Greece was far from usual and certainly most controversial due to a sudden decision by the Greek government to transfer the responsibility of forest firefighting from the GFS to the Fire Service. The decision was taken at the end of 1997 and it was mainly a political one. It was prompted by what was considered poor results of the Forest Service in the previous years and did not really consider in depth all the parameters of the undertaking. Actually, it lacked any serious scientific justification or planning. During winter and spring of 1998 many voices warned about an oncoming disaster including a number of politicians, Forest Service officers, many university professors, and the few forest fire experts in the country who were not given any opportunity to offer their input (Xanthopoulos 1998).

The law about the transfer of responsibility to the Fire Service finally took effect on May 25, 1998. That left very little time to the Fire Service to seriously prepare for the challenge since the actual fire season starts by mid-June. At the same time, it was evident that no provision had been made for cooperation between the personnel of the Forest and the Fire Services at all levels. The Fire Service officers, who had been contributing in the past to forest firefighting, mainly close to urban areas and most often from paved roads, never having command on forest fire incidents, believed they knew all they needed. The significant difference between wildfires and the other types of fires they had been trained for (industrial, ship-fires, home-fires etc.) was not obvious to them.

It took only the passage of a dry cold front on July 4, 1998, that was accompanied by very strong winds (7 Beaufort scale) and the typical in such cases wind shift, to demonstrate the inadequacy of the preparation of the Fire Service. The front followed four days of lull, low humidity and extremely high temperatures which had reached 44 degrees Celsius in many parts of the country including Athens. To the surprise of the Fire Service, which did not have a fire danger prediction capability in place, more than 100 fires erupted within an hour in various parts of the country. More than 20,000 ha of forest lands burned on that day (Xanthopoulos 1999).

What followed was a preview of the rest of the fire season. Fire Service officers quickly established a belief that all fires were part of a plan against them and against the new law. Forestry people, on the other hand, insisted publicly that the Fire Service was clearly inadequate. The mass media presented and often over-emphasized this disagreement. Relations became very tense and good cooperation between Forest and Fire Service personnel was rarely the case. Even at that moment no corrective measures were taken.

The rest of that fire season was a disaster. The conditions were difficult but not extreme, but the burned area nearly reached the previous all time high. There were even some deaths, including three firefighters and a volunteer who were fighting a forest fire in a box canyon on Ymettus mountain, just a few hundred meters from the last houses of Athens, on July 17, 1998. They left their firetruck in a relatively safe place, correctly parked, having more than 1.5 ton of water and fled uphill in the canyon with the fire chasing them. They were soon overtaken by the fire and died in the open while their truck remained practically intact. The signs of lack of training and experience were quite clear.

The 1999-2003 period

At the end of the fire season of 1998 the government decided to insist on its decision. In the next years it offered heavy support to the Fire Service, including additional permanent personnel, seasonal firefighters, more aerial means, increased funding and, equally important, full political support. The number of Fire Service permanent employees increased from 6,500 to about 11,000 persons, including approximately 2,000 firefighters transferred from the GFS. About 5,000 seasonal firefighters are also employed through the summer. The number of firetrucks grew to more than 1,100. Ten (10) new Canadair CL-415 were added to the state owned aerial fleet of 14 CL-215s. Furthermore, the government allowed the Fire Service to contract private helicopters (this was not permitted to the GFS earlier), and provided the necessary funding to choose among the largest in the market. As an example, in 2003, the helicopter fleet for the summer included three (3) Erickson S-64 "AirCrane", four (4) MIL MI-26, three (3) Kamov-32T, and one (1) MIL MI-14.

The total yearly costs of fire suppression more than tripled in five years. The results were mixed: they were very good in the relatively easy fire seasons of 1999, 2001, 2002, and 2003 but in the summer of 2000 which was hot and dry the burned area reached an all time high: >140,000 ha. This can be explained mainly by the massive initial attack from the air that has become the basic principle of the Fire Service operational procedure. Under "easy" conditions, all fires are stopped immediately. However, when demand exceeds the capacity of aerial means, the ground forces are not able to control fires effectively. Of course, training and acquisition of experience gradually brings improvements in this field as well.

In the meantime, the GFS lost its political head, the General Secretariat of Forests and Natural Environment, becoming a General Direction in the Ministry of Agriculture. Furthermore, it was broken down into a region-based structure. The regional offices now belong to the Ministry of "Interior, Public Administration and Decentralization". Funding declined, and although fire prevention still remained in the responsibility of the GFS, very little can be done without the appropriate funds. One example is the lack of needed funds to maintain the network of forest roads. Another example, is abandonment of efforts to control forest fuel built-up, and even abandonment of active forest management, except of the most productive forests. The personnel of the GFS that was conditioned to a work overload during the summer, now is able to relax and enjoy vacation time freely. Very few of them would be interested to get involved again in forest fire suppression.

In the late 1990s a new political entity was created. It is the General Secretariat for Civil Protection (GSCP). Its mission is to coordinate the organization efforts of prevention, suppression and relief of all disasters, natural or technological. The GSCP became really active since 2001. In the field of forest fires it has tried a lot to bring the GFS and Fire Service to work together, for example for making common presuppression plans at Prefecture level, and it has made some progress in this respect. However, the Fire Service, with all the political support it has experienced, does not generally try to cooperate with the other state organizations. It tries to do everything by itself, even if this means duplicating means, efforts and costs.

Pitfalls and problems

The Greek example illustrates a series of pitfalls and problems that are not unique in such situations:

- The decision for transferring the responsibility of firefighting was clearly a political one. It was clearly one-sided, since it focused on forest suppression only, and there was not any scientific justification for it.
- This resulted in a very strong disagreement and finally resentment on the part of the personnel of the GFS. Much of their productive potential, including specialized knowledge and experience has been wasted. This is especially true for senior officers who had devoted a big part of their life protecting the forests they were responsible for with poor means and support.
- It could be argued that the results of fire suppression in the last three years are positive.
- However, this can also be challenged: The huge burned area in 1998 and 2000, which included many of the most vulnerable forests reducing the overall fire potential, and the mild fire seasons that followed in combination with the extreme strength of the aerial means, may be falsely hiding inadequacies that will become evident in a difficult fire season a few years from now.
- The cost of firefighting has sky-rocketed. Even if the Fire Service has or will become more effective in fire suppression than the GFS, this is achieved at a very high cost. No-one will ever know how much more successful the GFS could have been if it had received only part of the political support and funding that the Fire Service has received.
- It has been demonstrated in practice that the politicians understand very little about forest management and fire prevention through that. Their interest, and support, is devoted to "visible" aspects of forest fires such as fire suppression and prevention campaigns through the mass media aimed at the public. As soon as prevention responsibility was disassociated from suppression, the latter got all the support and funding.
- Fire prevention has suffered as, in addition to lack of appropriate funding, there is no political strength and no real mentality of fire management within the GFS:
    - No effort to work on legislation or actions in support of resin collectors, rural populations, regulation of grazing, rational planning of new urban-wildland interfaces etc.
    - No thought about development of prescribed burning projects for forest fuel control or for the development of practical and realistic grazing schemes (in order to reduce shepherd caused fires, and to prevent further grazing site deterioration).
    - No effort for dynamic forest management with principles that incorporate considerations about fire.

  - Only limited work on forest road and firebreak maintenance.
  - Only limited work on fuel reduction.
  - Limited participation in the development of presuppression plans.
- As time passes since the deprivation of forest fire responsibility from the GFS, the collective knowledge and mostly the experience of its personnel on forest fires, is being lost. This is negative both in regard to better fire-aware forest management in the future, as well as in regard to introduction of prescribed burning.

Examples from other countries

Greece is not the only example of complications in regard to fire management responsibilities in various countries. Actually, the examples of different organizational schemes are as many as the fire prone countries around the world. Others can present the situation in their own countries in much better detail, so it will not be attempted here. However, it is worth noting that, as a general rule, in countries where forest fires do not have a prominent role in shaping the forest ecosystems, forest fire suppression responsibility lies with the Fire Service. Many central and northern European countries belong to this category (Germany, United Kingdom, Ireland, Sweden…). The same is true for Japan (Zorn and others 2002). France is a special case, since the forests are not highly flammable except for the southern part where the climate is Mediterranean. Since the mid-1980s, the Forest authorities are responsible for prevention while fire suppression is in the hands of the Civil Security. The latter is responsible for city fires and all other disasters as well.

Also, Portugal, for the most part, is not a true Mediterranean country. Its climate is influenced by the Atlantic Ocean. Forest productivity is high over most of the country. Much of the native pine forest there has been replaced by eucalypt plantations, through private initiatives, increasing fire potential steeply. A centuries old tradition of a volunteer Fire Service, has brought the responsibility of all firefighting to the hands of this organization. The forestry authorities are mostly responsible for prevention.

Sometimes differences exist even within countries. For example, Spain consists of many regions, which are highly autonomous. The fire prevention and suppression responsibility scheme varies a lot between them. In the highly flammable Andalucia in the south, the forest authorities are responsible for fire suppression. In the less flammable but more forest rich Catalonia in the north forest fire suppression responsibility lies with the Fire Service. The province of Madrid, where urban areas are many and the forests are not as flammable as in Andalucia, follows a mixed model, where the forestry authorities are not completely disassociated from fire suppression.

Forestry organizations, usually in cooperation with municipal fire brigades, are responsible for fire suppression in most Mediterranean countries such as Israel (Bonneh et al. 2004), Cyprus (Hadjikyriakou 2002), and Turkey, while Italy has a complex system with many players, with a special forest firefighting organization (Corpo Forestale) and a Civil Protection Directorate in Rome having key roles (Fuschetti, 1976). In the USA, the National Interagency Incident Management System (NIIMS) coordinates the pre-suppression and fire suppression actions of

many federal land management agencies, the States and the municipal Fire Services (Xanthopoulos 2000b).

In Canada and Russia, countries with vast expanses of forest and sparse population, the forestry authorities carry the responsibility for forest fire control. On the other hand, in most of Australia, volunteer organizations, such as the New South Wales Rural Fire Service, handle all fire emergencies in an effort to cope with the problem of achieving effective fire suppression in a large country that has areas of extremely flammable vegetation but also has a relatively small tax-payer base.

The effectiveness of all the above schemes is quite variable. However, large fires seem to be inevitable wherever fuel build-up occurs, forest management does not cope with it and meteorological conditions bring fire danger to extreme conditions. When lives and private properties also get affected forest fires may even be characterized as major disasters. The fire season of 2003 was very difficult in the south of Europe, from Portugal to Italy and Croatia. Independently of who is in charge of firefighting, all these countries suffered great damages. Portugal, with its forest management problems, and France with its wildland-urban interfaces, that included tourist infrastructures, suffered most.

Of course, there are other reasons, such as social, political or economic, and cases such as inadequate suppression capability of the firefighting organizations, that lead to catastrophic fire seasons in some areas of the world. The Amazon basin in Brazil and Indonesia are two such examples. In those cases, again, who is responsible for fire suppression is not the major issue. Forest management that is beneficial for the people, education and involvement of the public, and a basic firefighting organization and infrastructure is the answer.

Criteria on how fire management should be organized

Given all the information above, it is needed to focus on the central question of this paper: Who should be responsible for forest fires? The answer, in this author's view, is far from simple, but it is not difficult. It should be based on the realization of certain general truths:

- Organizations are made of people. They give value to the organizational scheme. Forest fire suppression needs dedicated, skilled and knowledgeable people. If a specific fire management scheme works, with its people and resources, it is foolish to try to change it drastically. As the saying goes: "*if it ain't broken don't fix it*".
- In certain environments the build-up of fuels makes it impossible to avoid occasional catastrophic fires. Fire management must take this into consideration, making long-term fire damage reduction one of its central objectives.
- Copying fire management schemes, even successful ones, from one country to another is not necessarily a good idea. Differences in environmental, social, and economic conditions, educational level of people, sophistication level of the society, etc. may lead to major failures. For example, GIS systems in fire management are not the solution for countries where there is little familiarity with computers in the workplace and there are no digital data (such as DTM) available.

- In regard to fire suppression per se, any well prepared, organized, equipped, funded and managed organization can do the job, once it acquires the necessary knowledge and experience and becomes familiar with the terrain and the conditions.

Having these truths in mind, the problem becomes one of achieving fire control objectives (burned area reduction, fire losses reduction), in a cost effective way, without compromising environmental concerns (Xanthopoulos 2004). The following recommendations provide a basis for an initial assessment of the required action:

1. Avoid disturbing a system that works well in the long-term.
2. Examine if fire control successes of a recently (10-20 years) established system can be maintained in the long-term. Fire history, fuel build-up assessment, evolution of the number of fires per year, the total burned area, the number of large fires occurrence and trends of firefighting costs are variables that must be examined at a minimum. Take corrective action if needed before problems become compounded.
3. If there is talk or pressure (political, popular) for changes consider points 1 and 2 above first. The level of success (or failure) of the current system must not be judged independently of the current level of funding. Compare level of funding in other countries with similar conditions.
4. If the indication is that changes may be needed, use the table below (*Table 1*) to classify the type of environment in the country or region of interest between the six "typical" types recognized. The recommendations for each of these types will help guide the basic approach towards a new organizational scheme.
5. Realize that from that point on it is a matter of study, brainstorming, good planning, involvement of the right people and careful well planned steps in order to establish the new scheme without serious turf battles, instability or loss of potential resources.

Conclusions

In a world that changes in regard to its mentality, economics, technology, social structure, and environment (including climate change), the question of "who should be responsible for forest fires" may come-up in many countries around the world, as it has come-up in Greece. The example of Greece was used here to illustrate some of the pitfalls and potential problems. It should be studied carefully, and examples from other countries should also be considered before a decision of how forest fire suppression should be organized can be made. The question is not a simple one to answer. There are specific criteria and conditions that must be taken seriously into consideration. The recommendations provided here are not a panacea and do not reach a deep level of analysis. However, they are a first attempt to provide a guide, mainly for those trying to make political decisions with limited knowledge about the realities of forest fires, that will help them realize the seriousness of their actions and to take careful steps in the right direction.

Table 1—*Recommendations on who should be responsible for forest fire suppression for various types of forest environment.*

Type of environment	Characteristics	Recommendations
A	High biomass production, high decomposition rates, fuel build-up slow, humidity generally high (tropical and subtropical environments). Forest floor biomass low.	Fire suppression demand is low. It can be handled by forestry administration, municipal fire departments, or volunteers. Cooperation between them is useful but not critical.
B	High biomass production, slow biomass breakdown. Quick fuel build-up. Highly flammable vegetation, high natural fire frequency (e.g. chaparral in California, maquis and Pinus halepensis forests in southern Europe, Mediterranean dry eucalypts in Australia).	Fire suppression demand is extreme. Fuel management including prescribed burning is essential but can only be carried out over limited areas. Fire control is costly. Cooperation of all organizations is important in order to keep firefighting costs at reasonable levels. A system like NIIMS should be considered. Emphasis must be given to good planning, e.g. of wildland-urban areas in order to reduce damages because of the occasional uncontrollable fires.
C	Medium biomass production rate, biomass decomposition rate quite good, humidity generally high, such as in temperate deciduous forests, usually at high elevations. Forest floor biomass accumulation slow, fire frequency low to medium, fire intensities low to medium.	Fire suppression is not demanding. It can be handled by forestry administration, municipal fire departments, or volunteers. Cooperation between them is useful but not critical.
D	Medium biomass production, medium rates of decomposition such as those in temperate coniferous forests mostly at higher elevations. Fuel accumulation on the forest floor is slow but fuel loads can become quite high. Low natural fire frequency but extreme fire behavior potential possible in mature stands.	Over extended landscapes the potential for occasional large wildfires exists. It is not rational to maintain a huge fire suppression mechanism. It is best to emphasize good fire-aware forest management in order to control fuel accumulation. Then, either forest authorities or municipal fire brigades can control fires successfully. If fuel accumulation has occurred, such as in parts of the USA, significant resources and good fire suppression capability is needed.
E	Low biomass production rate and low rate of biomass decomposition, such as in boreal coniferous forests. Accumulated biomass on the forest floor can reach very high levels. Very low natural fire frequency, because fuel build-up takes a long time and conditions conducive to fire are rare. Extreme fire behavior potential is possible in mature stands.	There is occasional need for large fire suppression capability. Forest management is needed where timber production is economically viable. Emphasis is needed on effective fire detection and initial attack. Knowledge of the terrain and the conditions is very important. Municipal fire brigades are not suited for such tasks and they are scarce in such environments anyway. Use of the forestry personnel for multiple functions makes sense.

F	Fine fuels, grasslands, such as in water limited environments (e.g. savannah). Fuel loads are low, fire frequency is high.	Limited fire suppression capability needed. Fire is not destructive, except to properties & livestock so planning is needed. Initial attack with relatively light, quickly mobilized resources is needed. It can be handled by forestry administration, municipal fire departments, or volunteers. In many cases, the latter coordinated by the authorities, are the best option.

Acknowledgments

This paper was prompted by and is based on work performed within the fire suppression work-package of the EUFIRELAB research project which is funded by the European Commission, DG Research, 5th Framework Programme (Contract EVR1-CT-2002-40028).

References

Bonneh, Omri; Ginsberg, Paul; Woodcock, John. 2004. **Integrated Forest Fire Management in Israel A 15 Year Review (1987-2002).** International Forest Fire News (ECE/FAO) 29: 00-00 (in press).

Fuschetti, Fernando. 1996. **Forest Fire Control in Italy.** Initial Attack magazine, Bombardier Aerospace. Spring 1996 issue.

Hadjikyriakou, Georgios. 2002. **The Forest Fire Situation in Cyprus.** International Forest Fire News (ECE/FAO) 23: 71-76.

Zorn, Tobias; Nakayama, Kouji; Hashiramoto, Osamu. 2002. **Forest Fire Situation in Japan.** International Forest Fire News (ECE/FAO) 26: 54-60.

Xanthopoulos Gavriil. 1998. **Forest fires in Greece: Past, present and future. Epikentra**. 6: 62-71 (In Greek).

Xanthopoulos, Gavriil. 1999. **The 1998 forest fire season in Greece: A forest fire expert's account.** International Forest Fire News (ECE/FAO) 20: 57-60.

Xanthopoulos, Gavriil. 2000a. **Fire situation in Greece.** International Forest Fire News (ECE/FAO) 23: 76-84.

Xanthopoulos, Gavriil. 2000b. **Principles of cooperation between organizations for forest fire defence: The example of the USA.** In: Proceedings of the workshop on "Saving the forests of Attica, an urgent social need"; 1999 January 18; Worker's Center of Athens (EKA), Athens, Greece; 176-185 (in Greek).

Xanthopoulos, Gavriil. 2004. **Evaluation of Forest Fire Policy Scenarios as a key element affecting the occurrence and characteristics of fire disasters.** In: Proceedings of the "EU-MEDIN Forum on disaster research. The road to harmonisation"; 2003 May 26-27; Thessaloniki, Greece. A. Avdelas, M. Yeroyanni, K. Fabbri, editors. European Commission. (in press).

Page left blank intentionally.

Control of Forest Fires as Part of the Spanish Forestry Plan[1]

Ricardo Vélez Muñoz[2]

Summary

- The analysis made by the Spanish Forestry Plan identifies the social and economic causes which have led to the intensification of forest fires in the last three decades. Among causes the following are noteworthy
- The abandonment of agricultural land
- Economic policies which encourage this abandonment and its subsequent reforestation with the aim of reducing agricultural surplus.
- Maintenance of traditional practices of burning agricultural waste products, pasture and rubbish.
- Conflicts arising from the limitations of use (Protected Open Spaces), the conflicts of hunting, the labour market in the forestry sector itself, the generalised process of urbanisation of the land, revenge, vandalism etc.
- Misuse of forestry areas by the urban population, either as visitors for recreational purposes, or to build second or permanent homes.

The number of outbreaks of fire shows a growing trend both in Spain and in the other Mediterranean countries of the European Union.

Suppression resources have notably have improved in terms of strength and technology in the last ten years, and have achieved a high degree of efficiency as illustrated by the reduction of the forest surface area burned. This efficiency has limited the impact of fire but paradoxically, this has led to risk that new fires spread due to the accumulation of fuel.

The problems and needs detected in the diagnostic phase of the Spanish Forestry Scheme cantered basically on identifying causes, the need to promote preventive action with particular emphasis on silviculture and the maintenance of suppression potential. As a result the three main objectives are:

- Determining and acting on the causes both immediate and structural.
- Continuous improvement in preventive actions with particular emphasis on preventive silviculture and heightening of social awareness.
- Homogenisation by raising the level of efficiency in all the competent suppression administrative departments.

The required measures are detailed in three sections: Planning and coordination, Prevention and Suppression

As an indicator of the results the annual "severity index" has been chosen calculated as the percentage of burned forest area in respect of national forest land. 0,3 percent was set as

[1] An abbreviated version of this paper was presented at the second international symposium on fire economics, planning, and policies: a global view, 19–22 April 2004, Córdoba, Spain.

[2] Director of Department of Forest Fire Control, Ministry of the Environment, DGCN, Gran Vía San Francisco4, 28005 Madrid, rvelez@mma.es.

an objective to be achieved by 2008 and in 30 years 0,2 percent. This is a realistic goal since in 2002 the severity index dropped to 0,39 percent, in contrast to 1,6 percent in 1994 and the indexes close to 1 percent which were customary in previous decades.

Introduction

Forest fires adversely influence the stability of forest ecosystems, stripping soils and contributing to erosion. The climatic characteristics of the Mediterranean medium with long summer droughts accompanied by high temperatures and often with strong overland winds, cause a high degree of drought in the vegetation raising the risk of ignition and propagation in the event of some agent or element of provocation In the last twelve years, the number of fire outbreaks shows a growing trend while the surface burned notably fluctuates from one year to the next according to drought and wind conditions of each particular year

Despite the reduced number of fires (0,2percent as an annual average) which become large scale fires covering over 500 ha. these cause the most serious environmental and economic impact. The extent of these fires is influenced by climatic conditions but also by the continuity of the fuel and also due to the application of fire fighting techniques unsuitable to a forest environment .

Analysis of the Situation

The analysis carried out by the Spanish Forestry Plan identifies the social and economic causes which have led to the intensification of forest fires in the last three decades, notably the following:

- Abandonment of agricultural land which is then invaded naturally by colonising species such as pines and scrub which grow into continuous dense masses with scant management and which provide no interruptions which would halt the progress of fire once it had broken out.
- The economic policies which encourage this abandonment and their subsequent reforestation with the aim of reducing agricultural surplus without the simultaneous implementation of preventive forestry programmes with sufficient economic resources to act on accumulation of fuel produced. This accumulation has a decisive influence on the extent of area burned.
- Persistence of traditional agricultural practice of burning pasture and waste which is identified as the cause of numerous deliberate fires, particularly in the rural Northeast and Cantabria.
- Among other motivations for deliberate fires, the conflicts arising from limited use may also be mentioned (protected areas) the conflict of hunting, the labour market in the forestry sector, the generalised process of urbanisation of the land, vengeance, vandalism etc.
- Misuse of forest areas by the urban population either as recreational visitors or in building second or permanent homes.

It is important to point out that the number of fires attributed to unknown causes, despite the fact that it has considerably reduced in recent years due to the

application of advanced investigation techniques, is nevertheless still significant, particularly in some Autonomous Communities.

From the attached analysis of indicators it may be deduced that the number of fire outbreaks shows a growing trend both in Spain and other Mediterranean countries of the European Union, although many of these fires are no more than outbreaks (burning less than 1 ha) their high number is a challenge to results obtained by suppression methods and requires the continuous increase of investment. Given that the aims of prevention include, among others, the reduction of this number; it is obvious that the level of desirable concentration of preventive action has not yet been reached.

Indicators also show that the degree of efficiency reached by suppression resources which have been technologically improved and reinforced considerably in the last ten years may be considered as high as is shown by the reduction in the forest surface area burned. This efficiency has let to limitation of fire impact however paradoxically to the gain of risk that new fires will extend further due to the accumulation of fuel.

However, the technological improvement in suppression methods has not reached the same levels in all the Autonomous Communities, therefore the results in respect of reduction of percentage of the area burned is heterogeneous. This has necessitated increased State support (Ministry of Environment) in the areas of most concern, such as promoting the application of new technologies, training personnel and investigating new methods and materials.

Objectives of the Spanish Forestry Plan

The problems and needs already defined in the Spanish Forestry Plan analysis are based fundamentally on the identification of causes, the need to promote preventive action with particular emphasis on silviculture and the maintenance of potential suppression. As a result the three objectives proposed are as follows:

- Determining and acting on the causes of fire, both immediate and structural.
- Continuous improvement of preventive action with particular emphasis on preventive silviculture and social awareness.
- Homogenisation by raising the level of efficiency in tall the Administrative departments involved in suppression.

Measures included in the Plan

In order to develop these objectives the following actions are proposed:

- With respect to **planning** and **coordination**
- Coordination of plans of the Autonomous Communities and the General State Administration through the Committee for the Control of Forest Fires (CLIF), based on distribution of risk and cost efficiency criteria.

- Promotion of localisation of forest fire control by drafting and applying local area control plans devised by technically competent personnel with specific training.
- Monitoring of fire hazard with detailed statistics (EGIF database), intensifying the application of remote detection and GIS technologies to assess damage and determine risk.
- Extension of hazard prediction systems and the behaviour of fire by reinforcing the forest meteorological network in coordination with the National Institute of Meteorology.
- Periodic review of hazard indices constantly adapting them to real conditions in specific zones.

  Contracting over several years, by the Administrative bodies responsible, of sufficient personnel and companies to control forest fires.
- Coordination of the services and supplies contracted by the state departments (State Dept/Autonomous Communities) to achieve scale economies.
- Promote professional capabilities of personnel working in forest fire control by means of a general system of approval (State Dept/Autonomous Communities) and certification bearing in mind, moreover practical experience.

With respect to **prevention**

- Improve the system for identification of causes to reduce the percentage classified as unknown by means of training courses for forest agents and police and the number of investigation brigades working in the various Autonomous Communities.
- Introduction of legal regulations which would discourage use of fire for economic interest and the application of sanctions envisaged by forestry legislation and the Penal Code.
- Increase public awareness to avoid the use of fire in forest land by means of both permanent and seasonal campaigns.
- Evaluation of possible undesirable effects of the application of community systems of grants for extensive livestock keeping..
- Specific programme for prevention of fires caused by farmers and stock keepers by means of:
    - Promoting direct awareness of the rural population of the dangers caused by fire to its economy
    - Joint organisation of controlled burning by the Administration and farmers and livestock owners' associations, promoting the running of local fire prevention teams
- Reinforcement of mobile vigilance in an effort to discourage, promoting the equipping of municipal patrols in areas of greater risk
- Promoting voluntary associations for preventive monitoring.

Encouraging the formation of forestry associations for intensification of preventive silviculture (fire break areas, species diversification, controlled burning etc) in private woodland and strengthening of protective infrastructure (water outlets, paths, small area bases etc.)

- Funding of silviculture projects and preventive infrastructure carried out by Autonomous Communities.
- Development of guidelines for fire break areas in the urban/forest interface for the self protection of housing complexes included in the urban planning..
- Monitoring of the application of the Programme for reforestation of Agricultural Land in order to ensure that preventive forestry work is carried out.

With respect to the maintenance and improvement of the level of efficiency of **suppression**

- Maintenance of a fleet of amphibious aeroplanes and helicopters for general aerial cover with the collaboration of the Air Force and the Guardia Civil.
- Improvement of coordination for addressing large scale fires by using all the State and regional departments (Autonomous Communities/Government Dept) Air Coordination Units, Mobile Meteorological and Transition Units and Reinforcement brigades (BRIF).
- Extension of decision making systems by means of applying to specific territories the computerised methods of prediction and simulation of fire behaviour and resource management.
- Maintenance of a system of normalisation of materials and equipment by means of the Committee for the Control of Forest Fires, (CLIF), to guarantee the quality and improve scale economies of the contracting by different administrative departments with their respective budgetary funds.
- Complementation of both suppression systems currently in use one based on urban fire fighters and the other in rural personnel duly specialised so as to make the most of the advantages of each in each case.

General Indicator of the results of Forest Fire prevention Plan

As indicator of the results the "severity index" calculated as the percentage of forest surface area burned with respect to national forest.

As an objective up to 2008 the target is 0,3 percent and in 30 years 0,2 percent This is a realistic objective since in 2002 the severity index was lowered to 0,39 percent, a contrast to 1,6 percent in 1994 and the indices close to 1 percent which were common in previous decades. In 2003, however the index has grown once more to 0,5 percent.

Implementation of the Plan

The Government approved the Spanish Forestry Plan in 2002, and its implementation required and urgent revision of basic forestry legislation which dated from 1957 and, although technically it continued to be valid it was not compatible with the new State structure or the principles of Forestry Strategy in force.

In 2003 the new Forestry Law which had been conceived by the National Forest Council, was debated and approved with the participation of all state and regional departments together with economic, professional and scientific sectors involved with woodland.

The inventory is currently being updated of all the material and economic resources for all the actions relating to the control of forest fires which the relevant departments provide overall, in order to identify the deficiencies in budget.

In addition, execution of the plan requires that priorities be established according to the circumstances as they develop.

Currently, following the 2003 campaign against forest fires the following stand out:

- Prevention of the urban/forest interface.
- Systemized coordination of suppression resources provided by administrative departments overall.
- Certification and authorization of the training of personnel at all levels.

References

Ministerio de Medio Ambiente, 2000.- Estrategia Forestal Española, Madrid.

Misterio de Medio Ambiente, 2002.- Plan Forestal Español, Madrid.

Boletín Oficial del Estado, 2003.- Ley 43/2003, de 21 de noviembre, de Montes, BOE nº 280, 22-11-2003.

APPENDIX

Prevention Indicators, National Total: 1991-2000

Annual Number of Disasters

Between 1991 and 2000, the annual number of disasters grew at a national level. From almost 14,000 disasters in 1991 the number rose to more than 23,000 in 2000.

Analysis of Causes

With respect to the percentage of disasters with known causes, a growing trend developed between 1991 and 1995, from 62 percent in 1991 to more than 80 percent in 1995. After 1996 the percentages were approximately 82 percent.

An analysis of the percentage of disasters according to the causes in the twelve years between 991-2000, noted that 60 percent were deliberate, with 47 percent of the forest area affected. This was followed by 13,7 percent of disasters identified as negligent, with 16,9 of forest surface affected. 3,9 percent of disasters were caused by lightning which burned 11,2 percent of the surface area. In this chapter it should be pointed out that in more than 19 percent of the disasters the cause is unknown (17,6 percent of the surface area).

Negligence

With regard to the type of negligence (13.7 percent of disasters between 1991 and 2000), fires caused by agricultural burning were those which had the greatest effect, both in number (27.3 percent) as in forest surface area (18.5 percent). 16.9 percent were through burning of pasture (13.3 percent of the surface), 11 percent due to burning of waste (15.7 percent of the surface), 8.5 percent caused by smokers (13.1 percent) and 5.3 percent by bonfires (12.8 percent of the surface area). It should be recalled that 18.4 percent of the number of disasters (more than 21 percent of the forest area affected) were not due to the typical negligence of the information gathered.

Deliberate Fires

Of the deliberate fires caused between 1991 and 2000 (60 percent), most outbreaks were in August (more than 27,000 disasters), March (more than 20,000) and September (20,000 disasters). Detection of deliberate fires was greater between 14:00 and 19:00 hours, with maximum number at 16:00 (more than 10,000 disasters detected). Development of the rest of the disasters was more or less parallel for both indicators with lower values.

With respect to motivation in 3.9 percent of the deliberate disasters were due to the following. Of these 38.5 percent were due to pasture burning, 35.2 percent by agricultural burning and 12.8 percent by pyromaniacs as the main causes.

Annual distribution of fires motivated by pasture burning reached its height in March with more than 240 fires.

Suppression Indicators, National Total: 1991-2000

Outbreaks

The percentage of outbreaks (fires which spread over less than 1 hectare) in the first five years of study showed a slightly lower trend from 65 percent in 1991 to 60 percent in 1995. In 1996 the value dropped to 45 percent and since then it has not stopped rising until it reached 60percent again in 2000.

The percentage of national outbreaks in the campaign period (1 July to 30 September annually) clearly exceeded the values observed outside the campaign (remainder of the year) while in 1995 values were the same for both periods (30 percent).

Forest Surface Area Affected

The percentage of forest surface affected by fire during the first five years studied (1991-1995) was greatest in 1994 (1.6 percent), followed by the value reached in 1991, of almost 1 percent. In the remaining years the affected forest area was less than 0.7percent, although a growing trend has been observed since 1996.

Except for the years 1992, 1995 and 1997, forest surface area affected was greater in the campaign period than outside it. In particular the year 1994 stands out, during which there were more than 350,000 ha. and also 1991, with over 210,000 ha. With respect to cultivated forest areas, the behaviour was clearly parallel to that described for overall forest area. The most affected years were 1994, with 220,000 ha approximately and 1991 with 100,000 ha. In the remaining years during the twelve year period 48,000 ha of cultivated forest areas were burned both during the campaign and outside it.

Arrival times

The average reports without information with respect to the period 1991-2000 were 2.8 percent and the percentage consigned to “without intervention” was 7.5 percent, figures which were discounted in the estimation calculations of the following indicators:

Less than 15 minutes

With respect to the percentage of fires with arrival time of less than 15 minutes values were maintained between 50 and 55 percent for 10 years with a slight downward trend from 1996 onwards.

Less than 30 minutes

The percentage of fires with arrival time of less than 30 was also similar during the ten year study period with values of around 80 percent. Similarly there is a slight downward trend from 1996 on.

The values reached for this indicator in campaign were more than those obtained outside it, between 5 and 10 percent annually.

Size

The percentage of outbreaks between 1991 and 2000 was 60.2 percent, and the surface area covered was 1.5 percent. 26 percent were fires covering between 1 and 5 ha. Although the percentage of forest surface area affected by these fires was 6.4 percent. 12.7 percent of fires burned between 5 and 100 ha., which was in fact 26.8 percent of the forest area affected. 20.4 percent of the forested area burned corresponded to 0.9 percent of the number of fires extending over between 100 and 500 ha. 8.2 percent of the forest area burned was related to 0.1 percent of fires between 500 and 1000 ha. Another 0.1 percent were fires between 1,000 and 5,000 ha, which were equivalent to 15,9 percent of the surface area affected and finally, less than 0.02 percent of fires covered over 5,000 ha burned 20.8 percent of the total of the surface area affected.

System of Detection

With respect to the system of detection used attention should be drawn to the permanent vigilantes throughout the study period with more than 30 percent of fires detected practically every year. For ten years the work of forest agents during this time was kept at between 10 and 15 percent of fires detected.

Percentages of around 5percent were attributed annually to mobile vigilante teams. Finally it should also be pointed out that from 1998 onwards detection by private individuals accounted for 25 percent in the year 2000. However, there still remained 20 percent (year 2,000) of fires assigned to the category “others” in terms of detection systems.

Annual Distribution

The greatest incidence of forest fires on a national level in the twelve year period 1991-2000, was in the summer months between June and October. This fact was due basically to outbreaks of fire, almost 30,000 in August since with respect to the number of fires another period between February and April was also noteworthy. The months with most fires were March and August with approximately 15,000 fires apiece. The greatest surface area affected of both cultivated forest and non-forested land occurred in July (almost 200,000 ha. of non-forested area and 250,000 ha. of forested areas) and August (260,000 ha. of non-forested and 190.000 ha of forested areas). The next most affected surface areas were in September and March.

Type of Vegetation

With respect to the type of vegetation affected, between 1991 and 2000 annually, the majority of fires affected only uncultivated forest land. Minor outbreaks covering less than 1000 m^2 and subsequently the fires which covered cultivated vegetation and natural forest land together. From 1995, the smallest number of fires was those which burned only cultivated forest.

Aerial Resources

With regard to the activity of aerial resources, the percentage of fires where aerial resources intervened showed a slight growth trend over ten years of study, exceeding 18percent in the most recent years. The intervention of these resources was clearly greater in the campaign months than at other times. 16.5 percent of fires where aerial resources intervened during the twelve year period in almost 59 percent helicopters were used in 19.6 percent fire suppression plans, 10.3 percent with suppression helicopters and 9.7 percent with amphibious planes. In 1.7 percent coordination airships were used and in these cases, in 38 fires in 1998, in 77 in 1999 and ion 132 fires in the year 2,000 at least five more airships intervened in fire-fighting.

Europe: Development and Fire[1]

Ricardo Vélez Muñoz[2]

Abstract

In response to socio-economic changes in recent decades, such as rural depopulation, concentration of the population in urban areas, and priority shifts in forestry policy, the risk of fires in the countries of southern Europe is on a rise. Until now, the large investments made in fire suppression resources have produced acceptable results. However, ecological, economic, demographic and political conditions have led to more and more difficult situations involving more frequent large fires. Multilateral assistance between countries and the development of a regional prevention policy should, in the immediate future, be the focal point for international cooperation in response to this shared problem.

Introduction

When one speaks of forest fires in Europe, one automatically refers to the Mediterranean Basin region. Although fires do, of course, occur in northern and central Europe, their impact is very limited in comparison with those in the southern countries.

Fires in the Mediterranean Basin more than just a consequence of long periods of drought; they can also be considered an indicator of the socio-economic differences between the different areas comprising the Mediterranean Basin and their respective levels of development. The highest number of fires and the most extensive areas are reported in the Mediterranean countries in the north of the basin (Europe). This tendency appears to be extending from the northwest to the east, to the countries that hope to join the European economic space (Croatia, Bulgaria, Rumania, Turkey, Israel). Development will perhaps allow them to enter more quickly in the "fire club" currently consisting of Portugal, Spain, France, Italy and Greece!

Socio-economic change in recent decades influences the risk of fires, given that it increases the flammability of the ecosystems. The changes with the greatest repercussions are:

a) **Rural depopulation**, which leads to neglected areas of land. These areas are then invaded by natural and spontaneous vegetation that burns with a greater flammability. In addition, the aging population staying behind also increases the risk, given that traditionally farmers and shepherds burn the land themselves to control vegetation.

b) Concentration of the population in urban areas, which widens the wildland/urban interface. The growing vegetation in the surrounding areas can eventually increase the risk to new residences (first or second homes).

[1] An abbreviated version of this paper was presented at the second international symposium on fire economics, policy, and planning: a global view, 19–22 April, Córdoba, Spain.

[2]Head of the Forest Fire Area, Ministry for the Environment, DGCN, Gran Vía San Francisco4, 28005 Madrid, rvelez@mma.es.

c) **Shifts in priorities in forestry policy**, which formerly were centred on the production of wood and other raw materials, are currently focused on nature conservation, landscape conservation and recreation. The decrease in timber removal and logging in some areas have led to increased amounts of biomass in woodlands, and hence increased flammability.

The reduced frequency of fires in the south and east of the Basin, where these changes have not occurred, contrasts noticeably with the high risk present the European countries of the basin.

To counter such a risk, during the last two decades the countries of the "fire club" have greatly improved their fire suppression resources at a high economic cost, with apparently acceptable results. Nevertheless, the possibilities of continuing to make large investments to combat the continued worsening of the problem seem almost expended. Thus, new approaches to forest fire defence are required to improve the strategies of prevention and suppression.

Determining factors

Ecological factors

Weather conditions and the way in which weather has been modified by the climate change do not seem to be leading to any lessening of the long periods of drought (3 – 6 months) in which vegetation becomes readily burnable. In addition, an increase in dry storms in those periods has been observed. As this coincides with extensive accumulation of fine fuels in the fields due to rural desertion, it could lead to highly intense fires in many zones at the same time.

Economic factors

The economic value of forest areas in the Mediterranean climate is lower than in any other sector, due to the slow growth of the species present and the scarce demand for the products that can be obtained from the land, except for cork.

Spain, with forest land counting for more than 50 percent of national territory, only obtains 0.15 percent of its GDP from the forest land.

The low direct economic value discourages investments that could improve the productivity of the land. In Spain, the forestry sector only contributes 5 percent to the environmental market (ASEMFO 2002).

The risk of forest fires is an additional negative factor for the economy. Until now it has not been possible to establish—not to mention consolidate—a fire insurance system that facilitates the process of obtaining credits and, as a result, investments.

Unfortunately, the environmental values in the forest areas are not able to attract capital investments geared toward high profitability.

Demographic factors

The Mediterranean Basin in a region with a growing population; from 1950 to 2000, the population grew from 225 million people to 450 million. Projections

indicate that by 2050 it could reach 600 million (Plan Bleu 2003). However, this population is concentrated in the costal areas and in some built-up urban areas inland.

Specifically, the urban population for the entire Basin constituted 60 percent of the total population in 1970 and reached 70 percent in 2000.

In the countries in the north of the Basin, the proportion is already at 90 percent. That is, rural areas are emptying and the mountainous woodlands, in particular, can already be considered deserted.

The current elevated migratory movements do nothing to alter this situation, given that immigrants settle mainly in urban areas and in highly-productive agricultural zones (that is, areas with the most employment opportunities).

By way of example, in Spain the active rural population (number of jobs), decreased from 1,600,000 in 1988 to 800,000 by 2002 (ASEMFO 2003).

In the short term, the desertion of rural areas leads to neglected land where natural regeneration takes over. During many years this land will present a high flammability.

In addition, a low population also means lack of labour for carrying out forestry work in general and fire protection work in particular.

Political factors

The situation described in the above points is naturally not attractive enough to interest politicians in woodland protection. However, the urban population's demand (through voting) for environmental protection has contributed to the establishment of permanent protection programs as one more of the services offered by the **welfare state.**

Nevertheless, these services suffer the usual defects of such an approach: firstly, priority is given to the **most urgent matters** (fire suppression), which barely leaves resources available for the **most important matters** (prevention).

Secondly, government intervention generates **passiveness among the population** on one hand, and, on the other hand, **a demand for** impossible **results** in extreme danger conditions not clearly understood by the public.

Results of suppression work

As stated above, the majority of resources are centred on fire suppression, with the general criteria that **all fires must be put out**. The U.S. policy of **allowing fires to burn in some areas (natural prescribed burning)** is not considered a possibility under any circumstances.

The large amount of property and goods to be protected in urban areas, as well as the development of fire services in those areas, has in many cases led to responsibility for fire suppression being transferred to those services, disassociating it from forestry activities.

As this shift in responsibility has not been accompanied by a specialization in forestry techniques, it has led to rather long periods of lack of coordination and inadequate results. Gradually, however, the concepts of forest fire behavior and

the specific techniques of fire-fighting have become more widespread and there is a greater coordination among fire services and forest management services.

The **principle of total fire suppression** and, fortunately, the availability of economic resources, has led to important improvements in the training and equipping of personal, as well as the spread of use of aerial resources. Each summer more than 400 aircrafts aid in suppressing forest fires in the European Mediterranean countries.

The results of these works are listed below. The percent of burned forest area in the at-risk area (national woodland surface area in Portugal, Spain, Southern France, Italy and Greece) is used as an indicator.

	Year									
Country	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Portugal	2,61	5,73	3,00	1,03	5,35	2,39	5,39	3,78	4,19	15,80
España	1,62	0,53	0,22	0,36	0,49	0,30	0,70	0,34	0,39	0,50
Sur de Francia	0,77	0,34	0,11	0,42	0,38	0,44	0,64	0,54	0,70	2,30
Italia	0,85	0,57	0,72	1,27	1,73	0,77	1,26	0,94	0,50	1,06
Grecia	0,82	0,39	0,36	0,75	1,60	0,27	2,38	0,44	0,09	0,05

Curiously, these results are not accompanied by a cost-efficiency analysis.

The **principle of total fire extinguishments** mentioned above means that all available resources are concentrated to fight a fire with the sole objective of minimizing damages at any cost, even if the cost is greater than the potential damages.

Budgets allocated for forest fire protection

There is no database charting the investments made to protect against forest fires. Nevertheless, it can be estimated that the five E.U. Mediterranean countries invest more than 2.5 billion euros per year in prevention and suppression. 60 percent of this figure is earmarked for suppression equipment, personal and operations, and the rest is allocated for preventative works.

New and old problems

The forest fire databases (MMA 2001, CE 2003, ECE/FAO 1998, Vélez 2000) show that forest fires are a permanent seasonally-based problem in the Mediterranean region.

Despite rural depopulation, the majority of fires continue to be caused by the traditional practices of burning for agricultural and farming purposes (burning of agricultural waste, burning of dry pastures). Winter fires in mountainous areas (the Cantabrian Mountains, the Pyrenees, the Alps) at times spread over a great area. Accordingly, fire services, which usually focus on the summer months, are forced to modify their strategies to include resources that are readily mobilized in winter as well.

Some of the recent fires caused by the burning of pastures have their root in the Community Agriculture Policy subsidies for encouraging the mountain economy, namely subsidies for extensive cattle raising.

In cases where the owner of the livestock is not the owner of the land, the former sometimes burns the terrain uncontrollably so that the goats, sheep, etc. keep producing not only meat and milk, but also cash subsidies.

The accumulation of fuel in large expanses of abandoned land, sets the right conditions for large fires. In addition, lightning, which until a few decades ago was a less common cause, can increase the incidence of large fires in these large expanses of land.

The tragic seasons of 1994 in Spain and 2003 in Portugal and France were caused mainly by the combination of lightning and extensive accumulation of fuels in the woodlands.

As is foreseeable, intense erosive effects appear after large fires (Vélez 2000). It is an example of a chronic problem aggravated in recent times.

A new problem, which is becoming increasingly visible each new summer season, is the risk of fire in the wildland/urban interface.

This problem, which was considered specific to other areas of the world such as California and Australia, is becoming more worrisome as construction is occurring in forest areas, namely of first or second residences either on the coast or in the mountains near large cities.

Disasters that destroy houses and take the lives of the residents are becoming more and more common.

Fire services are therefore forced to concentrate on protecting homes and no longer focus on protecting the vegetation.

Preventative legislation for this problem is either inexistent or insufficient. Consequently, it is foreseeable that this problem could reach catastrophic importance.

International Coordination

Constitutionally, the European Union lacks a forestry policy, as such a policy was not contemplated in the Treaty of Rome. Nevertheless, in the last decade some movements have filled this gap, such as the European Parliament's approval of a Forestry Strategy and the approval of a Reforestation Program for poorer agricultural areas.

In addition, a series of Regulations for Prevention of Forest Fires was in place from 1985 to 2001. These Regulations were supported by very small funds (an average of 12 million euros per year in the last decade distributed between 6 countries).

These Regulations are only a token support for certain preventive actions and have lead only to the creation of a very limited European forest fire database.

In 2003 the new Regulation (Forest Focus 2003) was approved, which will provide 13 million euros per year to the forest monitoring network, the forest fire database, and other preventative measures. This extends to the 15 current member

states plus the candidate countries. That is, E.U. support for prevention of forest fires has been reduced even further.

It is necessary to note that no Community contribution is provided for suppression operations. Rather, there is strong solidarity between neighbouring countries through bilateral and mutual assistance agreements (FAO 2000).

In recent years, the availability of aerial resources has made such operations more frequent. Accordingly, it is necessary to regulate their use through revising and renewing agreements and endeavouring to establish homogenous coordination regulations, i.e., a regional Emergency Management System (EMS).

The FAO/Silva Mediterranea Committee is promoting the elaboration of these regulations (Taller Zaragoza 2003).

Prospects

The problems identified (section 1) and the determining factors (section 2) are not caused by conditions of the forest itself. Rather, the forest simply suffers from these problems and factors, and reflects them in the form of forest fires.

Although global development for the forest sector has many advantages, it also has a serious drawback: greater frequency of devastating fires.

As discussed in section 3, Europe has a powerful fire suppression infrastructure and an acceptable database, but significant improvements are needed in some countries. Likewise, although a small group of researchers of forest fires does exist, their findings have only limited repercussion on the operating services in the sector.

Preventative silviculture is clearly insufficient, as are both the environmental education programs aimed at urban population and those aimed at rural populations.

New problems in the wildland/urban interface may motivate society to demand that greater attention be paid to prevention, in the form of effective actions and not only rhetorical declarations.

The saturation of suppression resources and their ever-growing cost can influence this as well. During the 1990s, aerial resources were developed by taking advantage of the low cost of restricted aircrafts of military origin, both from the U.S. and from Eastern countries.

The new regulations regarding aircraft safety are making it necessary to introduce technological improvements for both security and efficiency, which leads to significant supplementary costs. This will limit the possibility of further expansion of the aerial resources currently used.

The most obvious possibilities for improving the system can only be found in a conjunction of preventative actions reducing the frequency of fires and limiting their intensity through silvicultural treatments reducing biomass accumulations.

In these conditions, the improvement of the quality of fire suppression services, with well-equipped, well-trained and well-organized personnel applying specific forest fire fighting techniques, will make it possible to maintain and improve the results discussed.

In order to make this improvement of services a reality, it is crucial to maintain a high level of personal security through a wide-reaching system of personnel

certification and recognition. Such a system would also facilitate operations of multilateral assistance among countries. Given the current environment of globalisation, such operations are likely to be more and more frequent.

References

ASEMFO, 2003.- III Estudio de inversión y empleo en el Sector Forestal, Asociación Nacional de Empresas Forestales, Madrid, 68 pp.

European Commission, 2003.- Forest fires in Europe, 2002 Fire Campaign, European Commission, JRC, Ispra, 33 pp.

European Commission , 2003.- Reglamento (CE) 2152/2003 del Parlamento Europeo y del Consejo, 17 noviembre 2003, sobre seguimiento de los bosques y de las interacciones ambientales en la Comunidad (Forest Focus), DOUE, 11-12-2003, Brussels.

ECE/FAO, 1998.- Forest fire statistics 1994-1996, United Nations, Geneva, 19 pp.

FAO, 2002.- Legal frameworks for forest fire management: International agreements and national legislation, Forestry Department, Rome, 59 pp.

FAO/Silva Mediterranea CIHEAM, 2003.- Workshop on Multilateral Assistance against Forest Fires in the Mediterranean Basin, Zaragoza, CD Edition.

Ministerio de Medio Ambiente 2001.- Los incendios forestales en España. Decenio 1991-2000, DGCN, Madrid, 50 pp.

Plan Bleu, 2002.- Les espaces boisés méditerranéens, Jean de Montgolfier, Plan Bleu, Paris, 192 pp.

Vélez, R. et al, 2000.- La defensa contra incendios forestales. Fundamentos y experiencias, Ed. McGraw-Hill, Madrid, pp 2.1-2.8; 3.1-3.15

Page left blank intentionally.

Frameworks for Representing Large-Fire Decision Processes and Outcomes[1]

Donald G. MacGregor,[2] Armando González-Cabán[3]

Abstract

Although the vast majority of wildland fires are suppressed effectively in initial or extended attack, on relatively rare occasions fires become exceptionally large, resulting in unusual resource damages, significant financial impacts and/or loss of life. Understanding how to better manage large fires and to improve methods for controlling their costs and impacts requires a detailed knowledge of the decision making processes that were ongoing at the time of the incident. Fire reviews undertaken *post hoc* tend to focus predominantly on incident characteristics and not on the broader decision making context within which incident management occurs. The research described in this paper uses analytical approaches from the decision and risk sciences to develop a model for decomposing and reconstructing large-fire decision processes, including influence diagrams, decision tree analysis, multi-attribute utility analysis (MAU), and other models based on decision process tracing methodologies. A preliminary model for incident decomposition and reconstruction is developed based on the concept of an "Event-Frame Model" by which a sequential set of "Event Frames" are defined by temporal and contextual factors, and that lead to a visual representation of an incident decomposition. The set of event frames decomposes an incident into discrete units of analysis that can incorporate other models or processes (e.g., decision analysis) to describe decision elements of a fire incident. The paper describes progress to date on the modeling approach, including efforts to apply the model in the context of an actual incident.

Introduction

Each year, thousands of fires occur on public lands. The vast majority of these fires are effectively suppressed in initial attack at a relatively small size, usually an acre or two, or less. Of fires that exceed initial attack, most are suppressed in extended attack and rarely exceed 100 acres or more. However, for a small proportion of all fires, generally less than 1 percent, unusual environmental, fuel or resource capability conditions can result in particularly large or uncharacteristic fires that have as outcomes high monetary costs, loss of high-valued public or private resources, and (in the extreme case) loss of human life. Though large fires are relatively rare, they tend to lead to a high level of post-incident analysis to determine (a) the possible causes and attributions of the catastrophic outcomes, and (b) actions or steps that can be taken to help prevent or mitigate similar occurrences in the future. An accounting

[1] An abbreviated version of this paper was presented at the second international symposium on fire economics, planning, and policies: a global view, 19–22 April 2004. Cordoba, Spain.

[2] Senior Scientist, MacGregor-Bates, Inc., P.O. Box 10105, Eugene, OR 97440, Phone: 541.942.5727; email: donaldm@epud.net.

[3] Economist, Fire Management in the Wildland/Urban Interface Research and Development Program, Forest Fire Laboratory, Pacific Southwest Research Station, USDA Forest Service, 4955 Canyon Crest Drive, Riverside, CA 92507; Phone: 909.680.1525; email: agonzalezcaban@fs.fed.us.

of the incident is required in terms of decisions and decision factors that influenced the outcome.

This paper reports on the development of a process for analyzing fire incidents to help improve fire management practices. The focus of the research is to develop a method for analyzing fire incidents in terms of decision-making principles and to use the language of decision and risk analysis as basis for representing the relationship between fire management decision making and incident outcomes. The essential spirit of the approach is embodied in one of the central concepts from decision analysis, that of decomposition. The essence of decomposition is that large, complex problems can be understood better by breaking them down or "decomposing" them into smaller, more tractable problems that can be solved or characterized in some detail. The individual components of the decomposition are then reconstructed or assembled into a whole. Decomposition is the fundamental principle on which decision and risk analysis are based (Frohwein and Lambert 2000; Haimes 1998; Keeney and Raiffa 1976; Raiffa 1968), and has been applied in numerous other contexts including judgmental forecasting (e.g., Armstrong 2001; MacGregor 2001).

Social and Organizational Influences on Decision Outcomes

The process of analyzing fire incidents based on their outcomes is generally one of working backwards or upstream to determine the proximal causes of the outcomes. Most generally this is done in terms of one of three general categories of causal factors: environmental conditions (e.g., weather, fire behavior, fuels), technological conditions (e.g., equipment failure), or human error. As relatively clear causal influences emerge, the analysis becomes bounded and the pattern of causation becomes fixed. This approach contains key assumptions about the relationship between incident factors and incident outcomes. First, it assumes that the diagnostic or causative weight of an incident factor is greater the closer it is in time and space to the outcome. Second, it assumes that a "bottom up" approach will capture the majority of influences that are present in an incident management situation and that account for incident outcomes. Third, it assumes that the links between incident factors and incident outcomes is deterministic or strictly causal, rather than probabilistic.

The root influences on incident decisions and decision outcomes can come from factors far removed in space and time from the incident itself. As has been shown in other contexts, such as technological failure, accidents and events that result in monetary and material losses (including loss of human life) may evolve from "normal" operations, and the antecedents of decision outcomes can only be understood by resort to factors that are part of the social and organizational context within which events occur (Perrow 1984). As an example, Paté-Cornell (1993; Paté-Cornell 1990) used a combination of influence diagramming and decision analysis to model the failure of an offshore drilling platform (*Piper Alpha*) in the North Sea oil field. She found that the original failure analysis of the drilling platform accident was heavily driven by technical and engineering factors, which tended to focus the inquiry in such a way as to produce technical solutions to the problem. However, a more careful and extended analysis of the roots of engineering failure identified a number of organizational decisions that influenced failure probabilities in ways that were not readily identifiable by examining details of the incident alone. As a result

of the analysis a general model was developed that decomposed incident outcomes into a combination of social, organizational, and incident-specific factors.

Toward a General Model for Incident Decomposition

Decomposing a fire incident requires a guiding structure that identifies the factors influencing incident decisions and outcomes. A framework for this decomposition represents incident decisions and outcomes as the result of factors specific to an incident as well as factors and influences present at higher organizational and social contextual levels *(fig. 1)*. The framework is comprised of multiple levels of influence beginning at a broad social level that includes laws, statutes and cultural values (S_i's in the model). These general influences are exterior to the organization but influence organizational meta decisions (O_i's in the model) that include policies, plans and procedures that set an organizational contextual frame for how decisions specific to an incident are structured and evaluated. These incident-specific decisions are shown in the model as a set of alternatives ($A_{i,j}$'s) associated with decision problems that are linked to a temporal dimension associated with the incident. In the course of a given incident, a number of such decision situations arise and can be given a temporal location. Likewise, decision outcomes and effects (E_i's) resulting from incident decisions can be given a temporal location as well. In an actual incident analysis, decision outcomes and effects are linked to subsequent decisions.

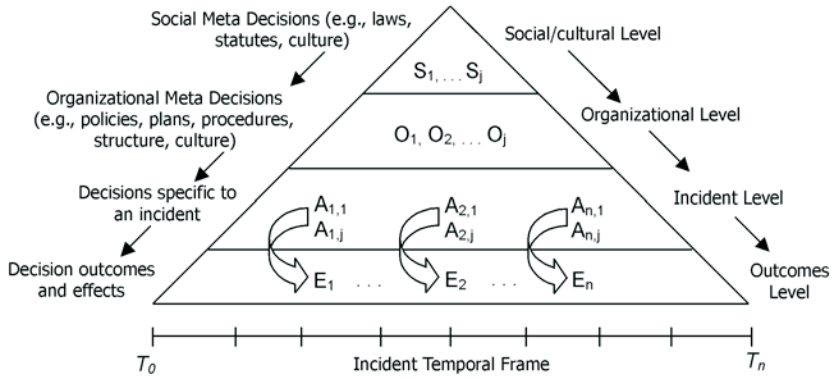


Figure 1 – General model of incident decomposition. Adapted from Pate-Cornell (1993)

.

An Influence Diagram Representation

The essential elements of the model can be represented as an influence diagram depicting the relationship between components at each of the levels. Influence diagrams are a form of visual representation that depicts relationships between components of a decision problem (e.g. Oliver and Smith 1990). Arrows between components denote an *influence*, where an influence expresses knowledge about relevance. A causal relationship is not necessarily implied, but an influence exerts a force such that knowing more about A directly affects our belief or expectation about B.

For an actual case, an influence diagram would be complex and would show not only the relationships between levels, but also the relationships between concepts at each level as well as the relationship between incident outcomes and the societal and

organizational levels. A relatively simple model serves to illustrate how the relationships might be portrayed in terms of influences using some general elements at each level *(fig 2)*. Starting at the bottom of the model is a sequence of major incident events starting at time T_0 and continuing through to the end of the incident at time T_n, where n can vary through a range of days, weeks or even months depending on the length of the incident. At the top level of the representation is the Societal Level, comprised of three components: Political/Public Values, Statutory Law, and Civil Law. In the middle is the Organizational Level, represented by three components: Organizational Culture, Formal Policy, and Plans & Strategies.

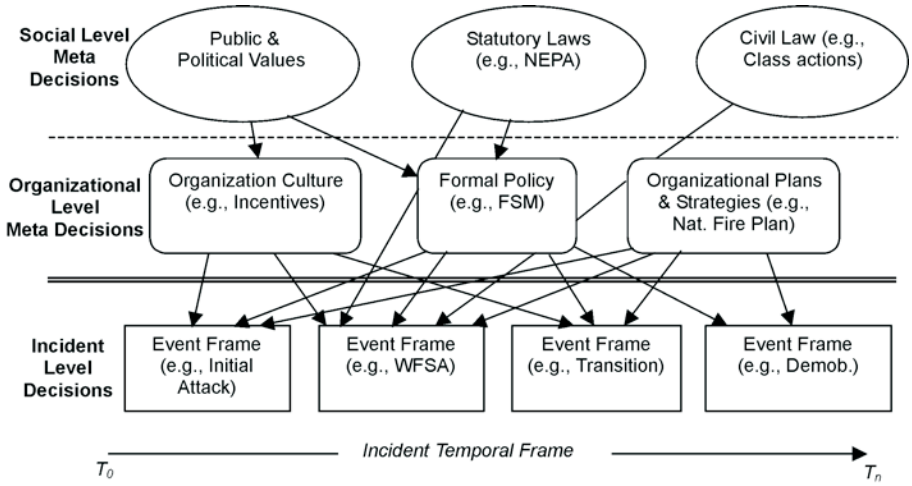


Figure 2 – Influence diagram representation of a simplified fire incident.

Social Meta Decisions

These are decisions made at a broad social level and reflect general cultural views and values. The decisions themselves are embodied in laws and statutes that govern and guide what organizations can do. Cultural values relevant to these laws can range from the general to the specific with respect to fire and its management. For example, broad sociopolitical values about the appropriate role of government in regulating organizations and the lives of individuals captures, perhaps, the broadest sense of this concept. More specific to fire and its management, social values about the environment, environmental protection, the role of fire in ecosystems and the like also impact social meta-decisions. As an example, the various federal statutes and laws that provide for protection of environmental amenities (e.g., threatened & endangered species, air quality, water quality) are the result of a combination of scientific and political processes that operate at the highest levels in society and that reflect a determination that overarching goals and objectives (many of them protective) be met as part of any actions that impact the environment (e.g., NEPA).

These influences can be thought of as upstream factors that exert their effects in a number of ways. They may take the form of specific standards and guides that organizations are required by law to abide by as part of their operations. Air quality standards, for example, fall into this category as do water quality, species protection laws and occupational safety standards. In some cases, these standards and guides

will be directly passed through to the organizational level, and in other cases they may be interpreted and incorporated into an organization's culture. Also, they may have an impact by sociopolitical pressures they exert on organizational decision making. For example, an imperative to reduce large-fire costs may be reflective of a relatively non-specific sociopolitical goal of cost reduction but without a specific rule or guide to identify either the means to use to achieve cost reduction or the specific cost-reduction end to achieve.

Another category of influence at the social level results from broad public views about factors relating to fire management decision making. Public attitudes about fire and fire management, including activities that have an impact on fire management such as the use of prescribed fire for fuels management, can exert powerful effects on how organizations frame decision problems and set priorities for fire management actions. For example, the *precautionary principle* as applied to risk management decision making is generally reflective of a broad public attitude that favors a conservative interpretation of risk and that corresponds to a generally risk-averse public attitude with respect to outcomes that are perceived as severe or catastrophic (e.g., Graham 2001; MacGregor, Slovic and Malmfors 1999; Sandin 1999; Slovic, 2000). In essence, the precautionary principle is a "better safe than sorry" view that prescribes protective action even when no harm is certain to occur. One consequence of this principle is a conservative interpretation of science by organizations charged with risk management: in the absence of science confirming the presence of harm, protective action should be taken until such time as science confirms the opposite.

Organizational Meta Decisions

Decisions at this level are reflected in a number of influences. Three general categories include Formal Policies of the organization, Organizational Culture, and Organizational Plans and Strategies *(fig. 2)*. Organizational culture is comprised of many components not shown here, such as the history of the organization and its organizational values, as well as the incentive structure (both explicit and implicit) that exists within the organization and that influences individual preferences and decisions. Formal policies include specific policies and manuals (e.g., Forest Service Manual; Interagency Standards for Fire and Fire Aviation Operations) that provide the general standards and guides that serve as the business framework for day-to-day activities and operations. Included here as well are periodic directives that may highlight, modify, or expand on a particular element of policy. Finally, there is a relatively large body of organizational plans and strategies (e.g., National Fire Plan; Cohesive Strategy) that serve to provide general management direction and strategy.

Incident-specific Decisions

At the incident level are decisions specific to the particular fire management action on the ground, depicted as a series of events, each of which could be further decomposed to reveal underlying decisions specific to the event *(fig. 2)*. The term "event" is used in this context to refer to the components of a fire incident that include elements of judgment and decision making. To express events having multidimensional or multi-attribute characteristics, we use the concept of an "Event Frame" (discussed below). For example, an Event Frame containing a WFSA

(Wildland Fire Situation Analysis) can be decomposed into a number of specific WFSA elements, each of which may be influenced by higher-level social and organizational meta-decisions, such as Air Quality Standards (Social Level, Statutory Law), Public Values (Social Level), and Organization Culture.

Structure of an Incident Analysis

The process of structuring an incident analysis begins by constructing a series of event frames along an incident temporal dimension *(fig. 3)*. The initial set of event frames is based on incident documentation. Large-fire incidents are generally documented in part through the Wildland Fire Situation Analysis and other procedural documents (e.g., Delegation of Authority) that provide a convenient and authoritative basis for collecting a set of initializing information, including the fire situation early in the incident, preliminary information about values at risk, strategic alternatives for fire management, and other land management issues that reflect decision priorities.

The general framework takes the form of a set of schematic event frames located along a temporal dimension that ranges from the beginning of an incident (Time = T_0) to the end of an incident (Time = T_n). T_0 corresponds to the date and time of fire ignition; T_n corresponds to the date and time the fire is determined to be out. In principle, the number of discrete event frames is unlimited. In practice, however, the number of event frames is determined by the desired granularity of the analysis and by pragmatic factors such as (a) characteristics of the incident, with longer and/or more complex incidents requiring a greater number of event frames, and (b) availability of information.

Each event frame is characterized by a set of event frame elements that include (a) values, goals and objectives, (b) decision alternatives, (c) expected outcomes associated with each alternative, (d) sources of uncertainty, (e) tradeoffs, (f) sources of risk, and (g) costs. Methods for representing these elements include multi-attribute value trees and decision trees. Risks associated with each event tree can be represented in terms of a basic risk assessment model that characterizes risk in terms of (a) events or scenarios that can happen, (b) the likelihood that each would happen, and (c) the consequences associated with their occurrence (e.g., Haimes, 1998; Kaplan and Garrick 1981). Further elaboration on this approach could extend to utilizing the Kaplan and Garrick Theory of Scenario Structuring (TSS) Model (e.g., Kaplan, Haimes and Garrick 2001). In practice, the extent to which more sophisticated methods for analyzing each event frame can be used are dictated somewhat by the value of greater analytic detail and rigor, and by the availability of information.

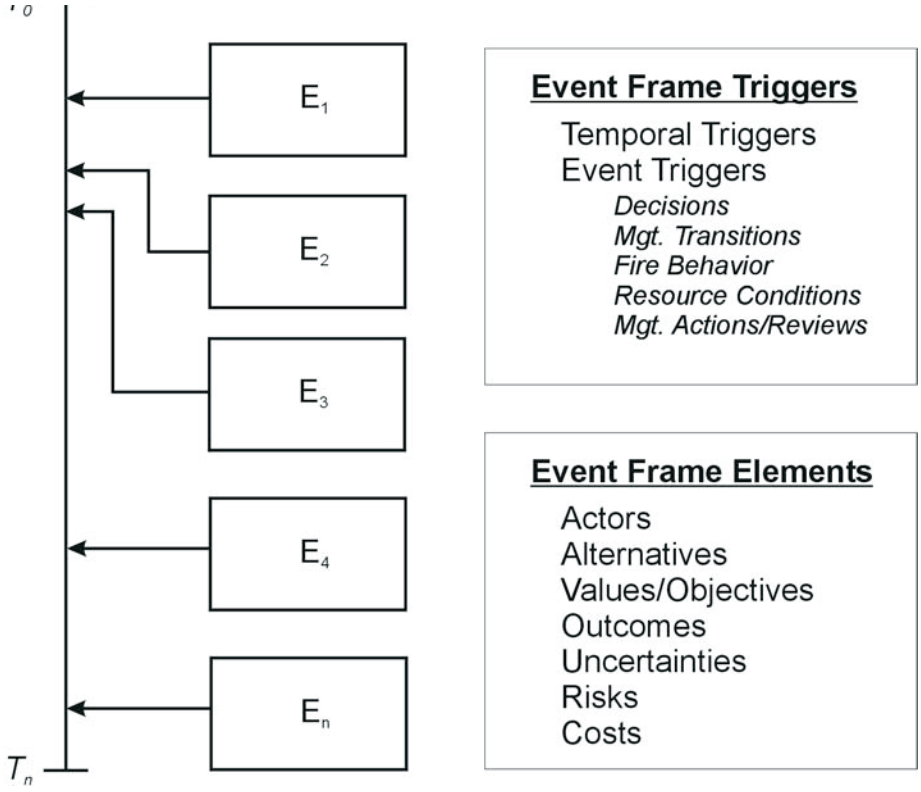


Figure 3 – General structure of the event frame model.

Information Sources: Incident Documentation.

Primary information for incident analysis comes from documents that are produced during the course of an incident. Incident documentation provides the basis for initial construction of an event frame model. Among the various federal wildland fire agencies in the the United States, typical documentation for large fires includes:

- Fire Situation Analysis (FSA)
- Briefing Documents
- Wildland Fire Situation Analysis (WFSA)
- Incident Complexity Analysis (ICA)
- Delegation of Authority
- Shift Plans
- Transition Plans
- Final Fire Report (e.g., FS 5100-29)

For example the Wildland Fire Situation Analysis (WFSA) is developed early in a fire incident and is continually updated (and in some cases redone) as part of incident management. The WFSA provides primary information about land management objectives and values at risk, strategic alternatives for fire management,

and preliminary estimates of fire suppression costs and monetized losses to the resource base. Monetary cost elements are periodically reviewed and updated, and provide the basis for a set of periodic event frames that directly relate incident costs to values at risk.

Information also comes from periodic plans and documents developed as part of incident management, including shift plans and transition plans. Shift plans can be used to structure a protocol process whereby incident decisions are reconstructed on the basis of (a) tactical alternatives and a chosen alternative, (b) control objectives for the incident, (c) critical resource concerns and values at risk, (d) resource allocations, and organization personnel assignments. Shift plans indicate the chosen tactical direction, but do not indicate other tactical alternatives that may have been considered, nor do they indicate the outcomes that are expected or the basis on which outcomes are evaluated. The decision problem structure that is (partially) implied by the tactical direction in shift plans must be supplemented with interviews to obtain a more complete representation of the structure.

Information Sources: Decision Process Tracing Protocol (DPTP).

Incident documentation provides an efficient means for identifying key parameters of incident decisions, including how decision problems are structured. Additional information pertaining to how decisions are actually made can only be gained by direct involvement with fire management personnel. To elicit this information requires the development of a Decision Process Tracing Protocol (DPTP) that serves as an interview guide for working with fire management personnel to reconstruct incident decisions. The framework for the DPTP comes from the incident documentation structured according to the event frame model described above. The DPTP provides a means for identifying a number of incident-related factors. These include:

- Influences that act upon incident decision processes;
- Decision problem structuring done by fire management personnel;
- Values at risk or fire management objectives not explicit in incident documentation;
- Individual preferences for risk that influence incident decisions;
- Patterns of information utilization;
- Communication protocols that influence incident decisions.

Case Study: Fork Fire.

A case study that illustrates the application of the event frame methodology is currently under development. The purpose of the case study is to demonstrate how the decision structure of an incident can be elicited and represented using the model and methods discussed in this paper. The selected case (the *Fork Fire*) is a fire that occurred in the summer of 1996 on the Mendocino National Forest (USDA Forest Service Region 5, California North Zone). The incident began on August 11, 1996, and continued for approximately 18 days, burning a total of 82,980 acres. The case

was chosen because of its size and complexity, as well as the availability of incident documentation and access to fire management personnel who took part in the incident.

A preliminary event model has been constructed based on the Wildland Fire Situation Analyses (WFSA's) conducted during the incident, periodic tactical plans and incident objectives, and the final fire report. The event model is currently being used to develop a protocol for interviewing fire management personnel and to identify additional incident documentation that may be required.

Acknowledgements

This research supported by the USDA Forest Service, Pacific Southwest Research Station, Research Joint Venture Agreement No. 02-JV-11272165-040 with MacGregor-Bates, Inc. Special thanks to Ray Quintanar and Carl Dammann for their helpful guidance on interpreting incident documentation. James Flynn and Bruce Tonn provided advice and review that contributed to this manuscript.

References

Armstrong, J. S. (ed.). 2001. **Principles of forecasting: A handbook for researchers and practitioners.** Norwell, MA: Kluwer Academic Publishers.

Frohwein, H. I., & Lambert, J. H. 2000. **Risk of extreme events in multiobjective decision trees Part 1. Severe events.** Risk Analysis, 20:113-123.

Graham, J. D. 2001. **Decision-analytic refinements of the precautionary principle.** Journal of Risk Research, 4:127-141.

Haimes, Y. Y. 1998. **Risk modeling, assessment, and management.** New York: Wiley.

Kaplan, S., & Garrick, B. J. 1981. **On the quantitative definition of risk.** Risk Analysis, 17:407-417.

Kaplan, S., Haimes, Y. Y., & Garrick, B. J. 2001. **Fitting hierarchical holographic modeling into the theory of scenario structuring and a resulting refinement to the quantitative definition of risk.** Risk Analysis, 21:807-819.

Keeney, R. L., & Raiffa, H. 1976. **Decisions with multiple objectives: Preferences and value tradeoffs.** New York: John Wiley &Sons.

MacGregor, D. G., 2001. **Decomposition for judgmental forecasting and estimation.** In J. S. Armstrong (ed.). ***Principles of forecasting: A handbook for researchers and practitioners.*** Norwell, MA: Kluwer Academic Publishers.

MacGregor, D. G., Slovic, P., Malmfors, T. 1999. **"How exposed is exposed enough?" Lay inferences about chemical exposure**. Risk Analysis, 4:649-659.

Oliver, R. M., & Smith, J. Q. (eds.). 1990. ***Influence diagrams, belief nets, and decision analysis.*** New York: Wiley.

Paté-Cornell, M. E. 1990. **Organizational aspects of engineering systems safety The case of offshore platforms.** Science, 250:1210-1217.

Paté-Cornell, M. E. 1993. **Learning from the Piper Alpha accident: A postmortem analysis of technical and organizational factors.** Risk Analysis, 13:215-232.

Perrow, C. 1984. **Normal accidents**. New York: Basic Books.

Raiffa, H. 1968. **Decision analysis**. Reading, MA: Addison-Wesley.

Sandin, P. 1999. **Dimensions of the precautionary principle.** Human and Ecological Risk Assessment, 5:889-907

Slovic, P. 2000. **Perception of risk**. London: Earthscan.

Using GIS to Test the Relationship Between Homeowner Willingness to Pay to Reduce Wildfire and Landscape Characteristics[1]

Pamela Kaval,[2] John Loomis[3]

Abstract

We evaluate whether wildland urban interface households willingness-to-pay for fire prevention is influenced by forest fire risk variables calculated using Geographic Information Systems (GIS). Specifically, we use spatial modeling to calculate estimated fire danger of homes in Colorado and then enter those variables in our logit model of household willingness-to-pay. Including the spatial variables in the models, we found that having a defensible space zone of 10 meters and having a high fire danger in the 100 meter area surrounding their home had a statistically significant influence on willingness-to-pay for fire prevention. For fire suppression, the weighted average fire danger within one mile of their home was the spatial variable that had an influence on willingness-to-pay. The explanatory power of the logit models was noticeably higher with the GIS fire risk variables included.

Introduction

Landscape characteristics such as vegetation type highly influence wildfire behavior. This study was undertaken to better understand how the role of landscape characteristics influence homeowner perceptions of fire danger and willingness-to-pay for two wildfire management practices: fire prevention and fire suppression. Fire prevention includes removing underbrush and cutting down some standing trees to thin the forest and reduce the chances of a large fire. Fire suppression includes having larger fire crews on standby and having more fire crews closer to fire prone areas of forests. The purpose of fire suppression crews is to extinguish all fire starts immediately before fires are given the chance to spread.

Over the years, due to the increase in risks, the cost of fire management has increased significantly (Ingalsbee, 2003). The increases in costs include, but are not limited to, helicopters, fuel, firefighter wages, and the ever-increasing costs of fire suppression and prevention.

Most recently, public opinion has become a required part of the decision criteria for federal land management. Since public opinion on fire management is becoming very important, this paper will focus on how the public perceives that fires should be managed. The public of interest are homeowners that live within a few miles of public lands (The Wildland Urban Interface) that bear the risk of landscape fires damaging property.

---

[1] An abbreviated version of this paper was presented at the second international symposium on fire economics, planning and policy: a global view, 19–22 April 2004, Cordoba, Spain.

[2] Research Fellow, Department of Economics, Waikato Management School, The University of Waikato, Private Bag 3105, Hamilton, New Zealand.

[3] Professor, Department of Agricultural and Resource Economics, Colorado State University, Fort Collins, CO 80523.

Wildfire Home Danger and Prevention

The population of the Wildland Urban Interface is growing. The increase in the number of homes increases the chance that a home will get caught in a wildfire and burn. In the wildland-urban interface, a home will catch on fire typically in one of two ways, ignition by wildfire flames and ignition by lofted burning embers called firebrands (Cohen, 2001). To reduce the chances of home burning, a defensible space should be established.

Defensible space is a "designated area around a home that is intentionally maintained so as to be free of any features that would tend to increase the risk of damage from wildfire (WHIMS, 2002; Larimer County, 2002)." As stated, having defensible space does not guarantee there will be no property loss from wildfire, but it does significantly reduce the chances. The proper defensible space zone should include all the land between the edge of the home and 100 meters surrounding the home, however, many studies show that 30 meters surrounding the home is adequate. Within this defensible space zone, a person should keep flammable material out; water lawns, mow grass, remove all debris from roofs and gutters, screen vents and chimneys, store gas and propane tanks a minimum of 9 meters away from the home, remove dead limbs and brush, and prune trees so no limbs are below 2 meters. In short, all flammable material should be removed from the area. This will significantly reduce chances of homes burning (WHIMS, 2002; Larimer County, 2002; Vicars, 1999; Alexander et al., 1998)

It has been found that homes with maintained defensible space zones that were hit by the 2002 Colorado Missionary Ridge Fire were all saved (Binkley, 2003). Some homes with defensible space that were hit by the 2002 Hayman fire were also saved. While defensible space has been shown to save homes from wildfire, defensible space is not mandatory in most of Colorado. Of the four counties involved in the Hayman fire, Teller, Park, and Douglas do not have any defensible space regulations for wildland-urban fire risks. Jefferson county has defensible space regulations but only on homes built after 1996 (Cohen and Stratton, 2003).

Fire Hazard Area

While defensible space will reduce the chances of your home catching on fire, it is not a complete determinant of wildfire, you must also be aware of the fire danger of the area in which you live. In assessing various fire models, it seems that the most important variable in determining fire hazard is dominant vegetation. The type of vegetation significantly impacts whether a fire will be present. Vegetative fuel types vary significantly, and therefore some types are more flammable than others. For instance, dense conifer forests are ideal conditions for crown fires. Deciduous forests, however, are unlikely to sustain crown fires.

In 2001, Romme et al. created a model of wildfire risk for La Plata County, Colorado. Using vegetation classifications, they were able to determine three parameters that seem to be key in fire behavior: total potential heat release, rate of fire spread, and flame length. They used GIS along with the fire behavior model "Behave" to create their wildfire hazard assessment and map (Romme et al., 2001).

Fire, Economics and GIS

In this paper, we are combining information from three disciplines: fire ecology, resource economics, and spatial modeling. While there have been many studies

completed in each of the individual disciplines and including two of the three disciplines, there have not been as many that have combined all three.

When combining wildfire issues, economics, and minimal GIS information, only two people have completed research in the area: Jeremy Fried and Greg Winter. Their research hypotheses were that people living in wildfire frequenting areas would be willing to pay to reduce their risk of wildfire. Potential participants were located by using a GIS program to create a buffer of 100 square miles around the center of a jack pine forested area known for frequent wildfires. The potential participant homes were all located within this buffer (Winter and Fried, 2001; Fried et al., 1999; Winter and Fried, 2000). It was believed that there were three ways that people living in the 100 mile buffer zone could reduce their risk of home burning: mowing the 30 foot defensible space zone around their homes regularly, removing all debris, such as brush piles, from the defensible space zone, and removing all jack pine trees that were adjacent to their homes. Respondents were told about wildfire risk reducing tactics. They were then asked what they felt the probability of fire was in the vicinity and the probability of their home burning. Fried and Winter used these two probabilities to calculate fire risk. Respondents were then were asked if they would be willing to pay for one and/or two of the risk reductions (Winter and Fried, 2001; Fried et al., 1999; Winter and Fried, 2000).

Once all information was obtained, they used a logit model to allow calculation of willingness-to-pay. Variables used included: initial risk level, perceived risk, and property tax tolerance. Results showed initial risk level, perceived risk and property tax tolerance to have a significant influence on respondent willingness-to-pay. Overall results showed that respondents preferred to reduce property risk themselves than to pay an annual tax increase to have someone do it for them (Fried et al., 1995; Winter and Fried, 2001; Fried et al., 1999; Winter and Fried, 2000).

Methods

In this project, we tested the hypothesis that homeowner willingness-to-pay (WTP) to reduce fire risk is directly related to the fire danger of the area in which the homeowner lives:

WTP to Reduce Fire= f (area fire danger)

Where fire danger consists of both perceived and actual fire danger.

Hypothesis testing required three major elements: (a) survey regarding perceived fire risk; (b) contingent valuation questions to determine willingness to pay; (c) spatial modeling to determine objective or actual fire danger.

Contingent Valuation Survey

Contingent valuation is a method in which the value of non-market goods are assessed by measuring a person's willingness-to-pay (Hanemann, 1994). Contingent valuation has been recommended by the National Oceanic and Atmospheric Administration (NOAA) Panel as a legitimate method for non-market good valuation (Arrow et al., 1993). Information is typically gathered by in-person, phone, or mail surveys (Hanemann, 1994).

A mail survey was developed through a series of focus groups and then pre-tested. This survey was conducted in the summer of 2001 to obtain contingent valuation information. This survey encompassed eight pages of questions and two color pictures (Douglas fir forest in Colorado one year after a prescribed burn and Douglas fir forest in Colorado one year after a wildfire) that were inserted into the

survey for use with some of the questions. The survey questions included demographics, willingness-to-pay for various fire prescriptions, and various other questions referring to how people feel about wildfires, prescribed fires, and fire suppression.

Survey participants were contacted randomly during the summer of 2001 through numbers in the phone book. Names were selected from various towns in Colorado that are on the border of public lands. The data from 73 respondents were used in this study. These respondents were from Leadville, Nederland, Rollinsville, Estes Park, Masonville, and Red Feather Lakes.

While many of the questions in the survey related to homeowners' opinion, the specific questions we will be focusing our attention on include:

> "Q11a. If fire prevention would reduce the frequency of a wildfire in the area where you live to half as often as it does now, would you pay an increase of $___ a year more in taxes for fire prevention each year?"
>
> "Q11b. If fire suppression would reduce the frequency of a wildfire in the area where you live to half as often as it does now, would you pay an increase of $___ a year more in taxes for fire suppression each year?"

The blank spaces ($___) on each survey were filled in with values ranging from $5 through $1500. While the dollar amount between participants was different, the values for the willingness-to-pay question in any one survey were the same. The yes/no answers to these willingness-to-pay questions are the dependent variables we will be using in the logistic regression models.

The independent variables we will be using include two perceived fire risk variables obtained from the following questions:

> "Q3. Are you concerned that a fire on public lands may endanger your home?
> (Circle One) Yes No"
> "Q7. Take a look at the wildfire photo. In your opinion, how often does a wildfire such as shown in the Wildfire Photo occur in the are where you live. For example, once every 5 years, once every 10 years, twice a year, etc. _____Fire Frequency."

Spatial Modeling

In this project we used ArcMap, a GIS program, to conduct the spatial analysis of the data. This process consisted of four map layers: vegetation, home point locations, slope, and fire locations. The first dataset is the vegetation layer, a fine grained statewide landcover map of Colorado. The Colorado Vegetation Map (CoVMap) was created at Colorado State University by David Theobald, Nate Peterson and Bill Romme. CoVMap is currently the best available statewide vegetation map for Colorado as it takes into account elevation, precipitation, slope, aspect, Bailey's ecoregions and soil. Vegetation types were cross referenced with Romme et al., 2001 La Plata County vegetation type to determine fire hazard. Use of GIS and Behave (a fire behavior model) aided Romme in calculation of heat release (BTU/ft^2), spread rate (chains per hour, a chain is 66 feet), and flame length (feet). We used the average heat release, spread rate and flame length for each of the fuel categories.

The second layer in the spatial model consisted of home point locations. To obtain the best available information at respondent home locations, each individual home was visited and the UTM coordinates were recorded. In addition, information on the 9 meter (approximately 30 foot) defensible space and general vegetation information were observed. Out of the original 99 data observations collected, 73 were able to be digitized in ArcMap. Twenty-seven of the observations were not able to be mapped as post office boxes were the contact information given and therefore home locations were not available. Out of the 73 homes, 23 had either the proper defensible space and/or were located in a downtown area where there was no fire danger. This information was entered into the database where "1 = minimum of 30 foot defensible space" and "0 = defensible space zone is not adequate to protect home from wildfire." Once UTM information was obtained for the 73 homes, home point locations were entered into an Excel database. The database was then saved as a dBaseIV file and added to ArcMap.

The next data layer was slope. Slope was calculated from a Colorado Digital Elevation Model (DEM) (USGS, 2001). The final layer of data consisted of overlaying wildfires from the year 2000 to a Colorado County Map. Homepoints were placed onto the county map and a proximity analysis was conducted. The four Colorado wildfire shapefiles represented the Bobcat Gulch, High Meadow, Bircher, and Pony fires.

Empirical Model Combining Survey and Spatial Variables

We created a buffer of 100 meters (328 feet) surrounding each home structure. This is the recommended defensible space zone. Since wildfires can travel great distances from where they begin, we not only considered the fire danger of the immediate area, but also of the surrounding area. This second buffer zone was one mile in radius.

Analyzing the two buffer zones yield information on both the type of vegetation and how much of each vegetation type was located in each home area buffer. Once this information was obtained, we were able to cross-reference it with Romme's heat release, flame length and fire spread to determine potential wildfire danger. We first did this for the fire danger of the immediate area (100 meter buffer). This yielded three variables: Heat100 – average heat release in the 100 meter buffer; Spread100 – average spread potential in the 100 meter buffer; Flame100 – average flame length in the 100 meter buffer.

Then came the complicated task of determining the danger of the surrounding area. We used the EucDistance procedure along with vegetation information to create a weighted fire danger average. To do this, we weighted the area closest to the home more than the area furthest away from the home. As suggested by Theobald, 0 distance would be weighted as 1, 402 meters (¼ mile) as 0.75, 804 meters (½ mile) as .5, and 1609 meters (1 mile) as .25 (Theobald, 2003). For this study, zero distance was the 100 meter buffer zone. This resulted in three weighted averages of wildfire danger over a one mile radius surrounding the homepoints: Avgheat - weighted average of heat, Avgspread – weighted average of spread, Avgflame - weighted average of flame.

The next data layer to consider was slope. Slope, in percent, was calculated from a Colorado DEM (USGS, 2001). Homepoints were then layered onto the slope map. Average slope was then calculated for the one mile buffer zone using the same procedure as for the weighted one mile buffer vegetation estimate.

Once all spatial variables were calculated, we were then able to create the willingness-to-pay empirical models. The hypothesis is that homeowner willingness-to-pay to reduce wildfire is related to the perceived and actual fire danger of the area in which they live. The model consists of data obtained from the spatial analysis, data from the survey, and calculated variables. In order to test the hypothesis we will be using a binary dependent logistic model. The logistic model is the most appropriate model to use since the dependent variable is binary in which "1 = the respondent is willing to pay for the particular activity" and "0 = the respondent is not willing to pay."

Four logistic regression models were estimated: the first two represented willingness-to-pay using just perceived fire risk variables and the second two represented willingness-to-pay for perceived and actual fire risk calculated from the GIS. The two willingness-to-pay variables are: willingness-to-pay for fire suppression (WTPFS) and willingness-to-pay for fire prevention (WTPFP). These two dependent variables were coded where "1= yes, they are willing to pay," and "0= no, they are not willing to pay." The independent variables are:

Bid: the dollar amount the homeowner is asked to pay

Danger: whether the homeowner believes there is a chance their home will catch fire, 1= yes; 0= no.

Freq: perceived frequency of a wildfire, where once every 10 years =10, etc.

Firedist: GIS estimated distance in meters from the homepoint to the edge of the closest fire in 2000.

Defspace: If home has a 9 meter defensible space, where 1= yes, 0=no.

Heat100, Spread100, Flame100, Avgheat, Avgspread, Avgflame.

Slope: Weighted average slope coefficient within 1 mile of home.

We expect the bid coefficient to be negative because as the bid amount increases, the respondent would be less likely to pay. We expect that as the distance to the nearest fire increases, the respondent would be less willing to pay, therefore, a negative coefficient is expected. The frequency or fire interval coefficient is expected to be negative, as the occurrence of a fire takes longer, the respondent is expected to be less willing to pay. We expect the coefficient on Danger to be positive, because if the homeowner perceives more danger, they would be more likely to pay. We expect the coefficients on Spread100, Heat100, Flame100, Avgspread, Avgheat, and Avgflame to all be positive, because as the fire danger in the immediate and more distant area increase, the respondent should be more likely to pay for a fire management prescription. We also expect the coefficient on slope to be positive because as the slope increases, the fire danger increases and therefore the respondent should be more likely to pay for a fire management prescription.

Prior to running the regressions, we checked the correlations of the variables, many of which had high correlations. Therefore, we will not be using all of them in the same model. The two most highly correlated variables were Avgflame and Avgheat (0.8799) and Flame100 and Heat100 (0.8738).

Results

For the first part of the analysis, two logit models using just perceived fire risk were run, one each for WTP for fire prevention and fire suppression (Equation 1, Equation 2). We find that the likelihood or probability of being willing to pay for fire

prevention and fire suppression is influenced by whether the respondent feels their home is in danger. The perceived frequency of fire or fire interval is negative as expected, but insignificant. Note one asterisk indicates significant at the 10% level and two asterisks denotes significance at the 5% level.

Equation 1:

WTP Fire Prevention = 0.945C – 0.004Bid** + 1.353Danger** – 0.018Freq

(Z-Statistic) (1.497) (-2.018) (2.017) (-1.174)

Equation 2:

WTP Fire Suppression = 0.251C – 0.002Bid* + 1.173Danger* – 0.007Freq

(Z-Statistic) (0.432) (-1.656) (1.927) (-0.460)

The next set of logistic regressions represent not only the perceived fire danger reported by the respondents, but also the estimated actual fire danger calculated using the spatial models. As different variables influenced the various fire management prescriptions, we will be presenting the best models from each of the management prescriptions (Equation 3, Equation 4).

Equation 3:

WTP Fire Prevention =

-0.686C – 0.004Bid** + 0.919Danger – 0.026Freq + 1.458Defspace* + 0.002Heat100*

(-0.675) (-2.263) (1.185) (-1.383) (1.665) (1.630)

Equation 4:

WTP Fire Suppression =

-2.142C – 0.003Bid* + 0.480Danger – 0.013Freq + 0.227Defspace + 0.008Avgheat**

(-1.719) (-1.782) (0.681) (-0.711) (0.354) (2.216)

In the fire prevention model, we find that if the respondent has a defensive space surrounding their home, then they are more willing to pay for fire prevention. We also found that if the average heat within the 100 meter area immediately surrounding the home increases, that the respondent will more likely be willing to pay for fire prevention. For the willingness-to-pay for fire suppression, we find the respondent is more willing to pay if the weighted average heat measure within one mile surrounding the home increases.

As interpretation of the coefficient in the logit models may be difficult, we converted the coefficients to willingness-to-pay values. To convert logit coefficients to willingness-to-pay values, coefficients were divided by all values except the bid amount by the absolute value of the bid coefficient. In the perceived fire risk model, the respondent will increase their willingness-to-pay for fire prevention by $338.25 annually if the respondent feels their home is in danger of wildfire. When the spatial variables are included in fire prevention we find that the respondent will increase their willingness-to-pay by $364.50 if their home has a defensible space. We also find that the respondent will increase their willingness-to-pay by $0.50 per unit of heat value (BTU/ft^2) if the average heat value in the 100 meter area surrounding their home increases.

For the perceived fire risk model of willingness-to-pay for fire suppression, we find that the respondent is willing to pay $586.50 more if they feel their home is in danger of wildfire. In the model with the spatial variables, we find that the respondent will increase their willingness-to-pay by $2.64 per unit of heat value

(BTU/ft^2) if the weighted average heat fire danger in the one mile area surrounding their home increases.

Conclusion

A survey was conducted to see if Colorado homeowners living within 10 miles of public lands would pay for fire prevention and fire suppression. It was determined that the respondents were likely to pay for both methods due to their perception of fire danger. We extended this model by adding objective measures of fire risk calculated from spatial modeling layers. Using GIS data we calculated an objective measure of fire hazard. In particular, we measured the distance between fires and respondents homes. We then calculated fire danger within the immediate area around the home, 100 meters, and the weighted average of fire danger within a 1609 meter (one mile) radius of the home. The weighted average slope within a 1609 meter (one mile) radius of the home was also calculated. This information enabled us to construct the potential fire hazard facing each homeowner in our sample. Fire hazard calculation in conjunction with on-site calculations of defensible space and survey responses enabled us to develop a more complete logit model for willingness-to-pay.

For the perceived fire danger models we find that whether the respondent feels that their home is in danger significantly affects willingness-to-pay for fire prevention and fire suppression. For the full model including spatial variables we find that defensive space and the wildfire heat value both have an effect on fire prevention willingness-to-pay. For fire suppression, the average weighted heat value for the area has an affect on willingness-to-pay. Overall, the inclusion of the landscape variables reflecting objective measures of fire risk increased the explanatory power of the logit willingness-to-pay models by about one-third for the fire prevention program and nearly double for the fire suppression program. This suggests that inclusion of landscape characteristics may be important explanatory variables in models of willingness-to-pay for natural resource protection.

References

Alexander, M.E., B.J. Stocks, B.M. Wotton, M.D. Flannigan, J.B. Todd, B.W. Butler, and R.A. Lanoville. 1998. The International Crown Fire Modeling Experiment: An Overview and Progress Report. In: Proceedings of the second symposium on fire and forest meteorology; January 12-14, 1998. Phoenix, AZ. Boston, MA: American Meteorological Society, pp. 20-23.

Arrow, K., R. Solow, P. Portney, E. Leamer, R. Radner, and H. Schuman. 1993. Report of the NOAA Panel on Contingent Valuation. Federal Register 58. 1993: pp. 4601-4614.

Binkley, Gail. 2003. Dolores Area Landowners Learn About Defensible Space. Community wildfire information series. http://www.southwestcoloradofires.org/articles/article28.htm

Cohen, Jack D. 2001. Wildland-Urban Fire - A Different Approach. www.firelab.com. Fire Sciences Lab, Missoula, MT.

Cohen, Jack and Rick Stratton. 2003. Interim Hayman fire Case Study Analysis: Home Destruction Within the Hayman Fire Perimeter. http://www.fs.fed.us/rm/hayman_fire/text/04cohen/04cohen.html.

Fried, Jeremy, Greg Winter, and Keith Gilless. 1999. Assessing the Benefits of Reducing Fire Risk in the Wildland-Urban Interface: A Contingent Valuation Approach. International Journal of Wildland Fire. 9(1):9-20.

Fried, Jeremy, Susan Stewart, and J. Keith Gilless. 1995. Objectives Setting in the Wildland Fire System: What Do the Customers Think? Proceedings of the 1994 Symposium on Systems Analysis in Forest Resources: management systems for a global economy with global resource concerns. Asilomar Conference Center, Pacific Grove, California. September 6-9, 1994. Corvallis, OR: Society of American Foresters: Oregon State University. p. 150-160.

Hanemann, W. Michael. 1994. Valuing the Environment through Contingent Valuation. The Journal of Economic Perspectives. 8(4):19-43.

Ingalsbee, Timothy. 2003. Money to Burn: The Economics of Fire and Fuels Management. www.americanlands.org/forestweb/fire.htm.

Kaval, Pamela. 2004. Public Values for Restoring Natural Ecosystems: Investigation into Non-Market Values of Anadromous Fish and Wildfire Management. Ph.D. Dissertation. Graduate Degree Program in Ecology. Colorado State University. Fort Collins, CO.

Larimer County. 2003. Wildfire: Did you know? www.co.Larimer.co.us. Larimer County, CO. Fort Collins, CO.

Larimer County. 2002. What is Defensible Space? www.co.larimer.co.us/wildfire/what_is_defensible_space.html

Larimer County GIS and Mapping Services Department (MSD). 2000. 1999 Black and White Aerial Photography/ Larimer County, CO. Fort Collins, CO.

Larimer County GIS and Mapping Services Department (MSD). 2001. Summer 2000 Color Aerial Photography/ Larimer County, CO. Fort Collins, CO.

Romme, William. November 28, 2001. Interview. Professor of Forestry at Colorado State University. Fort Collins, CO.

Romme, William. July 9, 2003. Interview. Professor of Forestry at Colorado State University. Fort Collins, CO.

Romme, William H., Peter J. Barry, David D. Hanna, M. Lisa Floyd, and Scott White. October 31, 2001. A Wildfire Hazard Assessment and Map for La Plata County, Colorado. Final Report on Phase I of the Study. Colorado State University. Fort Collins, Colorado.

Theobald, D.M. September 18, 2003. Interview. Professor of Geographic Information Systems at Colorado State University. Fort Collins, CO.

Theobald, D.M., N. Peterson, and W. Romme. 2003. The Colorado Vegetation Model: Using National Land Cover Data and Ancillary Spatial Data to Produce a High Resolution, Fine Classification Map of Colorado (v1.0). 28 April. Unpublished report, Natural Resource Ecology lab, Colorado State University. www.ndis.nrel.colostate.edu/davet/cvm.htm

USFS. 2003. Hayman Fire Case Study Analysis. www.fs.fed.us/rm/hayman_fire/

USFS. 2003. Fire Information. www.fs.fed.us

USGS. 2001. DEM Colorado. ESRI GRID 30 meters x 30 meters, NAD 1983 UTM Zone 13N Projected Coordinate System. GCS North American 1983 Geographic coordinate system.

Vicars, Maryhelen. Editor. 1999. Firesmart: Protecting your community from wildfire. Partners in Protection. Edmonton, Alberta.

Wildfire Hazard Information and Mitigation System (WHIMS). 2002. Boulder County, CO.

Winter, Greg and Jeremy S. Fried. 2000. Homeowner Perspectives on Fire Hazard, Responsibility, and Management Strategies at the Wildland-Urban Interface. Society and Natural Resources. 13:33-49.

Winter, G. and J. Fried. 2001. Estimating Contingent Values for Protection from Wildland Fire Using a Two-Stage Decision Framework. Forest Science. 47(3):349-360.

Costs and Benefits of Reducing Sediment Production From Wildfires Through Prescribed Burning: The Kinneloa Fire Case Study [1]

Armando González-Cabán,[2] Peter Wohlgemuth,[3] John B. Loomis,[4] David R. Weise[3]

Abstract

National Forests in southern California contain fire prone ecosystems and significant watersheds that are susceptible to post-fire erosion. Using the 2,348 ha Kinneloa fire near Pasadena, CA and associated debris basins as a case study, we found that a long time-interval wildfire resulted in $2.5 million of sediment management and watershed rehabilitation costs for several city, county, state, and federal agencies. The wildfire suppression costs were $7 million. There was also $.26 million in lost recreation due to the closure of the area to visitors. The total cost from the Kinneloa fire was $9.721 million. A multiple regression analysis of fire interval and resulting sediment yield indicated that reducing the fire interval from the current average 22 years to a prescribed fire interval of 5 years would reduce sediment yield by 2 million cubic meters in the 86.2 square kilometer watershed adjacent to and including the Angeles National Forest. Cost savings take the form of reduced sediment removal in debris basins reduced need for emergency infrastructure protection structures. Other savings include the lost recreation visitor days due to emergency fire closures of watershed recreation facilities. Direct cost savings to Los Angeles County Public Works in terms of reduced debris basin clean out would be $24 million. The ecological effects of a prescribed fire interval of 5 years were not included in this analysis..

Introduction

Wildfires are one of the principal causes of accelerated erosion problems in municipal watersheds in steep wildland/urban interface areas of the Intermountain and southwestern United States. A clear example of this is southern California. Several hundred thousand residents call the southern California mountains home. The mountains are visited by several million recreationists each year. Both these groups value the aesthetics of the mountains and the forests. However, these forests contain fire prone ecosystems and significant watersheds that are susceptible to post-fire

[1] An abbreviated version of this paper was presented at the second international symposium on fire economics, planning and policy: a global view, 19–22 April, 2004, Cordoba, Spain.

[2] Economist with the Fire Management in the Wildland/Urban Interface Research and Development Program at the Forest Fire Laboratory, Pacific Southwest Research Station, USDA Forest Service, 4955 Canyon Crest Drive, Riverside, CA 92507; Phone: 909.680.1525; email: agonzalezcaban@fs.fed.us.

[3] Hydrologist and Research Forester respectively with the Prescribed Fire and Fire Effects Research Work Unit at the Forest Fire Laboratory, Pacific Southwest Research Station, USDA Forest Service, 4955 Canyon Crest Drive, Riverside, CA 92507; email: pwohlgemuth@fs.fed.us; email: dweise@fs.fed.us.

[4] Professor, Department of Agricultural and Resource Economics, Colorado Sate University, Fort Collins, CO 80523; email: John.Loomis@colostate.edu.

erosion. This paper presents a methodology to estimate the costs and benefits of using prescribed burning to reduce erosion sediments following wildfires in these fire prone watersheds and associated ecosystems.

The cost savings take the form of reduced sediment removal in debris basins and reduced need for emergency infrastructure protection structures such as sediment traps or channel construction. Other savings include reduced watershed protection and rehabilitation via hydroseeding, as well as reducing lost recreation visitor days because emergency fire closures of watershed recreation facilities.

This work provides quantitative estimates of the sediment reduction and associated cost savings to society from using prescribed burning to generate a more frequent, low intensity fire regime in the wildland urban interface of the San Gabriel Mountains. The 1993 Kinneloa Fire is used to demonstrate application of the methodology in fire management analysis to determine the costs that could be avoided by prescribed burning.

Literature Review

For decades fire and erosion have been one thorny concern in fire management. On the Angeles National Forest, postfire erosion in the San Gabriel Mountains has been a major concern since WW II when the potential damages caused by increased run-off and erosion following a wildfire were investigated (Buck and others 1948). A few years later Row and others (1954) performed a hydrologic analysis of effects of fire on peak discharges and erosion rates in the San Gabriel Mountains of southern California. They found the first-year post-fire erosion averaged 35 times the unburned levels.

During the last 50-years these concerns have escalated dramatically as the level of development in the wildland urban interface has increased substantially. Fire risk is not the only peril faced by the increasing number of homes and value of homes in the wildland urban interface, but those surviving the fire, face post-fire risks in the form of debris flows and sediment. Wells and others (1987) demonstrated that wildfire in southern California increased sedimentation by more than an order of magnitude over unburned areas.

In some watersheds, increased post-fire erosion and debris adds to water supply system costs. It has been increasingly common after fires for debris to end up in water supply reservoirs, as recently happened after the Buffalo Creek fire outside of Denver, Colorado. The added sediment results in lost reservoir water storage capacity and increased treatment costs (Martin and Moody 2001; Holmes 1988; Moore and McCarl 1987). All of these costs have prompted a search for ways to reduce these episodic sediment and debris events following wildfire. Various postfire treatments are used to reduce these events (Robichaud and others 2003). Wohlgemuth and others (1999) was among the first to suggest that one of the many benefits of prescribed fire would be as a sediment management tool. They quantified the extent of sediment reduction in areas that had been previously prescribed burned prior to a wildfire. They found one-tenth to one-twentieth as much sediment coming from previously prescribed burned areas as compared to areas without previous prescribed burning prior to the wildfire. The purposes of the research reported here are: (1) to test the hypothesis that repeated fires would result in a statistically significant reduction in sediment yield in a wider range of watersheds along the San Gabriel Mountains; (2)

to quantify in monetary terms the cost savings that might have resulted from prescribed burning in the Kinneloa watershed.

Study Area and Values at Risk

The study area includes watersheds in the Los Angeles County foothills encompassing the Angeles National Forest and adjacent private land (86 km^2), generally referred to as the San Gabriel Mountains. Collectively, the area contains 57,227 houses, with a median value of $241,300. This study area was chosen because it is typical of wildland urban interface areas where houses exist in fire prone ecosystems and these private lands abut public land. These mountain ranges and canyons are fairly steep, with elevational gradients of 150 to 850 feet per mile. Chaparral, the multi-species shrub complex in the area, is a well- known flammable vegetative community (Moreno and Oechel 1994). The area is subject to strong winds (20 m s^{-1}) in the fall that often result in high intensity wildfires in one or more areas of southern California periodically, which are followed by winter rains that rapidly fill the debris basins with sediment. This pattern can possibly be altered by the use of prescribed burning on regular intervals. It is likely that the amount of additional debris from a prescribed fire would be small enough to be handled by the routine debris basin clean out, avoiding the need for emergency clean outs. More importantly, frequent prescribed burning could reduce the intensity of any fires that occur in the watershed by reducing the available fuels. Lower intensity fires will leave some of the larger shrubs and trees standing, and along with their intact root system, will reduce erosion from rainfall. Therefore, the amount of material coming down after a wildfire would be greatly reduced, again avoiding emergency clean out costs.

To test these ideas, we conducted a linked hydrological and economic analysis. The first step in this analysis was to determine statistically if sediment and debris flows can be reduced from repeated fire. If we find such a statistically significant relationship, then the cost savings from reduced sediment clean out and emergency watershed rehabilitation can be calculated.

Statistical Analysis of the Relationship between Fire Frequency and Sediment Yield

Hydrological Data

Records of sediment discharge to debris basins were collected for 41 watersheds along the southern flank of the San Gabriel Mountains of Los Angeles County. These records included topographic characteristics, fire histories, rainfall amounts, and sediment yields into debris basins in these watersheds over a 30-60 year period, depending on the age of the debris basin. However, it is worth noting that none of the fire events in the database are prescribed burns. We are using wildfire events as natural experiments to mimic what would occur with prescribed burning. We recognize that wildfires typically burn with higher intensity than prescribed fires so that sediment reductions associated with repeated wildfires may be different than with repeated prescribed fire. Nonetheless, we think the ability to utilize data from this natural experiment is still quite insightful and a reasonable proxy for evaluating an equivalent prescribed fire regime.

Sediment Yield Modeling

In southern California, a given sediment yield response from any watershed is the result of a complex set of interactions among these physical site, fire, and rainfall characteristics. Fire characteristics include percent of area burned, fire severity, and time of year. In this area fire severity is either high or very high, while time of year is either summer or fall so there is little variation in these two fire variables. However, there is variation in the percentage of watershed burned. One way to model the interaction of physical, hydrological and fire factors is to use a paired watershed approach. Specifically, in watersheds that burned multiple times, a pre-fire/post-fire comparison may be made to ascertain the effect of fire interval, controlling for rainfall and other influences. This approach allows us to determine the effect on sediment yields of prior fires on subsequent burns to estimate the reduced sediment yields as a function of time since burning, percent area burned, watershed characteristics, and rainfall patterns. As there are good comparisons for unburned versus post-burn sediment yields for virtually all 41 watersheds, the sediment yield reduction function is estimated with multiple regression. The equation is then used to calculate sediment responses for various fire interval scenarios. The resulting sediment reduction can be used in the economic analysis of the cost savings of the sediment reduction versus the costs of prescribed burning.

Statistical Analysis Methods

Multiple regression analysis was used to estimate sediment discharge as a function of fire interval controlling for other variables. Specifically the equation estimated is:

$$\ln(S) = \beta_0 + \beta_1 \ln(FireInterval) + \beta_2 \ln(RainLag) + \beta_3 \ln(TotalRain) + \beta_4 \ln(\mathrm{Re}liefRatio) + \beta_5 \ln(Burned\%)$$

where, S is the sediment produced per km^2, *FireInterval* is the number of years between fires; *RainLag* is the number of days between the fire and first significant rainfall (defined as 12.5 mm (0.5 inches) or more); *TotalRain* is the total mm of rainfall in the five largest events during the water year following the fire; *ReliefRatio* is an index of the watershed steepness; and *Burned%* is the percentage of the watershed burned.

Statistical Regression Results

Results from our multiple regression model show a reasonably good explanatory power. Slightly over 50% of the variation in sediment from the 66 observations is explained by the five independent variables (*table 1*). The longer is the fire interval preceding a fire event, the greater the sediment that comes down into the debris basin in the year of the fire. Because the dependent and independent variables are expressed in natural logarithms the coefficients can be interpreted as elasticites. Thus, a 1% decrease in the number of years between fires (i.e., the fire interval) leads to a 0.577% decrease in annual sediment. The signs of the other variables are plausible, i.e., the greater the percentage of the watershed burned (*Burned%*) and the more rain that fell that winter (*TotalRain*) the greater the annual flow of sediment into the debris basins.

Table 1—Sediment model regression results including inferred sediment for zero reported sediment

Variable	Coefficient	Std. Error	P	LvarMean
Constant	6.6611	1.0901	0.0000	1.0000
Ln(*FireInterval)*	0.5772	0.1847	0.0027	3.1113
Ln(*RainLag*)	-0.3372	0.1477	0.0260	3.6376
Ln(*ReliefRatio*)	0.8237	0.5499	0.1394	-1.1793
Ln(*TotalRain*)	1.3852	0.2715	0.0000	3.2958
Ln(*Burn%*)	0.6141	0.1749	0.0009	-0.3355

R-squared	0.5551	Mean dependent variable	8.5566
Adjusted R-squared	0.5180	S.E. of regression	1.0447
F-statistic	14.9720	Prob. (F-statistic)	0.0000

Using the Regression Equation as a Sediment Simulation Model for Prescribed Burning

The regression equation was used to forecast the reduction in sediment per km^2 if the fire interval was decreased from the current average fire interval of 22.45 years to shorter fire intervals such as 5, 10, and 15 years. This is done by changing the level of the Ln(*FireInterval)* variable. We used the regression equation in table 1, holding the other variables at their mean, to perform a simulation of the effect of different fire intervals on annual sediment production (table 2).

Table 2—Annual sediment per km^2 with Fire Intervals Longer than Five Years

Fire_Interval (Years)	Sediment production (m^3 km^{-2}) Postfire	ΔS
5	17166	
10	25614	**8448**
15	32367	**15471**
Current (22)	40843	**23677**

Table 2 can be read in one of two ways. First, there are significant annual increases in sediment as the fire interval gets longer than five years (table 2). Because the problem is the amount of sediment coming down at one time, cost savings would be realized by reducing the peak amounts of sediment coming down. This can be accomplished by a fire interval closer to every 5 years, rather than 22 years--the average in the data set. With a 5-year fire interval instead of a 22-year interval, the annual reduction in sediment is 23,677 m^3 using the adjusted sediment regression in Table 1. Over the entire study area (86 km^2), a 5-year fire interval would reduce annual sediment inflows to LA County debris basins by 2 million m^3 each year. Alternatively, one can use the information in Table 2 to calculate the reduction in sediment with a 10-year fire interval as compared to the current 22 year average fire interval. A 10-year fire interval would result in a reduction in sediment of 15,229 m^3 each year. Alternatively, one can use the information in Table 2 to calculate the

reduction in sediment with a 10-year fire interval as compared to the current 22 year average fire interval. A 10-year fire interval would result in a reduction in sediment of 15,229 m^3 km^{-2}. Given other multiple use considerations such as native plant and animal viability, a ten-year fire interval may be more optimal.

Cost savings from sediment reduction

LA County Debris Basin Clean-out Costs

The major cost savings from reduced sediment yield is decreased debris basin clean-out costs to LA County Public Works. Clean out costs for the 41 debris basins were obtained from LA County Public Works for the years 1969 to 1995. These costs were updated for inflation to 2000 dollars. The average cost across all 41 basins and all years is nearly $12 per cubic yard, with costs ranging from $2.48 to $32 per cubic yard (1 m^3 = 1.308 yd^3). Some of this cost variation may be related to the distance the removed sediment must be transported. This ranges from as little as a half mile to as much as 7 miles away. Some of this variation in cost is related to how wet the sediment is at the time it is hauled away (personal communication with Loreto Soriano, L.A. County Public Works; August 1, 2002). If heavy rains occur right after fires, this can wash large amounts of material into the debris basin, filling the basins. If this is early during the rainy season, this material must be quickly removed to provide space. Removing that material when it is wet, requires half loads of trucks due to the weight. Unfortunately data on water content of the sediment is not available.

Using the average cost of $11.87 per cubic yard, the direct cost saving to LA County Public works of a 2 million cubic yard annual reduction in sediment associated with a five year fire interval, would be $23.74 million.

Forest Recreation at Risk

The private residential land in the watershed is bordered by the Angeles National Forest. As a whole this National Forest receives an estimated 3.5 million to 4 million visitors each year, making it one of the most visited National Forests in California (USDA Forest Service, 2001). Recreation visitation to the Angeles National Forest accounts for 15% of all National Forest visits in California (USDA Forest Service, 2001). Within our study area, there are five developed campgrounds and 21 developed picnic sites. These sites include picnic tables, restrooms and piped water. There are also 15 backcountry trail camps that provide tables and fire grates. The area also contains more than 20 hiking trails. Given these facilities it is not surprising that the most common activities are hiking and picnicking.

To estimate recreation use in the study area we drew upon data from the USDA Forest Service National Visitor Use Monitoring (NVUM). Specifically we identified sample days at General Forest Area access points (GFA's), Day Use Developed Sites (DUDS) and Overnight Use Developed Sites (OUDS) sampled by the USDA Forest Service that were within our study area. The average length of stay of a site visit averages one day for the day use sites, general forest recreation and just slightly over a day (1.14) for the overnight developed use sites. Given these length of stay factors, the estimated 1,038,381 visits to our study area represent 1,049,315 visitor days.

We used a USDA Forest Service report that provides the net willingness to pay per visitor day calculated from TCM and contingent valuation studies for

the types of activities occurring in our study area (Rosenberger and Loomis, 2001). Table 3 of Rosenberger and Loomis (2001: 13) provides values per day for the geographic area containing our study area, the Pacific Coast states of California, Oregon and Washington. The value per day from existing studies is $28.95 for picnicking, $22.87 for hiking, and $77.27 for camping. These values are fairly close to the national values for these activities as well (Rosenberger and Loomis, 2001:4). In the baseline situation we have visitor days disaggregated by developed sites (e.g. Day Use Developed Sites and Overnight Developed Sites) and General Forest Recreation. Given the survey data discussed above that indicates that about 10% of visitors to Overnight Developed Sites camped, 30% went picnicking, and 60% went hiking, we used this activity mix to value visitor days occurring at Overnight Developed Sites. A weighted average of the value of hiking, picnicking and camping was used to compute the total annual visitor das and total annual recreation value in our study area (table 3). The weights are the percentage of users in each of the three recreation activities.

Table 3—Existing Study Area Visitation and Value

SITETYPE	Total Annual Site Visits	Total Annual Visitor Days	Value per Day	Total Recreation Value
Overnight Dev. Site	78,100	89,034	$30.13	$2,682,944
Day Use Dev. Site	362,113	362,113	$28.95	$10,483,159
General Forest Rec.	598,169	598,169	$22.87	$13,680,120
TOTAL	1,038,381	1,049,315		$26,846,223

The recreation value at risk from fire is $26.8 million annually. This is quite substantial, and suggests avoiding recreation closures due to fire or post-fire flooding is potentially an important benefit of avoiding catastrophic wildfires in our study area.

Benefit Cost Comparison of Five and Ten Year Fire Interval

While Table 2 indicates that a five year fire interval resulted in a larger reduction in annual sediment yield than a 10 year fire interval, this did not consider other multiple use resources, or costs. A five year fire interval is probably too short in southern California chaparral forests to allow sufficient regeneration of climax vegetation species needed to maintain ecological integrity and biodiversity. Potential vegetation changes resulting from a five-year fire frequency and associated changes in sediment production as a result were not included in the present study. This could adversely affect some wildlife that depends on the more mature vegetation. In addition, prescribed burning is expensive. Because the build up of fuel over an average 20 year time period, the initial prescribed burning requires significant precautionary resources be available. The costs for National Forests in southern California average $250 an acre for these initial burns (Walker 2001). Subsequent re-entries in five to ten years would likely be less costly, perhaps by half. In addition to the watershed

cost savings, prescribed burning would reduce the need for prolonged recreation closures following wildfire. As detailed in the next section we calculated the recreation benefits lost due to one wildfire in southern California.

Table 4 displays the results of a net present value analysis of the watershed and recreation cost savings with a five and ten year fire interval over a twenty year time period. We selected twenty years since this is approximately the average time a wildfire reoccurs in a site in our dataset. This analysis compares the sediment reduction benefits from a wildfire in year 20 with and without prior prescribed burning on a five year and ten year cycle (it is of course possible that prior prescribed burning would reduce the likelihood of a wildfire or reduce the extent of the area burned by a wildfire--we are not able to quantify these benefits). Using the sediment reductions from Table 2 and the cost per cubic yard of sediment, we calculated the amount of sediment that would come off in year 20 from a wildfire with no prior prescribed burning versus what would come off in year 20 with a ten year and five year prescribed burning program. The benefits in year 20 from a five-year fire interval of $281,046 and $180,768 with a ten year fire interval. Using the USDA Forest Service discount rate of 4%, this yields a present value of cost savings twenty years from now of the five year fire interval is $128,266 and $82,500 for a ten year fire interval. To this we add the present value of avoiding a recreation closure per km^2 as calculated using the recreation use data and values per day described in Table 3 and the case study in the following section.

In terms of the initial costs of prescribed burning we used the $250 an acre times 247 acres per square km. Follow-up prescribed burns used one-half this cost per acre and then discounted at 4% for the year in which that re-burn took place. The results are shown in Table 4.

Just considering the watershed cost savings and recreation closure avoided a ten-year fire interval has the highest (and positive) net present value. This means the present value of the benefits of prescribed burning exceed the present value of the costs. A five-year fire interval has a small negative net present value. If there are other multiple use costs associated with the shorter fire interval, then the five-year fire interval might have an even larger negative net present value. Given our data, it appears a ten-year fire interval would be most cost-effective.

Table 4—Net Present Value of Five and Ten Year Prescribed Burning Fire Intervals

Fire Interval	*Present Value of Cost Savings/km^2*		PV of Prescribed Burning Costs/km^2	Net Present Value/km^2
(years)	Watershed Savings	Recreation		
5	$128,266	$8,802	$138,679	-$1,611
10	$82,500	$8,802	$82,608	$8,694

Kinneloa Fire Case Study of Costs Avoided By Prescribed Burning

To show how the approach described here could be used in fire management analysis, we apply it to a case study fire to determine the costs that could have been potentially avoided by having a prescribed burning program. Because we cannot

determine the size or damage of a potential fire in the area treated we will assume that all suppression costs associated with this fire could have been avoided. In this analysis this would be the maximum possible savings from the prescribed burning program

The Kinneloa fire burned about 2,348 hectares (5,800 acres) in the study area (1,429 National Forest and 919 of private and county) in October 1993. Because the area of the fire directly corresponds to the Kinneloa watershed and the two debris basins it is most amenable for use as a case study. We used this case study to examine what costs federal, state, county agencies and two cities incurred to perform post-fire sediment control and watershed rehabilitation. These are cost that could have potentially been be avoided had the long (63 years) fire interval been reduced to a five year period.

The cost savings or benefits of these reductions in sediment were quantified by collecting data on: a) cost to Federal Emergency Management Agency ($160,000); b) cost to USDA Natural Resource Conservation Service, LA County Public Works, as well as cities of Pasadena and Sierra Madre for residential areas, other private land, protection of reservoirs, streets and other public infrastructure (USDA Soil Conservation Service 1994) by avoiding the need for hydroseeding, debris barriers, and construction of a gunnite flood channel ($1,700,000); c) cost to USDA Forest Service for Angeles National Forest burned area watershed rehabilitation (USDA Forest Service 1995) from avoiding aerial seeding and straw blankets ($600,000); and d) recreation loses avoided.

The Kinneloa fire resulted in closure of six different trails from October 27th until the following spring when the rainy season ended. These six trails are classified as general forest area, although they contain several trail camps (Mt. Lowe, Hoegee's, Idlehour).

Most of the trails are in the wildland urban interface and are just a short distance from major highways (I-210) and a few miles from residential areas. Therefore, for weekends, we used the average daily visitor estimates for "medium use strata", but to be conservative we used "low use strata" for weekdays. Thus, about 210 visitor days are expected on weekends and holidays, with about 20 visitor days on weekdays. The closure period began October 27, 1993 and was extended to the end of the March rainy season for visitor's safety because of flash flooding concerns in burned areas. Applying the daily visitation rates to the number of weekdays, weekends and holidays during this period results in an estimate of 11,339 visitor days lost during this period. Because the typical recreation use of General Forest Area recreation is hiking, and the areas closed were primarily hiking trails, we will use the benefit transfer value from Rosenberger and Loomis (2000: 13) for hiking. Using this value per day of $22.87, results in loss of recreation benefits of $261,582 (table 5).

We believe this figure represents a net loss in visitor benefits because the sites are the closest recreation sites to where many people live. While more distant sites were not closed, the additional travel cost and travel time to reach these sites would reduce the net benefits or consumer surplus of those visitors who had to endure longer travel. Further, given the high level of demand on weekends and holidays in the Los Angeles area, the other available trails were more than likely used to their maximum capacity. Attempts by displaced visitors to substitute to unburned areas would also lead to reduced net benefits if either there was not sufficient trailhead parking to accommodate the displaced visitors, or in cases where there was parking,

the added congestion caused by the addition of the displaced visitors would have reduced the benefits per day. Not only would the visitors displaced to these trails have received reduced benefits from a more congested experience, but so would existing visitors to those trails that remained open.

Table 5—Loss in Recreation Value due to Kinneloa Fire Closure

	Weekend	Weekdays	Total Days
Visitation Rate	210.7	19.7	
Days Closed	44	110	154
Visitor Days	9270.80	2167	11,438
Value per day	$22.87	$22.87	$22.87
Total Recreation Value Lost	$212,023	$49,559	$261,582

Kinneloa Case Study Summary

In 2001 dollars, the watershed management cost savings previously detailed in (a) to (c) from preventing the Kinneloa wildfire would have totaled $2.46 million. The recreation losses avoided would have been $261,582. In addition, wildfire suppression costs were nearly $7 million ($2981 hectare) (U.S. Forest Service 1995) would have been avoided. The cost of prescribed burning in the southern California Mountains is, on average, $250 an acre ($617.5 hectare) (Walker 2001). Prescribed burning the 5800 acres in the Kinneloa wildfire area would cost about $1.45 million initially, and an equivalent discounted amount each time after. Using the 4% U.S. Forest Service discount rate, an initial prescribed burn, followed by subsequent prescribed burns in year 11 and 21 would have a present value of costs of $3 million. The present value of the $9.721 benefits of avoiding a Kinneloa fire over that 22-year time interval would be $4.26 million. Thus, three prescribed burns over the 22-year time interval would have a positive net present value.

CONCLUSION

This research demonstrates an approach that can be used with prior fire frequency and erosion data to estimate a relationship between fire interval and sediment yield. In our study area in the wildland urban interface of the San Gabriel Mountains of Southern California, we found a statistically significant relationship between fire interval and sediment yield following wildfires. A 1% decrease in years between fires results in a 0.58% decrease in annual sediment yield into the debris basins. In our study area, this suggests that a five year fire interval would reduce annual sediment yield per km^2 from 40,843 M^3 with the current fire interval to 17,166 M^3. This annual reduction in sediment would save Los Angeles County Public Works $24 million annually in terms of reduced debris basin clean-out costs.

However, comparison of the net present value of a five and ten year prescribed burning interval suggests that a ten-year burning interval has positive net benefits. While a five-year prescribed burning interval gives greater sediment reduction, it has a lower net present value due to need for additional prescribed burning. In addition, the five year period may be too short a time period to maintain ecological integrity and biodiversity of many native plants and associated animal species. Our case study of the Kinneloa wildfire indicates that the costs of a prescribed burn would have been

much less costly than incurring the wildfire suppression costs and post-fire watershed rehabilitation effort.

The management implications of this research suggest that watershed benefits can be a substantial addition to traditional wildfire hazard reduction benefits arising from prescribed burning. Fire managers working in the wildland urban interface should include the cost savings from less sediment clean out, reduced watershed rehabilitation costs, and avoiding recreation area closures when performing economic evaluations of prescribed burning. This research provides some estimates of these savings in the San Gabriel Mountains, and presents an approach for estimating the cost savings in other wildland urban interface areas.

References

Buck, C.C., W.L. Fons, and C.M. Countryman. 1948. Fire Damage from Increased Run-Off and Erosion on the southern California National Forests. California Forest and Range Experiment Station, USDA Forest Service, Berkeley, CA.

Holmes, T. 1988. The Offsite Impact of Soil Erosion on the Water Treatment Industry. Land Economics 64(4): 356-366.

Martin, D. and Moody. J. 2001. Comparison of Soil Infiltration Rates in Burned and Unburned Mountainous Watersheds. Hydrological Processes 15: 2893-2903.

Moreno, J.M., Oechel, W.C. (eds.), 1994. The Role of Fire in Mediterranean-type Ecosystems. Ecological Studies 107, Springer-Verlag, New York. 201 p.

Moore, W. and B. McCarl. 1987. Off-Site Costs of Soil Erosion: A Case Study of the Willamette Valley. Western Journal of Agricultural Economics 12(1): 42-50.

Robichaud, P., McDonald, L., Freeouf, J., Neary, D., Martin, D., and L. Ashmun. 2003. Postfire rehabilitation of the Hayman Fire, pp. 293-314 In Graham, Russell T., Technical Editor. 2003. Hayman Fire Case Study. Gen. Tech. Rep. RMRS-GTR-114. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 396 p.

Rosenberger, Randy and John Loomis. 2001. Benefit Transfer of Outdoor Recreation Use Values. RMRS-GTR-72. Rocky Mountain Research Station, USDA Forest Service, Fort Collins, CO

Rowe, P., C. Countryman and H. Storey. 1954. Hydrologic Analysis Used to Determine Effects of Fire on Peak Discharges and Erosion Rates in Southern California Watersheds. California Forest and Range Experiment Station, USDA Forest Service. 49p.

USDA Forest Service, Angeles National Forest. January 30, 1995. Kinneloa Burned Area Accomplishment Report. 701 Santa Anita Ave, Arcadia, CA.

USDA Forest Service, Angeles National Forest. National Visitor Use Monitoring Results, Region 5.

USDA Soil Conservation Service. 1994. Kinneola Wildfire Emergency Watershed Protection Program. Natural Resources Conservation Service 4481 North Date Ave, Lancaster, CA.

Walker, Norm. 2001. Prescribed Fire Costs. Email from Norm Walker, Division Chief, San Jacinto District, San Bernardino National Forest to Lucas Bair, Colorado State University. January 26, 2001.

Wells, W., P. Wohlgemuth, A. Campbell, F. Weirch. 1987. Postfire Sediment Movement by Debris Flows in the Santa Ynez Mountains, California. In Erosion and Sedimentation in

the Pacific Rim. IAHS Publication No. 165. International Association of Hydrological Sciences, Washington DC. 275-276.

Wohlgemuth, P.; Beyers, J.; Conard, S. 1999. Postfire Hillslope Erosion in Southern California Chaparral: A Case Study of Prescribed Fire as a Sediment Management Tool. In Proceedings of the Symposium on Fire Economics, Planning and Policy: Bottom Lines. Technical Editors: Armando González-Cabán and Phil Omi. PSW-GTR-173, Pacific Southwest Research Station, USDA Forest Service, Albany, CA.

Managing Fire Risk in the Forests of the U.S. Inland Northwest: A Classic "Wicked Problem" in Public Land Policy[1]

Matthew S. Carroll,[2] Keith A. Blatner,[2] Patricia J. Cohn,[2] Charles E. Keegan III,[3] Todd Morgan[3]

Abstract

In their classic article published in the Journal of Forestry in 1986, Gerald Allen and Ernest Gould stated that the most daunting problems associated with public forest management have a "wicked" element: "*Wicked problems share characteristics. Each can be considered as simply a symptom of some higher order problem…The definition is in the mind of the beholder and how that person chooses to explain the problem determines the scope of the search for a resolution. Furthermore, there is no single correct formulation for a wicked problem, only more or less useful ones* (p. 22)." This description seems to fit very well the difficulties associated with managing the increasing risk of wildland fire in much of the western United States. The cause of the current state of affairs is a complex mix of physical, ecological, economic and social developments which occurred during a more than one hundred year period. Proposed steps to improve the current situation involve equally complex dynamics which do not lend themselves to simple linear thinking. Using the Inland Northwest region of the U.S. as a primary example, this paper explores these complex dynamics as they relate to possible improvements and the dilemmas inherent therein. Among the elements of the problem examined include longstanding political polarization over public land management, patterns of residential development in the so called Wildland-Urban Interface, a longstanding social belief that fire is the "enemy" of the forest, uncertainties concerning tolerance for and health effects of smoke from prescribed forest burning, the economics of utilizing small diameter wood as a byproduct of forest thinning, impacts of forest treatments (or lack thereof) on wildlife habitat and the impacts of controlled and uncontrolled fire on carbon sequestration and release. We conclude that any "solutions" to the problems associated with fire risk involve complex tradeoffs that demand careful scrutiny and public deliberation.

Introduction

In the last few years, the summer newspapers have been replete with headlines about wildfires and the destruction they bring to communities and forests particularly in the American West. A common sidebar to these stories is how the management of the public forests has led to these conflagrations and how the forests might be restored to

[1] An abbreviated version of this paper was presented at the second international symposium on fire economics, policy, and planning: a global view, 19–22 April, Córdoba, Spain.

[2] Associate Professor, Professor and Chair, Research Associate, respectively, Department of Natural Resource Sciences, Washington State University, Pullman, WA 99164-6410.

[3] Research Professor and Research Forester, respectively, The University of Montana, Bureau of Business and Economic Research, Gallagher Business Building, 32 Campus Drive #6840, Missoula, MT 59812-6840.

"health" with a combination of thinning, prescribed burning, and a streamlined environmental analysis process. The wildfire issue has returned the management of public forest lands to the national policy making agenda.

We suggest that just as the cause of the current state of affairs in these forests is a mix of physical, ecological, economic and social developments over the last one-hundred years, the solutions to managing fire risk are equally complex and come with a set of dilemmas. It is not our purpose here to propose a "solution" to the fire issue, but rather to lay out what we believe to be the most significant sources of complexity inherent in any attempt to make meaningful improvements to what we see as an archetypal wicked problem (Allen and Gould 1986). The evidence that the fire issue fits the "wicked problem" trope is abundant. Different stakeholders see the fire issue as a symptom of a higher order problem but disagree on the nature of that problem. Some see it as evidence of too much and the wrong kind of forest management and others, as a lack of adequate management. Each side can point to examples that bolster their case.

We use a *soft systems* or *soft systems methodology* (SSM) (Checkland, 1981, Daniels and Walker 2001, Wilson and Morren, 1990) to analyze this problem. This approach was conceived to deal with the less well defined problems common in complex public policy issues. These "fuzzy" problems are characterized by competing or multiple goals and purposes. The SSM approach recognizes that full agreement or a single solution may never be reached but rather achieving small improvements in the situation is a more realistic aspiration. The approach also assumes that all the requisite knowledge for making improvements may not exist in advance (at least not in any one place) but instead emphasizes incremental change public deliberation and learning as progress is made. (Daniels and Walker 2001). We use this approach to lay out in a broad way what we believe to be the major components of the fire problem using the Inland Northwest as our example and to suggest ways to think about the links between these components. In the spirit of SSM, we do not claim that our characterization of the problem is right in a once-and-for-all sense; we hope that it is useful as a heuristic device to advance thinking and to lead toward system improvements in an important problem faced by land managers and ultimately policy makers.

How did we get here?

We begin by asking "how did we arrive at the current state of affairs regarding the perceived risk of catastrophic wildfire in the public forests?" We need to recognize that there are two separable yet interconnected current states of affairs. One is the biophysical "here", or the current condition of the public forests in the Inland Northwest, and the second is the sociopolitical "here", and includes the current debate about wildfire risk, interface lands and communities, and management of public forests. Both have evolved over more than a one-hundred year period and are the result of a complex mix of physical, ecological, economic, and social developments.

Biophysical "Here"

The Inland Northwest covers eastern Washington (east of the Cascade Mountains), northern Idaho (north of the Clearwater River), and western Montana (west of the

Continental Divide). The ponderosa pine, Douglas fir and mixed conifer are the dominant forest types found in eastern Washington (Agee 1993, TriData 1997). Ponderosa pine, Douglas-fir, and lodgepole pine forest are the dominant forest types in Montana and Idaho (Adams 1995). The interaction of human and natural forces has wrought changes in forest structure and fire regimes. Native American burning, hunting, and other activities have occurred for at least 6,000 years (Barrett and Arno, 1999). Post-settlement logging, grazing, mining, farming, silviculture, and fire suppression over the last 150 years have also shaped the forests of the Inland Northwest (Arno and Allison-Bunnell 2002, Bassman and others 2003, Hessburg and Agee 2003). Now, forest structures are more homogenous and denser with multi-layered canopies; shade tolerant and fire intolerant species have increased; and there has been a corresponding decrease in fire resistant species. Ground and ladder fuel levels have increased, fire intervals have lengthened, and fire behavior and intensity are more extreme (Agee 1993, Hessburg and Agee, 2003).

Fire Severity Regimes

Hessburg and Agee (2003) characterize the historical fire regimes of the Inland Northwest forests as "…a full-spectrum of low (nonlethal), moderate (mixed), and high-severity (lethal) regimes," (p. 24). They describe each regime as follows: "Low-severity regimes displayed frequent fire return intervals, low fire intensity, small patch size, and little edge. Mixed-severity regimes exhibited less frequent fire return, a mix of fire intensities that included underburning and stand-replacement fires, intermediate patch sizes, and significant edge between patches. High-severity regimes displayed infrequent fire, generally high fire intensity, large patch sizes, and intermediate edge," (p.24). Vegetation types within these fire regimes are ponderosa pine and western larch (low severity); Douglas-fir (low to mixed severity); white and grand fir (low to mixed severity), lodgepole pine (mixed severity); western hemlock/western redcedar (high severity) and subalpine fir (high severity).

Sociopolitical here

Fire management on public forests has since passed through several stages since 1910, each with a protection, management, and research strategy (Pyne 1982). The era of fire control began after the fires of 1910. Aggressive fire suppression reduced losses yet allowed fuel to build up, especially in the low severity fire regime areas. In the 1970's fire management replaced fire control. Containment and confinement and prescribed fire received emphasis and prescribed natural fires popularly known as the "let burn" policy took hold. This policy fell out of favor with the Yellowstone fires of 1988 and the public debate over the place of fire in public forests began. This debate culminated with the National Fire Plan of 2000 that emphasizes a collaborative approach to managing wildfires and fuels, restoring fire adapted ecosystems and post-fire rehabilitation on state, federal, and private lands and initiates a new era of fire management (National Fire Plan 2000). At present, the debate over the role of fire and suppression strategy continues and has become enmeshed with the debate over the management of public forests and "forest health".

The wildfire paradigm has changed along with suppression tactics. After 1910, wildfire was "bad"; the paradigm has shifted somewhat to the view that some fires are good. But this shift has happened primarily among resource managers; much of

the public views wildfire as bad, a view exacerbated or strengthened in the Inland Northwest because of the catastrophic fires in 2000 and 2002.

Rural migration trends have gone through several dramatic swings in the last 50 years (Johnson and Fugitt 2000). A net out-migration phase that ended in the late 1980s was followed by an in-migration boom in the 1990s that continues today (McCool and Kruger 2003, Rudzitis 1999). The Inland Northwest has experienced this increase as well, and Montana's Bitterroot Valley is an oft-cited example of these migration trends. Population increased in 94 of 100 counties in the interior Columbia Basin, which includes the study area, in the years 1990-1994. The key feature bringing migrants to the Western U.S. is the presence of federal land or natural resource based amenities (McCool and Kruger 2003, Rudzitis 1999). Scenery, rivers, forests, and recreation opportunities are just as appealing as the traditional rural attractants of low crime rates, a lower cost of living, and a slower pace of life. This is especially true for retirees, who make up the largest group of in-migrants to counties with natural resource based amenities. This segment of the population is expected to grow in the coming decades as the Baby Boomers retire (McCool and Kruger 2003, Rudzitis 1999).

It is sometimes asserted that newcomers have attitudes and values that clash with the traditional commodity interests or extractive resource management emphasis of the old-timers. The existence of this attitudinal split between newcomers and old-timers is not as clear as some stereotypes would suggest however (McCool and Kruger 2003). Empirical evidence suggests that small differences in attitudes toward public land management are present but that both groups favor strategies that protect the environment (Rudzitis 1999). While preserving the amenities that brought them to these rural communities is important to newcomers, it is extra-local or national environmental groups who often appear to be the most vocal opponents to traditional extractive management activities. Decades of mistrust on all sides of the "forest management wars", increasingly restrictive legislation, and litigation have halted many management activities on public forest lands. Projects that survive in this environment are implemented after long delays, if at all, and legal or administrative gridlock is common. Those that favor active management on public forests perceive that land management agencies are not managing forests effectively. Those that oppose most or all federal timber sales are suspicious that any proposals calling for harvesting trees are a harbinger of the return to the era of federal forest management being dominated by commercial timber harvest. The result has been a downward spiral of trust on all sides.

At the local level the influx of new residents to rural communities has strained services, including volunteer structural firefighting departments. Wildland firefighting has been affected as well. Wildland firefighters have to consider homes and communities, and tactics have shifted from indirect attack to aggressive, direct attack that puts both wildland and structural firefighters in risky situations as they defend homes and communities in the wildland-urban interface (WUI) (McCool and Kruger 2003).

The majority of forestland in the Inland Northwest is managed by federal agencies (i.e., USFS and BLM). There is general agreement that wildfires threaten people, property, and forest resources, and that federal land management agencies need to act to reduce the threat of wildfire. Many of the dilemmas surrounding the proposed treatments to reduce wildfire hazard and restore public forests to something akin to historical forest conditions stem from these underlying political and value

disagreements. Other difficulties (i.e. increased fire danger in residential areas and threats to municipal water supplies) stem specifically from the unstable ecological conditions that currently exist in many forest stands. Indeed, these aforementioned disagreements make implementation of treatments to deal with fire hazard and related ecological conditions so contentious.

Treatment Options

This section addresses three broad treatment options and objectives for wildfire hazard reduction on public lands in the Inland Northwest: no treatment, prescribed fire, and mechanical removal of trees. The latter two are usually done in combination, but are described separately here. Debate over treatments does not usually focus on the scientific or technical aspects of implementing them, but on where they will be implemented (backcountry versus interface) and the motivation for doing them (restoration vs. exploitation). It should also be noted that although there is much scientific knowledge about the response of forest stands to silvicultural treatments, nothing on the scale of what is being currently considered in terms of fire hazard reduction treatments has ever been attempted in North American forests. Thus such would be by definition a learning process.

No Treatment

No treatment means no cutting of any kind- pre-commercial and commercial thinning, commercial harvest- prescribed burning, or other activity that mimics natural fires or otherwise changes existing forest conditions. A variation of no treatment is foregoing treatment only in the remote, high severity forest types where forest structures and fire regimes have not changed as dramatically (Hessburg and Agee 2003). This option does not include foregoing wildfire suppression activities.

Prescribed Fire

Prescribed fire is the use of anthropogenic or lightning ignited fire to achieve land management objectives, generally in low severity fire regimes. In the context of this paper, prescribed fire is used for hazardous fuels reduction in forests, especially those around WUI communities, and to restore fire adapted ecosystems. Given current forest conditions, this option alone cannot achieve hazardous fuels reduction and forest restoration goals without mechanical treatment beforehand. Current fuel loads in the low severity fire regime forest types are too high to implement this option safely without pre-treatment. Prescribed stand replacement fires would accomplish fire hazard reduction goals in mixed and high severity fire regimes, but they are risky and the public and land managers aren't likely to accept that risk (Arno 2000, Clark and Sampson 1995).

Mechanical removal of trees

One of the oft-advocated approaches to dealing with the relatively high, "unnatural" stocking levels present on portions of the forests of the western United States is an aggressive thinning program. This treatment option calls the mechanical removal of selected trees to reduce fuel levels, control insects and disease, and restore fire

adapted forests. This approach includes: low thinning; commercial harvest and commercial thinning, and ecologically based prescriptions.

Low thinning would remove all trees in a stand below a certain size threshold (diameter limit), to reduce density (i.e., TPA, BA) and ladder fuels. *Commercial harvest and thinning* would remove commercially valuable timber from public forests for hazardous fuel reduction in both the backcountry and WUI. *Ecologically based prescriptions* would retain and remove trees of various sizes and species within a stand to achieve a more sustainable forest condition. This approach would apply to backcountry as well as WUI areas, can substantially reduce fire hazard, and is generally low cost (Fiedler and others 2001 and 2002).

The Dilemmas of the Treatment Options

The treatment options are easily defined than implemented. Forest managers must confront difficult scientific and technical questions as well as social and political ones if the implementation of treatments is likely to be seen as broadly acceptable or successful. Perhaps the thorniest question is that of time scale. Although the treatments have potential to mitigate the wildfire or "forest health" problem, current estimates suggest it will take 50-100 years to treat fire prone forests and move forest ecosystems to a more sustainable condition (Pass 2004). This time scale is almost incomprehensible to a political system and a public notorious for its impatience for problems to be solved. This tangle of issues complicates the discourse over wildfire management on public lands and has the potential to hamper or prevent implementation (Figure 1). One-hundred-fifty years of fire suppression, logging, grazing, and human population growth and the resulting changes to forest ecosystems cannot be undone or reversed in a decade. Taken together the interaction of the technical and socio-political issues and the different time scales inherent in each constitute the wickedness of the "fire problem".

Prescribed burning dilemmas

One dilemma associated with broadcast burning is that of public tolerance for smoke and the attendant poor air quality and health impacts generated by such burning (Pyne, 2001, Sandberg and Dost, 1990, Schindler and Reed, 1996; Schindler and Toman, 2003; Winter and others 2002). Although expert opinion suggests that broadcast burning produces less smoke than the uncontrolled wildfires such burns may prevent (Hessburg and Agee 2003, Huff and others 1995), such analysis does not guarantee public acceptance.

Another dilemma associated with prescribed burning is the fear of escaped fire (Schindler and Reed 1996, Schindler and Toman, 2003). There is a high risk of public sanction for those who allow prescribed fire to escape as indicated by the public reaction to the Cerro Grande fire of 2000 (Pyne 2001). Therefore the timing of such burns is critical and problematic. Because prescribed fires are often conducted when weather conditions (low wind, high humidity, cool temperatures) are suited for better fire and smoke control, actual fuel combustion may be retarded. Consequently, fuel reduction and restoration goals may not be achieved by conducting burns when it is reasonably safe to burn. An associated issue is the legal liability associated with escaped fires (Carroll and others 2004).

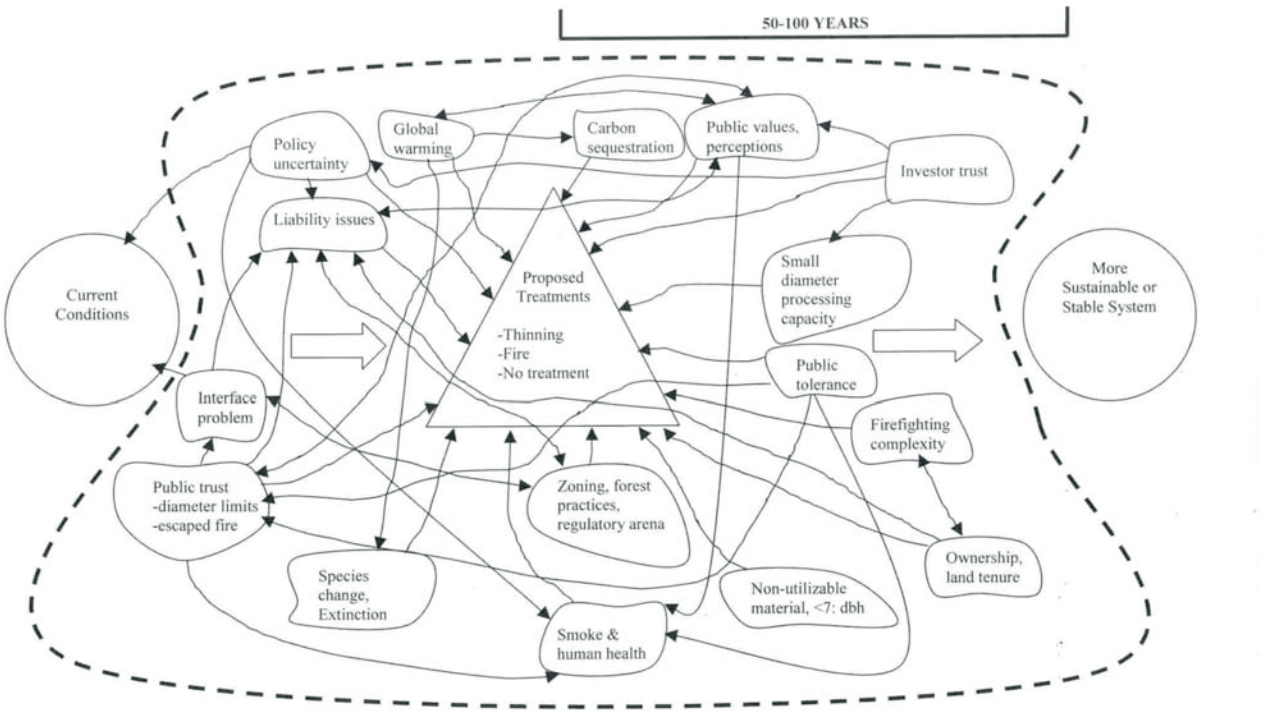


Figure 1--Soft systems model of treatment dilemmas

Global warming and carbon sequestration are intertwined dilemmas associated with burning and thinning; they make balancing the carbon budget and reducing fuel loading and fire hazard a challenge. Both treatments have the potential to affect carbon sequestration but in quite opposite ways. Carbon sequestration in ecosystems and utilization of woody growth as lumber products enhance carbon sequestration, yet prescribed burning for ecosystem restoration and fuel reduction will release more carbon (in the form of carbon dioxide) into the atmosphere, potentially aggravating climate warming trends (Rapp 2004).

Climate change models indicate that western summers will become hotter and wetter, leading to an increase in woody growth i.e. fuel. This increase in woody growth and fuel due to climate change is linked to increase fire risk as well as changes in other disturbance regimes as well as vegetation changes. For example, in the interior west, the acreage of ponderosa pine forests is expected to increase and the range of Douglas fir may expand. These vegetation changes also have implications for wildlife species as their habitats shrink or expand with the vegetation changes. (Rapp 2004).

Thinning Dilemmas

While many advocate thinning as a partial answer to the "fire problem" in the region, implementing this tool across the varied landscapes of the Inland Northwest United States is neither simple nor straightforward. Major issues include: 1) how many acres

need treatment or should be treated from biological and social perspectives; 2) how frequently will the treated acres have to be retreated through time; 3) how should we prioritize the treatment of acres across the landscape and 4) how many acres of those selected for possible treatment may actually be treated given current markets, harvesting technology and access constraints?

These operational issues are further confounded by the need to reduce fire risk to homes in fire-prone rural areas, as well the desire to preserve selected historically important and/or culturally significant areas. The intermingling of federal, state, and private lands also calls into question the efficacy of such efforts when adjacent lands are left untreated.

Further, land managers need to consider the effect of thinning on a wide array of vegetation management, wildlife habitat, biodiversity, and threatened or endangered species issues. For example, it is not clear how thinning would be applied in even-aged stands; thinning from below would prevent the development of uneven-aged stand structures, a common and ecologically desirable condition in the dry, low-elevation forest types. It is not clear if thinning would be effective in mixed and high severity fire regimes (i.e. the lodgepole pine forests of Montana) where fires are weather, not fuel driven (Arno and Allison-Bunnell 2002, Hessburg and Agee 2003).

Another significant dilemma related to thinning treatments is one of public trust and support for a broad scale thinning program. The federal government is promoting aggressive thinning programs under the recently passed Healthy Forests Restoration Act (HFRA), and one has to question how long the public will wait for these treatments to significantly reduce the fire hazard. Large areas of forestland threatened by wildfire may not be treated at all if thinning is applied only in the WUI. As noted previously, it could take as many as 50 to 100 years before thinning treatments begin to significantly reduce the risk of catastrophic wildfire. Others have found that some types of thinning do not substantially reduce fire hazard (Fiedler and others 2001 and 2002).

Thinning is expensive to implement, even more so if no commercially valuable material is harvested (Fiedler and others 2001, 2002). It is this non-commercial material that is implicated in the fire hazard problem. How should this material be handled after thinning? Most forestry professionals recommend burning, which comes with a set of dilemmas previously discussed. In many parts of the West there are limited markets for small diameter timber (7-9” dbh), which limits the ability of land managers to remove this material economically on many sites. Capacity and utilization studies show that less than 10% of the wood processed in the study area is from trees less than 10” dbh. Regional processing capacity is underutilized at present, but diameter and species preferences would limit full utilization (Keegan and others 2004). To further complicate this, recent research demonstrates that investments in new sawmills designed to utilize such material are not economical (Stewart and others, 2003a, b) and that the forest products industry will not invest in new mill capacity without some assurance of a long-term supply (10 to 20 years) (Keegan and others 2004). Conversely, given the historical problems with long-term supply contracts, the creation of new contracts appears unlikely or problematic at best from a public policy perspective.

Removal of commercially valuable timber would pay the way out of the woods for the non-valuable material and would make sales more appealing. However, this option is usually mentioned as a treatment for backcountry or roadless areas and

would undoubtedly meet with marked resistance from environmental groups. Removal of only the commercially valuable trees would not benefit stands with non-merchantable timber, leaving large areas of the WUI untreated. Logging slash could increase fire hazard if not handled properly.

A related dilemma associated with forest thinning is explicitly political, in part due to HFRA, which emphasizes thinning. This Act was proposed by the Bush administration, which is strongly mistrusted by the national environmental movement. This movement characterizes HFRA as "logging by another name", grouping HFRA with other Administration environmental proposals as being *anti*-environmental. On the other hand HFRA is generally supported by the forest products industry and its supporters whose rhetoric views the proposal as a return to "common sense" forest management. Thus HFRA may prove to be one more chapter in the polarization over public forest management.

No Treatment Dilemmas

The no treatment approach to management of wildfire threat on public land is arguably the default option when political or legal controversies prevent any specific treatment or prescription from being implemented (Arno and Allison-Bunnell 2002). The dilemmas this option generates are the same as those associated with the current wildfire threat: smoke, resource (e.g., water, timber, wildlife habitat, etc.) damage, invasive weeds, and impairment of ecosystem functions. More fires outside the historic range of variability are likely to occur, particularly in the low severity fire regimes if those forests are not treated. The result may be higher life and property losses, increased liability costs, and more capital and physical resources devoted to firefighting at the expense of other programs. As the wildland-urban interface expands, firefighting complexity will increase. Although no forest restoration or hazardous fuel reduction activities occur under this option, ecological and anthropogenic process that contribute to increased wildfire threat (e.g., forest succession and densification, fire suppression) will continue to operate. Consequently, threats associated with wildfire do not diminish and are likely to increase as more acres burn and other acres become increasingly likely to burn.

General Dilemmas

The issues and dilemmas associated with treatments for the fire problem in the region can be collapsed into three major categories. The first of these is trust. As we have indicated, there is a generally low level of public trust for government and public land management agencies in the region and indeed the country. It seems safe to assert that of all the myriad land management issues which generate trust issues, none has more potential for generating mistrust than those associated with fire. The second general category is that of tolerance for any given treatment when it is actually carried out on the ground. People tend to develop attachments to the way a given landscape looks even if its current condition is not historical or natural. Nearly any treatment changes the appearance and "feel" of the landscape, thus nearly any treatment is likely to be objectionable to someone (Arno and Allison-Bunnell 2002). The third general category is that of policy uncertainty. Policy uncertainty related to public lands in the region has become so endemic that it "breeds" on itself. In such an atmosphere, no actors can be guaranteed that good faith actions on their part will be

met with a desired response on the part of others. This is true no matter which side of the ideological divide one resides on.

Conclusion

There is near universal agreement that significant portions of the public forests in the Inland Northwest are outside the historic range of variability and that one consequence of this condition is an increased likelihood of catastrophic wildfire. And there is also near universal agreement, particularly among those who live near such forests, that such an increased likelihood is unacceptable given the consequences of such events. Given that the current situation is widely seen as unacceptable, it follows that changes in forest conditions are needed. However, the nature of such changes and the means to achieve them are subject to a variety of biophysical and socio-political dilemmas that confound implementation of the proposed treatments. As we have noted, Gould and Allen (1986) point out that such wicked problems tend to be viewed as symptoms of higher order problems and that different observers often disagree on the nature of such higher order problems. Current debate over the fire problem certainly illustrates this tendency. We suggest it is probably not productive to expend more energy in the philosophical debate over which higher order problem the fire dilemma reflects or to think in terms of once and for all or quick fix solutions to the "fire problem". Rather, it is perhaps more useful to think in terms of system improvements. Clearly the "fire problem" will be with us for a long time and it is perhaps a useful first step for forest managers to accept this biophysical reality and to prepare the public for the long haul. It will take at least a human generation before we really know if we have made significant landscape wide progress in addressing the "fire problem". Even then, real progress in terms of cause and effect relationships may be difficult to gauge given the impact from uncontrollable and nearly uncontrollable events such as moisture and drought cycles and climate change on fire frequency and intensity. It also seems useful to face up to the socio-political reality that any such improvements must necessarily be attempted, at least for now, in an environment of relatively low trust and significant scientific and political disagreement and uncertainty. All of this coupled with the fact that the "fire problem" stretches across jurisdictional boundaries, land ownership/tenure categories and a myriad of stakeholder groups, suggests an adaptive, deliberative people-centered approach as advocated by Gould and Allen (1986) rather than a "one size fits all" technocratic one. While it is indisputably important to take account of the broad scale landscape dynamics described by Hessburg and Agee (2003) and other landscape ecologists in their analysis of the "fire problem", we argue that any system improvements will necessarily take place on an incremental basis. Given the nature of such improvements and the lag time between treatments and ecological response, there is unlikely ever to be one emotionally satisfying moment when we can proclaim the problem is "solved". Instead the best that we can hope for is gradual change and the requisite social and ecological learning which can accompany such change.

References

Adams, David L. 1995. **The northern Rocky Mountain region.** In: Barrett, Robert J., ed. Regional silviculture of the United States. New York: John Wiley and Sons, Inc.; 387-440.

Allen, Gerald M.; Gould, Ernest M. 1986. **Complexity, wickedness, and public forests.** Journal of Forestry (84)4: 20-24.

Arno, Stephen F. 2000. **Fire regimes in western forest ecosystems.** In: Brown, J.K. ed. Effects of fire on flora. Gen. Tech. Rep. RM-GTR-42, vol. 2. Fort Collins, CO: Rocky Mountain Research Station, Forest Service, U.S. Department of Agriculture; 97-120.

Agee, James K. 1993. **Fire ecology of Pacific Northwest forests.** Washington, D.C.: Island Press; 493 p.

Arno, Stephen F.; Allison-Bunnell, Steven. 2002. **Flames in our forest: Disaster or renewal?** Washington, D.C.: Island Press; 227 p.

Barrett, Stephen W.; Arno, Stephen F. 1999. **Indian fires in the Northern Rockies.** In: Boyd, R., ed. Indians, fire and the land in the Pacific Northwest. Corvallis, OR: Oregon State University Press; 50-64.

Bassman, John H.; Johnson, Jon D.; Fins, Lauren; Dobrowolski, James P. 2003. **Rocky Mountain ecosystems: Diversity, complexity and interactions.** Tree Physiology (23): 1081-1089.

Carroll, Matthew S.; Cohn, Patricia J.; Blatner, Keith A. 2004. **Private and tribal forest landowners and fire risk: A two county case study in Washington State.** Unpublished paper supplied by authors.

Checkland, Peter. 1981. **Systems thinking, systems practice.** New York: John Wiley and Sons, Inc.; 330 p.

Clark, Lance R.; Sampson, R. Neil. 1995. **Forest ecosystem health in the Inland West: A science and policy reader.** Washington, D.C.: Forest Policy Center, American Forests; 37 p.

Daniels, Steven E.; Walker, Gregg B. 2001. **Working through environmental conflict: The collaborative learning approach.** Westport, CT: Praeger; 299 p.

Fiedler, Carl E.; Keegan, Charles E.; Woodall, Chris W.; Morgan, Todd A; Robertson, Steve H.; and Chmelik, John T. 2001. **A strategic assessment of fire hazard in Montana.** Missoula: Bur. Business and Economic Research, The Univ. of Montana. 39 p. Available from BBER. Missoula, MT.

Fiedler, Carl E.; Keegan, Charles E.; Robertson, Stephen H.; Morgan, Todd A.; Woodall, Chris W.; Chmelik, John T. 2002. **A strategic assessment of fire hazard in New Mexico.** Missoula: Bur. Business and Economic Research, The Univ. of Montana. 27 p. Available from BBER. Missoula, MT.

Hessburg, Paul F.; Agee, James K. 2003. **An environmental narrative of Inland Northwest United States forests, 1800-2000.** Forest Ecology and Management 178: 23-59.

Huff, Mark H.; Ottmar, Roger D.; Alvarado, Ernesto; Vihnanek, Robert E.; Lehmkuhl, John F.; Hessburg, Paul F.; Everett, Richard L. 1995. **Historical and current forest landscapes in eastern Oregon and Washington. Part II: Linking vegetation characteristics to potential fire behavior and related smoke production**. Gen. Tech. Rep. PNW-GTR-355. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 43 p.

Johnson, Kenneth N.; Glenn V. Fuguitt (2000). **Continuity and change in rural migration patterns, 1950-1995**. Rural Sociology 65(1): 27-49.

Keegan Charles E.; Morgan, Todd A; Wagner Frances G; Spoelma, Timothy P.; Cohn, Patricia J; Blatner, Keith A.; Shook, Steven R. 2004. **Timber use, processing capacity, and capability to utilize small-diameter timber within USDA Forest Service, Region One timber-processing area.** Missoula: Bur. Business and Economic Research, The Univ. of Montana. 24 p. Available from BBER. Missoula, MT.

McCool, Stephen F.; Kruger, Linda E. 2003. **Human migration and natural resources: Implications for land managers and challenges for researchers**. Gen. Tech. Rep. PNW-GTR-580. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 19 p.

National Fire Plan. 2000. **A collaborative approach for reducing wildland fire risks to communities and the environment 10-year comprehensive strategy implementation plan.** http://www.fireplan.gov/reports/11-23-en.pdf

Pass, James. 2004. **A ponderosa pine forest stand and fuel dynamics model.** Pullman, WA: Washington State University; M.S. Thesis.

Pyne, Stephen J. 1982. **Fire in America: A cultural history of wildland and rural fire.** Princeton: Princeton University Press; 654 p.

Pyne, Stephen J. 2001. **The perils of prescribed fire: A reconsideration.** Natural Resources Journal 41: 1-8.

Rapp, Valerie, ed. 2004. **Western forests, fire risk and climate change.** Science Update 6(1). Portland, OR: Pacific Northwest Research Station, Forest Service, U.S. Department of Agriculture; 12 p.

Rudzitis, Gundars. 1999. **Amenities increasingly draw people to the rural west.** Rural Development Perspectives 14(2): 9-13.

Sandberg, David V.; Dost Frank N. 1990. **Effects of prescribed fire on air quality and human health.** In Walstad, John D.; Radosevich, Steven R.; Sandberg, David V. eds. Natural and prescribed fire in Pacific Northwest Forests. Corvallis, OR: Oregon State University Press; 191-218.

Schindler, Bruce; Reed, Michelle A. 1996. **Forest management in the Blue Mountains: Public perspectives on prescribed fire and mechanical thinning.** Corvallis, OR: Department of Forest Resources, Oregon State University 70 p.

Schindler, Bruce; Toman, Eric. 2003. **Fuel reduction strategies in forest communities: A longitudinal analysis of public support.** Journal of Forestry 101(6):8-15.

Stewart, Hayden G.; Blatner, Keith A.; Wagner, Frances G.; Keegan, Charles E. 2003a. **Risk and economic feasibility of processing small-diameter material in the U.S. West part I: Structural lumber.** Unpublished draft supplied by the authors.

Stewart, Hayden G.; Blatner, Keith A.; Keegan, Charles E. 2003b. **Risk and economic feasibility of processing small-diameter material in the U.S. West part II: market Pulp and OSB.** Unpublished draft supplied by the authors.

TriData. 1997. **Fire program review: Final report for the State of Washington.** Olympia: Department of Natural Resources. 284 p. Olympia, WA.

Winter, Gregory J.; Vogt, Christine; Fried, Jeremy S. 2002. **Fuel treatments at the wildland-urban interface: Common concerns in diverse regions.** Journal of Forestry 100(1): 15-21.

Wilson, Kathleen K.; Morren, George E.B. 1990. **Systems approaches for improvements in agriculture and resource management.** New York: MacMillan; 361 p.

Estimation of Risk Factors of Human Ignition of Fires in Spain by Means of Logistic Regression[1]

Jesús Martínez,[2] Emilio Chuvieco,[3] Pilar Martín[4]

Abstract

Human activity is the main factor of forest fires ignitions in Spain, as in all countries of southern Europe. As most of fires are the result of human activity and behavior, their analysis must be based on the signs left in the territory by those who are held responsible. But since this is normally difficult to achieve directly, a good solution could be inferring human sources of ignition from indirect indicators of its number, activity and distribution. The first objective of this work was to identify significant variables than can be used to predict the human ignition risk in Spain. The second one is to propose a human caused fire occurrence prediction model, with a long-term scope. The model is constructed using logistic regression by exploring relationships between the density of human caused fires in the municipality forest area during a period of 13 years (dependent variable) and 26 geographical, socio-economical and environmental variables (independent ones) for 7704 municipalities of the Spanish peninsular territory and Baleares Islands. The model predicts properly the probability that each spatial unit have of high or low incidence of man-caused fires and provides an idea of the relative importance of each human factor in the explaining ignition.

Introduction

According to data published by the General Board for Nature Conservation (GBNC) for the period 1988-99, 96 % of the fires in Spain were due, either directly or indirectly, to human intervention, which indicates the close link between fires and human activities. In view of these figures, it is obviously interesting to include the human factor in prevention plans. Nevertheless this evidence contrasts with the scant importance attributed to human, as opposed to physical, factors in quantitative analysis of fire risk.

Human risk of ignition may be defined as the probability of a fire occurring as a result of the presence and activity, either directly or indirectly, of human activity. The evaluation of human activity as an agent of ignition is a complex task, one reason being the lack of data in respect of the number of people present in a forest zone, and another being their activities and their use of fire (Vega García et al 1993). In fact,

[1] An abbreviated version of this paper was presented at the second international symposium on fire economics, planning, and policy: a global view, 19–22 April 2004, Córdoba, Spain.

[2] Research fellow at the Dept. of Geography University of Alcalá. C/ Colegios 2, 28801 Alcalá de Henares. Spain. jesus.mar@uah.es.

[3] Professor of Regional Geographical Analysis. University of Alcalá.

[4] Senior Scientist at the Institute of Economy and Geography of the Senior Council for Scientific Investigation C/ Pinar 25, 28006 Madrid. Spain.

the temporal and daily data needed to evaluate the human factor in fire risk is not generally available (Martell and others 1987) in contrast to variables such as temperature or relative humidity. Moreover, man is one of the most dynamic elements of space and his activity or attitudes on certain occasions does not tend to follow specific spatial patterns, or rather these are more difficult to determine, as in the case of pyromania or specific deliberate motivation. However, for other causes, such as those relating to recreational activities or agricultural burning it would seem easier to obtain spatial variables. All these difficulties have frequently led to investigators and the responsible fire-fighting bodies to adopt two solutions in this respect; either leave the human risk factor out of their prediction models or at least deal with it only very marginally, or they obtain some indirect estimators of human risk activity, namely indicators of activities which are the usual cause of fire and which are generally structural in nature, i.e. they refer to the most permanent feature of the land and population.

This study is based on the hypothesis that fires caused by man in a reiterated manner in a specific geographical sector cannot be explained by physical or natural conditions alone. Nor can the cause be reduced to factors of random individual human behavior. We consider that this type of fire is usually the result of a social norm and that we need to look for its cause in the conditions of the forest land, and the environmental, social and economic conditions of each area.

Studies have been carried out since the nineteen sixties in respect of the human risk of ignition in an attempt to consider the human factor by way of explanation or to predict the occurrence of fire using more or less indirect variables for the number, distribution and activities of human beings on the land, obtained mainly from censuses and survey sources (Altobellis 1983, Bertrand and Baird 1975, Christiansen and Folkman 1971, Cole and Kaufman 1963, Doolittle1972, Hasbrough 1961, Johnson 1968, Jones et al 1965). In general these studies tend to conclude that the activities perpetrated are more important than the incendiaries themselves.

In the nineteen eighties the first studies of fire risk began to appear, clearly focused more on spatial or cartographic aspects, which considered together with physical variables and human variables (Aerial Information Systems Inc. 1981, Bradshaw et al 1987, Chuvieco and Congalton 1989, Donoghue and Main, 1985, Phillips and Nickey 1978). The number of such studies increased in the nineteen-nineties due to the greater availability of digital cartographic and statistical information incorporated in Geographical Information Systems (among others: Abhineet et al 1996, Benvenuti et al 2002, Chou 1990 and 1992; Chuvieco et al 1999, Kalabokidis et al 2002, Salas and Chuvieco 1994, Vega-García et al 1993 and 1995, Vasconcelos yet al 2001, Vliegher 1992). All these studies basically use variables relating to recreational activities in the forest areas, means of communication (proximity to roads and paths etc) or to anthropic presence and pressure (population density, human settlements). These are the variables used from the outset in almost all the research since they are the easiest to spatialise, although depending on zone, they are not always the most important. Sometimes certain modifications are introduced or different means are proposed to estimate a specific factor, (for example, using the distance to the most populated zones instead of roads, or using the accessibility of certain recreational elements instead of camping zones)or new elements are introduced which have not been previously considered, such as the commercial value of the forest or they type of property.

Despite the existence of these empirical works, there is still a long way to go in terms of prediction and modeling of fire risk of human origin. An initial step in the right direction would be to identify and establish the relative importance of all the risk factors linked to human activity in each study zone. This previous effort is lacking in some of the research reviewed, which in addition might even seem somewhat reductionist, since some studies only consider a small part of the overall human factors which in reality would be linked to the occurrence. However, it is positive to note that there is a developing interest in the use of this type of variable.

Objectives

The aim of this study is to present a method and provisional results obtained for modeling human risk on a national scale in Spain. We attempted to obtain an index by means of logistic regression to predict the probability of a spatial unit having high or low occurrence of fires caused by human activity. In turn the intention was for the model to provide an idea of the relative importance of each human factor in the occurrence of fires. The results are represented as risk maps.

Study area and unit of analysis

Since the objective is to obtain an overall view of the human ignition factors in Spain, the study area covers the whole Spanish peninsula and the Balearic Islands. The regions of Navarra and the Canary Islands could not be included due to a lack of significant variables. In future works, the diverse causes and risk situations throughout the country will be taken into account, comparing different models for various regions.

The spatial unit of analysis was chosen in function of the dependent variable, i.e. bearing in mind the availability of data regarding fires. In Spain for example, the ignition points cannot be considered, as the parts of fires where the coordinates x and y can be assembled are very scarce. The townships (7004 in the study zone) were used as a base, both for geographically locating fires using parts supplied by the DGCN and for generating independent variables.

Methodology

The first step in our study was to identify, through bibliographic sources and by consulting experts, the anthropic factors relating to the occurrence of forest fires in Spain (Martínez et al 2004). We were then able to draw up a list of risk factors in which one or several variables are proposed for quantitative measurement. Depending on the data source, these variables were either statistical and/or cartographic.

Generating risk and spatial analysis variables

The "geo database" created for the 7004 municipalities in the study area comprises 23 variables of historic occurrence and causality of forest fires, and 108 independent variables relating to social, demographic and territorial characteristics. The statistical variables were compiled from censuses, and spatial variables such as the road network, protected natural spaces, land use etc. were obtained from digital maps provided by national bodies. In order to obtain municipal surfaces and other types of derived variables it was necessary to make varied spatial analyses using GIS tools:

the following programmes were used: ArcInfo 7.2, ArcGis-ArcInfo 8, ArcView 3.2. e Idrisi 3.2.

Dependent Variable

One of the most relevant questions was the choice of dependent variable, which we would attempt to explain and predict, and which was finally defined as the number of fires caused by human intervention occurring between 1988 and 2000. There are two reasons for the selection of this time period: the availability of data and the greater homogeneity of that data both in terms of compilation of the information and the nature of the causes of fires occurring in this period. Due to the variety of size of the municipality, which was the spatial unity of reference chosen for the analysis, it was necessary to normalize the variable by dividing the number of fires per municipality by the municipal forested area, according to what the GBNC considers to be the ignition index.

Independent Variables

One of the main difficulties of this work was to find digital data in an accessible format which was up to date and homogeneous for all the municipalities in the country. Frequently the data necessary to measure a specific factor does not exist for all or any of the study units. On other occasions the economic or compilation effort was extremely high. Therefore it was not possible to obtain an "ideal" number of variables, and several variables were discarded which, theoretically, were closely related to fires (for example recreational areas, hunting , suppression and prevention resources, agricultural burning permits, electrical lines, waste dumps, forest paths etc.). Altogether 108 independent variables were generated, grouped according to the type of human risk factor to which they contributed. Although many of them in reality represent similar concepts, an attempt was made to ensure that each variable would have some specific characteristic which would differentiate it from the rest. Nevertheless, as long as we work with a group of variables the degree of multiple co-linearity is inevitably very high. Despite this fact, the aim was to select solely those variables which due to a specific factor had a greater influence on or relation to the occurrence of fires which we did not know at the start.

In order to reduce the possible effects of multiple co-linearity and the noise of irrelevant variables, exploratory analyses and correlation matrices were made between all the variables. Moreover, various statistics of the diagnosis of multiple co-linearity obtained in linear regression analysis were examined, such as the tolerance coefficient, the variance inflaction factor (VIF), etc. Subsequent to these analyses 26 variables were selected to create the final risk model.

In order to ascertain that these 26 variables were adequate, several comparative statistical tests were carried out on the data groups. We wished to verify whether or not there was a significant difference in the values of the variables corresponding to the two municipal samples, some with a high and others with a low incidence of fire. If these test showed a scant difference between the values of a specific variable in these two groups of municipalities it could be assumed that this variable was not related to the occurrence of fires. U-Mann-Whitney and Ji Cuadrado's parametric and non-parametric proofs were applied to two samples and H de Kruskal-Wallis' for four samples. The three proofs showed very similar results, significantly indicating all the pre-selected variables at a level of less than 0,05.

Logistic Regression

A logistic regression model has been used previously and with good results to predict the probability of fires and to examine the most critical factors of incidence both on a local (Chou 1992, Chou et al 1993, Latham and Schilieter 1989, Loftsgaarden and Andrews 1992, Vasconcelos et al 2000, Vega-García *et al* 1993 and 1995) and on regional and global scale (Chuvieco *et al* 1999, Martell et al 1987 y 1989). This regression technique which is flexible and easy to use is the most well known and frequently used method when the dependent variable to be predicted is dichotomous according to the values of a group of predictor variables. It is based on the following function:

$$f(z) = \frac{1}{1+e^{-z}}$$

where z is obtained by an estimated linear combination of independent variables by means of maximum probability adjustment. The z values may be interpreted as the probability of occurrence of the phenomenon. converts the values for z into a continuous function with a rank oscillating between 0 and 1. Values less than 0,5 are usually assigned to non-occurrence of the phenomenon and those which are equal or greater are interpreted as occurrence. $f(z)$

Before making the regression analysis, only the municipalities which fulfilled two requirements were chosen: those which had one or more fires during the study period and those which comprised more than 50 ha (0,5 km^2) of forest surface. This was an effort to reduce cases with extreme or unusual values in the dependent variable. Thus the number of cases was reduced from 7,704 to 6,080 municipalities. In addition, in order to validate the results obtained, 60% of the cases were selected at random (that is, 3619 municipalities) which were finally used to calculate the regression function. The remaining 40% were subsequently used to validate or measure the quality of the estimations.

On the other hand, as it was a question of predicting the high or low probability of fires, the dependent variable needed to be converted to a dichotomous variable. In order to do so it was decided to order the 3,619 municipalities selected from lesser to greater incidence taking as reference the dependent variable. The variable was then divided into three groups with an identical number of cases (1206). The municipalities in the first group (low incidence) were given the value 0 and those of the third group (high incidence) were assigned the value of 1. The municipalities in the second group (average incidence) were not taken into account in construction of the model.

Calculations of logistic regression were made with the statistical packet SPSS v.11.5. S Various automatic methods were tested controlling the criteria for which the variables were introduced and eliminated from the equation**:** by one step forward, one step back and by introducing all. The cut off point for classifying the cases was established at 0.5.

Results

Having tried various automatic methods of variable selection the “stepwise forward selection algorithm” was finally chosen, which provided 17 different models. Among these the final model was chosen which achieved the highest overall result and

included the greatest number of variables. Although perhaps it is not advisable to include such a high number of variables in the model, we chose this method in an attempt, rather than obtain good predictions, to achieve an explanatory model in which it would be possible to observe the most influential variables and factors in the occurrence. The variables included in the model (with Arabic numerals) and grouped by factor type (indicated in italics) and are as follows:

Social and economic transformations in urban areas: anthropic pressure on forest areas and urban growth:

1. Percentage of urban forest interface zone in the municipality (IUFSUP_P)

2. De facto population variation between 1950 and 1970 (CRE50_70)

Social and economic transformations in rural areas: rural exodus, population ageing, abandonment of woodland cultivation and traditional activities.

3. Percentage of agricultural area which became forest land between the nineteen-seventies and nineties. (ICO_90)

Maintenance of traditional activities linked to fire in rural areas: agriculture and stock keeping

4. Occupied percentage in the primary sector (OCUPAGRA)

5. Percentage of cultivated forest land interface in the municipality (ICFSUP_P)

6. Livestock density in extensive regime on the forest surface area (GAN_FOR)

7. Percentage of woodland pasture interface in the municipality (IPFSUP_P)

Disinterest in forest land and its conservation. Insufficient protection and management of forest land:

8. Percentage of forest surface with less management, control and planning over time (private forest land, land belonging to local authorities with free use, consortiums and neighboring forest common land). (NOGES_PF)

Accessibility and risk deriving from communication roads

9. Density of roads per municipal surface area (ROADMU_D)

10. Density of railway lines per municipal surface area (FFCCMU_D)

Other factors which might cause fires through accidents or negligence:

11. Density of agricultural machinery on the municipal surface area (MAQUIN_D)

12. Percentage of the interface zone between risk infrastructures (waste dumps mines and quarries) and forest areas (IFIFSU_P)

Structure of the landscape, land and population:

13. Density and agricultural plots (agricultural fragmentation) (PAR_SEXP)

14. Percentage of population living in disseminated sites (DISEM_P)

15. Density of singular population entities (ENTSIN_M)

16. Municipal average of fragmentation index. (FRAG7X7)

Factors which generate conflicts and which could lead to deliberate fires

17. Unemployment rate (PARO)

Table 1 shows the regression coefficients and the *Wald* statistic, with its corresponding level of significance for each independent variable. Variables have been arranged in descending order according to the *Wald* statistic. The change was also calculated in –2LL if a variable is eliminated at each step (-2LL is the Napieran logarithm of the coefficient verisimilitude multiplied by –2), which is also a complementary measure of the importance of variables in the model. The variables which appear first in *table 1*, in descending order, are those which have had the most influence on the outbreak of fires at a national level: The density of agricultural machinery, density of agricultural plots, the density of singular population entities, density of livestock in extensive regimes in forest areas and the unemployment rate.

Table 1— *Variables included in the model and regression coefficients*

Variables: Step 17	Coef B	E.T.	Wald	gl	Sig.	Exp(B)	Change in -2LL if the variable is eliminated
MAQUIN_D	0,538	0,047	129,150	1	0,0000	1,7132	186,234
PAR_SEXP	0,013	0,002	64,595	1	0,0000	1,0130	76,107
ENTSIN_M	6,999	0,974	51,647	1	0,0000	1095,8907	71,469
GAN_FOR	0,013	0,002	51,451	1	0,0000	1,0127	88,979
PARO	0,026	0,005	25,014	1	0,0000	1,0259	25,047
ICFSUP_P	-0,130	0,027	22,853	1	0,0000	0,8778	23,785
CRE50_70	0,011	0,002	22,796	1	0,0000	1,0109	27,955
ROADMU_D	0,002	0,000	16,492	1	0,0000	1,0020	17,040
FRAG7X7	102,114	25,165	16,465	1	0,0000	2,225E+44	16,895
DISEM_P	-0,027	0,007	15,474	1	0,0001	0,9731	17,271
FFCCMU_D	0,003	0,001	9,377	1	0,0022	1,0030	9,624
OCUPAGRA	0,010	0,004	7,391	1	0,0066	1,0101	7,431
IPFSUP_P	-0,125	0,046	7,282	1	0,0070	0,8827	7,549
IFIFSU_P	0,767	0,317	5,840	1	0,0157	2,1531	7,609
IUFSUP_P	0,319	0,141	5,100	1	0,0239	1,3752	6,490
ICO_90	0,011	0,005	4,759	1	0,0291	1,0109	4,667
NOGES_PF	-0,005	0,002	4,443	1	0,0350	0,9949	4,420
Constant	-3,766	0,326	133,579	1	0,0000	0,0231	

According to these results, risk factors such as land structure, specially fragmentation of agricultural activity and the negligent use of fire in traditional activities in rural areas (burning brush carried out by shepherds to regenerate pasture and burning slash and the remains of pruning and thinning) are of considerable importance in the outbreak of fires in Spain. Other variables included in the model are: the urban-forest interface, presence of road and railway density and the population variation between 1950-1970. Most of the coefficient signs for each variable are logical with respect to prior knowledge of the causes of fires in Spain.

For some variables the relation is not expected, as in the case of the agricultural forest interface which has a negative coefficient. These contradictory signs may be due to possible effects of multiple co-linearity which it was not possible to eliminate.

The goodness of fit of the regression is indicated in *table 2*. The percentage of overall success of classification is over 85 % and reaches 90% for municipalities with a low incidence of fire. It may be said that the accuracy of the classification is very good if we consider that the study area is quite large and covers extremely varied situations of human risk and causality and the fact that physical variables were not taken into account.

Table 2— *Contingency table of success/error of the classification by logistic regression. Predicted cases opposed to observed cases(sample of 60%)*

OBSERVED	**PREDICTED**			
	Lowa	Alta	% de acuerdo	
	0	1		
Low occurrence	0	1080	117	90,23
High occurrence	1	221	976	81,54
Global percentage of success	**85,88**			

In order to confirm the validity of the results, the equation resulting from the model was applied to the control sample which included 40 % of the municipalities (1640). The global percentage in agreement is almost the same (84% correctly classified) as that obtained with the original sample of 60% with which the model was constructed.

Figure 1 shows a map contrasting the probability of fire predicted with that observed for the group of municipalities used in the validation (sample of 40%). The municipalities where prediction and occurrence do not coincide are represented in blue (overestimated or predicted but not observed) or in green (observed but not predicted or underestimated). In these cases the model does not function adequately, which indicates that it would be necessary to take into account other explanatory

variables or even to design another different model for these cases. The correctly classified models are indicated in red and orange.

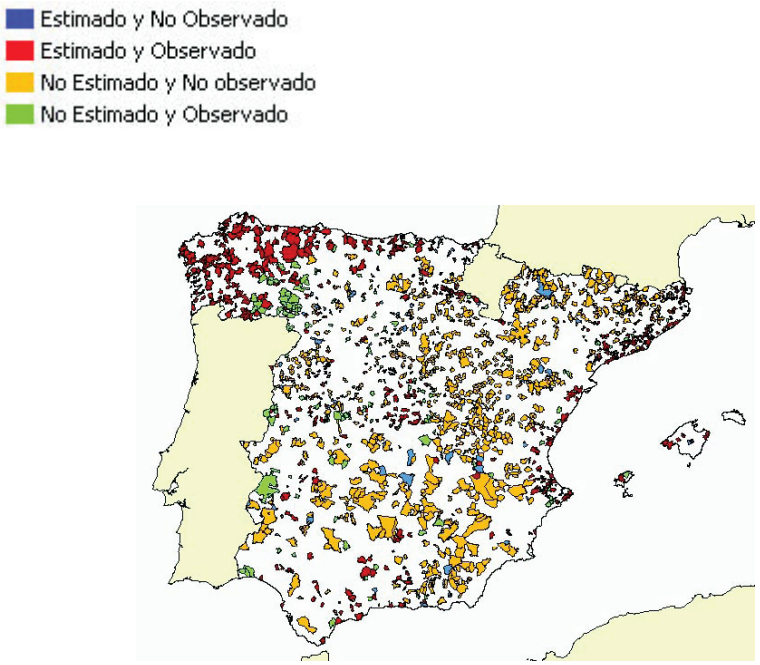


Figure 1—Validation of the model of estimation of outbreak . Predicted outbreak as opposed to observed outbreak (sample of 40%)

Once the validity of the model had been observed, it was applied to all the cases in the study area which fulfilled the previously mentioned requirements (6080 municipalities) and a map was generated expressing on a probability scale of 0 to 1, the estimated possibility that a municipality would have a high incidence of fires caused by human activity (*fig. 2*). The scale has been divided into five intervals with the same number of cases (quantile) to facilitate visualization. The municipalities in white are those which were not considered in the analysis since they had not suffered any fires and did not have over 50 hectares of forest land.

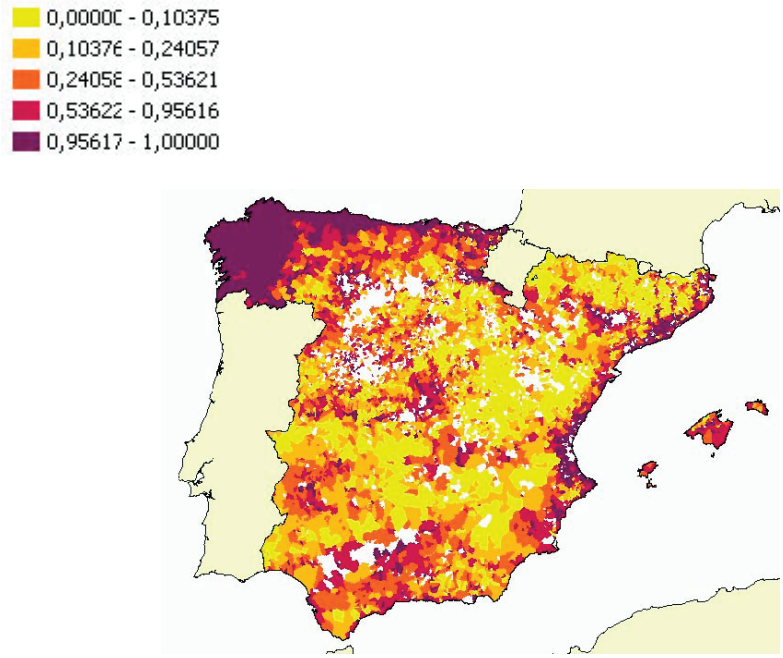


Figure 2—Probability of high incidence of fires due to human factors

A visual comparison of this map and the map featured in *figure 3*, which represents the original dependent variable provides an idea of the appropriateness of the model to the reality of historical incidence.

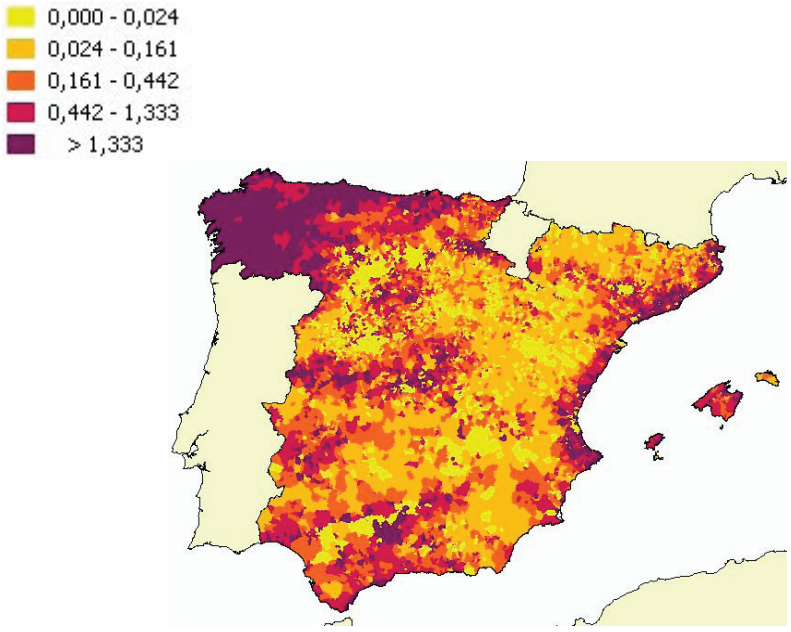


Figure 3— Ignition index: number of forest fires caused by human intervention /forest surface area of the municipality (classification of intervals by quantile)

Conclusions

This paper has attempted to show the potential of spatial statistics and cartography of structural risk as tools for improving knowledge of forest fires, particularly necessary with a view to planning and designing prevention plans and policies at a national level. The method of logistic regression has once more shown that although there are some limitations, it is a simple and efficient technique for studying the variables which explain fire risk, in this case to identify the most influential human factors on a global scale in Spain.

The results obtained confirm the importance of the negligent or intentional use of fire in agricultural activities in rural areas. According to the data on causes for the period 1988-2001, burning of underbrush to regenerate pasture and agricultural fires for various purposes are the main recognized cause of both negligence(42,7%) and deliberate fires (69,6%). Both presuppose 20,4% of the total causes of fires, although it is estimated that they may reach 50%. On the other hand, factors referring to the structure of the landscape or territory such as the division of agricultural plots (smallholdings) or the rate of fragmentation linked to the abandonment of agricultural land (percentage of agricultural to forest land) would seem to contribute to the creation of extremely hazardous situations. We consider that the generalized abandonment of agricultural plots, however small in size, which have been colonized by highly inflammable vegetation constitutes a serious threat to the neighboring forest, despite the latter being well tended. This situation is sometimes aggravated by the existence of social conflict and exploitation of the area.

The results also confirm that the proximity of certain types of occupation may contribute to the outbreak of fire (forest/agricultural, forest/pasture and urban/forest interfaces) since in addition to the risk associated with negligent or deliberate use of fire in rural or urban activities, these structures imply a greater transit through forest zones as opposed to large homogeneous forest masses. Specifically, risk may be very high in the urban forest interface zone. Other influential factors are the form in which the population inhabits and is distributed throughout the territory (density of singular entities of population and population living in disseminated areas) since this may encourage a greater presence of human agents in habitual contact with the forest area.

Finally as expected, the presence and density of roads and railways shows a significant link with fires, as well as the variation of population between 1950 and 1970, an period which was notable in Spain for its rural exodus and urban growth. In addition the unemployment rate appears to be quite related to the occurrence. In this sense some authors (Bertrand y Baird 1975, Leone y Vita 1982, Vélez 2000), have indicated that economic difficulties may influence the appearance of conflicts manifested in the use of intentional fire.

All these results should be considered only as valid for Spain, since there is no guarantee that they might be applicable in any other place. It is highly likely that some of the variables selected here are not linked to the occurrence of fire in other regions or countries. Also the model developed is global in nature, in the sense that it does not take into account local and regional variations within the study area, which of course are quite important. We therefore consider that this work should be extended to construct regression models weighted especially for each of the units of analysis by means of spatial statistical technique of a local type which would enable

us to identify the variables with regression coefficients, which vary significantly throughout the area both in sign and magnitude (Fotheringham 2002).

References

Altobellis, A. 1983. **A survey of rural population density and forest fire occurrence in the South, 1956-1970**. Report S0-294. New Orleans, Southern Forest Experimental Station. Forest Service, U.S. Department of Agriculture.

Abhineet, J.; Ravan, S. A. et al. 1996. **Forest fire risk modelling using remote sensing and geographic information system**. Current Science 70(10): 928-933.

Aerial Information Systems Inc. 1981. **Final report spatial risk method for predicting wildland fire occurrence**. Crestline, California, USDA, Pacific Southwest Forest and Range Experiment Station. Report C0027.00

Benvenuti, M., Testi, C. et al. 2002. **Forest Fires Ignition Probability Model: test and validation on FORFAIT Italian pilot site.** En: IV International Conference on Forest Fire Research & 2002 Wildland Fire Safety Summit, ADAI & Univ of Coimbra.

Bertrand, A.L.; Baird, A.W. 1975. **Incendiarims in Southern Forest: a decade of sociological research**, Southern. For. Exp. Stat. Social Science Research Center at Mississipi University. Bulletin nº 838. Forest Service.U.S. Department of .Agriculture.

Bradshaw, W.G.; Webster, A.L. et al. 1987. **GIS and Wildland Fire Prevention Planning: an on-the-Ground Test**. En: Proceedings of GIS' 87, San Francisco, California.

Chou, Y.H. 1990. **Modeling Fire Occurrence for Wildland Fire Management: A GIS Spatial Analysis for Fire Control and Prevention**. En: Proceedings of GIS/LIS'90, Anaheim, California.

Chou, Y.H. 1992. **Management of Wildfires with a Geographical Information System**. International Journal of Geographical Information Systems 6(2): 123-140.

Christiansen, J.; Folkman, W. 1971. **Characteristics of people who start fires...some preliminary findings**. Berkeley, Cal., Pacific Southwest Forest and Range Experiment Station. Research Note PSW-251. Forest Service. U.S. Department of .Agriculture.

Chuvieco, E.; Congalton, R.G. 1989. **Application of remote sensing and Geographic Information Systems to Forest fire hazard mapping**. Remote Sensing of Environment 29: 147-159.

Chuvieco, E.; Salas, F. J. et al. 1999. **Integrated fire risk mapping**. En: Chuvieco, E., ed. Remote Sensing of Large Wildfires in the European Mediterranean Basin. Berlin, Springer-Verlag: 61-84.

Cole, L.W.; Kaufman H.F. 1963. **Socio-economic factors and forest fire in Mississipi counties**. Preliminary Report 14. Mississipi. USA: Mississipi State University Social Sciences Research Centre; 68 p.

Donoghue, L.R.; Main, W.A. 1985. **Some Factors Influencing Wildfire Occurence and Measurement of Fire Prevention Effectiveness**. Journal of Environmental Management 20(1): 87-96.

Doolittle, M.L. 1972. **The dimensions of man-caused forest fire risk: a systematic assessment**.. Seattle, University of Washington, College of Forest Resources. Tesis Doctoral.

Fotheringham, A. S., Brunsdon, C. y Charlton, M. 2002. **Geographically Weighted Regression. The analysis of spatially varying relationships.** West Sussex, John Wiley & Sons, Ltd.: 269 p.

Hasbrough, T. 1961. **A sociological analysis of man-caused forest fires in Lousiana**. Baton Rouge, Lousiana State University. Ph.D. Thesis.

Johnson, F.B. 1968. **Demographic and socioeconomic factors and forest fire in the southearstern United States.** Mississipi, USA., Mississippi State University M.Sc.Thesis: 73 p.

Jones, A.R.; Taylor, M.L. et al. 1965. **Some human factors in woods burning**. Agricultural Experiment Station Bulletin Nº. 601. Baton Rouge, La., La. State University: 28 p.

Kalabokidis, K.D.; Konstantinidis, P. et al. 2002. **GIS analysis of physical and human impact on wildfire patterns**. En: IV International Conference on Forest Fire Research & 2002 Wildland Fire Safety Summit, Coimbra, Portugal, ADAI & Univ. of Coimbra.

Latham, D.J.; Schlieter, J.A. 1989. **Ignition probabilities of wildland fuels based on simulated lighting discharges**. Res. Pap. INT-411. Ogden. UT: Intermountain Research Station. Forest Service, U.S. Department of Agriculture: 16 p.

Leone, V.; Vita, F. 1982. **Incendi boschivi e marginalitá economica: il caso della Puglia**. Cellulosa e Carta 7/8: 41-57.

Lin 1999. **Modeling probability of ignition in Taiwan Red Pine Forests**. Taiwan Journal Forest Science 14(3): 339-44.

Loftsgaarden, D.; Andrews P.L. 1992. **Constructing and testing logistic regression models for binary data: applications to the National Fire Danger Rating System**. General Technical Report INT-286. Ogden, UT: Intermountain Research Station. Forest Service U.S. Department of Agriculture: 36.

Martell, D.L.; Bevilacqua, E. et al. 1989. **Modelling seasonal variation in daily people-caused forest fire occurrence**. Canadian Journal of Forest Research 19(12): 1555-1563.

Martell, D.L.; Otukol, S. et al. 1987. **A logistic model for predicting daily people-caused forest fire occurrence in Ontario**. Canadian Journal of Forest Research 17: 394-401.

Martínez, J., Martín, M. P. et al. 2004 [en prensa]. **El factor humano en los incendios forestales: análisis de factores socio-económicos relacionados con la incidencia de incendios forestales en España**. En: Chuvieco E.; Martín. M.P. e.d. Nuevas tecnologías para la estimación del riesgo de incendios forestales. Madrid. Colección de Estudios Ambientales del Consejo Superior de Investigaciones Científicas.

Phillips, C.B; Nickey. 1978. **The concept of spatial risk and its application to fire prevention**. Fire Management Notes 39(4): 7-8-19.

Salas, J.; Chuvieco, E. 1994. **GIS applications to forest fire risk mapping**. Wildfire 3:7-13.

Vasconcelos, M.J.P.; Silva, S. et al. 2001. **Spatial prediction of fire ignition probabilities: comparing logistic regression and neural networks**. Photogrammetric Engineering and Remote Sensing 67(1): 73-83.

Vega Garcia, C.; Woodard, P.M. et al. 1993. **Geographic and temporal factors that seem to explain human-caused fire occurrence in Withecourt Forest, Alberta**. En: Proceedings of GIS'93 Symposium, Vancouver, British Columbia.

Vega García, C.; Woodard, P.M. et al. 1995. **A logit model for predicting the daily occurence of human caused forest fires**. International Journal of Wildland Fire 5(2): 101-111.

Vélez, R. 2000. **La defensa contra incendios forestales. Fundamentos y experiencias**. En: McGraw-Hill/Interamericana de España S.A.U. Madrid: 1281 p.

Vliegher, B.M.d. 1992. **Risk assessment for environmental degradation caused by fires using remote sensing and GIS in a Mediterranean Region (South-Euboia, Central Greece)**. En: IGARSS'92. Int. Geoscience and Remote Sensing Symposium. Houston, TX: 44-47.

Socioeconomic Value of Fire Weather Services: A Case Study of Fire Weather Information for Prescribed Burning [1]

Don Gunasekera, Graham Mills, Tony Bannister [2]

Abstract Head style

Fire weather services ranging from fire weather warnings to special forecasts for hazard reduction burns are important inputs into the decision making processes of fire management authorities that enable effective decision making at various stages of fire management. For example, fire management authorities can pre-position personnel and equipment to minimise fire damage based on timely and accurate fire weather forecasts and warnings. The socio-economic value or benefit of the forecasts reflects the improvement in economic and related outcomes resulting from the use of fire weather services. The focus of this study is the socio-economic value or benefit of current and improved fire weather services aimed at prescribed burning in the Victorian region in Australia. The study has three major components. The first relates to the formulation of a conceptual framework to analyse the likely outcomes resulting from the better use of fire weather services in undertaking prescribed burning, and the associated benefits. Depending on the circumstances, these outcomes will relate to improved fuel reduction and reduced incidence of high intensity fires with extensive spread. The associated potential benefits will relate to minimisation or avoidance: of damage to timber assets, private property and public infrastructure; of agricultural production losses; of disruption to other economic activities; of human injury and fatalities; of damage to recreational sites and public amenities; of adverse ecological and environmental impacts; and of adverse effect on public health and general visibility due to smoke dispersion. The second major component of the study relates to an assessment of the associated benefits resulting from the better use of fire weather services. Some of these benefits will have market values and the others non-market values. The final component of the study will make a comparison between the potential socio-economic benefits of the better use of fire weather services aimed at prescribed burning and the costs associated with the provision of the current and improved fire weather services. The benefit-cost comparisons can provide useful information for improvement of existing fire weather programs and also assist in making decisions on future investments in specific activities.

Introduction

Bushfires are a major phenomenon in the Australian environment, which have the potential to threaten human life and damage property, infrastructure, agricultural and forest production, livestock, biodiversity, clean air and water, and cultural heritage. Over the past three decades, Australia has been affected by between 20 to 25 major bushfires (see BTE 2001). In addition to these large-scale major bushfires, every year many small-scale bushfire incidents occur across Australia, which cause damage to property and in some instances the loss of human

[1] An abbreviated version of this paper was presented at the second international symposium on fire economics, planning, and policy: a global view, 19–22 April, 2004. Córdoba, Spain.

[2] The authors are attached to the Australian Bureau of Meteorology, GPO Box 1289K, Melbourne, VIC 3000, Australia.

life. The risk to property and human life continues to grow as forest areas on the fringes of urban areas become more densely populated (see CIE 2001).

Bushfire management involves decision making at various stages of fire management including prevention, mitigation and response. Effective fuel reduction can play a crucial role in bushfire prevention and mitigation. Although there is a range of fuel reduction methods, prescribed or planned burning is the most common and efficient method of fuel reduction for large areas of land. There is a renewed emphasis on fuel reduction programs including prescribed burning, following the major bushfires in the recent past. Prescribed burning can be regarded as a method by which the impact of bushfires can be reduced (Victorian Government 2003). Associated with prescribed burning is the issue of the dispersion of smoke plumes produced and their potential impact on human health. Fire weather services including special forecasts for specific locations are important inputs into the decision making processes of fire management authorities who are engaged in a range of fire management activities including prescribed burning.

The process of providing and using fire weather services is resource intensive and involves challenging tasks. One of the primary objectives of providing and using fire weather information in prevention and mitigation of bushfires is to ensure that the potential and actual threats to human life, property and other assets due to bushfires are minimized or avoided. Hence the focus of this paper is value or benefits likely to result from the use of fire weather services with a particular emphasis on fire weather services aimed at prescribed burning.

The next section will describe a conceptual framework to analyze the likely outcomes and associated benefits resulting from the use of fire weather services in undertaking prescribed burning. In the third section of the paper an attempt will be made to assess the associated benefits resulting from the better use of fire weather services using the Victorian region in Australia as a case study. A comparison of the benefits and the costs of the better use of fire weather services is attempted in the fourth section. The final section will have some concluding remarks.

Conceptual Framework

It is important to recognize that the impact of bushfires is influenced by many factors including weather and climatic conditions, the extent and condition of fuel load, forest structures, human activity, fire management and mitigation procedures etc. It is not easy to quantify the relative importance of individual factors and then clearly attribute the effect of each of these factors on the impact of bushfires. Nevertheless, it is clear that closer examination of each of these factors could provide useful insights into the management, control and reduction of the impact of bushfires. The focus in this paper is on the impact of the fire weather services provided to fire management agencies in support of fire management and mitigation.

Fire Weather Services

There is widespread recognition of the importance of fire weather services in understanding and dealing with the effect of weather and climatic conditions on the impact of bushfires. Without a clear understanding of the ‘counterfactual’ – the world without the Australian Bureau of Meteorology (the Bureau) fire weather services – it is impossible to assess the true impact that the fire weather services have had, and

continue to have, on controlling and reducing the impact of bushfires. However, given the considerable expenditure on public good meteorological services including fire weather services, it is important t As indicated earlier, the provision of fire weather services in general is funded by the Government. The question then is what does the community (and the economy) get for their money in terms of controlling and reducing the impact of bushfires?

The Bureau provides a range of fire weather services in each state including Victoria as part of a national framework for the provision of such services (Bureau of Meteorology 2004) (see *box 1*). Efforts are being made in an ongoing basis to enhance these services in order to improve the accuracy and operational utility of fire weather forecasts, warnings and outlooks. These enhanced efforts on service improvement and delivery are internally funded within the Bureau (as part of the ongoing continuous improvement process) and in some cases externally funded through a range of collaborative efforts such as the newly established Cooperative Research Center (CRC) for Bushfires.

Box 1—Fire weather services provided by the Bureau in Victoria

The Australian Bureau of Meteorology provides fire weather services in Victoria as part of a national framework for the provision of such services in accordance with the provisions of the Meteorology Act (1955).

The primary objectives of the fire weather service are:

a) To provide the public with:

- Routine forecasts of fire danger during the fire season;

- Fire Weather Warnings when the fire danger is expected to exceed a certain critical level; and

b) To provide fire management authorities, civil defence organizations, police and other emergency services with:

- Detailed routine forecasts during the fire season;

- Fire weather warnings when the fire danger is expected to exceed a certain critical level;

- Operational forecasts to assist in combating ongoing fires;

- Special forecasts for hazard reduction burns;

- Advice regarding the installation and operation of special meteorological stations operated by fire authorities;

- Consultative advice and climatological information to assist with assessment of risk, development of fire prevention strategy, and other aspects of fire management

The Routine Services

During the fire season in Victoria (normally November through April), the Bureau's Victorian Regional Forecasting Center (RFC) routinely provides the Country Fire Authority (CFA) and Department of Sustainability and Environment (DSE) with the following services:

- forecasts issued at 6.30 am each morning of weather and Forest and Grass Fire Dangers for the current day for 25 Victorian centers (plus State border areas);

- written Fire Weather Briefings issued at 10.45 am each morning that focuses on current daytime conditions and how the situation described in the 6.30 am forecast is actually evolving;

- a 4-day forecast suite issued each afternoon comprising: - forecasts of weather and Forest and Grass Fire Danger Ratings for the next two days for 25 sites around Victoria;

- longer-term forecasts of weather and Fire Danger for days +3 and +4 for 9 sites around Victoria;

- a sequence of prognosis charts and accompanying text describing the expected evolution of the weather pattern over the next 4 days.

Routine fire weather forecast information is also provided to the general community in the form of Fire Danger Ratings that are appended to District Forecasts.

Warnings and Special Fire Services

As well as routine services that are provided each day during the Fire Season, additional services are provided when extreme fire danger is expected and/or when fires are burning. These include:

Fire Weather Warnings issued on a District basis when the fire danger is expected to reach Extreme. These are issued publicly and are used by CFA as a key input into decisions about the declaration of a Total Fire Ban;

Wind Change Chart: This is issued to the fire agencies on days of significant fire risk when a wind change is expected to affect the State. These charts show the current and expected future position of the change and are used by agencies when developing operational fire management strategies and tactics;

Spot Fire Forecasts: These are highly detailed fire weather forecasts that are issued for specific locations in which a fire is burning or where a controlled burn is planned. They include information on the expected wind, temperature, relative humidity and other meteorological factors such as the timing of any wind changes.

On request, the Bureau can provide a forecaster at CFA Headquarters on critical days and, for large ongoing fires, a forecaster may be 'outposted' to a fire incident control center;

Regular consultation is maintained between Bureau forecasters and the fire agencies. Bureau staff provides detailed briefing to fire chiefs, senior operational personnel and participate in operational briefings, both in person and by teleconference.

Outcomes of Fire Weather Services

It can be argued that the current and enhanced fire weather services from the Bureau, once incorporated into the decision making processes and the fire management activities of the fire management authorities will assist the authorities to operate in a timely and effective fashion by better mobilizing their personnel and equipment, resulting in reduced impact of bushfires and risks to personnel. There is a wide range of economic, social and environmental effects of the provision and use of current and enhanced fire weather services *(fig. 1)*. There is a common view that the community and the economy receive considerable benefits (or reduced losses) as a result of the use of fire weather services (Sol 1994). However not all of the benefits or reduced losses are easy to quantify, and those that are easy to quantify are most likely to be the benefits or reduced losses to individuals, private firms or farms and any other specific entities. Quantifying all the benefits or reduced losses is an almost impossible task.

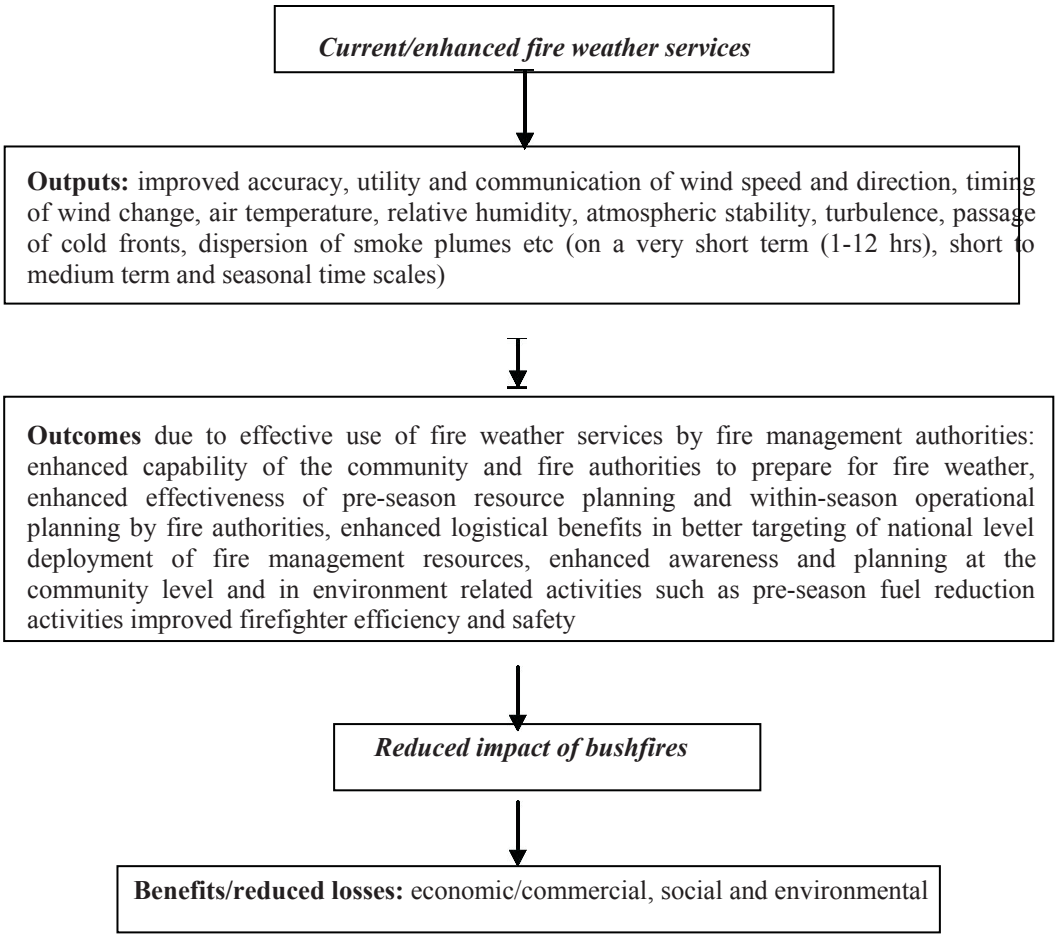


Figure 1— Summary of outputs and outcomes of fire weather services

Potential Benefits or Reduced Losses

The potential benefits of reduced impact of bushfires can be viewed from the perspective of economic/commercial, social and environmental outcomes. The economic and/or commercial outcomes may involve reduced damage to timber assets, property and infrastructure, buildings, fences and vehicles, farm production, activities of businesses, personal belongings, etc. The social outcomes could range from reduced human fatalities and injury, psychological trauma, and destruction of personal memorabilia. The environmental outcomes may include reduced damage to native flora and fauna, water quality, amenity values and reduced greenhouse gas emissions (see CIE 2001). Failure to reduce the impact of bushfires means a range of costs on the community and the economy. Some of these costs have market values (tangible) and can be easily quantifiable while others have non-market values (intangible) and may not be easily quantifiable. Based on CIE (2001) and BTE (2001), the main types of costs and the appropriate techniques for estimating each cost item are summarized in *table 1*. It is very likely that the current and enhanced

fire weather services from the Bureau, once incorporated into the decision making processes and the fire management activities of the fire management authorities do assist the authorities to operate in a timely and effective fashion by better mobilizing their personnel and equipment, resulting in reduced impact of bushfires, and hence reduced costs to the community and the economy.

Comparison of Scenarios

A plausible approach to analyzing the likely outcomes and the associated benefits resulting from the provision and use of fire weather services is to compare the outcomes emanating from a 'base line' scenario with those of an 'alternative' scenario. The 'base line' scenario can be described in the form of future expected impact of bushfires over a specified period assuming the use of *current* fire weather services in assisting the prevention and control procedures that are applied to manage bushfires. The alternative scenario is a case in which the impact of bushfires is reduced as *improved* fire weather forecasts are used in assisting the prevention and control procedures that are applied to manage bushfires. The overall or gross benefits of *improved* fire weather services can be expressed in the form of the difference in bushfire damage costs 'with' and 'without' the adoption of improved fire weather services.

The base line scenario represents the provision of the current suite of fire weather services issued by the Bureau including the extent and nature of the services aimed at assisting the fire authorities and the community to prevent and/or minimize bushfires. A plausible assumption to make is that, given other relevant factors remained unchanged, the use of the current suite of fire weather services by the fire authorities and the community will result in a continuation of the status quo level of the impact of bushfires.

An alternative scenario can reflect an improvement to the current suite of fire weather services including the improved timeliness, enhanced accuracy and better communication of the services provided by the Bureau. Under this scenario, it is expected that the fire authorities and the community will better use these improved services. Likely outcomes due to the better use of these improved fire weather services by the fire authorities may include effective prescribed burning which could result in improved fuel reduction and reduced incidence of high intensity fires with extensive spread. Also, better use of the improved fire weather services will enable the fire authorities and other emergency management service providers to better pre-position their resources including the relocation/deployment and mobilization of staff and equipment leading to reduced impact of bushfire related damages or losses. As indicated earlier, the associated potential benefits could be wide ranging depending on the location and circumstances of the specific bushfires cases. These potential benefits will relate to minimization or avoidance: of damage to timber assets, private property and public infrastructure; of agricultural production losses; of disruption to other economic activities; of human injury and fatalities; of damage to recreational sites and public amenities; of adverse ecological and environmental impacts; and of adverse effect on public health and general visibility due to smoke dispersion.

The assessment of the overall benefits of *improved* fire weather services would require an estimation of bushfire damage costs 'with' and 'without' the adoption of improved fire weather services. In estimating the bushfire damage costs, CIE (2001) highlights two broad procedures: first, the importance of evaluating the *damage costs*

on a per hectare burnt basis for *minor bushfire events* and the associated timber losses; and for other cases such as injuries, fatalities and damage from *major bushfire events*, the appropriateness of basing the *damage costs on event frequencies basis* rather than areas burnt basis. Hence, according to CIE (2001) it is inappropriate to assess health and safety risks associated with a bushfire as a function of area burnt. Instead, it is more appropriate to estimate the total damage costs including the cost of injuries and fatalities by multiplying the estimated cost of an individual bushfire event by the expected future frequency of events with and without the adoption of, for example, improved fire weather services (see CIE 2001).

Table 1—Summary of the types of costs that could be reduced by effective use of fire weather services.

Cost item	Estimation technique
Market or tangible items	
Damage to timber assets	Market value
Damage to private property assets	Insurance pay-out
Farm production losses	Market value or insurance pay-out
Damage to public infrastructure	Replacement or repair costs
Disruption to businesses	Lost net income
Disruption to road freight and transport services	Delay costs incurred by affected businesses
Degradation of water quality in affected areas and catchments	Additional water treatment costs
Transaction costs (eg. legal proceedings)	Observed costs from previous events
Non-market or intangible items	
Human fatalities	Human capital approach or stated preference method
Human injury	Human capital approach or stated preference method
Loss of personal memorabilia	Stated preference method
Psychological trauma	Stated preference method
Damage to recreation sites	Stated preference or revealed preference method
Damage to native flora and fauna	Stated preference method
Greenhouse gas emissions	Estimated cost of carbon emissions under permit trading scheme

Source: Based on CIE (2001) and BTE (2001)

Assessment of Benefits or Reduced Losses

In this section a preliminary attempt will be made to assess the associated benefits or reduced losses resulting from the better use of fire weather services using the Victorian region in Australia as a case study. The idea here is to assess these benefits by making certain plausible assumptions about several key factors, namely, the current level and suite of fire weather services provided by the Bureau in the Victorian region, the efforts in terms of research and analysis, (and hence the flow on expected results) which is underway at present to improve these services in the future, and the likely consequences of the effective use of improved fire weather services by fire authorities, other emergency management service providers and the

community on the impact of bushfires. Based on the available data and information from various sources, a back-of-the-envelope analysis is undertaken to estimate the bushfire damage costs 'with' and 'without' the adoption of improved fire weather services.

Estimates of Bushfire Damage Costs

The bushfire damage costs used in this paper are based on a detailed analysis of such costs calculated by the CIE (2001) in a recent study of the anticipated benefits of reduced impact of bushfires in Australia expected to result from a research and development study carried out by the Commonwealth Scientific and Industrial Research Organization (CSIRO). The CSIRO study (Project Vesta) aimed at developing improved protocols for prescribed burning based on the research into behavior and spread of high-intensity bushfires. The results of the CSIRO study are expected to be used to: reduce the incidence of damaging forest fires by improving prescribed burning guidelines and procedures; reduce the health and safety risks to firefighters by providing improved tactical decision aids; and reduce the health and safety risks to the public by developing better early warning systems (CIE 2001). Although the CSIRO study and the Bureau's ongoing efforts to improve the fire weather services are not directly comparable, they both are aimed at reducing the impact of bushfires. In other words, in both cases the ultimate objective is to reduce the impact of bushfires. Given this and also due the paucity of information and estimates of the bushfire damage costs, this paper relies heavily on the cost of bushfire damages estimated in the CIE (2001) based on the CSIRO Project Vesta.

CIE (2001) estimates of bushfire damage costs are based on the analysis of two major sources of primary data. These sources include a database called EMATrack, which is maintained by Emergency Management Australia, and various electronic records held by State land management agencies in Australia.

Damage costs per area burnt – minor bushfires

By extrapolating the information on the cost of major bushfire events contained in EMATrack to the minor bushfire events recorded in State fire databases, CIE (2001) has estimated the unit cost associated with minor events, expressed as losses per area burnt. This amounts to a damage cost of $133 000 for every 1000 hectares burnt by bushfires. These costs relate to damage caused to property, assets and agricultural production (CIE 2001). CIE (2001) analysis based on State agency statistics indicates that average annual area burnt due to bushfires nationally in Australia (excluding Northern Territory) is around 440 000 hectares. In the state of Victoria, it is estimated that the average annual area burnt due to bushfires is around 110 000 hectares with an average annual number of fires of around 600 (CIE 2001). This means that 25 percent of the area burnt in Australia (excluding Northern Territory) due to bush fires generally takes place in Victoria.

Damage costs – major bushfires

Major bushfire events lead to various losses ranging from insured losses to property, assets and agricultural production, to human fatalities and injuries. As indicated earlier, since mid 1960s Australia has experienced between 20 to 25 major

bushfire events. According to CIE (2001), this equates to one major bushfire event in every 17 months (or approximately every one and half years) and on average each major event has caused $106 million of insured losses in present value terms. This implies that the annual insured loss due to major bushfires is around $70 million per year *(table 2)*.

The majority of Australia's forests (just over 90 percent) is regarded as non-productive, meaning that it is either protected from logging or not commercially viable for harvesting (see CIE 2001). Most of the remainder constitutes native hardwood forests, with small proportion comprising hardwood and softwood plantations (CIE 2001). These timber resources collectively are estimated to have a standing value of $10.4 billion (see CIE 2001). Based on the average area of forests affected by bushfires annually, CIE (2001) has estimated that the current value of annual timber losses is around $7.3 million per year *(table 2)*.

CIE (2001) has also calculated the economic cost of human fatalities and injuries associated with bushfires based on estimates made by the BTE (2001) in relation to economic cost of natural disasters. BTE (2001) estimates on the economic cost of human fatalities and injuries are based on the use of 'value of human capital' approach to quantifying the cost of death and non-fatal injuries. According to these estimates, the costs per human fatality and per serious injury are around $1.4 million and $0.2 million respectively (BTE 2001 and CIE 2001). According to CIE (2001) estimates based on national bushfire damage statistics, on average nine fatalities have occurred per major bushfire event. This implies that the economic cost of human fatalities per major bushfire event is around $12.5 million (or $8.3 million per year assuming that one major bushfire event occurs in every 17 months (or approximately every one and half years) as discussed earlier) *(table 2)*. CIE (2001) estimates also indicate that over the past several decades the average number of people injured due to bushfires is around 104 per event and the ratio of serious to minor injuries has been around 1 to 3, implying that the average number of serious human injury per event is around 26. Based on the estimated cost of $0.2 million per serious injury as indicated earlier, these figures imply that the economic cost of serious human injury per major bushfire event is $5.2 million or $3.5 million per year *(table 2)***.** As illustrated in *table 2* the overall damage cost per year due to major bush fires in Australia is estimated to be just under $90 million per year.

Table 2—Summary of estimated damage costs due to minor and major bushfires in Australia

Type of cost	Estimated cost
Minor bushfires	
Damage costs per area burnt	$133 000 for every 1000 hectares burnt by bushfires.
Major bushfires	
Insured losses (e.g. to property, assets and agricultural production)	$70 million per year
Damage to timber assets	$7.3 million per year
Cost of human fatalities	$8.3 million per year
Cost of serious human injury	$3.5million per year

Source: Based on CIE (2001) and BTE (2001)

As described earlier, it is estimated that the average annual area burnt in Victoria due to bushfires is around 110 000 hectares. Assuming a damage cost per area burnt

of $ 133 000 for every 1000 hectares burnt *(table 2),* this amounts to $14.6 million per year. Furthermore, on the basis that 25 percent of the area burnt in Australia due to bush fires generally takes place in Victoria, it could be inferred that 25 per cent of overall damage cost per year due to major bush fires in Australia of $90 million per year, that is $22.5 million per year, will also occur in the state of Victoria. Although the extent of bushfire damage impact discussed here is an approximation, it provides a broad indication of the likely average damage costs over time based on the best available information and plausible assumptions.

Baseline scenario

Under the baseline scenario, it is assumed that the provision and use of current fire weather services by the Bureau in the Victorian region in assisting the prevention and control procedures that are applied by fire authorities, other emergency management service providers and the broader community will continue. This also implies that the fire authorities, other emergency management service providers and the broader community will continue to adopt their current approaches and methods for preventing and controlling bushfires in Victoria resulting in a status quo level of bushfire impact. Hence, the bushfire damage costs in Victoria under the base line scenario will remain at their current level based on historical estimates implying an estimated $14.6 million of damage cost due to the area burnt and an additional damage cost of around $22.5 million due to insured losses, damage to timber assets, and losses due to human fatalities and serious injuries. Overall, this amounts to an estimated $37 million per year on average.

It is important to recognize the on-going continuous improvement that is likely to take place over time with respect to fire weather forecasting services, activities of the fire management authorities and the services of the other emergency management service providers. As a result of these continuous improvement of overall services aimed at managing bushfires, it is likely that there will be some reduction in expected damage costs and losses associated with future bushfires over time. Such reductions in damage costs and losses are not explicitly taken into account in this analysis.

Alternative scenario

At present the Bureau is continuing to improve its fire weather services by undertaking several projects. Some of these efforts are internally funded and the rest is externally funded through various collaborative arrangements such as the Bushfire CRC.

It is assumed under the alternative scenario that the Bureau will provide *improved* fire weather services in Victoria, assisting the prevention and control procedures that are applied by fire authorities, other emergency management service providers and the broader community. These improved fire weather services will consist of further enhancements to the current suite of fire weather services including the improved timeliness and enhanced accuracy of the services provided by the Bureau, as well as other enhanced services. Under this alternative scenario, it is assumed that the fire authorities, emergency management service providers and the community will better use these improved fire weather services. Likely outcomes due to the better use of these improved fire weather services by the fire authorities could include more effective prescribed burning which could result in improved fuel

reduction and reduced incidence of high intensity fires with extensive spread. Also, better use of the improved fire weather services will enable the fire authorities and other emergency management service providers to better pre-position their resources including the relocation/deployment and mobilization of staff and equipment leading to reduced impact of bushfire and the related damages or losses.

It is assumed here that the improved fire weather services by the Bureau in Victoria will lead to a reduction in the impact of bushfires and the related damages and losses culminating in, for example, a 5 to 10 percent reduction in overall damages that can be expected, over a medium term time period (5 –10 years), (i.e. over a 7 year period). As discussed earlier, the estimated overall damage cost due to bushfires in Victoria is around $37 million per year on average, which is around $260 million over a 7-year period. Based on the analysis presented above, an assumed 5 to 10 percent reduction in overall damages due to the better use of improved fire weather services will lead to a $13 – 26 million reduction in overall damage costs over a 7 year period. If such improvements to fire weather services are applied across the whole country, the overall reduction in bush fire damage losses could be expected to be four times more, amounting to $50 – 100 million over a 7 year time period.

Comparison of Benefits and Costs

As indicated earlier, the Bureau is planning to use additional resources allocated as part of the extra funding from the newly established CRC for Bushfires to finance the efforts to improve the fire weather services discussed in this paper. Those additional funds amount to around $0.4 million per year for 7 years commencing in 2003-04 (that is, $2.8 million over 7 years). These additional funds are treated as the additional cost of improving the accuracy, timeliness and the nature of the enhanced fire weather services described in this paper. It is assumed here that the cost of disseminating and using the enhanced fire weather services is negligible as the processes involve ‘doing things better’ with existing resources (from the perspective of forecast delivery services, fire management authorities and other emergency management service providers) rather than increasing the amount of effort associated with managing the bushfires. As a result, no additional costs are added to the $0.4 million per year for 7 years (that is, $2.8 million over 7 years) in the alternative scenario analyzed here.

Assuming that the additional cost of improved fire weather services by the Bureau will be around $0.4 million per year for 7 years, and that the use of such improved services will lead to a 5 to 10 percent reduction in the impact of bushfires and the related damages over a 7 year period, the consequent reduction in losses is estimated to be around $13 – 26 million in Victoria over that period. This implies a benefit (or reduced damages) of 5 to 9 times the additional cost of fire weather services, in the case of Victoria. If such improvements to fire weather services are applied across the whole country, the overall reduction in bush fire damage losses could be expected to be four times more, amounting to $50 – 100 million, implying a benefit (or reduced damage) of 18 to 36 times the additional cost of providing enhanced fire weather services, on a national basis.

Concluding Remarks

A basic conceptual framework for analyzing the socio-economic value of fire weather services is presented in this paper. Also, a back-of–the-envelope, preliminary analysis of the potential benefits or reduced losses that could result from the use of improved fire weather services is undertaken in this paper with available data and information. The initial analysis based on best available data and plausible assumptions illustrate that likely benefits from the use of improved fire weather services can be 5 to 9 times the additional cost of fire weather services, in the case of Victoria. If such improvements to fire weather services are applied across the whole country, the overall potential benefits can be 18 to 36 times the additional cost of providing enhanced fire weather services, on a national basis. This benefit – cost comparison is based on a key assumption that the provision and use of improved fire weather services is likely to lead to a reduction in the impact of bushfires and the related damages and losses culminating in, for example over a 7 year period, a 5 to 10 percent reduction in overall damages that can be estimated. An important area of future research that is noteworthy here is a detailed examination of the applicability of this assumption.

Acknowledgments

Responsibility for the views expressed rests with the authors. The authors appreciate the valuable comments and suggestions by Mike Manton, Bob Brook, Tom Keenan, John Zillman, John Handmer and Stephen Dovers.

References

BTE (Bureau of Transport Economics) 2001. **Economic costs of natural disasters in Australia,** Report No. 103, Canberra

Bureau of Meteorology 2004. **Meteorological aspects of the Eastern Victorian fires, January-March 2003,** Melbourne.

CIE (Center for International Economics) 2001. **Assessing the contribution of CSIRO – CSIRO pricing review,** prepared for CSIRO, Canberra and Sydney, http://www.bbm.csiro.au/vesta/assets/pdf/Vesta_Final_Report.PDF

Sol, B. 1994. **Economic impact of weather forecast for forest fires**, Meteorological Applications 1: 155-158

Victorian Government 2003. **Report of the inquiry into the 2002-03 Victorian bushfires,** Melbourne

Reconstruction of Forest Areas Using Geostatistics as an Aid in the Evaluation of Burned Areas[1]

J. Germán Flores G.,[2] David A. Moreno G.,[2] Francisco Rincón R.[3]

Summary

There are frequently no bases for economically evaluating a forest, following fire. An evaluation needs to consider: a) The original commercial value of the forest (timber, tourism, germ plasma etc.) b) The cost of restoring the forest to its original condition; and c) The opportunity cost involved in restoration. This is essentially feasible, provided that the original state of the forest area prior to the fire is known. However, one of the most frequent problems in the management of forest resources is the difficulty in defining the spatial distribution of the forest characteristics. In this study the use of geo-statistical techniques are described and the manner in which they are used to define the continuous surfaces of some characteristics of a forest: the base areas; number of species; average diameter; the number of trees per hectare, as a basis for the reconstruction of a forest area prior to a fire. The data was taken from a forest in the state of Chihuahua, México (1998). 554 points were chosen as random samples, within a 1400 hectare area. The definition of continuous surfaces was made on the basis of ordinary kriging (OK), from which it was possible to model acceptably the spatial distribution of the characteristics mentioned. In this way the original form of any area can be estimated within the study zone. If there is no previous inventory available, it is suggested that this methodology be used by taking information from the sample points around the burned area.

Introduction

The element of fire has played a part in the development process of forest resources and has long been a useful work tool for the inhabitants of the rural areas of Mexico, who employed fire to cleanse their agricultural areas (Rincón, 2002). Nevertheless, when used without due precaution it can lose control and spread to large forested areas. As a result, enormous damage is caused to forest ecosystems and other associated natural resources. This has repercussions on the economy not only of the villages working directly in production, but also affects the forestry market. Despite the importance of these effects, there are currently no strategies to reliably evaluate the loss of forest resources in the event of fire. There is a need to implement a method for evaluating the damage caused by forest fires to society; the following should be taken into consideration: a) The original commercial value of the forest (timber, tourism, germ plasma, etc.); b) The cost of restoring the forest to its original condition; and c) The cost involved in the restoration. In addition the ecological and

[1] An abbreviated version of this paper was presented at the second international symposium on fire economics, planning, and policy: a global view, 19–22 April, 2004, Córdoba, Spain.

[2] Forestry Researcher, Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias. Parque Los Colomos S/N, Col. Independencia. Guadalajara, Jalisco. México. 44660.

[3] Forestry Engineer, Secretaria de Medio Ambiente y Recursos Naturales. Colima, Colima. México.

social impact on the region should be evaluated, as well as damage to the area water basin.

Evaluation of the economic impact of fires is relatively feasible, provided that the original state of the forest prior to the fire is known. However, one of the most frequent problems in the management of forest resources in Mexico is the difficulty in defining the spatial distribution of the characteristics of the forest. Although information in the form of forest inventories is available at the surface level statistics are managed at a mean and variance level (UCODEFO,1997), and do not reflect the potential variation in spatial distribution of the forest parameters. However it is important to point out that if the area in question is homogeneous, those statistics may be of use (Hunner et al, 2000). Nevertheless, the diversity of environmental conditions and management have led in most cases to considerable spatial variations in the conditions of forest areas (Hunner, 2000). This means that any evaluation of the economic impact of a forest fire should be considered not only in terms of the form and degree to which it is affected, but also in terms of the spatial distribution of this impact. This, in conjunction with information on the distribution of the original condition of the forest will help to provide a more precise estimation of the damage. This study describes the use of geo-statistical techniques to define the continuous surfaces of some of the original characteristics of a wooded area in a forest in the state of Chihuahua, México.

Methodology

Study Area

The study was carried out with information on a commercial forest in the ejido "El Largo and Surroundings". This area is located in a region known as Mesa del Huracán, in the eastern part of the state of Chihuahua (figure 1). The predominant tree species are: *Pinus durangensis, P. arizonica, P. engelmannii and Quercus sideroxyla.* The topography of the area is mountainous, with some valleys. Average annual temperature is between 8.5 to 12^{o} C. The lowest temperature registered is–26^{o}C, and the maximum 38^{o}C. Precipitation ranges from 690 to 1,130 mm per annum. The minimum elevation of the study was 1400 m above sea level (masl), and the maximum as defined as 2400 masl. Forest fires occur in summer in the drought season (May to June) (UCODEFO, 1997).

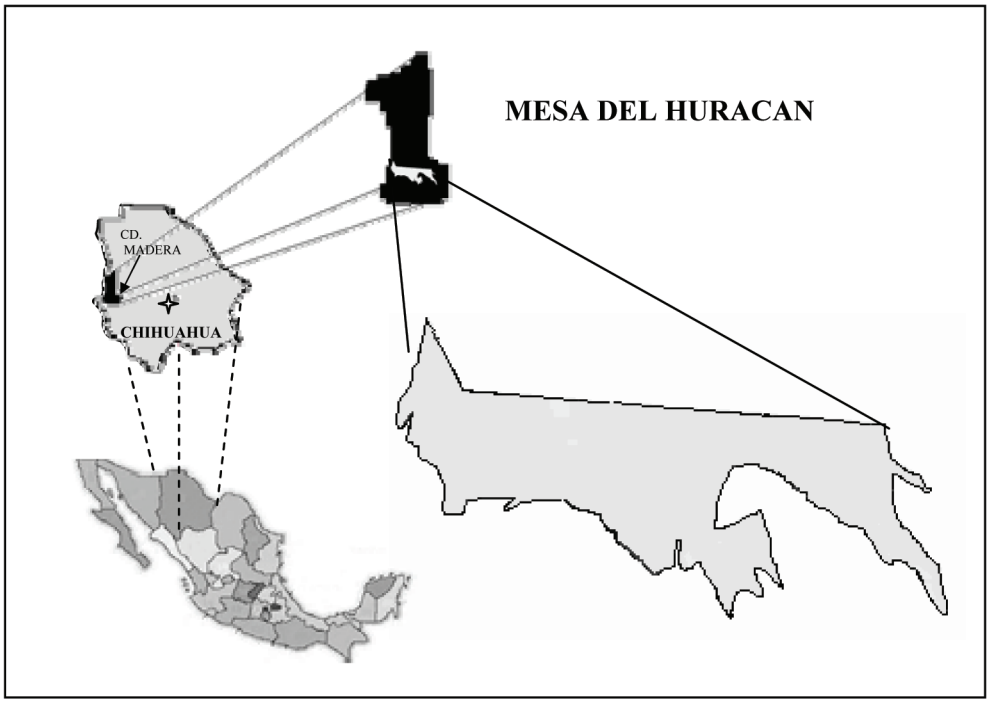


Figure 1-Approximate location of the area under study within the region of Mesa del Huracán, close to Ciudad. Madera, Chihuahua.

Sampling strategy

For management purposes the woods in the ejido[4] "El Largo" are divided into sections based on their productive potential. At the same time each section is subdivided into stands (based on density, gradient and exposure) and sub-stands (based on species) (figure 2). Within this framework, the data used in this study was inventoried in 554 sample areas distributed at random in Section 3 of "El Largo" (approximately 1400 hectares). The number of sample points per sub-stand was defined by its size (UCODEFO 2) (Table 1). Although these points were chosen at random, a minimum distance was established between the stands in accordance with the following formula:

[1] $$\text{Distance} = (\text{Area } m^2/\text{Number of points})^{1/2}$$

[4] Ejido is an administrative unit of land ceded on perpetuity to peasants by the government on a communal basis. The land can be transfered from family to family but cannot be sold.

Table 1--*Number of sample points per sub-stand according to its size; Criterion employed by the UCODEFO 2 in Ciudad Madera, Chihuahua.*

Size of sub-stand (ha)	Number of sample points
5-10 ha	4
11-15 ha	5
16-20 ha	6
21-25 ha	7

The sample areas were circles of 1000 m^2, and the following information was obtained: (a) tree species; (b) diameter; (c) height; (d) height of crown; (e) basal area; and (f) number of trees per hectare.

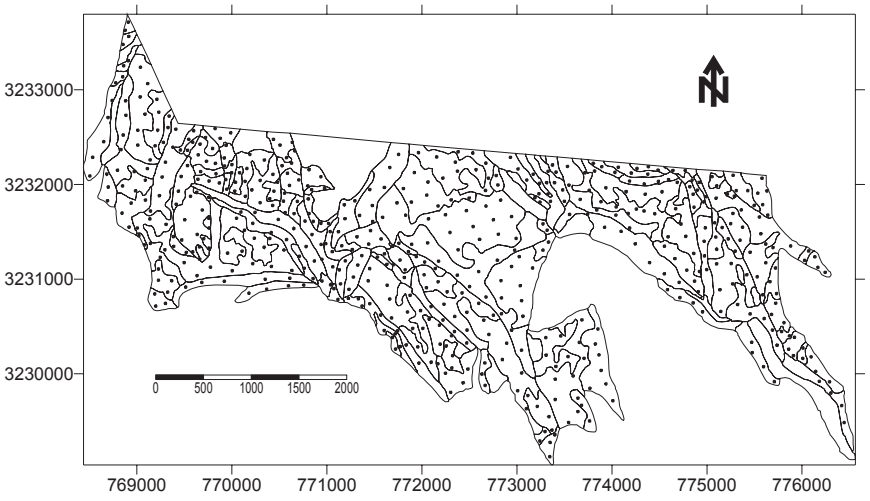


Figure 2--Location of the 554 sample points of within the study area. The divisions correspond to 143 sub-stands classified by UCODEFO 2. The coordinates correspond to zone UTM 12**.**

Damage estimate

Following a fire, the degree to which the forest is affected varies spatially and thus the degree of damage caused should be evaluated. In this way permanently affected areas can be identified and also those which may be recovered. Relating this information to the knowledge of spatial distribution obtained from the initial conditions of the forest mass evaluated, will enable a more precise estimate of the economic value of the forest resources affected.

All the characteristics of the affected area should be considered in an initial evaluation. To assess the economic damage of the affected forest resources (raw forestry materials which have economic value) the following information is needed: (Rincón, 2002): a)Geographical location considering: coordinates, municipal district (s), property (ies) and places; b) Duration in days and hours, c) Calculation of the

surface affected (hectares or m²). This last point may be covered either by aerial photographs, satellite images, or with the use of GPS covering the periphery of the burned area (on foot, horseback or by helicopter). It is important to identify the type of fire since it is this which will permit an estimation of the degree of potential damage.

The spatial distribution of the types of vegetation in the area should be considered, since these are associated both with the behaviour of the fire and with damage potential. This last is related to fire intensity which may spread on the basis of level of trees burned. This may be referred to in a qualitative manner considering the percentage affected in each substratum, using the following classification (Rincón, 2002):

Low - When vegetation is affected at a level of approximately 1 to 25%., bearing in mind the total structure of the vegetation, timber and foliage, in general the damage is scant and individual trees are not at risk of death

Medium - When the damage is moderate between approximately 25 and 50%, and individual trees may be at risk of death, particularly the weakest and most infirm.

High - When the damage is considerable, between approximately 50 to 80% most trees are likely to die and those which survive are seriously damaged and prone to pestilence and disease, particularly adult trees.

Damage should be assessed by vegetation substratum: 1) Adult trees or high; 2) Bushes and medium undergrowth; 3) Renewed growth or undergrowth, and 4) Herbs and pasture or undergrowth. The respective volume and distribution of products by vegetation substratum should also be established. In order to be able to infer the total affected surface so as to obtain the

Ordinary Kriging

Given that, as mentioned above, to assess the economic cost of a fire it is necessary to ascertain both the surface of the damaged area as well as dasometric characteristics, the ultimate aim of this study was to generate continuous surfaces of: (a) base area [BA]; (b) number of species [NS]; (c) average diameter [AD]; and (d) number of trees per hectare [NTH]. The definition of continuous surfaces was obtained on the basis of ordinary kriging (OK). This is a geo-statistical technique based on the theory of rationalized variables (Oliver y Webster, 1990). Ordinary **k**riging is a geo-statistical technique applied when the mean data is stationary but unknown. OK is considered as the "best unbiased linear estimator". (Olea, 1991): (a) it is linear because its estimations are linear combinations weighted from available data; (b) it is unbiased because it tends to generate a mean square of error equal to zero (E[Estimated x_0)-Real(x_0)] = 0, and $\sum \lambda_i = 0$); and (c) is better because it tends to minimise the variance of errors (E{[Estimatedx_0) – Real(x_0)]^2 = minimum). The following formulas are used to calculate the estimates with OK and the corresponding standard deviation of those estimations (Hunner, 2000; Isaaks and Srivastava, 1989):

$$\hat{Z}_{OK}(x_0) = \sum_{i=1}^{n} \lambda_i \cdot Z(x_i) \quad \textbf{[1]}$$

$$\sigma^2_{OK}(x_0) = C(x_0, x_0) - \sum_{i=1}^{n} \lambda_i \cdot C(x_i, x_0) + \mu \quad \textbf{[2]}$$

where:

$\hat{Z}_{OK}(x_0)$ = OK estimate in point x_0;

λi = weighted value of the sample point i at point x_i;

$Z(x_i)$ = value of the variable observed Z at point xi;

$\sigma^2_{OK}(x_0)$ = covariance of ordinary kriging at point x_0 with itself

$C(X_I,X_0)$ = covariance of the sampled area at point x_i and the place to be estimated at point x_0; y

μ = parameter of Lagrange

The required parameters of ordinary kriging were defined by means of structural analysis of the data (Phillips et al, 1992). The spatial continuity of each characteristic was defined by means of variograms, considering an isotropic point of view (Ramírez, 1980).

Results

Spatial autocorrelation

The four cases presented low spatial autocorrelation (Chou, 1991), which is reflected in the spatial continuity defined by the corresponding experimental variograms (Armstrong, 1998) (figure 3). The maximum distance in which spatial correlation was found corresponded to DP (approx. 2550 m). Whilst AB showed a maximum distance of 1000 m. NE and NAH defined a spatial correlation up to 1750 and 1850 m, respectively. Each of the experimental variograms was adjusted to a "defined positive" model (Flores, 2001). In accordance with this, the variables NAH, AB, DP and NE were exponential, exponential, spherical and exponential, respectively.

Despite the low spatial autocorrelation of the variables studied, it was possible to define the required pa**rameters by OK (Nugget [Co], Sill [Co+C] and Rango [Ao]).** By means of OK, the corresponding continuous surfaces were generated. Figure 4 shows the resulting surfaces for each of the variables in the study. It is possible to observe that the greater variability of DP is in the NE part of the studied area. In the case of species numbers, the spatial distribution is a little more homogeneous, with some peaks in the SE part. The zones with a greater base areas are situated in the NW part of the area studied. This coincides with the spatial distribution of the species number per hectare. It is important to point out that although the greater densities are found in the NW part, the greater diameters are

found the NE zone. There is some logic in this, since at greater densities there is more competition between trees and therefore lesser diameters are to be expected.

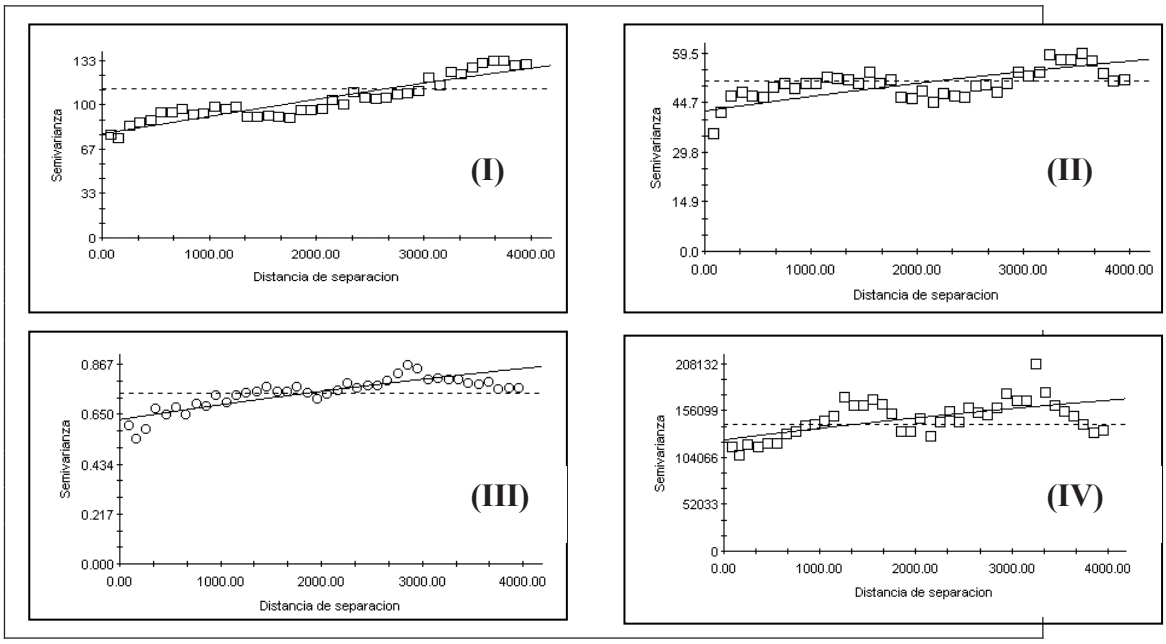


Figure 3—Spatial continuity of the variables in the study expressed in variograms: (I) average diameter [AD]; (II) total basal area [BA]; (III) number of species [NE]; and (IV) number of trees per hectare [NTH].

Once the continuous surfaces were generated, the corresponding maps were defined using geographic information. The final corresponding map can be seen in *figure 5*. The average diameter of all tree species was 36.67 cm with a maximum and a minimum of 14.05 and 72.95 cm respectively. The standard deviation was 10.58 cm. Average diameters between 30 and 40 cm were distributed along the study area. The average basal area was 10.62 m squared and a maximum and minimum of 1 and 48 m squared respectively. The standard deviation was 7.16. The majority of the basal areas in the study area were between 5 and 15 m squared. The number of tree species per hectare varied from 7 to 3,580 with a standard deviation of 376. Most of the sample areas had less than 500 trees per hectare. There was a definite pattern of distribution for density classes between 150 and 500 trees per hectare. On the other hand, the density class greater than 500 trees per hectare had a scatter distribution. The number of species per sampling site varied between 1 and 7. However, 80.3 percent of the sites had between 1 and 2 tree species. The most frequent dominant species were *Pinus durangensis, P. arizonica* and *P. engelmannii*, which were found in 45.49, 30.14, and 12.64 percent of the sampled sites respectively. All throughout the study area the spatial distribution of 1 and 2 species was very homogenous. Areas with more than 3 tree species were few.

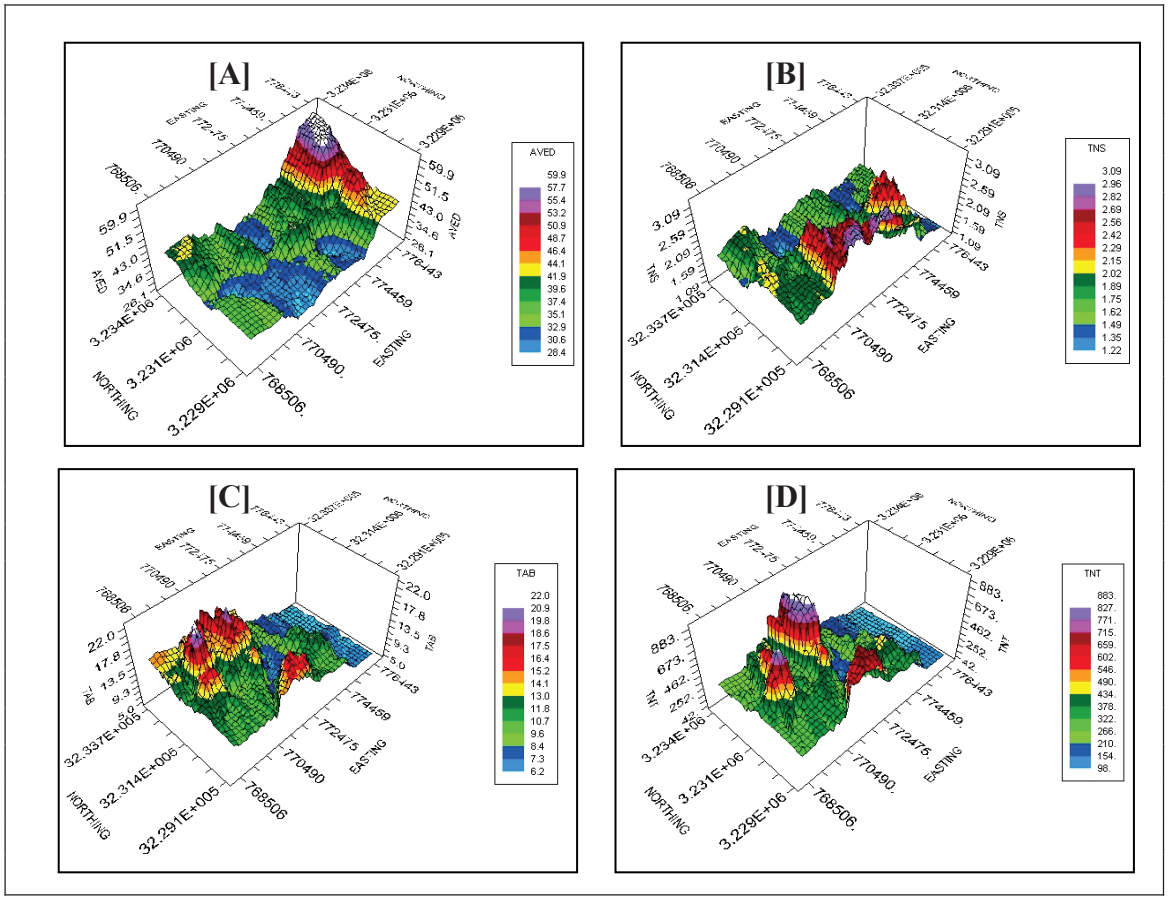


Figure 4—Continuous surfaces generated through the ordinary kriging: (A) average diameter [AD]; (B) total basal area [BA]; (C) number of species [NE]; and (D) number of trees per hectare [NTH].

Discussion and Conclusions

Spatial Continuity

The economic valuation of Forest fire damage can not be done accurately without knowledge of the condition of the Forest prior to the fire. Considering the existence of abundant forest inventory information for a specific area it is not convenient to use only general statistical information like the median and the variance to estimate the economic loss. This approach would imply, as shown in *figure* 6a, that the dasometric characteristics of the forest mass were very homogenous. In turn this would imply a spatial continuity defining large areas, as in the case of climate (Atkinson y Lloyd, 1997). Even though this may be possible in forests with pure and similar age structure stands, in Mexican forests it is difficult to find such uniform spatial continuity. This lack of spatial continuity could be the result of the different management strategies applied in a particular site. Plagues, infections, and illegal harvesting could also be factors altering the spatial continuity of the dasometric characteristics. Fire itself is a factor affecting the continuity.

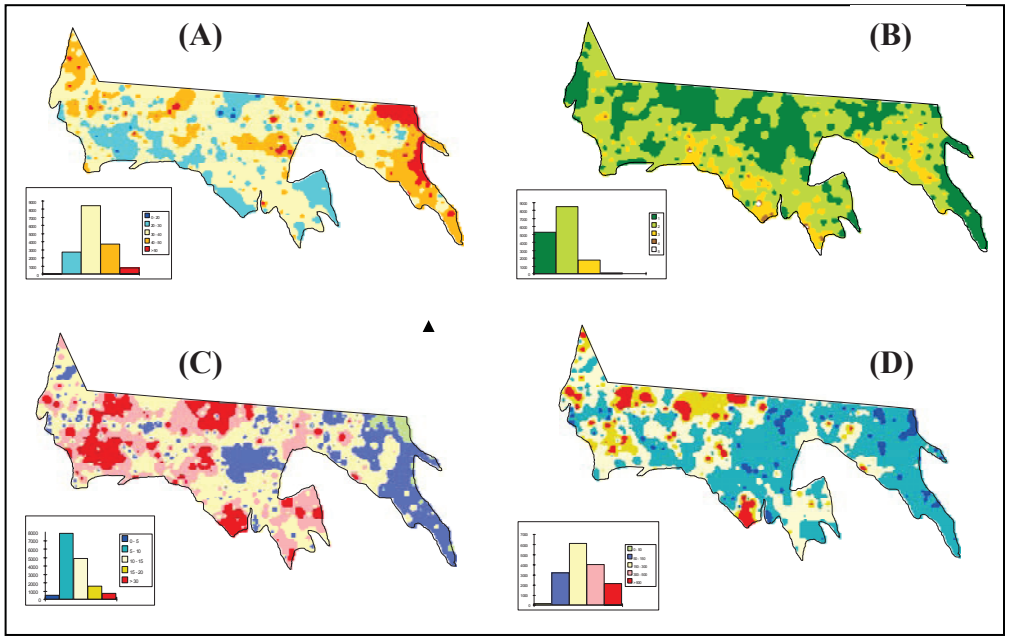


Figure 5—Final maps of the study variables spatial distribution: (A) average diameter [AD]; (B) total basal area [BA]; (C) number of species [NE]; and (D) number of trees per hectare [NTH].

Because of what explained before we need to keep in mind that just because there are spatial variations in forest characteristics, these do not follow a strict polygon defined pattern. On the contrary, this is rather a continuous variation ranging slowly, for example, from very high densities to low densities (*fig. 6b*). This spatial behavior is impossible to capture from the estimation with the mean and the variance (*figure 6a*). As illustrated here it is important to use alternatives that allow consideration of the space factor in estimating the dasometric characteristics of a forest. This will allow not only an economic valuation closer to the reality of the forest mass condition but could also allow for spatial identification of areas with lesser or grater damage. We can thus estimate not only affected areas by damage and recovery costs but establish spatially the opportunity cost of the recovery period. Finally, the integration of all this information will help in selecting priority areas (by damage and recovery costs), and even define areas not needing any investment (due to its high recovery capacity).

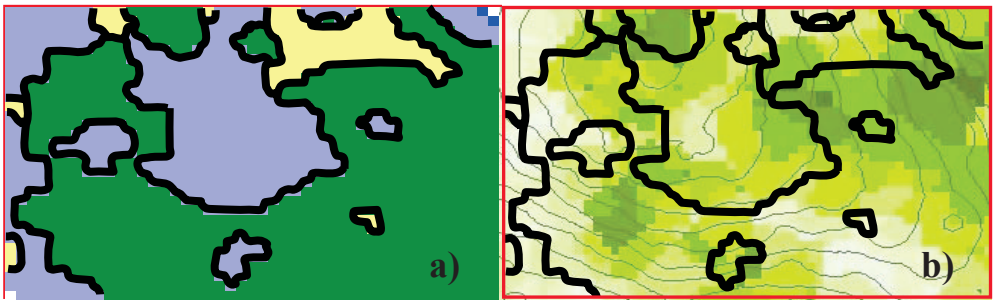


Figure 6—The variation in the dasometric characteristics of a forest could have a homogenous pattern defining large polygons (a), or a pattern of continuous spatial variation (b).

Interpolation

The use of geostatistical techniques requires that the variables studied are spatially autocorrelated. The low spatial autocorrelation found in this study suggest the use alternative methods such as co-kriging. The type and the intensity of the sampling must also be considered. Never the less, the methodology used here is relatively simple and can be used prior to a fire to define the spatial distribution of the dasometric characteristics of the forest mass. It is important to note that the methodological procedure in performing geostatistical interpolations imply a good knowledge of the spatial characteristics of the species studied. Thus, before performing the kriging iterative procedure it is important to study carefully the circumstances defining the presence of a variable. For example, as mentioned in the results section, we expected the spatial distribution of the higher density zones to be related to the areas with smaller average diameter. Other possible useful factors in the case of forestry characteristics are elevation, exposure, or slope. This type of information is relevant in the economic valuation of a fire damages.

Future work

One advantage of the geostatistical techniques (though not presented in this work) over the deterministic alternatives is that they allow you to compute the standard error of the estimates. This permits us to identify those areas in which are estimates are most reliable. The utility of this is determining the propriety of the sampling design, as well as in designing future sampling strategies. For future work is recommended to compare not only other geostatistical alternatives (for example, universal kriging, block kriging, and cokriging [Goovaerts 2000]) but also non-stochastic interpolation techniques (for example, Spline [Bishop and others 1999], polygonal mapping, and Thiessen polygons). This type of analysis will provide more precise maps, which will allow a more objective economic valuation of fire damages. This would provide support to the answers given to the following questions: a) What was the commercial value of the forest (timber, tourism, germoplasm, and others) prior to the fire? b) What would be restoration cost to the original condition? c) What is the opportunity cost of the restoration period? The answers to these inquiries require not only knowledge of the forest conditions prior to the fire but also taking

into account a series of ecological (species, soil, population dynamics) economic (supply, demand, costs), and social factors (employment levels, recreation, landscape).

References

Armstrong, M. 1998. **Basic linear geostatistics**. Springer, New York. 153 pp.

Atkinson, Peter M. and Lloyd, Chris D. 1997. **Mapping precipitation in Switzerland with ordinary and indicator kriging**. Journal of Geographic Information and Decision Analysis 2(2):72-86.

Bishop, T.F.A.; McBratney, A.B.; Laslett, G.M. 1999. **Modelling soil attribute depth functions with equal-area quadratic smoothing splines**. Geoderma 91: 27-45.

Burrough, P. A, and McDonnell. 1998. **Principles of geographical information systems**. Claredon Press Oxford; p. 333 p.

Chou, Yue Hong. 1991. **Map resolution and spatial autocorrelation**. Geographical Analysis, 23(3): 228-246.

Flores G., J. G. 2001. **Modeling the spatial variability of forest fuel arrays**. Ph.D. Dissertation. Department of Forest Sciences. Colorado State University. 169 p.

Goovaerts, P. 2000. **Geostatistical approaches for incorporating elevation into the spatial interpolation of rainfall**. Journal of Hydrology Amsterdam 228: 113-129.

Hunner, G. 2000. Modeling **forest stand structure using geostatistics, geographic information systems, and remote sensing**. Ph.D. Dissertation. Forest Sciences Department. Colorado State University. 217 p.

Hunner, Gerhard; Mowrer, H. Todd, y Reich, Robin M. 2000. **An accuracy comparison of six spatial interpolation methods for modeling forest stand structure on the Fraser Experimental Forest, Colorado**. In: Proceedings of the 4th International Symposium on Spatial Accuracy Assessment in Natural resources and Environmental Sciences. July, 2000. Amsterdan. pp 305-312.

Isaaks, E.H. y Srivastava, R.M. 1989. **An introduction to applied geostatistics**. Oxford University Press. New York. 561 p.

Laslett, G. M.; McBratney, A. B.; Pahl, P. J., and Hutchinson, M. F. 1987. **Comparison of several spatial prediction methods for soil pH**. Journal of Soil Science 38:325-341.

Olea, R.A. 1991. **Geostatistical Glossary and Multilingual Dictionary**. Oxford University Press, New York.

Oliver, M. A. and Webster, R. 1990. **Kriging: a method of interpolation for geographical information systems**. International Journal of Geographical Information Systems 4(3): 313-332.

Phillips, D.L.; Dolph, J.; Marks, D. 1992. **A comparison of geostatistical procedures for spatial analysis of precipitation in mountainous terrain**. Agricultural and Forest Meteorology 58: 119-141.

Ramírez M., H. 1980. **On the relevance of geostatistical theory and methods to forest inventory problems**. Ph.D. Dissertation. University of Georgia. 163 p.

Rincón R., F. 2002. **Metodología propuesta para estimar el valor económico y ecológico de los daños causados por los incendios forestales**. Procuraduría Federal de Protección al Ambiente. Secretaria de Medio Ambiente y Recursos Naturales. México. 20 p.

UCODEFO 2, 1997. **Aplicación del invenstario forestal continuo (I.F.C.) en los bosques del "Ejido El Largo", Chihuahua, México**. Unidad de Conservación y desarrollo Forestal No. 2. Cd. Madera, Chihuahua. México. 34 pp.

Fuel Treatment Timing and Suppression for Wildfire Risk Mitigation[1]

Mariam Lankoande,[2] Jonathan Yoder[3]

Abstract

Wildfire risk mitigation through *ex ante* vegetation management is receiving more attention in the United States after a strong emphasis on suppression for a hundred years. This paper presents a dynamic economic model with three sets of input choice variables: the timing of pre-harvest vegetation management interventions, harvest date, and expected suppression effort in a context where pre-harvest vegetation management reduces the risk of wildfire. The model is applied to three important policy issues: 1) a general characterization of the relationship between *ex ante* risk mitigation via vegetation management and wildfire suppression that can be applied to a broad range of specific settings; 2) the consequences of high potential damage from fire as on the wildland-urban fringe for vegetation management regimes, 3) the structure of liability for both prescribed fire and excess fuel loads on vegetation management decisions. Numerical simulation results are presented and discussed as illustrations of the implications from the model.

Introduction

Many approaches exist for reducing the risk of economic losses associated with wildfires. Various forms of mechanical thinning and chemical treatments can reduce wildfire risk, as can the application of fire-proofing methods to human-made structures. Fire itself in the form of a planned controlled burn can be useful for reducing wildfire risk (Prestemon, and others 2001; Pattison 1998; Babbitt 1995).

This paper explores the economic tradeoffs between *ex ante* fuel management and *ex post* suppression. Because fuels grow and mature over time and wildfire risk changes with it, we focus on the timing of fuel management interventions, where these interventions can take the form of prescribed fire or mechanical thinning. The analysis is composed of two parts. First, a dynamic economic model of the timing of wildfire risk mitigation interventions, harvest timing, and suppression. Second, we examine three specific policy and management issues: a) a general characterization of the relationship between *ex ante* risk mitigation via vegetation management and wildfire suppression that can be applied to a broad range of specific settings; b) the consequences for vegetation management regimes of high potential damage from fire as on the wildland-urban fringe, c) the effect of liability for excess fuel loads and for suppression costs on vegetation management decisions. Numerical simulation results are presented as illustrations of the analytical model.

---

[1] A abbreviated version of this paper was presented at the second international symposium on fire economics, policy, and planning: a global view, 19–22 April, 2004, Córdoba, Spain.

[2]Mariam Lankoande, graduate student, Department of Agricultural and Resource Economics, Washington State University, P.O. Box 646210, Pullman, WA 99164.

[3]Jonathan Yoder, Assistant Professor, Department of Agricultural and Resource Economics, Washington State University, P.O. Box 646210, Pullman, WA 99164.

A model of timing for fuel management and harvest

The net benefit from forest stand management is modeled as a modified Faustmann rotation in which the landowner maximizes the expected net present value of the rotation by choosing the expected dates of vegetation management interventions, harvest, and suppression given a wildfire. At any point in time in the maturation of the forest stand, a wildfire might occur that can impose damage on both the forest stand and other non-timber property. The time-path of wildfire risk is affected by fuel management interventions (*interventions* for short), and the extent of damage given that a wildfire occurs before harvest can be reduced by suppression effort. Other models of timber rotations under wildfire risk and vegetation management have been developed by Reed (1984, 1987), Yoder (in press), and others. This model is different in that it amounts to a nested rotation that considers both timing intervention dates and harvest dates.

Optimization in this context, amounts to jointly maximizing over n-1 pre-harvest interventions and one harvest date (the n^{th} intervention), and suppression effort in the event of a fire. A central component of the problem is that interventions affect the probability of wildfire. Given the optimal timing vector $\mathbf{T}_n = [T_{n,1}, T_{n,2}, ..., T_{n,n}]'$, the probability of wildfire occurring at any time t_0 within the rotation is

$$F(t_0, \mathbf{T}_n) = \int_0^{T_1} f(t)dt + \int_{T_1}^{T_2} f(t - T_1)dt + ... + \int_{T_{i-1}}^{t_0} f(t - T_{i-1})dt$$

where $f(t)$ is the probability of a fire occurring at time t. Note also that every intervention results in resetting the probability of destructive wildfire back to the initial state. In the calculations below, we shall need a discounted version of $F(t_0, \mathbf{T}_n)$, evaluated at intervention times:

$$G(T_{n,i}, \mathbf{T}_n) = \int_0^{T_1} e^{-rt} f(t)dt + \int_{T_1}^{T_2} e^{-rt} f(t - T_1)dt + ... + \int_{T_{i-1}}^{T_i} e^{-rt} f(t - T_{i-1})dt .$$

The manager maximizes the expected net present value of the benefits given the uncertainty of wildfire occurrence. The components of benefits and costs of timber production and wildfire risk mitigation can be broken down as follows:

1. If no wildfire occurs before harvest, the owner receives the stumpage value, the present value of which is $e^{-rT}V(T_{n,n})$. For simplicity we assume that timber growth is not a function of interventions, just time from planting.

2. If a wildfire occurs, the owner receives $(1 - g(s))V(T_{n,n})$ in period $T_{n,n}$, where $g(s)$ is the fraction of timber value lost to wildfire. Suppression effort s reduces the fraction lost, but at a diminishing rate, such that $g'(s)<0$ and $g''(s)>0$. No financial loss in terms of timber value is realized at the time of the wildfire because the timber is not sold then. We assume that timber is harvested at the same time regardless of whether a wildfire occurs or not.

3. If a wildfire occurs at some time X, total suppression costs $\tau \cdot s$ are expended, the present value of which is $e^{-rX}\tau s$. However, because X is

random, the owner will maximize over the discounted expected value of this random variable, which is $s \cdot \tau \cdot G(T_{n,n}, \mathbf{T}_n)$.

4. Some fraction of non-timber property of value may be damaged. To allow this, we introduce a constant *D* that represents potential damage to non-timber property. This damage accrues when and if there is a wildfire, and the extent of loss can be mitigated by suppression. Thus the expected present value of damage to non-timber assets is $g(s) \cdot D \cdot G(T_{n,n}, \mathbf{T}_n)$.

5. Given marginal intervention costs *w*, the present value of intervention costs at intervention *i* of *n* are $we^{-rT_{n,i}}$ if there is no wildfire before $T_{n,i}$. However, a wildfire might occur before any given intervention. Therefore, the expected present cost of any given intervention $T_{n,i}$ is $w \cdot e^{-rT_{ni}} \cdot \left(1 - F(T_{n,i}, \mathbf{T}_n)\right)$.

Putting each of these components together and discounting appropriately for an infinite series of harvest rotations, the present value of the expected net benefit function to be maximized is

$$E\left[PV\left(NB\right)\right]_n = \frac{1}{1-e^{-rT_{n,n}}}\begin{pmatrix} E\left[\text{PV(timber value)}\right] \\ -E\left[\text{PV}\left(\text{suppression costs +damage}\right)\right] \\ -E\left[\text{PV}\left(\text{intervention costs}\right)\right] \end{pmatrix}$$

$$= \frac{1}{1-e^{-rT_{n,n}}}\begin{pmatrix} \left[e^{-rT_{n,n}}\left(1-F(\mathbf{T}_n, T_{n,n})g(s)\right)V(T_{n,n})\right] \\ -\left[G(\mathbf{T}_n, T_{n,n})\left(\tau s + g(s)D\right)\right] \\ -I_{n>1}\left[w\sum_{i=1}^{n-1} e^{-rT_{n,i}}\left(1-F(\mathbf{T}_n, T_{n,i})\right)\right] \end{pmatrix}$$

Where, to summarize the notation:

- $E\left[PV\left(NB\right)\right]_n$ is the present value of the expected net benefit given *n* interventions;
- *r* is the discount rate;
- $\boldsymbol{T_n}$ is an $(n \times 1)$ vector of (*n*-1) intervention dates and a harvest date;
- $T_{n,i}$ is the time of the i^{th} intervention; harvest is the n^{th} intervention;
- $V(T_{n,n})$ is the timber's stumpage value at harvest time;
- $F(\boldsymbol{T_n}, T_{n,i})$ is the probability of wildfire occurring before time $T_{n,i}$ given the intervention vector $\boldsymbol{T}_n$;
- $G(\boldsymbol{T_n}, T_{n,i})$ is the discounted (present value) probability of wildfire occurring before time $T_{n,i}$ given the intervention vector $\boldsymbol{T}_n$;
- *s* is the fire suppression effort in the event of a wildfire;
- $g(s)$ is the fraction of potential value lost in case of fire.

- D is the potential damage to non-timber property value;
- τ is the cost per unit of suppression effort;
- w is the cost for each prescribed fire**.** If no pre-harvest interventions are applied, the sum of total intervention costs equals zero;
- $I_{n>1}$ is an indicator variable that equals one if there are pre-harvest interventions (i.e. if n>1), and zero otherwise.

The number of choice variables, and therefore the number of first-order conditions for the problem, depends on the number of interventions before harvest. Therefore, assuming that a solution for a maximum exists, finding the vector of arguments that maximizes this function is approached in two steps. First, the vector of optimal intervention times $\boldsymbol{T}_n$ and suppression effort s is chosen conditional on a specific number of interventions. Conditional optimization is performed over feasible intervention sets $n=1...m$, to find the m conditionally optimal vectors $\boldsymbol{T_1 \ldots T_m}$ and each of their associated values of optimal s**.** The vectors [$\boldsymbol{T_i}$, s] that maximize $E\left[PV\left(NB\right)\right]_n$ is then chosen.

Simulation specification

The above model must be specified completely for simulation. For a base case, we specify the model in an attempt to approximate ponderosa pine forest of the inland northwest region. For the fire return interval, we use a Weibull distribution with location, scale, and shape parameters of a=0, b=30, c=2, respectively. This results in a probability density function of $f(t)=0.002e^{-0.001t^2}t$, and a cumulative density function of $F(t)=1-e^{-0.001t^2}$, for which the mean fire return interval is approximately 26.6 years (see Smith and Fischer 1997). We follow Yang, Kozak and Smith (1978) and use a Weibull distribution to represent the timber volume growth function, the parameters of which were estimated from data presented in Oliver and Powers (1978), and then rounded. The estimated Weibull density function was then weighted by 500,000 to represent the growth in timber value over time: $V(t)=500000\left(1-e^{-0.0005t^2}\right)$. The productivity of suppression is measured in terms of damage foregone. For simplicity in this illustration, we define this function in terms of the fraction of potential damage saved, and base this savings function as an exponential density function, $g(s_n)=e^{-0.1\,s_n}$, where suppression effort s_n is defined such that one unit of suppression costs $\tau=5,000$. The unit cost of one fuel management intervention is set at 1,000, and the discount rate is set at 0.05. Finally, to allow for damage from wildfire in addition to timber value losses, we set D to equal either 200,000, or zero (in the case of no external damage or no liability for damage).

Results

Table 1 contains the results for four sets of management strategies: the use of both fuel management interventions and suppression, intervention only, and suppression only with no fuels management. Each of these management strategies is examined

for two different scenarios: one with non-timber damage potential of zero, and one with non-timber damage potential of 200,000. Landowners are generally not legally liable for wildfire damage that was in part due to fuel buildup on their land, although the law in relation to these risks may be changing (see Bakken 1995).[4] Thus, even if external damage may occur, landowners have weak incentive to account for it fully in their decision process. The timber rotation lengths for the scenarios are rather short. However, the results suffice to illustrate the tradeoffs being made in terms of fuels management, timber harvest, and wildfire suppression.

Table 1— *Simulation results*

Management strategies	Liability structure	Timing for Prescribed fires	Optimal # of Fuels Treatment	Optimal rotation length	Units of Suppression	Net Benefit
Case 1: Intervention and Suppression	Not liable	$x_{6,1}$=4.8, $x_{6,2}$=9.1, $x_{6,3}$=13.1, $x_{6,4}$=16.7, $x_{6,5}$=20.0, $x_{6,6}$=22.8, s_6=1.9.	5	22.8	1.9	45419.3
	Liable ($200,000)	$x_{4,1}$=4.6, $x_{4,2}$=9.6, $x_{4,3}$=15.0, $x_{4,4}$=20.8, s_4=16.5.	3	20.8	16.5	37696.5
Case 2: Intervention only	Not liable	$x_{6,1}$1=4.9, $x_{6,2}$=9.2, $x_{6,3}$=13.1, $x_{6,4}$=16.6, $x_{6,5}$=19.8, $x_{6,6}$=22.5.	5	22.5	--	45351.7
	Liable ($200,000)	$x_{7,1}$=2.7, $x_{7,2}$=5.5, $x_{7,3}$=8.3, $x_{7,4}$=11.2, $x_{7,5}$=14.2, $x_{7,6}$=17.2, $x_{7,7}$=20.3.	6	20.3	--	33018.8
Case 4: Suppression only	Not liable	--	--	13.4	--	42003.2
	Liable ($200,000)	--	--	7.1	14.3	9221.6

Consider case 1, where both fuel interventions and suppression are applied, and there is no external damage to worry about (D=0 from the timber owner's perspective). Given the parameters of the model, the expected net present value of the objective function is maximized with the application of 5 fuel management interventions, a harvest date of 22.8 years, and suppression effort of 1.9 units. The intervention rotation lengths shorten as the timber rotation progresses starting with

[4] A number of states, including the state of Washington, have statutory law imposing liability for activity fuels, but not for other types of undisturbed vegetation.

the first, at 4.8 years, and the last (ending at harvest) of 2.8. The reason for this is that the potential loss from wildfire grows as timber value grows, so it makes economic sense to reduce wildfire risk more frequently as timber value grows. Now consider what happens when potential damage increases by 200,000. Suppression effort increases from just fewer than two units to over 16 units, and the timber harvest date is earlier. Interestingly, the number of interventions drops from five to three, and the length of time between interventions increases. This is undoubtedly at least partly due to the very large increase in suppression expenditures.

When fuel management intervention is used exclusively and suppression is not (case 2), the number of interventions jumps back up to five and six, with and without external damage, respectively. With no damage, the optimal rotation length is slightly shorter than when suppression is used. Furthermore, though the differences are subtle, the interventions are postponed slightly and bunched up nearer the end of the timber rotation in comparison to the results for case 1. Thus, intuitively, fuel interventions are used to substitute for suppression more frequently when timber values are highest. When external damage is involved, the timber rotation drops by more than two years, and the number of interventions increases by one, to six.

In case 3, no fuels management regime is implemented, and suppression and timber harvest timing alone are relied upon as choice variables. In this case, the timber harvest dates are strikingly lower, at 13 and 7 years, respectively.[5] Interestingly, with no fuels management and no potential non-timber damage, the result is that wildfire risk is dealt with entirely by shortening the timber rotation length, rather than relying on suppression. When non-timber damage is set to 200,000, however, suppression jumps to over 14 units.

Implications for Wildfire risk Management in a Forest Setting

The above simulation results shed some light on the tradeoffs between *ex ante* fuels management and the incentive effects of both high potential damage and incomplete liability for fuels management incentives. The tradeoffs between fuels management for wildfire risk mitigation and suppression can be seen in the different scenarios presented above, which illustrate that fuels management, and even timber harvest, can be used as a means to reduce suppression. If potential damage from wildfires is large, such as on the wildland-urban interface, it makes sense to alter fuel management interventions and harvest accordingly by either increasing the number of interventions and/or increasing the timber harvest frequency, even when suppression is used in the event of a wildfire. Finally, even though the owners of land with flammable vegetation may contribute to the incidence and severity of wildfires, they tend not to face liability for those contributions. For this and other reasons, incentive for fuels management on private land is relatively weak. If suppression costs are also borne by public agencies, these incentives to reduce wildfire risks associated with their land are even weaker.

[5] Again, these timber harvest ages are exceedingly low, but the case illustrates the main implications of the model.

Acknowledgements

This research is supported by the Washington State Agricultural Research Center.

References

Babbitt, Bruce; Sampson, Neil. 1995. **To Take Up the Torch**. American Forests 101:17.

Bakken, Stephen R. 1995. **The Liability and Environmental Consequences of not Burning in California. In: Proceedings of the Environmental Regulation and Prescribed Fire Conference,** 1995 March 14-17; Tampa, Florida; 131-138.

Oliver, William W; Powers, Robert F. 1978. **Growth models for ponderosa pine: I. Yield of unthinned plantations in northern California**. Research Paper PSW-133, 21p. Pacific Southwest Forest and Range Experiment Station, Forest Service Berkeley, U.S.D.A, Berkeley, Calif.

Pattison, Malka. 1998. **Fighting Fire with Fire: A Policy to Improve Resource Management and Reduce Risk**. Renewable Resources Journal pp. 13–17.

Prestemon, Jeffrey P.; Mercer, D. Evan.; Pye, John M.; Butry, David T.; Holmes, Thomas P.; Abt. Karen L. 2001. **Economically Optimal Wildfire Intervention Regimes**. Chicago, IL: American Agricultural Economics Association Annual Meeting.

Reed, William J. 1984. **The Effects of the Risk of Fire on the Optimal Rotation of a Forest.** Journal of Environmental Economics and Management 11:180-190.

Reed, William J. 1987. Protecting Forest Against Fire: **Optimal Protection Patterns and Harvest Policies.** Natural Resource Modeling 2:22-53.

Smith, Jane K.; Fischer, William C. 1997. **Fire Ecology of the Forest Habitat Types of Northern Idaho.** Technical Report INT-GTR-363, USDA Forest Service, September.

Yang, Richard C., Antel Kozak, and J. Harry G. Smith. 1978. **The potential of Weibull-type functions as flexible growth curves.** Canadian Journal of Forest Resources 8:424-431.

Yoder, Jonathan. In press. **Playing with Fire: Endogenous Risk in Resource Management. American Journal of Agricultural Economics.**

Page left blank intentionally.

Wildland-Urban Interface Analyses for Fire Management Planning [1]

Raffaella Marzano,[2] Andrea Camia,[3] Giovanni Bovio[4]

Abstract

In Southern Europe wildfires involving settlements are becoming more and more frequent because of the increasing number of houses and infrastructures located within and adjacent areas prone to wildfires. This phenomenon has become a real challenge for wildland fire protection managers and public policy makers.

The work presented describes some results of a research on fire management in wildland-urban interface (W-UI) areas that is being carried out within the WARM (Wildland-Urban Area Fire Risk Management) Project, funded by the European Commission.

A study area of about 100 km^2 has been selected, according to its relevance to the W-UI problem, nearby Turin, the main city of Piemonte Region, situated in the Northwestern part of Italy. The characterization of the bio-geophysical environment of the study area through spatial analysis has been realized. Very high resolution satellite images (Quickbird) of the study area have been acquired and image analysis procedures with object oriented image classification approach are being realized. Landscape analysis methods derived from Landscape Ecology are being employed, selecting specific indicators to be applied to the W-UI conditions for the description of the wildfire environment and trying to obtain analytical tools to optimize planning processes.

Introduction and objectives

Wildland-urban interface (W-UI) environments can be described as composite systems where various structures (most notably private homes) and other human constructions meet or are intermingled with forest, wildland and other vegetation fuels. The wildland-urban interface presents many challenges and concerns for natural resource managers, one of the most urgent being wildfire management. The phenomenon of wildfires occurring in the wildland-urban interface has actually experienced a considerable increase in the last decades.

The purpose of this work, which is carried out within the WARM (Wildland-Urban Area Fire Risk Management) Project, funded by the European Commission, is to provide new tools to enhance natural resource management, planning and policy-making at the wildland-urban interface.

---

[1] An abbreviated version of this paper was presented at the second international symposium on fire economics, planning and policy: a global view, 19–22 April 2004, Córdoba, Spain.

[2] Forest engineer, PhD Student, Dep. Agroselviter, University of Turin, Via Leonardo da Vinci 44, 10095 Grugliasco (TO), Italy. email: raffaella.marzano@unito.it.

[3] Doctor in Forestry, Dep. Agroselviter, University of Turin, Via Leonardo da Vinci 44, 10095 Grugliasco (TO), Italy. (Current affiliation: Joint Research Centre, Institute for Environment and Sustainability - TP 261, I-21020 Ispra (VA) Italy. email: andrea.camia@jrc.it).

[4] Full Professor, Dep. Agroselviter, University of Turin, Via Leonardo da Vinci 44, 10095 Grugliasco (TO), Italy. email: giovanni.bovio@unito.it.

Among the objectives of WARM Project there is the definition of methodologies to study and characterize specific components of wildland-urban areas, including elements of bio-geophysical environment, socio-economic medium, land-uses, administrative division and fuels. The characterization of these typical elements and their mapping will provide useful supports for the elaboration of strategic management planning of wildland-urban interface environments.

In this manuscript results are presented concerning the development of analysis methods for W-UI environment characterization through Geographic Information Systems (GIS) and remote sensing techniques, and the subsequent production of meaningful derived maps. Wildland-urban interface landscape is characterized by a number of components that have to be identified, described and mapped in order to obtain useful information for the elaboration of integrated forest fire defense planning. GIS tools have proved to be really functional for W-UI management, through their capability of handling in an integrated environment multi-source and multi-resolution spatial data (Camia and others 2003). On the other hand, the use of very high resolution (VHR) satellite images provides the possibility of obtaining a high degree of detail, helping in the definition and mapping of components of the W-UI landscape.

Methods

Study Area

The area selected for the study is situated in Piemonte Region and located 15 km North-West from Turin, the main city of the Region *(fig. 1)*.

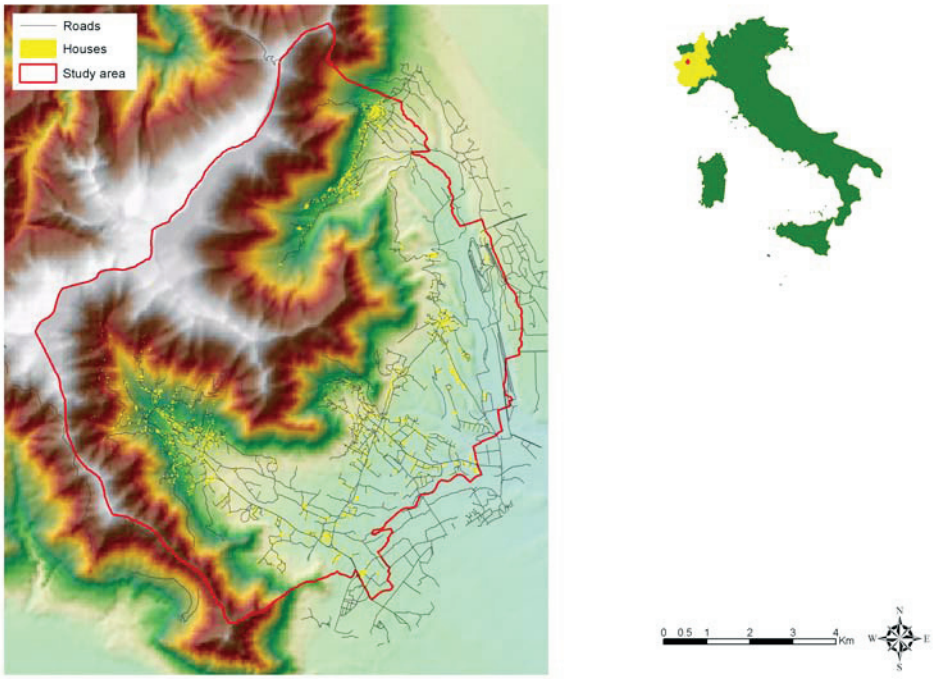


Figure 1— Boundary map and general location map of the study area.

This area corresponds to the Consortium of Communes in the mountain area of Ceronda and Casternone Valley and consists of 5 municipalities with a total extension of about 90 Km^2. It is located at the beginning of Lanzo Valley and it

comprises two valleys: Ceronda Valley and Casternone Valley. The topography is quite complex and characterized by a range of altitude that goes from 300 m to about 1600 m a.s.l.. The highest elevation belt presents mainly grazing land with forests typically concentrated on slopes, while the lower and flatter part presents mainly agriculture. Urban areas are frequently concentrated in the lower part or at the beginning of slopes. Forest vegetation cover is mainly composed by mixed broadleaved stands, with a predominance of *Quercus spp*. Some coniferous artificial stands are also present, covering a small percentage of the area.

From the analysis of the demographic database of Piemonte Region, the resident population has increased in the last six years of about 6,7 percent, reaching about 8500 people. This phenomenon is mostly evident in the municipalities of La Cassa and Val della Torre, since, as a consequence of their position next to Turin, many people working in the chief town decided to move and live here. Moreover the area is characterized by an increasing of population during holiday periods and week-ends, because of the presence of many holiday houses.

As to the W-UI areas, the selected test site presents both situations of classical interface and intermix. There are in fact villages with a more or less well defined boundary towards natural vegetation but also clusters of houses and isolated structures, the latter often completely surrounded by woodland or brushes. There are a total of 5 small towns (Givoletto, La Cassa, Val della Torre, Vallo Torinese and Varisella), one for each municipality, and many little villages and hamlets. These settlements, as previously underlined, are mainly situated in the lower and flatter parts of the study area, following the development of the valleys.

The fire season in the study area and in Piemonte Region in general is a Winter-Spring one, just in agreement with the driest period of the year (Bovio and Camia 1998). Wildfires are mainly concentrated in the months from January to April and they develop mostly under strong wind condition due mainly to Phön Wind (Bovio and Camia 1997). An analysis of the historical wildfire series from 1980 to 2001 showed that the study area was interested by 129 wildfires and that 98 of them involved W-UI conditions (Bovio and others 2002; Camia and others 2002).

Remote sensing applications

Remote sensing applications have been experimented in wildland-urban interface areas. In particular, considering the nature and characteristics of the phenomenon under investigation, it has been decided to work with very high resolution (VHR) satellite images. The possibility offered by these kinds of images to obtain a high degree of detail can surely help in the definition and mapping of components of the W-UI landscape. QuickBird is currently the world's highest resolution commercial satellite providing images at 0.61 m (panchromatic) and 2.44 m (multispectral) resolution as well as 70 cm pan-sharpened composite products in natural and infrared colors. We have thus acquired Quickbird images of the study area; both panchromatic imagery, collected in 11-bit format (2048 gray levels) and delivered in 16 bit format, and multi-spectral imagery were purchased. This latter consists of four discrete, non-overlapping bands (Blue: 450 - 520 nm; Green: 520 - 600 nm; Red: 630 - 690 nm; Near-IR: 760 - 900 nm) at 11 bit depth, delivered in 16 bit.

Object oriented classification

In order to map in detail fuels and land uses in the wildland-urban interface we have tested object-oriented classification techniques using eCognition software. In contrast to traditional image processing methods, the basic processing units of object oriented

image analysis are image objects or segments, and not single pixels. This kind of classification is based on the consideration that important semantic information, useful to facilitate classification process, can be derived by image objects and their relationship, not by single pixels. The software does not classify single pixels, but image objects that are previously extracted with a process of image segmentation, called multiresolution segmentation. This procedure permits to extract image objects, working at different resolutions and creating a hierarchical network. Classification is conducted in the software by fuzzy logic. Class description are performed with a fuzzy approach of nearest neighbor or using combinations of fuzzy sets on object features, applying membership functions (Baatz and others 2001). These two different approach support respectively different classification procedures, one based on the selection of typical objects marked as representative samples, the other applying features for classification based on image objects, addressing a wide variety of information.

Working with Quickbird images we have at first tried various procedures of multiresolution segmentation, to extract image objects at different resolutions. Then we have applied supervised classification techniques to obtain a preliminary fuel type (according to Prometheus system) and land use map. We have performed the first classification using only a nearest neighbor fuzzy approach, marking typical objects as representative samples. These samples correspond to training areas typically representing a particular land use or fuel type class. The initial results, obtained using nearest neighbor as unique classifier, were successively improved correcting inaccuracies in iterative steps by assigning typically wrongly classified image objects as samples into the right class, after the declaration of sample objects. The resulting map, an example of which can be seen in the following figure *(fig. 2)*, was checked through test areas corresponding to ground truth and obtained with a specific field work realized in the study area.

The map here presented can be considered as a very preliminary result that is expected to be improved in the following phases of the work. We are now working on the definition of membership functions to be added to the previous approach in order to refine the maps. These membership functions are based on the additional information (intrinsic, topological and context features) which can be derived based on image objects.

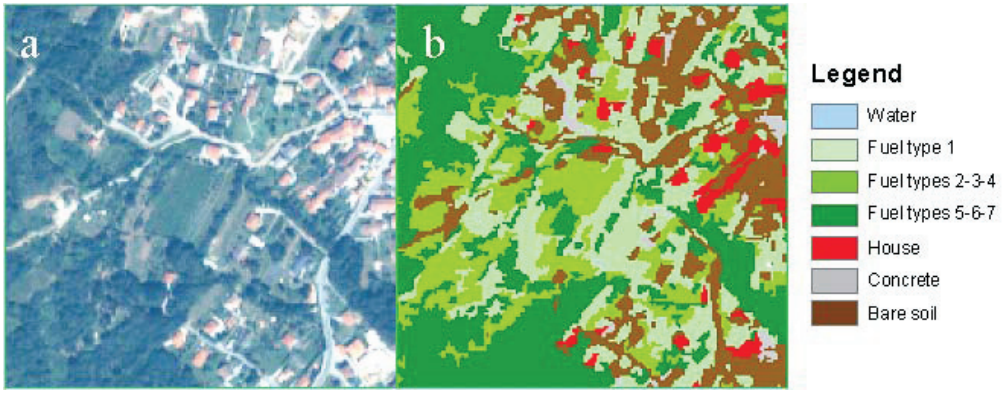


Figure 2—(a) Quickbird multispectral image. (b) Preliminary land use and fuel map obtained through a VHR satellite image object-oriented classification.

Landscape analysis applications

Landscape analysis methods derived from Landscape Ecology have been tested, aiming at selecting specific indicators to be applied to the W-UI conditions for the description of the wildfire environment and trying to obtain analytical tools to identify common denominators leading to W-UI fire events and to optimize planning processes for the W-UI fire defense. The methodologies that are being set up will provide the fire managers with the opportunity to define the W-UI zones and study in a comprehensive way the spatial relationships among W-UI elements and their interaction with wildland fires.

There are many different definitions for the term "landscape" depending on the research or management context. These different interpretations usually include an area of land containing a mosaic of patches (Urban and others 1987) or landscape elements, whose boundaries are artificially imposed. They represent the basis (or building blocks) for the elaboration of categorical maps. Size is not necessarily important to define a landscape, what must be taken into account is the patches interacting together and creating a mosaic, whose dimension is depending upon the phenomenon taken into account.

A disturbance, like a wildfire, has the possibility to spread across a landscape according to the abundance and arrangement of habitats being susceptible to that particular kind of disturbance (Lloret and others 2002). The key point of the analysis that is being carried on is to study landscape heterogeneity and the fragmentation introduced by the presence of settlements in relation to wildfires, assessing the effect of a complex landscape pattern, like those characterizing wildland-urban interface environments, and of its structural composition on fire regime. A basic assumption is represented by the fact that the fuel arrangement in a territory has a strong influence on fire spread and that the type of land cover and fuels characteristics are closely related (Turner and Romme 1994). Working at settlement scale, the effects of different patch configurations within a reference W-UI landscape in determining different levels of vulnerability to wildfire are being studied.

To apply landscape concepts and metrics to the research, it has been necessary to choose a reference landscape and to identify the single patches within this landscape. It has been decided to focus on settlements and their immediate surrounding and to concentrate the efforts on them; for this reason it has been selected a settlement within the study area to experiment procedures based on landscape ecology. Starting from the boundaries of the selected settlement, a buffer of 500 m has been realized with GIS techniques. An area of 253 ha was obtained with this elaboration *(fig. 3a)*. The idea was to obtain polygons (vector format) or grid cells (raster format) classified into discrete land use classes. Patches were delineated interpreting aerial photographs and Quickbird satellite images. A divisive approach was applied *(fig. 3b)*. Each patch was digitized starting from a single patch (the entire landscape), corresponding to the boundaries of the above mentioned buffer, and then successively partitioning this into homogeneous patches, a vector map constructed from digitized lines was obtained.

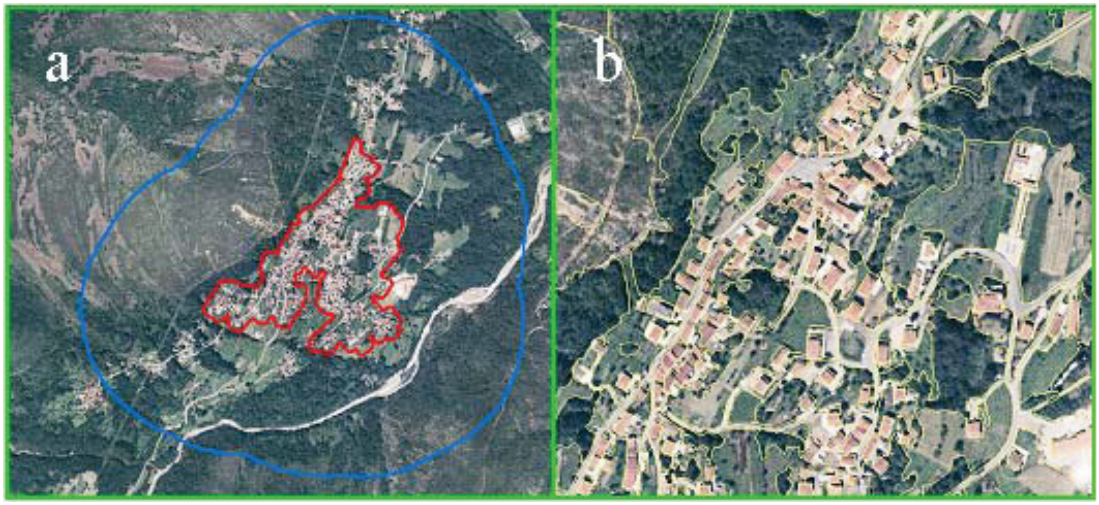


Figure 3—(a) The selected "landscape" (the red line identify the settlement boundaries, while the blue line corresponds to the 500 m buffer). (b) Patch digitization.

For the initial analyses, eight land use types were selected to identify the different patches, according to the phenomenon under consideration and the area characteristics: *brushes; fields; grass; grass – trees; house; non combustible; shingle; trees.* The final patch mosaic was then converted from a vector *(fig. 4a)* to a raster format *(fig. 4b)* obtaining a 1 m pixel raster map, in order to apply software algorithms for landscape metric calculation.

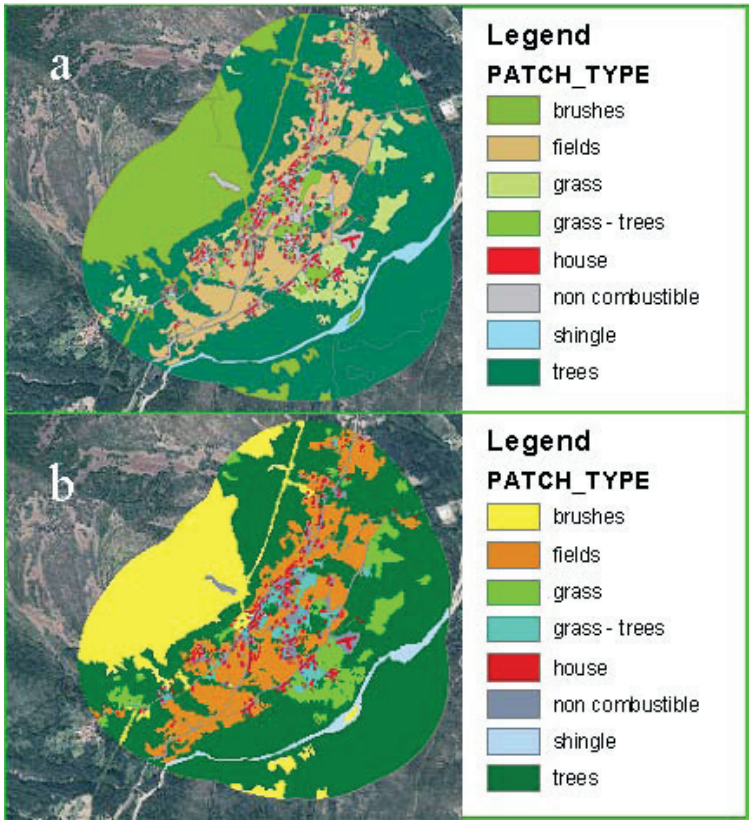


Figure 4—(a) The final patch mosaic (vector format) with its fuel and land use legend. (b) The final patch mosaic (raster format) its fuel and land use legend.

Selection of vulnerability indicators

Landscape metrics are algorithms that are used to quantify specific spatial characteristics of patches, classes of patches, or entire landscape mosaics (McGarigal and Marks 1995). Landscape metrics quantify the pattern of the landscape within a designated landscape boundary, focusing on the spatial character and distribution of patches. There are three different analysis levels and consequently three different metric levels:

- Patch metrics
- Class metrics
- Landscape metrics.

Landscape metrics are usually divided into two general categories: one includes metrics that are able to quantify the *composition* of the map without taking into account spatial attributes, and the other includes metrics that quantify the *spatial configuration* of the map, requiring spatial information to be implemented (McGarigal and Marks 1995, Gustafson 1998).

Once realized a categorical map of different land uses, the goal was to characterize the composition and spatial configuration of the patch mosaic, through landscape metrics. Attention was focused mostly on *structural metrics,* able to measure the physical composition or configuration of the patch mosaic without explicit reference to an ecological process (McGarigal and Marks 1995); just in a following step the functional relevance of the metric value will be interpreted. To calculate landscape metrics, we made use of FRAGSTATS (McGarigal and Marks 1995) that was applied to the 1 m pixel raster map. For a given landscape mosaic, the software can compute several metrics for each patch in the mosaic, each patch type (class) in the mosaic and the landscape mosaic as a whole. Almost all metrics available with FRAGSTATS have been at first computed for the settlement selected as study case. The selection of metrics that could provide indication about settlement vulnerability is right now being realized, in order to find a relationship between metrics and fire risk. To accomplish this task metrics obtained from real landscapes, corresponding to settlements located on the territory, are being compared with simulated landscapes, representing different levels of wildfire risk.

Conclusions

The paper aims at presenting the conceptual and methodological approach that is being applied for the analysis of W-UI areas in relation to wildfire management. The final goal of the research is actually the elaboration of useful recommendations about wildland-urban interface environments and their relation to wildfire risk, in order to enhance management decision making processes. Some preliminary results were presented, but the work is still in progress.

Remote sensing and geographical information system techniques, together with landscape analyses applying concepts and indicators derived from Landscape Ecology, can be usefully applied to the study of W-UI environments, providing crucial information for land-use planning and policymaking.

Acknowledgments

This research was funded by the European Commission - Energy, Environment and Sustainable Development Research Programme; Project WARM - Wildland-Urban Area Fire Risk Management (EVG1-CT-2001-00044).

References

Baatz, M.; Benz, U.; Dehgani, S.; Heynen, M.; Holtje, A.; Hofmann, P; Lingenfelder, I.; Mimler, M.; Sohlbach, M.; Weber, M.; Willhauck, G. 2001. **eCognition user guide.** Definiens imaging GmbH, München, Germany.

Bovio, Giovanni; Camia, Andrea. 1997. **Fire danger rating and land features in Winter-Spring seasons of Northwestern Italy.** Report of Minerve Project, EC-DGXII**.** 19 p.

Bovio, Giovanni; Camia, Andrea. 1998. **Operational Scenarios of Forest Fires in Italy**. In: Domingos Xavier Viegas, technical coordinator. Proceedings of 3rd International Conference on Forest Fire Research, November 16-20, 1998, Coimbra, Portugal.

Bovio, Giovanni; Camia, Andrea; Marzano, Raffaella. 2002. **Incendi boschivi in interfaccia urbano-foresta: metodi di indagine a scale regionale e locale**. Linea Ecologica, 2: 34-41.

Lloret, Francisco; Calvo, Eduard; Pons, Xavier; Díaz-Delgado, Ricardo. 2002. **Wildfires and landscape patterns in the Eastern Iberian Peninsula.** Landscape Ecology 17: 745-759.

Camia, Andrea; Marzano, Raffaella; Bovio, Giovanni. 2002. **Preliminary analysis of wildland-urban interface fire prone areas in Italy.** In: Domingos Xavier Viegas, technical coordinator. Proceedings of 4th International Conference on Forest Fire Research, November 18-23, 2002, Coimbra, Portugal.

Camia, Andrea; Varela, Vassiliki; Marzano, Raffaella; Eftichidis, George. 2003. **Spatial analysis in European Wildland-Urban Interface environments using GIS.** In: Proceedings of the International Workshop "Forest Fire in the Wildland-Urban Interface and Rural Areas in Europe". 15–16 May 2003, Athens (Greece).

Gustafson, E. J. 1998. **Quantifying landscape spatial pattern: What is the state of the art.** Ecosystems: 143-156.

McGarigal, K.; Marks, B. J. 1995. **FRAGSTATS: spatial pattern analysis program for quantifying landscape structure**. USDA For. Serv. Gen. Tech. Rep. PNW-351.

Turner, M.G.; Romme, W.H. 1994. **Landscape dynamics in crown fire ecosystems**. Landscape Ecology 9: 59-77.

Urban, D. L.; O'Neill, R. V.; Shugart, H. H. Jr. 1987. **Landscape ecology: A hierarchical perspective can help scientist understand spatial patterns**. BioScience 37: 119-127.

Three Great Myths of Wildland Fire Management[1]

Douglas B. Rideout, Pamela S. Ziesler[2]

Abstract

Three longstanding and pervasive myths of wildland fire management are identified and explained using a basic application of economic theory. Each myth is explained and the collection of myths is examined to identify a common misapplication of the theory that ties them together. The myths examined are:

- Fuels treatment reduces optimal suppression expenditures (including initial attack)
- Minimizing the C+NVC bowl provides an optimal solution
- High initial attack success rates are preferable to low rates of success

By correctly applying microeconomics, the user can easily avoid the confusions in policy and management promulgated by these common misperceptions. Correct applications of microeconomic theory can promote better wildland fire policy, avoid misperceptions, and lead to an improved development of fire management programs.

Why Three Great Myths

There are many misconceptions in fire management that are beginning to be revealed in the light of new inquiry into the management sciences related to wildland fire and wildland fire policy. So, why identify three myths? First, it seems that many good stories about some number of things are often about three things; like the three wishes in Aladdin, or Three Blind Mice, or The Three Stooges. More pragmatically, the myths listed here were chosen because they are pervasive and have had a fundamental impact on national and international wildland fire policy. Each myth is directly tied to understanding the fundamentals of the fire economics model known as "Cost Plus Net Value Change" or C+NVC. This paper will show that by developing a better understanding of the basic economics of wildland fire management we can make more knowledgeable scientific inquiry to better inform policy formation and management direction.

Most of the economic theory of wildland fire management has been in serious error for many years. A summary of much of the error in the basic economic model was provided by Donovan and Rideout (2003). This paper will further clarify the issue and implications will be demonstrated. Because errors in the theory of C+NVC have persisted since the work of Sparhawk in 1925, the three myths have each gathered steam over the years and each has reach greatness in its own right.

---

[1] An abbreviated version of this paper was presented at the second international symposium on fire economics, policy, and planning: a global view, 19–22 April, Córdoba, Spain.

[2] Professor and graduate student, respectively, Fire Economics Laboratory, Department of Forest, Rangeland, and Watershed Stewardship, Colorado State University, Fort Collins, Colorado.

Myth One: Fuels Treatment Reduces Optimal Suppression Expenditures and Optimal Wildland Fire Damage

This myth, while widely assumed to be true in each of its two parts, will be shown to have no basis in the economic theory as represented by the C+NVC model. Understanding this myth requires an understanding of the impact that fuels treatment may have on the NVC function. The NVC function shows how net damage from a wildland fire is affected by a particular decision variable. In our development, NVC is reduced by increasing dosages of fire fighting effort. Each part of this myth is developed below.

Fuels Treatment May Increase Optimal Fire Fighting

Contrary to the myth, fuels treatment may increase optimal fire fighting effort and expenditure. This is best explained by examining Figure 1. Figure one shows total cost on the vertical axis and total fire fighting effort on the horizontal axis. Net value change is shown as a declining function of fire fighting effort and the cost of fire fighting effort is shown as a linear increase (for ease of illustration) over fire fighting effort. These two cost functions are vertically summed to form the "C+NVC" bowl shape shown in the illustration. The usual objective function is to select the firefighting effort that will produce the minimum point on the bowl. As shown in Rideout and Omi (1990) and other works, the minimum point will occur when the slopes of the two underplaying cost functions are equal in absolute value. Important to understanding the nature of the myths is that only the slopes, not the locations, of the cost functions matter in locating the minimum point on the bowl.

To understand how fuel treatment may increase optimal fire fighting, consider how fuel treatment can affect the NVC function. In figure one, the "before (dashed) and after" (solid) picture is taken of the NVC functions. In this example, the NVC function lowers and steepens throughout. It lowers because we would expect lower damage at higher levels of fire fighting effort and it steepens because we expect firefighting effort to increase in marginal productivity. In fact, these are both frequent reasons given for hazardous fuels treatments. If the NVC curve steepens enough, the minimum of the C+NVC bowl will migrate to the right of the original bowl as shown in Figure 1. In this example, optimal damage has greatly decreased as a result of the lower NVC function (NVC before treatment is higher than NVC′ after treatment) but fire fighting effort and corresponding expenditure have increased.

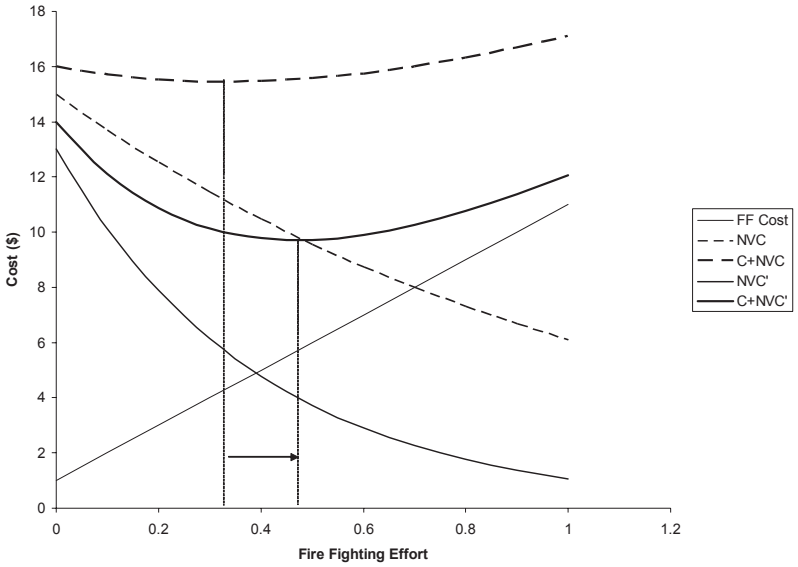


Figure 1—Fuels Treatment May Increase Optimal Fire Fighting Effort.

It is important to note that this is only one possible outcome. However, to be consistent with economic theory one must consider the possibility that fuels treatment may well cause an increase in optimal fire fighting effort. The point is that fuels treatment may increase *or* decrease optimal firefighting effort and expenditure, but this outcome is not predictable by the theory alone.

Fuels Treatment May Increase Optimal Damage

A direct parallel to the result in Figure 1 is a different kind of shift in the NVC curve as a result of fuels treatment. Suppose that the fuels treatment operated on the NVC function by lowering it while also decreasing its slope. It becomes flatter throughout as in Figure 2. Here our fuels treatment has done something to the vegetation or to the site condition that reduces the marginal productivity of fire fighting. If the reduction in slope is large enough relative to the other functions, the counterintuitive result can be achieved that optimal damage may increase as shown in Figure 2.

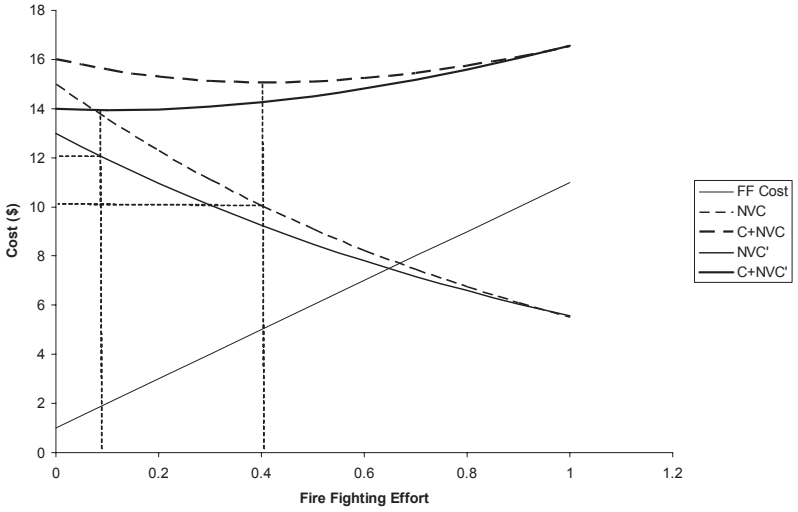


Figure 2—Fuels Treatment Increases Optimal Damage.

Here, with fuels treatment, the NVC function has shifted from NVC to NVC′ and C+NVC has shifted to C+NVC′. Because the marginal productivity of fire fighting has diminished, a lower dose of fire fighting is purchased. While the lower NVC function acts to reduce damage, this is off-set by the decline in optimal fire fighting effort such that optimal damage increases from 10 to 12 in the figure. Optimal damage may increase or decrease and this cannot be resolved without further information.

Myth Two: Minimizing the C+NVC Initial Attack Bowl Provides an Optimal Solution for the Fire Program.

Since the early days of Sparhawk and the development of the "Contemporary Sparhawk" (nearly 30 years ago) as shown in Figure 3, there has been recognition that the firefighting problem is composed of at least two parts: initial attack and extended attack. In some instances, the problem can be subdivided into even more parts, but we will consider just two for this development.

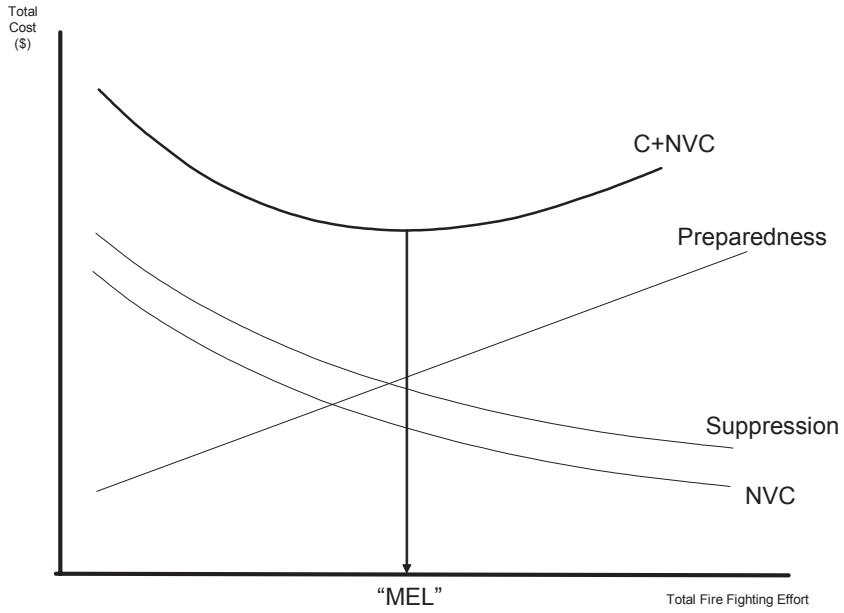


Figure 3—Contemporary Sparhawk Error (Donovan and Rideout 2003).

Figure three is an attempt to include the cost of extended attack in the C+NVC framework through a function confusingly labeled "suppression." The horizontal axis is often labeled "program level" or "preparedness", but for simplicity and consistency let's consider it to be fire fighting effort in the initial attack phase. Functions are defined as in the previous section except for the inclusion of the suppression function that is shown to decline with increasing initial attack. The rationale is characterized as this: the greater the effort in initial attack, the lower the optimal effort should be in extended attack or suppression. The key error in the

diagram that is discussed here for the first time is the "mixing of accounts" between initial and extended attack. While the cost effect of initial attack on extended attack is accounted for, the NVC portion of extended attack is not. In effect, the diagram brings over the cost function from extended attack and blends it with initial attack in an incorrect manner while omitting any effect of extended attack on NVC. We now have an account (initial attack) and a half (extended attack) so that the bowl itself is economically meaningless. Nevertheless, it incorrectly suggests that increases in program funding will lead to reductions in suppression costs. While this might occur, it would not be based on Figure 3.

One approach would be to remove the suppression function and minimize the bowl for initial attack. This correction is at the root of the second myth: that the minimum of the initial attack bowl produces an optimal initial attack solution. This solution is provided in the "Initial Attack" panel of Figure 4.

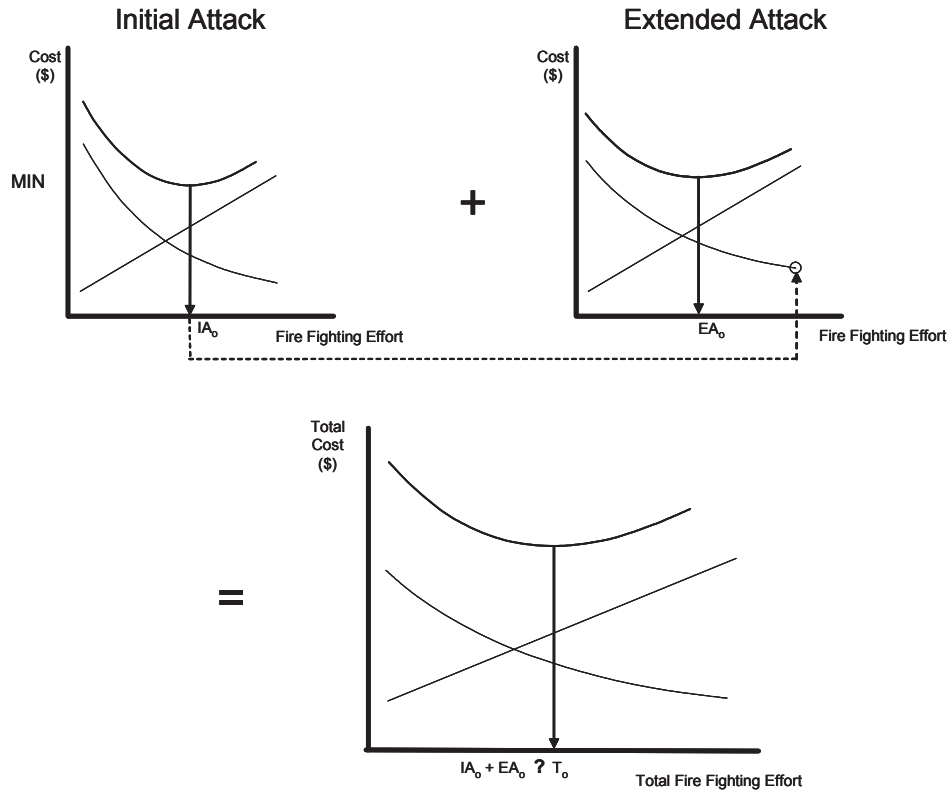


Figure 4.—Optimal Program Illustration.

The minimum of the C+NVC bowl in the Initial Attack panel provides an incorrect answer to the optimal fire fighting problem because fires that are not successfully contained in initial attack represent a cost that must be addressed elsewhere—usually in the extended attack phase. Therefore, the minimum of the initial attack bowl (unadjusted) contains an externality that is not accounted for without a more holistic approach. Like a factory spewing effluent into a river, the unadjusted initial attack framework spews the cost of large fires into extended attack. The general problem and corrections for this are well known in economics.

Here we correct for this problem by minimizing the sum of the initial and extended attack C+NVCs as shown in the panel "Total Fire Fighting Effort." We can also correct the Initial Attack panel to adjust for the externality (not shown). Three conclusions are apparent: (1) the minimum of the initial attack bowl represents an incorrect solution that can be fixed and (2) the "fix" included in the contemporary Sparhawk is erroneous and (3) a correct solution is to minimize the sum of the C+NVCs.

Myth Three: High Initial Attack Success Rates are Preferable.

While high initial attack success rates are preferable sometimes, this is not always the case. This myth is often at the heart of defining useful performance measures.

In Figure 4 we can see that there is an optimal amount of resources to expend on initial attack (assume the initial attack panel to be corrected for the externality in myth two). This directly implies that there are an optimal number of fires to successfully contain in initial attack and an optimal number of fires to manage under extended attack. For example, we often hear that something like 98 percent of fires are contained under initial attack. When the percentage of fires contained in initial attack is unrelated to a cost minimizing performance measure, how is the policy analyst to respond? Perhaps the optimal success rate was found to be 80 percent. We might then interpret the 98 percent measure to be excessive and costly such that a more cost-effective program could be designed. Alternatively, a careful cost-minimizing analysis might show a 99 percent success in initial attack to be optimal.

It is important to be clear regarding what constitutes a useful performance measure. In the heat of battle, fire fighters attempt to contain a particular fire and fire fighting performance at there may be viewed differently than at the federal program level. At the program level, where there are both costs and benefits of initial attack, such that there will always be an optimal level of containment success, and it will not likely be 100 percent.

Conclusion

Good applications of the basic economic theory of C+NVC can provide direction for addressing wildland fire policy and for avoiding misconceptions. Not knowing the theory, or by misrepresenting it as in the contemporary Sparhawk figure, can lead to policy based upon beliefs that may not be supported. In the fuels treatment examples, it is clear that the results of fuels treatment on the marginal productivity of fire fighting can affect the answer and may require empirical analysis to resolve. In

initial attack, just working with the minimum of the bowl without considering a potential externality on extended attack can lead to too conservative of an initial attack program. In each of these, knowing the relevant performance measure and how it is related to the production function can be central to sound decision making.

Literature Cited

Donovan, Geoffrey H., Rideout, Douglas B. 2003. A reformulation of the cost plus net value change (C+NVC) model of wildfire economics. Forest Science 49(2):318-323.

Rideout, Douglas B. Philip N. 1990. Alternative expressions for the economics of fire management. Forest Omi Science 36(3):614-624.

Page left blank intentionally.

Defining Initial Response: Integrating Fire Use With Initial Attack[1]

Stephen J. Botti,[2] Douglas B. Rideout,[3] Andrew G. Kirsch[3]

Abstract

Fire use enables fire managers to take advantage of the beneficial effects that natural ignitions may have on the landscape. Under the right circumstances, fire managers may choose to forgo initial attack in favor of monitoring and managing natural ignitions in ways that improve the condition of the ecosystem. As our knowledge and techniques for managing fires have advanced, so has fire policy and fire use. With increasing interest in fire use, comes a greater need for improved programmatic approaches and analysis. Here we explain how program management and planning efforts can integrate fire use into the initial attack planning and budgeting. We show how an integrated programmatic framework can take advantage of the important relationships that fire use has with initial attack. For example, because many of the fire management resources that are employed for initial attack are also those employed on use fires, an integrated program can take advantage of joint costs to realize potentially significant cost savings. We show how an integrated program can improve the efficiency of both initial attack and fire use while better informing the budgeting process. Such an integrated programmatic approach is currently in the developmental stages for the Fire Program Analysis (FPA) system currently under construction.

Introduction

Fire use refers to ignitions where the best response may be to manage and monitor the fire for resource objectives in lieu of aggressive suppression. These purposes are stated in land management plans and fire management plans (FMP). As defined by Zimmerman and Bunnell (1998) [1], wildland fire use is:

"The management of naturally ignited wildland fires to accomplish specific restated resource management objectives in predefined geographic areas outlined in FMP's."

The new integrated federal wildland fire management policy recognizes fire as an integral part of managing ecosystems and encourages managers to consider the full range of management options [2]. Evidence suggests that fire use is increasingly accepted and relied upon as a management tool that is finding its way into more land and resource management plans (e.g. Rideout and Botti, 2002 [3]). However, the employment of fire use may vary depending upon the fuels and fire behavior conditions, agency, land management goals, objectives and other considerations. Fire use strategies are unevenly accepted and applied among the federal land

[1] An abbreviated version of this paper was presented at the second international symposium on fire economics, policy, and planning: a global view, April 19–22, 2004 Córdoba, Spain.

[2] Manager, National Fire Program, USDI National Park Service, Boise, ID.

[3] Professor and graduate student, Fire Economics Laboratory, Department of Forest, Rangeland and Watershed Stewardship, Colorado State University, Fort Collins, CO 80523.

management agencies. In some agencies or administrative units, wildland fire use may be extensively applied while in other units it may be considered inappropriate.

Fire use represents a modeling hybrid between initial attack fire suppression and prescribed burning that poses unique challenges. The spatial and temporal extent of prescribed fires generally can be planned in advance. However, fire use fires are unplanned events, and the specific time, location, weather, and topography of each event are unknown. This is true even though fire use events may conform to a basic fire prescription specifying spatial and temporal conditions and a range of weather conditions. Like prescribed burning, fire use is used to restore or maintain natural conditions. Like unwanted wildfires, the conditions under which fire use fires occur are fraught with uncertainty.

Despite this uncertainty, initial response to wildfires and use fires can be modeled as a means of preparing for future fire seasons. These models are used to guide strategic decisions about the staffing and equipment required to prepare for fire seasons, not to make tactical decisions about how to manage real-time events. For both wildfires and use fires, the specifics of future events are unknown and therefore introduce issues of modeling accuracy and precision.

Fire use and suppressed wildfires represent two points on a continuum of appropriate management response strategies that can be applied to a given naturally-ignited wildland fire as shown in Figure 1.

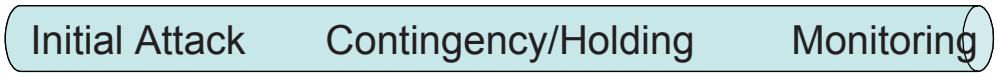


Figure 1—*Continuum of appropriate initial response*

As stated by Zimmerman and Bunnell (1998) [1], "When the Fire Management Plan has been completed and approved, and wildland fires are from natural ignition sources, the full extent of management options is available, depending upon resource management objectives presented in the FMP." These options include suppression only strategies where wildland fire is damaging, monitoring only strategies where it benefits ecosystems, or a combination of monitoring and holding strategies where it benefits resources in some areas but threatens values to be protected in other areas.

The resource benefit objectives that drive fire use are similar to those that drive the ecological use of prescribed fire. For this reason, early modeling discussions focused on combining fire use with prescribed fire and other fuels treatments. However, the uncertainties surrounding fire use events, along with the fact that an initial response is required for all wildland fires regardless of the management strategy employed, argue for including fire use within an overall strategic preparedness module.[4] Because the staffing and other resources employed on use

[4] Resources to prepare for wildland fire use generally are funded from budgeted operating accounts, while costs to manage events generally are funded from emergency accounts. This is because management costs are unpredictable, varying significantly each year depending on the number, size and location of fires. The strategic planning model presented here is designed to identify local resources required for managing use fires, not the resources

fires and initial attack suppression fires compete for the preparedness budget, it makes sense to analyze them together and determine the cost-effectiveness of all initial response strategies jointly within one module. Use fires and suppression fires draw upon a similar fire management resource base such that many resources acquired for one purpose can serve the other. For example, helicopters can transport fire crews to suppress an unwanted wildfire, or the same crew to monitor and manage a use fire. This multi-functionality of wildland fire preparedness resources suggests that an integrated management and budgeting approach should be considered.

A preparedness organization requires the capability to make an initial response to all wildland fire ignitions regardless of the strategy employed. The nature of that response should be guided by the benefits and costs of the fire as identified by measurable criteria, such as goals and objectives, from the fire or land and resource management plan. By modeling the full range of initial response strategies, managers can strategically plan the integrated use of initial response resources for monitoring, holding actions and limited suppression actions. This will incorporate management actions, such as modified and limited suppression strategies in Alaska, that may not be called fire use but which mirror the objectives of fire use in other areas.

While there is no option for modeling fires that begin with suppression strategies and are converted to monitoring strategies, this type of management rarely occurs and has little impact on initial response needs. The management requirements of fires that escape initial response, whether they escape initial attack and are converted to monitoring strategies or escape from fire use and are converted to suppression strategies are to be addressed separately.

Integrating Fire Use in Initial Response Planning

This modeling approach will provide fire managers with a much more powerful analytic process than has been previously available. This approach combines a rule-based system for defining management and monitoring requirements for AMR fires with production functions for containing wildfires, and makes this information directly available for an integrated optimization of initial response. This process will better inform the manager of resource use and resource interaction between initial attack suppression and fire use (and other AMR) at alternative budget levels in ways that have not been previously available. For example: the model will solve for optimal staffing of management and monitoring (M&M) resources used on wildland use fires. Management actions would include holding actions and other efforts to herd or influence the burning pattern, intensity, or extent of a fire use fire within a maximum manageable area without converting to a suppression strategy. It will show how M&M resources are shared with and complement the initial attack program. And it will show the development of a unified budget to address both fire use and initial attack suppression.

This approach quantifies and makes the objective basis explicit for current management decisions regarding the deployment of resources between fire use and initial attack. Figure 2 summarizes the overall approach.

---

required if they become large fires requiring contingents of non-local holding or suppression resources.

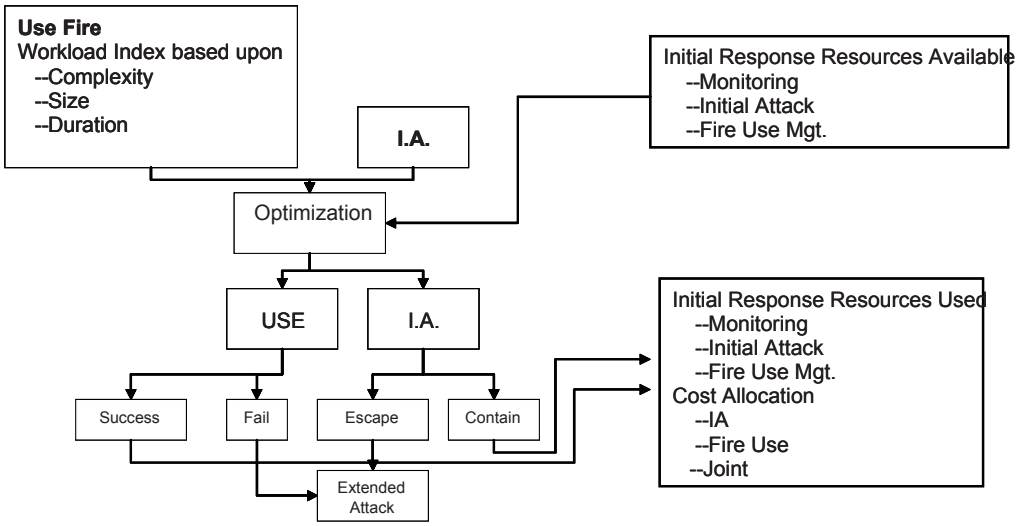


Figure 2—*Fire use integrated into optimization model.*

Think of the use fire as being managed by the following series of steps:

Sorting Fires

A planning unit would sort fires to be modeled for the preparedness planning process into two categories: those that are suitable to accomplish resource objectives and those that threaten values to be protected. Use fires would be fully defined regarding all of their meaningful characteristics including size, duration, complexity, location etc. An important distinction is that use fires have a defined size derived from historic records, whereas initial attack suppression fire size depends upon the vigor of attack. The optimizer will utilize data on these characteristics to model the M&M requirements for fire use fires. The scope of initial response would include only use fires meeting the planning unit level criteria. Fires that would require regional or national resources would be modeled through a different process from the one that would identify local preparedness requirements.

Fire Use Workload

Given the goals and objectives of the unit, historical data are analyzed and ignition estimates for the planning season are generated. Fire planners will sort initial attack suppression fires from fire use fires based on a combination of historical occurrence and planning standards and guidelines. Using this approach, current land and fire management objectives guide the sorting process and not the actual response strategies reflected in the historic data. Thus, the balance between the fire use workload and the initial attack workload is responsive to changing management needs, the current policy [2], and will accommodate plans for expanded fire use, rather than being constrained by the way decisions were made in the past. For example, fire management strategies associated with a geographic zone may change with time. Historic ignitions that were suppressed because they were within a full suppression zone at the time might now be managed as fire use fires because of changing land and fire management objectives within the geographic zone.

Wildland use fires would be sorted again based on their management workloads. How difficult or easy the fire is to manage would depend, in part, upon its

complexity, size and duration. For example, more complex fires would generate higher workloads. This second sort would separate fires whose complexity, size, and duration could be managed by local resources from those that would require regional or national resources. Those that could be managed with local resources would then compete with initial attack fires for the preparedness budget.

The data and process for generating a fire workload score for M&M could be accomplished by using a multiple regression framework. Analysis of data records could be used to estimate M&M workload scores for each fire and record each fire's complexity score, size, duration and other potentially relevant information. A list of fires could be generated with varying complexities, sizes and durations. This data would be recorded and analyzed according to the following functional form to produce a workload score—one for fire use management and one for fire use monitoring.

$$FireMgtWorkloadScore=\hat{\beta}_{MGT}=\beta_a+\beta_1+Complexity+\beta_2 Size+\beta_3 Duration+...$$
$$FireMonitoringWorkloadScore=\hat{\alpha}_{MTR}=\alpha_o+\alpha_1 Complexity+\alpha_2 Size+\alpha_3 Duration+...$$

$Beta_o$ and $alpha_o$ suggest that any use fire may require some management or monitoring regardless of its complexity, size and duration. Beta1 and alpha1 one would indicate how much an increase in the complexity value would add to the workload scores. Beta2,3 and alpha2,3 would quantify how much an increase in size (duration) would contribute to the workload scores.[5] It is possible that additional elements would need to be evaluated, but the suggestion is to keep the estimation process as simple and effective as is practical and defensible. After each of the alphas and betas are estimated, it is then possible to enter complexity, size and duration data for fires to estimate a M&M score. Establishment of a workload index for each potential use fire is a crucial step for this approach. The workload scoring process suggested here would quantify the decision process that managers have been using to determine how many resources are needed for managing and monitoring fire use fires. Bringing this rule-based decision approach into an optimizer would model more accurately the underlying multi-purpose nature of preparedness resources, rather than assuming that fire use resources are managed separately from initial attack resources

Management and Monitoring Resources

M&M resources would need to be organized for input into the optimizer. For initial attack, each potential firefighting resource carries an attribute that indicates how much it contributes toward cost and fire line production. Fire use would necessitate that these resources also carry a score identifying how effective they are in monitoring or managing use fires. Such a score would reflect how much the resource would contribute to fulfilling the workload associated with the fire. Workload fulfillment scores, one for monitoring and one for management, would be estimated

[5] Care would be taken to ensure that potential correlations between size and duration were properly managed, for example a combined variable might need to be constructed.

for each fire resource. Some resources might receive zero scores, i.e. an engine that would not be used for monitoring would receive a zero monitoring score.

Combining Fire Workload with Resource Workload Score

Various combinations of resources could be used to fulfill M&M fire workloads. Specifying the resource combination that most efficiently fulfills the fire workload can be addressed through a straightforward constraint set such as:

$$\hat{\beta}_i^{MGT} \leq \sum R_{i,r}^{MGT} \text{ and}$$
$$\hat{\alpha}_i^{MTR} \leq \sum R_{i,r}^{MTR}$$

where "R" denotes the resource management score that is "turned on" if the resource is used. The symbol "i" denotes a particular fire and "r" a particular resource. This will enable the optimization program to "deploy" the most efficient mix of fire management resources to the fire use fire while fulfilling the fire workload (β+α). The optimizer will choose that combination that maximizes effectiveness for a given budget.

This approach will enable the system to take advantage of jointness that is a crucial feature of the cost structure between initial attack and fire use. Many firefighting resources can be used for fire fighting as well as monitoring, holding, and limited suppression actions on fire use fires, while others could be specialized to one or the other. For example, a fire crew may serve as an initial attack resource on some fires and the same crew may be used to hold one side of a use fire occurring at a different time during the fire season, or to monitor the progress of that fire. This formulation prevents the system from effectively building two entirely separate sets of resources: one for initial attack and another for fire use. A corollary is that the fixed cost of having a resource on site is effectively To optimize the deployment of resources, the optimizer can weigh the relative importance of treating different acres through initial response. Acres that achieved resource benefits by being burned by fire use fires would be assigned a weight to indicate the relative importance by treating these acres through fire use. The number of acres burned times the weight would provide the weighted acres improved (WAI). WAI would represent the performance measure, or effectiveness of each wildland use fire. Acres protected by suppressing unwanted wildfires also would be assigned a weight. The number of acres burned by suppressed wildfires would be subtracted from the total acres that would burn without suppression to determine the acres protected. The acres protected times the weight of each acre would be the Weighted Acres Protected. The total weighted acres protected plus the total weighted acres improved would provide an integrated measure of weighted acres managed by these elements of the initial attack program. This is shown below in the integrated objective function.

Workload Contribution Scores

While scoring individual resources for their workload contribution may seem abstract, this overall approach would likely be required of any viable system that related fire use staffing and equipment needs to thresholds of workload and program complexity outside an optimizer. This is the rule-based system referred to under Fire Use Workload above. This scoring process requires a clear quantification and insertion at the point in the process where the information can be used to its greatest advantage. Also note that scoring resources for fire use management is analogous to

the scoring of resource productivity for initial attack: in initial attack the score is line productivity making the analogy direct.

Weighted Acres

To optimize the deployment of resources, the optimizer can weigh the relative importance of treating different acres through initial response. Acres that achieved resource benefits by being burned by fire use fires would be assigned a weight to indicate the relative importance by treating these acres through fire use. The number of acres burned times the weight would provide the weighted acres improved (WAI). WAI would represent the performance measure, or effectiveness of each wildland use fire. Acres protected by suppressing unwanted wildfires also would be assigned a weight. The number of acres burned by suppressed wildfires would be subtracted from the total acres that would burn without suppression to determine the acres protected. The acres protected times the weight of each acre would be the Weighted Acres Protected. The total weighted acres protected plus the total weighted acres improved would provide an integrated measure of weighted acres managed by these elements of the initial attack program. This is shown below in the integrated objective function.

Organizing Information for Processing

The concepts and suggested processes require careful organization before submitting to the optimizer. First, we recognize that the cost of fire fighting and managing resources depends upon their employment in fire use and in initial attack. This can be expressed as:

Cost of Resource (r) = Variable (IA) Cost + Variable (UF) Cost + Fixed Cost

Many resources would be available for use in initial attack and for use fires. Others might only be used for one. This is specified by the input data associated with the resource as supplied by the user. A more specific cost (focusing on fire use) can be expressed as:

$$C(r) = \Sigma Di * \text{Unit Cost} + \text{IA Cost} + \text{Fixed Cost}$$

Because use fires are of a defined duration, the approach in the above equation is to multiply a cost per unit time by the duration (D) that the resource would be deployed. These cost concepts can be organized as reflected in Table 1:

The first section of Table 1 (rows 4-6) shows the information that would be entered for each potential use fire. Cells E6 and G6 are optional. The binary variable f appears in the objective function below (Fig. 3) to indicate selection of the wildland fire use project (1), or (0) that the scarce budget is better allocated elsewhere. Fire use effectiveness is evaluated as an input to the process and would be the product of the fire size (F6) and the weight (H6). The second section (rows 9-16) shows entries for a particular use fire. The resource column would list the set of individual management and monitoring resources that would be available to deploy to the fire. Each of these would be associated with a monitoring and management score that would be used to evaluate its potential for satisfying the fire workload scores (C6 and D6). Enough resources (B11-B16) would have to be deployed to the use fire to satisfy these scores.

In this suggested approach, there are three options for each preparedness dollar:

- allocate funds to initial attack,

- allocate funds to fire use (M&M),
- a joint allocation (fixed costs),

Table 1—*Fire use resource input data.*

	A	B	C	D	E	F	G	H	I	J
1	**Data suggestions for integrated optimizer.**									
2										
3	**Use fire data**									
4					Workload Scores					
5	Variable	Success/Failure	Mgt	Mtr.	Complexity	Size	Duration	Weight	Effectiveness (F6*H6)	
6	f =	0/1	β	α	#	#	#	#	#	
7										
8	**For a specific use fire:**									
9			Scores			Variable UF cost				
10		Resource	MGT	Mtr	Unit Cost	Unit Cost * Duration	$R_{i,t}$			
11		1	#	#	#	#	0/1			
12		2	#	#	#	#	0/1			
13		3	#	#	#	#	0/1			
14		4	#	#	#	#	0/1			
15		5	#	#	#	#	0/1			
16		6	#	#	#	#	0/1			
17										
18										
19	Some of resources 1-n must be chosen to satisfy workload constraints indicated in cells c6 and d6.									
20	Otherwise the use fire is considered a failure and a suppression costis charged.									

The optimizer will evaluate a potential use fire to designate as accepted or unaccepted successful depending upon its cost and effectiveness relative to the cost and effectiveness of alternative uses of the budget, such as initial attack fires.

Integrated Objective Function

Integrating fire use with initial attack into the same optimizer requires adjustment of the objective function. Whereas the initial attack objective function would use only measures of weighted acres protected, the reformulation Fig. 3. adds a set of terms to reflect the effectiveness added by (weighted) acres improved by fire use. This reformulation will aid with communicating the initial attack/fire use integration process and the approach to initial response. We suggest an objective function6 like the one in Figure 3.

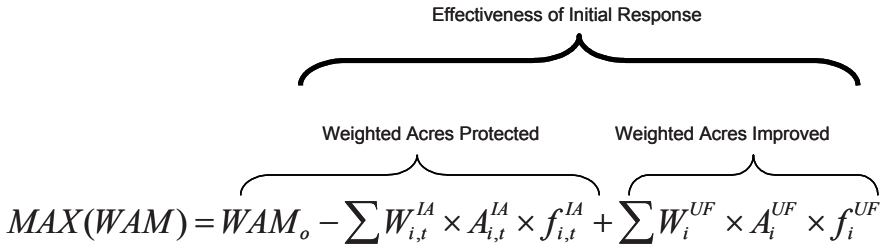


Figure 3—Initial response objective function

In Figure 3, weighted acres managed (WAM) from initial response are maximized and they are comprised of two parts: weighted acres protected through

[6] There is no t subscript on use fires because, unlike initial attack fires, their duration is an input.

initial attack and weighted acres improved through fire use. Acres protected are as before where each acre that burns from an unwanted fire is multiplied by a weight to indicate the relative value of protecting it. The subscript (i) denotes a particular fire and the subscript (t) denotes the fire duration. Weighted acres that would burn with no management are indicated by WAMo and this value need only be large -- it is not required to be accurate or precise. Weighted acres protected are defined as WAMo minus weighted acres burned. For example, if our FPU has 1,000 weighted acres to manage (WAMo) and 200 weighted acres burn, then we have protected 800 weighted acres. The greater the number of acres that burn, the lower the value of our objective function.

Weighted acres improved through fire use are arrived at by multiplying each acre improved by its weight. If, through fire use, we improve 500 weighted acres, then we would improve the value of the objective function by 500 WAM.

To include both protection and improvement, assume that the weighted acres burned (200) was arrived at by multiplying 50 acres by a weight of four and that the 500 acres improved were arrived at by multiplying 250 acres by two. Computation of WAM would include 800 weighted acres protected and 500 weighted acres improved as follows:

WAM = 1,000 – 4*50 + 2*250 = 1,300

Note that in both applications the weights on acres are positive. We expect that managers will better relate to positive weighting for both applications. The meaning of the weights remains unaffected. For example, a weight of two in protection means that it is twice as valuable to protect as an acre with a weight of one. Similarly an acre improved with a weight of six is twice as valuable to improve as an acre with a weight of three. Finally, it is three times more valuable to improve the acre weighted six than it is to protect the acre weighted two. There is only one rule regarding weighting. That is, all weights must represent proportionate valuation or importance.

Enriching the Output

There are many ways in which including fire use as part of an integrated initial response process will greatly enrich the output available to managers at the unit level and to program managers. Some examples include showing how resources can be organized to address the integrated management of use fires and initial attack fires over the season, showing which fires would produce the greatest return in effectiveness from scarce budgets and at different budget levels. To demonstrate how these kinds of enhancements could aid with decision making, consider the following example that shows how the integrated response funding can be identified by fire use vs. initial attack component.

The example is purposefully simple for illustrative purposes. Suppose our integrated program is funded at a hypothetical level of $860,000 that is to be divided between initial attack and fire use program components as organized in Table 2.

Table 2—*Program component formation from allocation of the preparedness budget.*

	A	B	C	D	E
1		Cost			
2	**Resource**	**I.A. Variable**	**U.F. Variable**	**Fixed**	**Deployed to:**
3	Engine #1	100,000	120,000	75,000	I.A.
4	Engine #2	150,000	300,000	75,000	I.A. & UF
5	Crew #1	75,000	50,000	30,000	UF
6	Monitors	0	50,000	30,000	UF
7					
8	**Program**	**Program Cost**			
9	I.A.	325,000	=B3+D3+B4		
10	U.F.	460,000	=C4+C5+D5+C6+D6		
11	Joint between I.A and U.F.	75,000	=D4		
12	Total	860,000			

In Table 2, there is only one initial attack fire, one fire use fire, and no unmanaged events. Four resources were made available to the optimizer for potential use in both fires. Suppose that the optimizer chose to send Engine #1 only to the initial attack fire, Engine #2 to both fires, Crew # 1 only to the use fire, and Monitors only to the use fire. Crew # 1 and Engine #2 would represent management resources to be used for holding actions along the fire use perimeter, and Monitors would represent monitoring resources to assess the daily progress of the use fire. The total preparedness budget of $860,000 (B12) would be allocated among the fire program components as in cells B9-B11. The initial attack program component would be the variable costs of the resources sent to initial attack fires (B3+B4) plus the fixed cost of Engine #1 (D3) because it was only sent to the initial attack fire. The allocation to the fire use program component (B10) would be arrived at similarly. Engine #2 was sent to both fires and has a fixed cost of $75,000 which is a cost that is jointly held between the programs and cannot be meaningfully allocated between them.

Unsuccessful use fires are fires that the optimizer did not have enough funds to manage as use fires, or found better uses of funds in initial attack. The optimization routine works with a limited budget and not all wanted initial responses may be afforded with a fixed budget. Fires that are not managed as use-fires within the initial response optimizer are managed under extended response. Extended response refers to management actions taken by non-local resources. This could occur because either the initial sort of use fires by size, duration and complexity indicated that fires could not be managed by local resources, or because the optimizer found a more cost-effective use of available resources than deploying them on these fires.

CONCLUSION

Integrating wildland fire use with initial attack in preparedness planning furthers interagency efforts to form an integrated initial response planning system. This provides a major step towards implementing the new interagency wildland fire policy where planners are encouraged to consider the full range of potential responses to each natural ignition, depending on the threats or benefits it presents to protection of life and property and resource values. The process outlined here provides a straightforward approach for integration. The fact that most of the firefighting resources that would be deployed in initial attack would also be the resources employed for wildland fire use means that modeling these as separate programs is

problematic. Many fire management resources are associated with significant fixed and procurement costs that cannot be allocated between separate programs. Integration to achieve an initial response preparedness program enables a more informed process for evaluating the purchase, location, and deployment of various firefighting resources that is not possible under separate programs.

ACKNOWLEDGEMENT

This paper has benefited from comments and suggestions made by Pamela S. Ziesler, Graduate Student at the Fire Economics Laboratory, Colorado State University, Fort Collins, Colorado.

LITERATURE CITED

Zimmerman, T.G. and D.L. Bunnell, Wildland and Prescribed Fire Management Policy: Implementation Procedures and Reference Guide. 1998, US Department of the Interior and USDA Forest Service. 82 pp.

Review and Update of the 1995 Federal Wildland Fire Management Policy. 2001, US Department of the Interior and USDA Forest Service. 78 pp.

Rideout, D.B. and S.J. Botti, Blueprint for Fire Planning. Journal of Forestry, 2002. 100(5): p. 36-41.

Page left blank intentionally.

The Effect of the Wildland-Urban Interface on Prescribed Burning Costs in the Pacific Northwestern United States[1]

Hayley Hesseln,[2] Alison H. Berry[3]

Abstract

The fire suppression policy on American public lands during the last century has resulted in increased fuel loadings, necessitating the use of prescribed fire and mechanical treatments to decrease hazardous fuels and risks of catastrophic wildfire. While these practices are widespread, there is great variability in project costs making planning difficult. Previous studies have examined the factors that influence management costs, yet grapple with the lack of consistent and reliable data. This study uses the FASTRACS (Fuel Analysis, Smoke Tracking, and Report Access Computer System) database from the Pacific Northwest Region of the Forest Service. The database provides information on costs, physical site characteristics, and managerial concerns for fuels management activities from 1993 to the present. Through multiple regression analysis, important influences on fuels management costs were identified. Projects conducted in the wildland-urban interface consistently exhibited higher treatment costs for both prescribed fire and mechanical treatments.

Introduction

In recent years, wildland fire has come to the forefront of public interest. Decades of successful wildfire suppression during the 20th century have resulted in unnaturally elevated levels of burnable wildland fuels that if ignited could lead to catastrophic fires (Arno and Brown 1991). Fuels reduction is of added importance in the wildland urban interface (WUI), where growing populations are making fuels management more complex (Snyder 1999). In populated areas, aesthetics, air quality, structure protection, and risk add new dimensions to management projects. Such complexities may increase costs; however, there is little information available on the relationship between the WUI and costs of management projects.

Cost studies have typically focused on managerial, operational, or physical factors, yet rarely combine all three. Similarly, studies are often focused on either mechanical fuels treatments or prescribed burning. Finally, research across agencies has been difficult given the lack of consistent data. Notwithstanding, Cleaves and others (1999) analyzed trends and influences on prescribed burning costs in the National Forest system during the period from 1985-1994. Similarly, Rideout and Omi (1995) looked at economic data for fuels management on a national level, using

[1] An abbreviated version of this paper was presented at the second symposium on fire economics, planning, and policy: a global view, April 19–22, 2004, Córdoba, Spain.

[2] Associate Professor, Department of Agricultural Economics, University of Saskatchewan, Saskatoon, SK Canada email: h.hesseln@usask.ca.

[3] MS Bozeman, Montana, email: ahberry@yahoo.com.

a National Park Service database. The database included project information, physical site characteristics, and administrative factors. Using a constant elasticity model of declining cost with increases in scale, they found that the costs of fuels treatment varied with respect to the goals of the management efforts. Two general goals were identified in fuels treatment: maintaining or restoring ecosystems and hazard fuel reduction. Higher precision was found in cost estimates for traditional hazard reduction treatments, as compared to ecosystem management treatments. Rideout and Omi also note the lack of available cost data and call for further testing across agencies, fuel treatment purposes, and time.

With respect to fuels treatments in the wildland-urban interface, research is becoming more prevalent albeit complicated. In recent years, there has been increased migration into the rural fringe, (Synder 1999, Davis 1990) giving rise to controversy regarding who is responsible for structure protection (Bakken 1995). While several studies concerning the wildland urban interface have focused on public attitudes and expectations, there are few that examine the effect of the WUI on costs.

The Federal Wildland Policy of 1995 directs federal managers to implement fuels management plans with regard to both ecological and economic principles (USDI/USDA 1995). As funding is allocated, land managers will look towards economic analyses for answers to fuels management questions. While it is apparent that fuels management costs can be highly variable, it has been difficult to identify sources of variation, frequently due to the lack of available data; records are often non-existent or incomplete.

This study seeks to look at costs using a region-wide analysis of USDA Forest Service (FS) and USDI Bureau of Land Management (BLM) fuels management data. We pay particular attention to the influence of the WUI on fuels management costs. We develop two regression equations to study the factors that affect costs for prescribed burning, and for mechanical fuels treatments. It is necessary to derive two equations given the difference in variables collected for each management project. We begin by discussing our methodology and assumptions and regression results, and conclude with a discussion of our findings.

Methodology

The Pacific Northwest Region of the Forest Service and the BLM in Oregon and Washington have been tracking fuels management projects for almost a decade as part of the Fuel Analysis, Smoke Tracking, Report Access Computer System (FASTRACS). This system enables managers to record fuels management project information including costs, physical site characteristics, and managerial factors. In its fullest, unedited form the database contains 18,600 observations with 196 data categories representing years 1993 to 2002, with the bulk of the information from 1999 to 2001. Most of the data are from Forest Service (FS) Ranger Districts and BLM Resource Areas.

For both mechanical and fire analyses, we focused only on the years after the National Fire Plan came into effect; beginning in the fall of 2000. This legislation made more money available to fuels managers for fuels treatment; therefore, it is logical that the cost structure before this legislation would be somewhat different than following it. Overall, only 17% of the fire and mechanical treatments in FASTRACS occurred before or during 2000, with the remaining 83% from 2001 and

2002. A t-test of both databases indicated significant ($p < 0.05$) differences in costs during 2000 vs. in 2001 and 2002. Furthermore, a preliminary study of the mechanical database indicated strong evidence (t-test $p < 0.001$) that costs differed between 2001 and 2002. Therefore, we used only data from 2001 in the analysis of the mechanical treatments. For fire treatments, there was no observable difference between 2001 and 2002 (t-test $p = 0.326$), therefore, records from both years were included. Based on previous studies, data availability, and completeness, we selected variables that have been instrumental in explaining treatment costs. Data include physical site information, managerial and administrative factors, and operational information. For a full listing, see Appendices A and B.

Factors were selected via backwards elimination based on an extra sums of squares F-test. Elimination criteria was $p > 0.100$. For categorical variables such as activity type and season for example, reference levels were tested to assess significance. Levels of categorical variables were either retained or eliminated as a group. To assess the role of the wildland urban interface, a WUI indicator variable was included in analyses of both fire and mechanical treatments. We first fit a rich model with as many independent variables as possible and then worked through the backward elimination process. The resulting equations for mechanical fuels treatments and prescribed burning are depicted by (eq. 1) and (eq. 2),

$$\begin{aligned}\ln CPA = {} & \beta_0 + \beta_1 WUI + \beta_2 DPA + \beta_3 \ln Acres + \beta_4 Slope + \\ & \beta_5 Winter + \beta_6 Summer + \beta_7 Fall + \beta_8 Handpile + \beta_9 MachinePile \\ & + \beta_{10} MachineLeave + \beta_{11} Ladder + \beta_{12} Thinning + \beta_{13} PCT + \\ & \beta_{14} FRI + \beta_{15} FRIII + \beta_{16} FRIV + \beta_{17} NaturalFuels + \beta_{18} NFPproject ,\end{aligned} \quad [1]$$

$$\begin{aligned}\ln CPA = {} & \beta_0 + \beta_1 WUI + \beta_2 DPA + \beta_3 \ln Acres + \beta_4 Slope + \\ & \beta_5 Elevation + \beta_6 Cascade + \beta_7 Broadcast + \beta_8 MachinePile + \beta_9 HandPile \\ & + \beta_{10} LandingPile + \beta_{11} Defensible + \beta_{12} WUI + \beta_{13} EcoSys + \beta_{14} 4x4 + \\ & \beta_{15} 6x6 + \beta_{16} 8x8 + \beta_{17} HarvOther + \beta_{18} WholeTree + \beta_{19} BrushGrass \\ & + \beta_{20} DougFir + \beta_{21} Lodge + \beta_{22} Mixed + \beta_{23} FRII + \beta_{24} FRIII + \beta_{25} FRIV\end{aligned} \quad [2]$$

where, the dependent variable is the natural log transformation of cost. Costs were also adjusted for inflation using the GDP deflator to year 2000. The independent variables are WUI, designated protection area (DPA), the natural log of acres (lnAcres), slope and elevation, season, activity method, fire regime, natural fuels indicator, NFP project, objectives and fuels types.

Results

Results will be presented first for the mechanical treatment model, and then for the prescribed burning model. We will then turn to a general discussion of the results.

Mechanical Fuels Treatments

Factors included in the final regression equation (Equation 1) for costs of mechanical treatments are WUI indicator, designated protection area indicator, lnAcres, average

slope, season, activity type, fire regime, natural fuels indicator and National Fire Plan project indicator. Variance inflation factors indicated no collinearity (VIF < 10). Coefficients, t-tests and 95% confidence intervals for each variable are listed in Table 1.

lnCPA = 0.219 + 1.271WUI + 0.469DPA – 0.190lnAcres + 3.203-2Slope + 0.988Winter + 0.943Summer + 1.293Fall + 1.447Handpile + 1.375MachinePile – 0.125MachineLeave + 0.774Ladder – 0.694Thinning + 1.391PCT + 1.693FRI + 1.925FRIII + 2.061FRIV + 0.967NaturalFuels – 0.607NFPproject (1)

The regression accounts for 57.8% (adjusted R-squared 0.578) of the observed variation in the dependent variable, lnCPA, based on 526 observations (Table 1).

Based on the extra sums of squares F-test, the regression variables were strongly significant ($p < 0.02$) with the exception of lnAcres ($p = 0.2889$). The variable lnAcres was retained for practical purposes for cost estimation. The estimated effect of the number of acres after anti-log transformations of both dependent and independent variables indicates that as the number of acres doubles, the cost increases by a factor of 0.927 (95% confidence interval {0.851 to 1.0069}). If the number of acres increases tenfold, the cost increases by a factor of 0.778 (95% confidence interval {0.586 to 1.030}). These economies of scale are also supported in the literature (Rideout and Omi 1995, Jackson and others 1982).

There was very strong evidence (t-test p value < 0.001) that the wildland urban interface indicator variable had an effect on per-acre costs. After anti-log transformation, the estimate of the coefficient for the WUI indicator is 3.56 (95% confidence interval {2.52 to 5.05}) indicating costs are almost four times greater in WUI areas. There was also strong evidence (t-test p value = 0.011) that the designated protection area indicator had an effect on cost per acre. The effect of DPA was 1.60 (95% confidence interval {1.11 to 2.29}), indicating that mechanical activities in protected areas are associated with per acre costs 60% higher than those in non protected areas.

Slope had a small but significant positive effect, signifying that increases in slope are associated with slight increases in per-acre costs. The natural fuels indicator also had a positive effect, suggesting that higher costs are associated with natural fuels as opposed to activity fuels or 'undetermined.' There was a negative effect from the NFP project indicator, which shows that NFP projects tend to have lower costs than non-NFP projects for mechanical treatments.

Three multi-level categorical variables; season, activity type, and fire regime were included in the final regression equation. Reference levels for these variables were spring, 'hand leave,' and fire regime II, respectively, and were not therefore shown in the regression. The coefficients indicate that mechanical activity costs were estimated to be significantly higher in all seasons when compared to spring activities (t-test $p < 0.02$). Furthermore, fire regime II was associated with lower per-acre costs than fire regimes I, III, and IV (t-test $p < 0.001$).

Table 1--Coefficients, t-tests, and 95% confidence intervals for independent variables in the regression model for mechanical treatments from the year 2001.

Mechanical Treatments 2001[a]

	Unstandardized Coefficients		Standardized Coefficients			95% Confidence Interval for B	
	B	Std. Error	Beta	t	Sig.	Lower Bound	Upper Bound
(Constant)	.219	.542		.404	.686	-.846	1.285
ind.WUI	1.271	.177	.270	7.194	.000	.924	1.619
DesignatedProtectionArea	.469	.184	.102	2.553	.011	.108	.830
LNACRES	-.109	.062	-.058	-1.750	.081	-.232	.013
AverageSlope	3.203E-02	.005	.210	5.841	.000	.021	.043
ind.winter	.988	.387	.080	2.557	.011	.229	1.748
ind.summer	.943	.175	.202	5.381	.000	.599	1.288
ind.fall	1.293	.209	.238	6.195	.000	.883	1.704
act.Handpile	1.447	.422	.304	3.426	.001	.617	2.277
act.MachinePile	1.375	.477	.168	2.882	.004	.438	2.312
act.MachineLeave	-.125	.445	-.022	-.280	.780	-.998	.749
act.LadderFuelReduction	.774	.460	.131	1.682	.093	-.130	1.677
act.Thinning	-.694	.482	-.085	-1.439	.151	-1.642	.253
act.PCT	1.391	.611	.100	2.275	.023	.190	2.592
ind.FireRegime1	1.693	.209	.364	8.100	.000	1.282	2.103
ind.FireRegime3	1.925	.284	.289	6.769	.000	1.367	2.484
ind.FireRegime4	2.061	.286	.311	7.202	.000	1.499	2.623
ind.NaturalFuels	.967	.167	.209	5.772	.000	.638	1.296
NFPProject	-.607	.232	-.103	-2.620	.009	-1.062	-.152

a. Dependent Variable: LNCPA R Squared = 0.593 Adjusted R Squared = 0.578 n = 526

Prescribed Burning

Factors included in the final regression equation (Equation 3) for costs of fire treatments are WUI indicator, designated protection area indicator, lnAcres, average slope, midpoint elevation, Cascade slope indicator, activity type, management objectives, harvest specifications, fuels species, and fire regime.

lnCPA = 5.205 + 0.358WUI + .0300DPA – 0.178lnAcres + 3.282-3Slope – 1.55Elevation + 0.517Cascade – 0.258Broadcast – 1.503MachinePile – 1.259HandPile – 1.652LandingPile – 0.351Defensible + 0.205WUI – 0.300EcoSys - 0.3174x4 – 0.1206x6 + 0.2518x8 + 0.391HarvOther – 0.566WholeTree – 0.173BrushGrass + 0.306DougFir + 0.618Lodge + 0.427Mixed + 0.427FRII + 0.268FRIII + 0.355FRIV (3)

Variance inflation factors indicated no collinearity (VIF < 10). Coefficients, t-tests, and 95% confidence intervals for each variable are listed in Table 2.

The remaining variables were retained given strong statistical significance (extra sums of squares F-test $p < 0.04$). Factors which were eliminated from the fire equation include season, year, county population, state, natural fuels indicator, pile calculation method, pile tons, pile indicator (y/n), NFP project indicator, load calculation method, agency, work agent, multiple ignition indicator, and ignition method. The final regression equation had an adjusted R-squared of 0.610, based on 837 observations (Table 2).

Table 2--Coefficients, t-tests, and 95% confidence intervals for independent variables in the regression model for fire treatments from the years 2001 & 2002.

Fire Treatments 2001 & 2002[a]

	Unstandardized Coefficients		Standardized Coefficients			95% Confidence Interval for B	
	B	Std. Error	Beta	t	Sig.	Lower Bound	Upper Bound
(Constant)	5.205	.196		26.589	.000	4.821	5.590
ind.WUI	.358	.070	.156	5.101	.000	.220	.496
DesignatedProtectionArea	.300	.065	.130	4.604	.000	.172	.427
LNACRES	-.178	.022	-.227	-7.944	.000	-.222	-.134
AverageSlope	3.282E-03	.002	.050	1.689	.092	-.001	.007
MidpointElevation	-1.55E-04	.000	-.147	-4.383	.000	.000	.000
ind.CascadeSlope	.517	.135	.150	3.816	.000	.251	.782
act.Broadcastburn	-.258	.200	-.036	-1.292	.197	-.651	.134
act.MachinePileBurn	-1.503	.108	-.395	-13.936	.000	-1.714	-1.291
act.HandPileBurn	-1.259	.066	-.546	-19.048	.000	-1.388	-1.129
act.BurnLandingPiles	-1.652	.132	-.358	-12.543	.000	-1.910	-1.393
obj.DefensibleSpace	-.351	.113	-.078	-3.110	.002	-.572	-.129
obj.ForestHealth	-.303	.086	-.103	-3.502	.000	-.472	-.133
obj.WUI	.205	.090	.068	2.265	.024	.027	.382
obj.EcosystemRestoration	-.300	.119	-.074	-2.527	.012	-.533	-.067
HarvSpecs.4X4	-.317	.113	-.078	-2.813	.005	-.538	-.096
HarvSpecs.6X6	-.120	.094	-.034	-1.275	.203	-.304	.065
HarvSpecs.8X8	.251	.167	.039	1.505	.133	-.076	.579
HarvSpecs.other	.391	.092	.114	4.233	.000	.209	.572
HarvSpecs.WholeTreeYard	-.566	.112	-.136	-5.054	.000	-.786	-.346
fuel.BrushGrass	-.173	.174	-.026	-.994	.321	-.516	.169
fuel.DougFirHemlockCedar	.306	.139	.073	2.209	.027	.034	.579
fuel.Lodgepole	.618	.110	.178	5.613	.000	.402	.834
fuel.MixedConifer	.427	.077	.186	5.561	.000	.276	.578
ind.FireRegime2	.467	.109	.102	4.295	.000	.254	.680
ind.FireRegime3	.268	.098	.095	2.727	.007	.075	.461
ind.FireRegime4	.335	.117	.097	2.863	.004	.105	.564

a. Dependent Variable: LNCPA R Squared = 0.622 Adjusted R Squared = 0.610 n = 837

The WUI indicator was again strongly significant (t-test $p < 0.001$) with an estimated coefficient after transformation of 1.430 (95% confidence interval {1.246 to 1.642}), indicating that the per-acre costs for WUI fire treatments are about 43% more than the per-acre costs of non-WUI fire treatments. Additionally, there was strong evidence (t-test $p < 0.001$) to include the designated protection area indicator variable in the regression model for fire treatments. After anti-log transformation, the estimated coefficient for DPA was 1.349 (95% confidence interval {1.188 to 1.533}), indicating that per-acre costs of fire activities in designated protection areas are approximately 35% percent higher than those in non-protected areas.

There was strong evidence (extra sums of squares F-test $p = 0.039$) to include lnAcres in the regression model, and again, the sign of the coefficient indicated economies of scale. Midpoint elevation and average slope both had a small but significant (t-test $p < 0.10$) effect on costs. Estimated effects were such that steeper slopes were associated with slight increases in cost, and higher elevations were associated with slight decreases in cost. The estimated effect of the Cascade slope indicator suggested that per-acre costs of fire treatments are higher on the west side of the Cascade ridge.

Multi-level categorical variables (and reference levels) in the fire regression included activity type (underburn), primary project objective (fuel reduction), harvest specifications (not applicable), fuels species (ponderosa pine), and fire regime (fire regime I). Burning activities in all fire regimes were associated with higher per-acre costs when compared to fire regime I. Where primary project objectives are concerned, activities with the objectives defensible space, forest health, and ecosystem restoration were estimated to have significantly lower costs than those with the objective of fuel reduction (t-test $p < 0.02$). In contrast, activities with the objective 'WUI' were associated with significantly higher costs than those with fuel reduction objectives (t-test $p = 0.024$). All of the burn activity types were estimated to have lower costs than underburning. However, there was only very weak evidence (t-test $p = 0.197$) supporting a difference of costs between broadcast burning and underburning. All of the fuels species were associated with significantly higher costs than ponderosa pine (t-test $p < 0.03$), with the exception of brush/grass, for which there was no evidence of a difference (t-test $p = 0.321$).

Discussion

Despite the large amount of information available in FASTRACS and extensive records, the R-squared values were somewhat lower than have been observed in previous studies (Rideout and Omi 1995, Jackson and others 1982). Lower observed R-squared values may be due to the lack of information regarding key factors. For example, Rideout and Omi (1995) used information on escapes as a variable, and ranking scores on values including ignition complexity, natural resources, historic importance, and wildlife habitat. Additionally, previous studies have focused more specifically on only one or two management objectives, resulting in less cost variability.

It is notable that WUI was a significant factor in both mechanical and fire treatments. Analysis of the FASTRACS data clearly indicates that costs are higher for WUI activities. For mechanical treatments, WUI activity costs were estimated to be more than three times as much as for non-WUI activity costs. For fire treatments,

WUI per-acre activity costs were estimated to be 43% higher than those of non-WUI activities. The discrepancy in the size of the effect of WUI on costs between fire and mechanical treatment is somewhat unexpected. It is possible that when WUI fuels treatments are associated with particularly high risk (and high cost), they are more likely to be treated via mechanical activities than via fire activities. Additionally, managers noted that burning costs can be prohibitively high in the WUI, so it may be the case that the data are skewed to include a greater relative number of low-cost WUI fire treatments. DPA was also a significant factor in both the fire and the mechanical analyses, indicating that proximity to population centers or areas of smoke management concern can be associated with elevated fuels treatment costs. These results quantify the role of the wildland urban interface in fuels management costs and suggest that it may be worthwhile to consider WUI and DPA when estimating activity costs.

Activity type and unit size are generally considered to be two important factors influencing treatment costs (Cleaves and Brodie 1990, Cleaves and others 1999). Activity types were found to be significant for both fire and mechanical treatments. Since this is a primary factor considered in budgeting, it is not surprising that different activities were associated with different costs. The variable lnAcres was included in both regression equations and results support the findings of previous studies (Rideout and Omi 1995, Jackson and others 1982) that per-acre costs generally decrease as the number of acres treated increases. For the fire data this observation was strongly significant, but this was not the case for the mechanical data. Because the number of acres treated does not greatly affect the per-acre costs of mechanical treatments, this analysis indicates that other factors are more important for estimating costs. With respect to the number of acres treated, mechanical treatments are more likely to have higher fixed costs and lower variable costs than fire treatments. Therefore, mechanical treatment per-acre costs will be less sensitive to overall treatment scale.

Primary project objectives were significant in the analysis of the fire data, supporting the findings of previous research (Cleaves and Brodie 1990). Furthermore, burning activities with WUI objectives were associated with higher costs than those with fuel reduction objectives. All other primary project objectives were associated with lower costs than those of activities with fuel reduction objectives. This result strengthens the argument that costs associated with WUI fire treatments are higher than those associated with non-WUI treatments. Primary project objectives were not found to be significant in the analysis of the mechanical data. It is possible that the significance of this factor was masked by other significant factors in the mechanical analysis.

Conclusion

The results of this analysis clearly indicate that per-acre costs of fuels treatments are higher in wildland urban interface areas for both mechanical fuels reduction and prescribed burning methods. Additionally, per-acre costs were found to be higher in areas of concern for smoke management or near population centers. Currently, WUI and DPA are not specifically factored into budgeting for fuels management activities in the Pacific Northwest. However, this analysis indicates that considering WUI and DPA could produce more accurate cost estimates. DPA is, of course, only a factor in Oregon where the smoke management plan delineates these areas. It would be

possible, however, to develop similar classifications in other states based on smoke management concerns and population densities.

The FASTRACS database has great potential for future studies. It may become a more central part of the management system of the Pacific Northwest region. As more managers use FASTRACS, it will become a more complete record of management activities across the region. Additionally, perhaps it can serve as a model for a nation-wide data management system. It is apparent from discussions with managers that Region 1, in particular, completely lacks any kind of tracking program of fuels management projects and costs. For accurate economic analysis of the FASTRACS database, however, it will be necessary to more precisely define what activity costs are composed of, as well as to define actual vs. planned costs. This will insure that costs may be compared across districts, forests, and regions. Additionally, for future studies of wildland urban interface issues, it will be necessary to develop a working definition of this term.

For statistical analysis purposes, more complete records are needed in the FASTRACS database. For example, many observations in this study were incomplete in the potentially important fields of weather, fuel moisture, condition class, threatened and endangered species, predominant aspect, and position on slope. Furthermore, it may be possible to record information on factors like unit shape, access, distance traveled to worksite, crew composition, hours of labor, days of mop-up, and occurrences of escapes in future editions of FASTRACS. This would enable a more comprehensive analysis, and the ability to predict a greater portion of cost variability. At this point, while FASTRACS is the best source for region-wide information on fuels management projects, there is still a lot of room for improvement.

Acknowledgements

We would like to acknowledge fuels managers of Regions 1, 4, and 6, for taking the time to provide data, and to answer many questions. In particular, we want to express gratitude to Mary Ann Sanford, Tim Rich, and John Orbeton. McIntire Stennis funding supported this research.

Literature cited

Arno, Stephen F., and James K. Brown. (1991). Overcoming the paradox in managing wildland fire. Western Wildlands. 17(1):40-46.

Bakken, Stephen. (1995). Conflicts between natural resources and structural protection. In The Biswell Symposium: Fire Issues in Urban Interface and Wildland Ecosystems. USDA Forest Service Gen. Tech. Rep. PSW-GTR-158.

Cleaves, David A. and Douglas Brodie. (1990). Economic analysis of prescribed burning. pp. 271-282. in Natural and Prescribed Fire in Pacific Northwest Forests, J.D. Walstad, and others, eds. Oregon State University Press, Corvallis.

Cleaves, David A., Terry K. Haines, and Jorge Martinez. (1999). Prescribed burning costs: trends and influences in the National Forest System. P.277 in Proceedings of the Symposium on Fire Economics, Planning and Policy: Bottom Lines. USDA Forest Service Gen. Tech. Rep. PSW-GTR-173.

Davis, James B. (1990). The wildland-urban interface: paradise or battleground? Journal of Forestry. 88(1):26-31.

Davis, Kathleen M., B.D. Clayton, and W.C. Fischer. (1980). Fire ecology of Lolo National Forest habitat types. USDA Forest Service Gen. Tech. Rep. INT-122. Intermountain Forest and Range Experiment Station. Ogden, UT. 22pp.

González-Cabán, Armando, and Charles W. McKetta. (1986). Analyzing fuel treatment costs. Western Journal of Applied Forestry. 1:116-121.

Heinselman, M. L. (1973). Fire in the virgin forests of the Boundary Waters Canoe Area, Minnesota. Quat. Res. 3:329-82.

Jackson, David H., Patrick Flowers, Robert S. Loveless, Jr., and Ervin G. Schuster. date Predicting prescribed burning costs of wildlife habitat management. Fire Management Notes. 43(4):20-22.

Rich, Tim. (1984). Sources of costs associated with prescribed burning on the Powell Ranger District. Thesis, 56pp. University of Idaho, Moscow, ID.

Rideout, Douglas B. and Philip N. Omi. (1995). Estimating the cost of fuels treatment. Forest Science. 41(4): 664-674.

Snyder, Glenn W. (1999). Strategic holistic integrated planning for the future: fire protection in the urban/rural/wildland interface (URWIN). In Proceedings of the Symposium on Fire Economics, Planning, and Policy: Bottom Lines. USDA Forest Service Gen. Tech. Rep. PSW-GTR-173.

USDI/USDA. (1995). Federal wildland fire management policy and program review report. U.S. Department of the Interior, U.S. Department of Agriculture. Washington, D.C. 41p.

Appendix A) Mechanical treatments: Variables and descriptive statistics

Variables	Levels (# of Observations)	n	Min.	Max.	Mean	Standard Deviation
Cost Per Acre (CPA)		840	0.01	2,077.80	176.81	241.37
lnCPA		840	-5.12	7.64	4.23	2.10
Acres Treated		771	1	2,322	89.86	176.74
lnAcres		771	0	7.75	3.66	1.27
Cost Year		840	2001	2001	2001	0
IND.2001		840	1	1	1	0
Season	Winter (24)	768	0	1	0.03	0.17
	Spring (193)	768	0	1	0.25	0.43
	Summer (334)	768	0	1	0.43	0.50
	Fall (217)	768	0	1	0.28	0.45
WUI	(439)	840	0	1	0.52	0.50
DPA	(326)	785	0	1	0.42	0.49
Average Slope (%)		751	0	60	17.10	14.66
Midpoint Elevation (Feet)		743	500	6,450	4442.59	1148.35
Activity Type	Hand pile (274)	840	0	1	0.33	0.47
	Hand Leave (37)	840	0	1	0.04	0.21
	Machine Pile (169)	840	0	1	0.20	0.40
	Machine Leave (142)	840	0	1	0.17	0.38
	Ladder Fuel Reduction (139)	840	0	1	0.17	0.37
	Thinning (61)	840	0	1	0.07	0.26
	PCT (18)	840	0	1	0.02	0.14
Fire Regime	Fire Regime 1 (350)	652	0	1	0.54	0.50
	Fire Regime 2 (109)	652	0	1	0.17	0.37
	Fire Regime 3 (95)	652	0	1	0.15	0.35
	Fire Regime 4 (98)	652	0	1	0.15	0.36
Natural Fuels	(424)	840	0	1	0.50	0.50
County Population		827	2,397	322,959	69,522.15	72,026.73
Cascade Slope	(West = 78)	827	0	1	0.09	0.29
State	(WA = 40)	827	0	1	0.05	0.21
Primary Project Objective	Forest Health (157)	840	0	1	0.19	0.39
	WUI (132)	840	0	1	0.16	0.36
	Ecosystem Restoration (76)	840	0	1	0.09	0.29
	Fuel Reduction (475)	840	0	1	0.57	0.50
NFP Project	(636)	840	0	1	0.76	0.43
BLM	(144)	840	0	1	0.17	0.38
Work Agent	Timber Sale Purchaser (10)	839	0	1	0.01	0.11
	Contractor (552)	839	0	1	0.66	0.47
	Force Account (227)	839	0	1	0.33	0.47
Valid N (listwise)		515				

Appendix B) Fire treatments: Variables and descriptive statistics

Variables	Levels (# of Observations)	n	Min.	Max.	Mean	Standard Deviation
Cost Per Acre (CPA)		1946	0.65	1,426.00	85.24	107.78
lnCPA		1946	-0.43	7.26	3.84	1.21
Acres Treated		1316	0	15,222	101.85	563.91
ln(Acres Treated + 1)		1316	0	9.63	3.07	1.55
Cost Year		1946	2001	2002	2001.49	0.50
Year	2001 (999)	1946	0	1	0.51	0.50
	2002 (947)	1946	0	1	0.49	0.50
Season	Winter (217)	1423	0	1	0.15	0.36
	Spring (289)	1423	0	1	0.20	0.40
	Summer (30)	1423	0	1	0.02	0.14
	Fall (887)	1423	0	1	0.62	0.48
WUI	(826)	1946	0	1	0.42	0.49
DPA	(784)	1879	0	1	0.42	0.49
Average Slope (%)		1769	0	87	19.95	16.89
Midpoint Elevation (ft)		1778	500	6,500	4057.96	1141.87
Activity Type	Broadcast Burn (49)	1946	0	1	0.03	0.16
	Machine Pile Burn (211)	1946	0	1	0.11	0.31
	Hand Pile Burn (811)	1946	0	1	0.42	0.49
	Burn Landing Piles (227)	1946	0	1	0.12	0.32
	Underburn (648)	1946	0	1	0.33	0.47
Fire Regime	Fire Regime 1 (884)	1529	0	1	0.58	0.49
	Fire Regime 2 (152)	1529	0	1	0.10	0.30
	Fire Regime 3 (317)	1529	0	1	0.21	0.41
	Fire Regime 4 (176)	1529	0	1	0.12	0.32
Natural Fuels	(1014)	1946	0	1	0.52	0.50
County Population		1927	1,547	322,959	85,050.01	78,959.44
Cascade Slope	(West = 225)	1927	0	1	0.13	0.34
State	(WA = 247)	1927	0	1	0.13	0.33
Primary Project Objective	Defensible Space (82)	1848	0	1	0.04	0.21
	Forest Health (255)	1848	0	1	0.14	0.34
	WUI (284)	1848	0	1	0.15	0.36
	Ecosystem Restoration (152)	1848	0	1	0.08	0.27
	Fuel Reduction (1075)	1848	0	1	0.58	0.49
NFP Project	(1288)	1946	0	1	0.66	0.47
BLM	(261)	1946	0	1	0.13	0.34
Work Agent	Timber Sale Purchaser (57)	1930	0	1	0.03	0.17
	Contractor (244)	1930	0	1	0.13	0.33
	Force Account (1629)	1930	0	1	0.84	0.36
Fuels Species	Brush/Grass (40)	1404	0	1	0.03	0.17
	D-Fir, Hemlock, Cedar (149)	1404	0	1	0.11	0.31
	Lodgepole (253)	1404	0	1	0.18	0.38
	Ponderosa (328)	1404	0	1	0.23	0.42
	Mixed Conifer (634)	1404	0	1	0.45	0.50

Appendix B, continued

Variables	Levels (# of Observations)	n	Min.	Max.	Mean	Standard Deviation
Harvest Specifications	4"x4' (114)	1787	0	1	0.06	0.24
	6"x6' (134)	1787	0	1	0.07	0.26
	8"x8' (39)	1787	0	1	0.02	0.15
	Other (167)	1787	0	1	0.09	0.29
	Whole Tree Yard (96)	1787	0	1	0.05	0.23
	N/A (1237)	1787	0	1	0.69	0.46
Load Calculation Methods	NA/piled (307)	1711	0	1	0.18	0.38
	Other (445)	1711	0	1	0.26	0.44
	Transect (9)	1711	0	1	0.01	0.07
	Local (714)	1711	0	1	0.42	0.49
	Photo Series (236)	1711	0	1	0.14	0.34
Pile Calculation Methods	Non Pile (681)	1609	0	1	0.42	0.49
	Aerial Survey (5)	1609	0	1	0.00	0.06
	Local Method (294)	1609	0	1	0.18	0.39
	Pile Wizard (288)	1609	0	1	0.18	0.38
	Ocular (344)	1609	0	1	0.21	0.41
Pile Tons		1442	0	3,876.60	76.79	238.43
Pile y/n	(yes = 1249)	1946	0	1	0.64	0.48
Ignition Methods	Aerial (32)	974	0	1	0.03	0.18
	Combination (36)	974	0	1	0.04	0.19
	Hand (906)	974	0	1	0.93	0.25
Multiple Ignitions	(124)	1155	0	1	0.11	0.31
Valid N (listwise)		585				

Page left blank intentionally.

Policy Incentives for Wildland Fire Management in the United States [1]

Sara E. Jensen[2]

Abstract

Researchers, politicians, and land managers have described a "fire crisis" in the United States during the late 20th and early 21st centuries: Fuels have built up over decades of fire suppression and combined with an ever-expanding urban-wildland interface to result in economically and ecologically disastrous wildfires. Recent policy debate in the United States suggests that regulatory environmental policy at the federal level conflicts with the new priorities of fire management. This should be seen as very real and serious criticism of federal environmental policy. I suggest three possible analyses of this debate: first that the goals and principles of fire management inherently contradict the goals and principles of federal environmental policies; second, that some aspect of the implementation of environmental policies may constrain or contradict good fire management practices; and third, that no significant conflict exists either in policy or in implementation and that the policy dialogue described above is wholly or primarily a political construction. In a systematic comparison of the goals of federal wildland fire management and two major environmental regulatory policies, I find only very few and very minor conflicts. Where conflicts do exist, they are most commonly the result of insufficient scientific information or of paradoxes of priorities within fire management that will require significant flexibility in policy implementation. Finally, I present some preliminary evidence on the possibility of a conflict in policy implementation, a framework for evaluating the possible political construction of this policy debate, and some directions for future research.

Introduction

Researchers, politicians, and land managers have described a "fire crisis" in the United States during the late 20th and early 21st centuries: Fuels have built up during decades of fire suppression and combined with an ever-expanding urban-wildland interface to result in economically and ecologically disastrous wildfires. In addition, several consecutive seasons of significant fires and an expanding popular awareness of the resulting property damage have led the general public to become more attentive to fire issues and policy changes. It is now clear that effective management of fire regimes will be a major challenge for land managers and policymakers in the foreseeable future.

Because of our new understanding of 20th century forest management practices, priority is now given to minimizing fire risk rather than to complete fire exclusion or suppression. One result has been an emphasis on managing fire through fuel treatments. Land managers have focused on two major methods for resolving the

[1] An abbreviated version of this paper was presented at the second international symposium on fire economics, policy and planning: a global view, April 19–22, 2004, Córdoba, Spain.

[2] Graduate Assistant, University of Arizona, School of Renewable Natural Resources, Biological Sciences East 325, Tucson, AZ 85721; email: sejensen@email.arizona.edu.

current fuels problem, namely mechanical fuels management (usually in the form of forest thinning) and the use of prescribed and naturally ignited fire ("wildland fire use") to restore a "natural" fire regime.

Recent policy debate in the United States suggests that regulatory environmental policy at the federal level conflicts with the new priorities of fire management. Substantial evidence of this perceived conflict appears in the public record, including public statements and press releases by the president and key federal agency leaders and policy documents relating to wildland fire.

Much of this dialogue has come from President George W. Bush's public statements surrounding his Healthy Forests Initiative and related legislation. For example, the president's comments on signing the Healthy Forests Restoration Act included the following statement (USDA 2003a):

> "The bill expedites the environmental review process so we can move forward more quickly on projects that restore forests to good health. We don't want our intentions bogged down by regulations."

Similarly, in an earlier statement on the same act, the president argued that (Office of the Press Secretary 2003):

> "...there's too much confrontation when it comes to environmental policy. There's too much zero-sum thinking. What we need is cooperation, not confrontation... current law makes it too difficult to expedite the thinning of forests."

The heads of several federal land management and environmental agencies have also expressed pessimistic views on the applicability of environmental policies to fire management. In a proposed rule change concerning the Endangered Species Act, the U.S. Fish and Wildlife Service refers to "unnecessary regulatory obstacles that have at times delayed and frustrated active land management activities" (DOI/DOC 2003). Similarly, in an agency press release, Secretary of Agriculture Ann Veneman referred to regulatory requirements as "layers of unnecessary red tape and procedural delay that prevent agency experts from acting quickly to protect communities and our natural resources from devastating wildfire" (USDA 2003b). An opinion piece authored by Secretary Veneman and Secretary of the Interior Gale Norton stated that efforts at fire management "have been thwarted by burdensome regulations and litigation" (Norton and Veneman 2003). Given that these departments and agencies are charged not only with the responsible management of public lands but also with the implementation and enforcement of the very policies they find "burdensome," these comments should be seen as very real and serious criticism of federal environmental policy.

In light of this criticism, there are at least three analytical conclusions. First, it is possible that the goals and principles of fire management inherently contradict the goals and principles of federal environmental policies. Second, it is also possible that some aspect of the implementation of environmental policies may constrain or contradict good fire management practices; that is, the conflict may be not in the letter of the law but in its implementation on the ground. Third, it may be that no significant conflict exists either in policy or in implementation and that the policy dialogue described above is wholly or primarily a political construction. It is worth noting that these three options are not entirely mutually exclusive. For example, a relatively minor policy discrepancy might be exacerbated by the way that policy is currently being implemented, or several small contradictions might be exaggerated by the political construction of fire issues.

The primary aim of this paper is to evaluate the first possible conclusion, that there is an inherent contradiction between good fire management and federal environmental policies. I outline the new principles of federal fire management and evaluate the compatibility of those aims with two major federal environmental policies. The goals and priorities of fire management will be summarized from several bipartisan, cooperative policy statements, including the Federal Wildland Fire Management Policy, the National Fire Plan, and the 10-Year Comprehensive Strategy. The principles drawn from these documents will be used to evaluate the effectiveness of the National Environmental Policy Act (1970) and the Endangered Species Act (1973) in permitting, supporting, and mandating the effective management of wildland fires. Finally, I will briefly consider the other two possible conclusions and suggest some directions for further research.

Principles of Fire Management

Under the Clinton and George W. Bush administrations, wildland fire has emerged as a major issue in natural resource management. Especially severe fire seasons and well-publicized large fires have tended to focus governmental (as well as popular) attention on wildland fire, often resulting in the development of significant policy statements and initiatives.

One such severe fire season occurred in 1994. Thirty-four lives were lost and more than 4.7 million acres burned, and a working group was convened by Secretary of Agriculture Dan Glickman and Secretary of the Interior Bruce Babbitt to develop a common approach to wildland fire for the federal land management agencies (NIFC 2003, USDI/USDA 1995). The resulting document was the Federal Wildland Fire Management Policy and Program (or Federal Wildland Fire Policy), which was non-legislative but had lead personnel of several relevant agencies as signatories.

Following even more extensive fires in the 2000 season (a total of 122,827 wildfires and more than 8.4 million acres burned), President Clinton asked the same secretaries to prepare an analysis of the wildland fire situation (USDI/USDA 2001). The report, titled *Managing the Impact of Wildfires on Communities and the Environment: A Report to the President in Response to the Wildfires of 2000*, became the basis for the National Fire Plan, a further attempt to clarify priorities for fire management, especially in terms of allocating funding (USDI/USDA 2001). Another result of Clinton's request was the reassembly of the 1995 working group for an analysis, review, and revision of that policy. The outcome was a 2001 review and update document that replaced the 1995 version. Although the guiding principles of the policy changed very little, the working group found that implementation was inconsistent and incomplete and that the failure of federal agencies to fully implement the 1995 policy had significantly undermined its effectiveness.

In 2001, based on the ideas of the National Fire Plan, a broad cross-section of governmental and non-governmental stakeholders developed an implementation plan: a "collaborative approach for reducing wildland fire risks to communities and the environment," generally referred to as the 10-Year Comprehensive Strategy (Western Governors' Assoc. 2001, p. 1). The Comprehensive Strategy addressed the National Fire Plan priority of community involvement by designing a "proactive, collaborative, and community-based approach to reducing wildland fires," as opposed to the more agency-centered approach of, for example, the Federal Fire Policy (Western Governors' Assoc. 2001, p. 3).

Together, these three policies represent a relatively comprehensive picture of the bipartisan, multi-stakeholder goals and priorities of federal wildland fire management. (The more recent Healthy Forests Initiative and Healthy Forests Restoration Act are not explicitly included, because those documents make direct and exclusive reference to the goals and priorities of the National Fire Plan and 10-Year Comprehensive Strategy.) From a synthesis and condensation of these key points, I propose the following key principles of federal wildland fire management:

- Protecting firefighter and public safety is the first priority in fire management;
- Fire management practices should aim to restore landscapes and rebuild communities, with particular focus placed on hazardous fuel reduction and on returning fire to fire-adapted ecosystems;
- Fire management practices should be based on existing land and resource management plans, economic viability, best available science, and principles of sound risk management;
- Public health and environmental quality should be considered in fire management planning; and
- Cooperation and coordination among numerous groups, including federal agencies, state, tribal, and local governments, international partners, and communities, is key to effective fire management.

As noted above, recent debate suggests that federal environmental policies come into direct conflict with the principles and priorities of fire management. In the following section, two federal environmental policies will be summarized and evaluated with respect to the principles outlined above.

Federal Environmental Policy

The National Environmental Policy Act

The underlying intent of the National Environmental Policy Act (NEPA) is to require federal agencies to incorporate environmental considerations into project development and decision-making processes. Its application is not limited to formal planning but covers a variety of federal activities from small-scale public resource allocations to major land use planning to federal legislation. Even more importantly, NEPA requires federal agencies to put this decision-making process into writing and makes it open to public and judicial review at several levels.

NEPA itself barely comprises ten pages, largely because the details of its implementation are set out separately, in the Code of Federal Regulations and in other regulations set forth by individual agencies. The statute itself consists of three main parts. The first, section 101, outlines the intent of the act by setting goals for the environmental health of the nation and establishing the role of the federal government in assuring "for all Americans safe, healthful, productive, and aesthetically and culturally pleasing surroundings," (42 USC 4331(b)). Section 102 forms the core of the act, stating in part that every federal agency must examine the environmental impacts of its decisions and must include these environmental considerations in the decision-making process. Furthermore, it must do so in a formal, systematic, and interdisciplinary manner (42 USC 4332). The third key point

of NEPA, found in section 202, is to establish the President's Council on Environmental Quality (CEQ) (42 USC 4342). The CEQ was established to provide the federal agencies with guidance in implementing NEPA, and it developed a set of guidelines for that process that are widely used by agencies and courts and play a substantial role in its interpretation and implementation.

The Supreme Court has repeatedly ruled that NEPA is a strictly procedural statute, meaning that although it forces agencies to formally consider the environmental impacts of their actions, it does not in any way dictate the final decision on the action. An agency could legally take the most environmentally destructive course of action of all its alternatives, provided that it appropriately considered the impacts and alternatives and set forth its reasoning as required by NEPA regulations (see *Strycker's Bay Neighborhood Council, Inc. v. Karlen* 444 U.S. 223 (1980)).

The procedural nature of NEPA is critical to its compatibility with fire management activities. With fire management, as with many natural resource management situations, there is often no management decision that is clearly more environmentally preferable than all other alternatives. NEPA allows federal agencies significant flexibility in balancing fire management priorities, while still ensuring that these priorities are considered in a formal and public manner. The following sections more specifically evaluate the compatibility of NEPA with the five fire management priorities discussed above.

Firefighter and Public Safety

Firefighter and public safety takes first priority in environmental policy as well as in fire management. The NEPA regulations developed by the Council on Environmental Quality (CEQ) allow agencies to make special arrangements when emergency circumstances prevent full NEPA documentation from being completed before an action is taken (40 CFR 1506.11). The U.S. Forest Service criteria for making these arrangements require an "immediate imminent risk to public health or safety" or "immediate imminent threat to substantial loss of private property" (USFS 1992). As a result, fire suppression activities have not been subject to environmental analysis under NEPA. Notably, the 2001 Federal Wildland Fire Policy mandates the development of Fire Management Plans, which must outline all strategic fire management practices, including fire suppression. Although very few have been developed thus far, these documents should be subject to NEPA analysis, both because they form part of the broader Land Management Plans (which are subject to NEPA) and because they do not constitute an emergency response to any imminent danger.

Restoration of Fire-Adapted Landscapes

NEPA's procedural nature also allows significant flexibility in restoring fire-affected landscapes and communities. In general, mechanical fuel reduction projects, prescribed fires, and wildland fire use fires (the use of naturally ignited fires to reach land and resource management goals) are all subject to NEPA requirements: Briefly, federal agencies must determine whether a proposed activity will have a significant environmental impact (usually through an environmental analysis, or EA) and, if so, must develop an environmental impact statement (EIS) describing the potential

impacts and the impacts of a range of viable alternatives to the project and incorporating significant public comment and participation. While the responsible agency must respond to public comments, the NEPA process does not mandate or prohibit any specific action or decision. In other words, the agency, once it has completed and documented the necessary procedural requirements, is free to choose any alternative, including one that has serious negative environmental consequences. Therefore, from the text of the policy itself and associated regulations, it is difficult to imagine how NEPA could interfere with the restoration of fire-adapted landscapes or fire-affected communities.

In 2003, The USDA Forest Service and the Department of the Interior announced a rule change that included certain fire management activities under "categorical exclusions:" that is, categories of actions that do not normally significantly effect the human environment and therefore do not require development of an EA or EIS except under special circumstances. Among the activities listed are any hazardous fuels reduction and post-fire rehabilitation activities that fit certain requirements (e.g., those that will not be conducted in wilderness areas, will not involve the construction of new roads, and do not exceed certain size limits) (USDA/USDI 2003). In other words, following this rule change, many of the smaller hazardous fuel reduction and post-fire rehabilitation projects will be effectively exempted from NEPA.

Fire Management Planning

Fire policy and guidance documents state that fire management decisions should be based on existing management plans (including, for example, the Forest Service's Land and Resource Management Plans or Fire Management Plans), as well as principles of economic viability, best available science, and sound risk management. NEPA's procedural requirements clearly support this planning process by providing a formal process for decision-making in a format that is common to all federal agencies and transparent to the public. If developed according to CEQ regulations, an environmental impact statement (EIS) generally consists of a clear comparison of the proposed action with a range of alternative actions (including a "no action" option), including the environmental consequences of each potential action. Projects covered under the Healthy Forests Reform Act of 2003 (HFRA) are subject to less stringent requirements and generally need present and analyze only the proposed agency action, the "no action" alternative, and one additional alternative. Certain kinds of actions in the wildland-urban interface may not be required to develop either a "no action" or an additional alternative (16 USC 6501 et seq.). Agencies commonly use economic considerations to evaluate action alternatives, especially when dealing with the public, so the economic viability of the different options is often included (formally or informally) in the EIS process. Furthermore, CEQ regulations require agencies to "rigorously explore and objectively evaluate all reasonable alternatives" (40 CFR 1502.14(a)). Through a clear and formal evaluation of the costs, benefits, and risks of each alternative, good planning practices are strongly encouraged. Finally, by mandating the inclusion of a "no action" alternative, NEPA acknowledges that, as is common in fire management, a failure to act can in have significant consequences.

Public Health and Environmental Quality

One of the stated goals of NEPA is "to promote efforts which will prevent or eliminate damage to the environment and biosphere and stimulate the health and welfare of man" (42 USC 4321). NEPA is, in essence, a legislative attempt to ensure that public health and environmental quality are considered in all federal agency actions and is therefore effectively a legislative mandate to comply with this fire management principle.

Cooperation and Coordination

Public involvement in agency decision-making is stressed in the CEQ's NEPA regulations. As part of the NEPA process, agencies are required to "(e)ncourage and facilitate public involvement in decisions which affect the quality of the human environment" (40 CFR 1500.2(d)) and to "(m)ake diligent efforts to involve the public in preparing and implementing their NEPA procedures (40 CFR 1506.6(a)). In addition to publicizing hearings, decision notices, and the like, the responsible agency must make a draft EIS available for public comment before the final EIS is prepared. The agency must obtain comments from any other federal agency with special expertise or legal jurisdiction over the process and must request the comments of the general public (especially any people or organizations that might be interested or affected), any private applicant involved in the proposed action (e.g., a permittee), all relevant state and local agencies and any tribes that may be affected, and any agency that had previously requested to receive statements on similar actions (40 CFR 1506.6). Interagency cooperation is also strongly encouraged, and agencies are permitted to designate joint lead agencies if state or local agencies are closely involved in the proposed project (provided at least one federal agency is included) (40 CFR 1501.5(b)). Special provisions are also made to allow joint processes in order to avoid overlaps in documentation between federal and state or local procedure (40 CFR 1506.2). However, when more than one lead agency is involved in a project, a lead agency must be designated (40 CFR 1501.5(a)). In some cases this may discourage agencies from cooperating in fire management planning by prompting interagency competition or conflict (Gebow, personal communication).

This analysis of NEPA suggests that this federal policy actually supports the principles of good fire management and in some cases even mandates the suggestions made by fire policy documents. The idea that the NEPA process causes unnecessary delays in fire management projects (especially in fuels management) has been a common point of criticism in the policy debate. However, considering the high degree of overlap between NEPA requirements and fire management principles, this must be seen as an issue of implementation and is therefore addressed in this paper's final section.

The Endangered Species Act

The stated purposes of the Endangered Species Act (ESA) are (16 USC 1531(b)):

> …to provide a means whereby the ecosystems upon which endangered species and threatened species depend may be conserved, to provide a program for the conservation of such endangered species and threatened species, and to take such steps as may be appropriate to achieve the purposes of the treaties and conventions [on international trade in endangered species].

Certainly the best-known impact of ESA is the establishment of broad prohibitions against any take of animal species that are listed as endangered or threatened. In addition, federal agencies are required to (a) actively promote the conservation of listed species; and (b) avoid any actions that would have negative effects on listed species and their critical habitat. The application of the Endangered Species Act to fire management on federal lands is somewhat complex. In many cases, scientific understanding of a listed species' relationship with fire is limited or even nonexistent. While it is often assumed that wildland fire poses a threat to endangered species, many species actually need fire to maintain their populations or habitat, and many more tolerate fire well. Many animal species are able to avoid fire, and a recent summary of U.S. Fish and Wildlife data showed that just four of the 186 listed, proposed, and candidate plant species that are found on Forest Service lands are actually harmed by fire (Brown and Smith 2000). However, there is no doubt that not only wildfires but also prescribed fires and fuel treatments can have confusing, complex, and sometimes adverse effects on endangered species' habitats. It can be difficult to weigh long- and short-term impacts of different fire management decisions within the context of ESA.

Firefighter and Public Safety

The agency responsible for enforcement of the Endangered Species Act (the U.S. Fish and Wildlife Service, in conjunction with the National Marine Fisheries Service) has made it clear that firefighter and public safety is the first priority in any fire management decision. Federal regulations related to ESA state that in an emergency situation, consultation may be informal and may take place either during or after the necessary response measures (50 CFR 402.05). This alternative is applicable for fire suppression tactics in general, and the wildfire itself is considered an act of God and not an agency action; thus, consideration of endangered species never takes priority over human life. The Secretary of the Interior has periodically released statements clarifying and emphasizing this position.

Restoration of Fire-Adapted Landscapes

The most common conflicts between ESA and attempts to restore fire-adapted landscapes and fire-impacted communities have been centered on selective logging efforts (including both fuel reduction treatments and post-fire "salvage" logging). Section 7 of the act mandates that (16 USC 1536(a)(2)):

> Each Federal Agency shall, in consultation with and with the assistance of the Secretary, insure that any action authorized, funded, or carried out by such agency… is not likely to jeopardize the continued existence of any endangered species or threatened species or result in the destruction or adverse modification of habitat of such species which is determined by the Secretary… to be critical, unless such agency has been granted an exemption for such action by the Committee…

In other words, the standard for agency actions in terms of listed species is "no likelihood of jeopardy;" with very few exceptions, an agency action must not threaten the continued existence of a listed species or destroy or degrade its designated critical habitat (*Babbitt* v. *Sweet Home Chapt. Comms. for Ore*., 515 U.S. 687 (1995)). The section 7 process is relatively straightforward and is outlined within the act; relatively few external regulations dictate the process. However, it is important that the agency complete each step of the consultation process (see *Thomas* v. *Peterson*, 753 F.2d

754 (9th Cir. 1985)). The consultation generally results in the secretary either finding that there is no likelihood of jeopardy associated with the proposed action or suggesting alternative actions to the agency's proposed action that would not be likely to result in jeopardy. ESA is often seen as unnecessarily hindering fire management practices, especially the fuel-thinning techniques described above, because the act does not recognize that avoiding these management activities for fear of harming species and their critical habitat could theoretically lead to even higher mortality of an endangered species by creating more severe fire conditions in the future. However, the Secretary of the Interior is given substantial leeway in interpreting the "no jeopardy" clause and may easily choose a broader, more long-term view of potential species impacts. Perhaps more importantly, the purpose of the act with respect to federal agencies is to ensure that management actions, no matter how well intentioned they may be, do not directly threaten the continued existence of listed species. When confronted with a decision such as whether to conduct a fuel thinning project in critical habitat or risk the eventual destruction of such habitat to a severe fire, it seems logical that an agency decision-maker might welcome a formal consultation with the Fish and Wildlife Service and the opportunity to form a reasonable, science-based opinion on the management practices in question.

As noted above, it is also difficult to anticipate the effect a prescribed burn or wildland fire use ("let burn") fire will have on any given species. Fortunately, while ESA requires decisions to be science-based, it does not force agencies to wait for exhaustive studies or complete information on a question. Rather, agencies are to use the "best scientific and commercial data available" in fulfilling the requirements of section 7 (16 USC 1536(a)(2)). An agency must develop a biological assessment, generally within 180 days of the initiation of the consultation and before beginning the activity, describing any listed species that might be affected (16 USC 1536(c)(1)). The time constraint, in combination with the fact that monitoring can be and often is recommended as part of the consultation, functions to encourage the continuing improvement of management practices.

Fire Management Planning

As described above, ESA requires that fire management planning be based on the best available science, and section 7 considerations should be crucial in the development of a Fire Management Plan. However, ESA does not permit economic considerations to take priority over listed species; the courts have upheld that this was the clear intention of Congress (in *Tennessee Valley Authority* v. *Hill*, 437 U.S. 153 (1978), for example, the court stated, "The plain intent of Congress in enacting this statute was to halt and reverse the trend toward species extinction, whatever the cost."). It is possible, for example, that section 7 requirements might prevent hazardous fuel reduction activities from taking place, which might in turn result in a later fire of greater magnitude causing greater long-term threat to the species and resulting in substantial suppression costs. Because ESA can make it difficult for agencies to weigh short- and long-term or direct and indirect risks, this kind of risk management can be a somewhat questionable proposition. However, any conflict between the short- and long-term survival of a species might more appropriately be seen as an inherent paradox of conservation efforts than as a policy failure. Significantly, this paradox could be resolved in many cases through better scientific knowledge of listed species. Furthermore, as noted above, the secretary has

substantial leeway in interpreting the "no jeopardy" clause, and ultimately, this conflict must also be seen as one of implementation.

Public Health and Environmental Quality

Although the substantive portions of the Endangered Species Act focus on single-species management, it is a stated purpose of the act to "provide a means whereby the ecosystems upon which endangered species and threatened species depend may be conserved" (16 USC 1531(b)). While no specific provision is made for public health issues, it is difficult to imagine a situation in which conservation of a listed species threatens public health or environmental quality (except in emergency situations as discussed in section 1).

Cooperation and Coordination

One of the unstated goals of ESA seems to be integrating the U.S. Fish and Wildlife Service's (and the National Marine Fisheries Service's) biological expertise into decision-making processes in federal land management agencies. In this sense, the entire section 7 process, might be seen as mandated cooperation. Biological assessments may be developed in conjunction with the NEPA process to expedite a project (16 USC 1536). Consultation with the states is also required in several aspects, and the responsible secretary may enter into cooperative agreements at the state level (16 USC 1535). International cooperation is also explicitly encouraged (16 USC 1537). Public participation is relatively limited, but citizens are explicitly granted the right to sue for enforcement (16 USC 1540(g)) and may also petition the secretary to list a species or revise critical habitat designation (16 USC 1533(b)). Landowners may also enter into a variety of different agreements for species conservation.

In summary, the Endangered Species Act does appear to conflict somewhat with fire management principles in terms of economic viability. It is clear that the legislative mandate was to prevent agencies from directly threatening the survival of listed species regardless of economic cost. The balancing of long- and short-term conservation goals appears to pose a problem in implementation – from one view, there may be no alternative available to agencies that does not place a species' survival in jeopardy – and this dilemma warrants further examination.

Conclusions

This analysis finds only very few and very minor conflicts between these two pieces of environmental legislation and the currently accepted principles of fire management. Where conflicts do exist, they are most commonly the result of insufficient scientific information or of paradoxes of priorities within fire management that will require significant flexibility in policy implementation.

The two alternative conclusions presented at the beginning of the paper, namely that the perception of a conflict between environmental policies and fire management has been produced either by implementation problems or by political construction, would benefit from closer analytical examination. Some preliminary ideas are presented here.

It is possible that significant conflicts exist in the implementation of these laws in the fire context. One outstanding theme of the policy debate has been that of administrative or bureaucratic delays. For example, some managers have argued that the NEPA documentation process in particular is unreasonably lengthy and time-consuming. Others argue that the citizen appeals and litigation permitted under these laws are slowing implementation and interfering with fire management efforts. As with any policy, it may be that the ground-level implementation of NEPA and ESA is significantly different than what might be suggested by the policy document itself. Similarly, it may be that the current fuels situation is such a crisis that agencies simply do not have time to meet the procedural requirements of the laws without further exacerbating the problem.

However, some initial evidence suggests that these conclusions may be inaccurate. The CEQ regulations concerning NEPA implementation clearly address issues of timeliness, and the CEQ allows agencies to set time limits for each part of the NEPA process based on the potential for harm, the magnitude of the action, the degree of controversy, and other criteria (40 CFR 1501.8). A recent report from the non-partisan General Accounting Office suggests that litigation has played a relatively minor role in delaying hazardous fuels projects. Of 762 fuels-related decisions in fiscal years 2001 and 2002, only 180 were appealed (affecting 900,000 of a total 4.7 million acres) and only 23 were litigated (affecting 100,000 acres) (GAO 2003). The same GAO report also found that 79 percent of appeals were handled within the mandated 90-day period.

A final alternative is that the policy dialogue described here is primarily or wholly a political construction. L. Earl Peterson, a Florida state forester, began his welcome address to the 1995 Environmental Regulation and Prescribed Fire Conference with what may be a telling story (Peterson 1997):

> During a skit on the Smothers Brother Show, Tommy Smothers fell into a large vat of chocolate, and began to yell "FIRE". When asked by his brother Dick why he yelled fire, he responded, "Well, do you think anyone would have come if I had yelled 'CHOCOLATE'?"

Recent criticism by some citizen groups has effectively accused government agencies and the president of yelling "fire" instead of "chocolate." Popular dialogue has made wildland fire an increasingly sensitive and emotional subject, which in turn makes it a good catchphrase for mobilizing support for new policies and regulations. In the absence of reliable data to either support or deny the claims that excessive litigation, burdensome procedures or conflicting policies are thwarting federal attempts to bring a fuel/fire crisis under control (or even to gauge the magnitude of the fire crisis itself) sweeping policy changes would be ill advised.

Schneider and Ingram (1997) provide what may prove to be a useful framework for evaluating the possible political construction of this policy debate. They describe a situation in which public policy design has become increasingly hyperpoliticized; in other words, they argue that through the political and social construction of oppositional target groups, "policies deceive, confuse, and in other ways discourage active citizenship, minimize the possibility of self-corrections, and perpetuate or exacerbate the very tendencies that produced dysfunctional public policies in the first place" (p. 5). Because the debate described here is based on the assumption that past fire policy has been dysfunctional, and because it is rapidly evolving into new policy designs (e.g., the Healthy Forests Restoration Act), a unique opportunity exists to examine whether the emerging federal fire policy is an example of hyperpoliticization. There are some hints that this might be the case, especially in the

new restrictions on citizen suits and decreasing transparency that have developed from the fire debate.

If fire policy is a hyperpoliticized issue, academic analysis of its implications has generally been depoliticized. However, a worthwhile analysis of these policies should incorporate an explicit discussion of the political and economic interests involved. If, as Schneider and Ingram's (1997) framework suggests, the emerging wildland fire policies build different incentives for different target groups, promote self-interested conflict among constructed target groups, and show signs of subverting democratic values, any further policy analysis should make explicit the policy incentives for different stakeholders in fire management.

Exploring these research questions will require substantial on-site work with federal land, resource, and fire planners and managers, but the issues addressed are critical ones: Finding the exact points of contention between fire management and environmental policy may allow policymakers to solve those specific problems rather than undermining otherwise effective legislation.

Acknowledgements

This project has been funded by the Environmental Protection Agency's Science to Achieve Results (STAR) program under grant number R-82873201-0.

References

Brown, James K.; Smith, Jane Kapler, eds. 2000. **Wildland fire in ecosystems: effects of fire on flora.** Gen. Tech. Rep. RMRS-GTR-42-vol. 2. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 257 p.

Gebow, Brooke. Senior Research Specialist, Wildlife and Fisheries Resources, University of Arizona. [Personal communication]. 12 November 2003.

General Accounting Office. 2003. **Forest Service: information on decisions involving fuels reduction activities.** GAO-03-689R. Washington, DC. 43 pp.

National Interagency Fire Center. 2003. **Wildland fire statistics.** http://www.nifc.gov/stats/index.html, site accessed 13 February 2004.

Norton, Gail A. and Ann M. Veneman. 2003. **Cut the red tape, restore our forests.** The Seattle Times 22 August 2003. (Op-Ed).

Office of the Press Secretary. 2003. **Remarks by the President on the Healthy Forests Initiative.** http://www.whitehouse.gov/news/releases/2003/08/20030821-4.html, site accessed 13 February 2004.

Peterson, L. Earl. 1997. **Welcome address.** In: Bryan, Dana C., ed. Proceedings of the environmental regulation and prescribed fire conference: legal and social challenges. March 14-17, 1995. Tampa, FL. Tampa: Center for Professional Development, Florida State University; 6-7.

Schneider, Anne Larason and Helen Ingram. 1997. **Policy design for democracy.** Lawrence, KA: University Press of Kansas; 241 pp.

U.S. Department of Agriculture, Forest Service. 1992. **Environmental Policy and Procedures Handbook**. 15-92-1.

U.S. Department of Agriculture. 2003a. **Remarks By President George W. Bush at signing of H.R. 1904, the Healthy Forests Restoration Act of 2003.**

http://www.usda.gov/news/releases/2003/12/hfiremarks.htm, site accessed 13 February 2004.

U.S. Department of Agriculture. 2003b. **Cabinet officials report progress on President Bush's Healthy Forests Initiative**. http://www.usda.gov/news/releases/2003/05/0177.htm, site accessed 13 February 2004.

U.S. Department of Agriculture/U.S. Department of the Interior. 1995. **Federal Wildland Fire Management Policy of 1995.** Washington, DC: USDI/USDA; 39 p.

U.S. Department of Agriculture/U.S. Department of the Interior. 2003. **National Environmental Policy Act documentation needed for fire management activities; categorical exclusions.** Federal Register 68 (108): 33814-33824.

U.S. Department of the Interior/U.S. Department of Commerce. 2003. **Joint counterpart Endangered Species Act section 7 consultation regulations (proposed rule).** Federal Register 68 (108): 33806-33812.

Western Governors' Association. 2001. **A collaborative approach for reducing wildland fire risks to communities: 10-year comprehensive strategy.** Washington, DC: WGA; 24 p.

Page left blank intentionally.

Fire Management Planning–Developing Strategies and Setting Measurable Objectives for Adaptive Management[1]

S.L. Robertson,[2] H. Roose [3]

Abstract
Direction for fire management planning has been recently revised for all federal wildland fire agencies in the U.S. Fire management plans have become important planning tools that spatially document fire management strategies that support land and resource management planning objectives. Increasingly, however, fire management plans are tools that ensure program accountability and program effectiveness through the development of specific measurable objectives that track the implementation of strategies and their success. The development of measurable objectives in fire management plans addresses not only resource management objectives for wildland fire, but also tie to national performance measures for the federal wildland fire program. These measurable objectives are the cornerstone for the Fire Program Analysis System that measures program effectiveness for adaptive management and the development of the federal wildland fire budget.

Background

The task of designing and implementing new standardized fire planning direction for the five federal wildland agencies, including the Bureau of Indian Affairs (BIA), the Bureau of Land Management (BLM), the Fish and Wildlife Service (FWS), the National Park Service (NPS), and the USDA Forest Service (USFS) has been a challenging endeavor considering the wildland fire events that have taken place in the last few years here in the U.S.. The events which occurred during the fire seasons of 2000 and 2001 are remarkable in that they shape much of the federal wildland fire program as we know it today. Of particular note were the Cerro Grande prescribed fire in Los Alamos, New Mexico in May of 2000; the subsequent 2000 fire season; and the Thirty-Mile Fire Fatalities in July of 2001.

These events resulted in several important reports and initiatives that continue to guide the wildland fire program in the U.S. including, "Managing the Impact of Wildfires on Communities and the Environment - A Report to the President in Response to the Wildfires of 2000" (September 2000); the National Fire Plan (2001); Western Governors' "A Collaborative Approach for Reducing Wildland Fire Risks to Communities and the Environment: Ten-Year Comprehensive Strategy" (2001) and "Implementation Plan" (2002); "Restoring Fire-Adapted Ecosystems on Federal Lands – A Cohesive Fuel Treatment Strategy for Protecting People and Sustaining

[1] An abbreviated version of this paper was presented at the second international symposium of fire economics, policy, and planning: a global view, 19–22 April, 2004, Córdoba, Spain.

[2] U.S. Forest Service, National Park Service, National Interagency Fire Centre, 3833 South Development Avenue, Boise, ID 83705-5354 USA, email: sara_robertson@nps.gov.

[3] Bureau of Land Management, National Interagency Fire Centre, 3833 South Development Avenue, Boise, ID 83705-5354 USA.

Natural Resources" (2002); and the "Thirty-Mile Hazard Abatement and Accident Prevention Plan" (2002).

The manner and degree to which fire management planning and fire management plans implement these initiatives and policies is significant. The public, congress, the federal Office of Management and Budget (OMB), and the Government Accounting Office (GAO) all have increased awareness and expectations about the function and accountability fire management plans have in addressing these wildland fire program issues. The need for sound fire management planning will continue as fire management plans play an increasingly pivotal role in implementing the federal wildland fire program.

In addition to responding to the events and policies above, the five federal wildland agencies also have a shared concern in regards to measuring the efficiency and effectiveness of their fire management programs. Agency managers at the national level have begun working together to develop and implement a compatible, interagency, performance-based fire program and budget analysis process.

Federal Wildland Fire Policy stipulates:

- Agencies will use compatible planning processes, funding mechanisms… operational procedures, values-to-be-protected methodologies… for all fire management decisions,

- Fire management programs and activities will be based on economic analyses that incorporate commodity, non-commodity and social values,

- Federal agencies will use a compatible fire planning system that recognizes both fire use and fire protection as inherent parts of natural resource management; this system will ensure that adequate fire suppression capability and support for fire reintroduction efforts is provided.

In December 2001, a study team released a report titled, "Developing an Interagency, Landscape-scale Fire Planning Analysis Tool". Findings in the report are serving as the basis for development of a new interagency fire program evaluation system. This new system will replace budget and analysis systems currently used by the wildland agencies such as the US Forest Service National Fire Management Analysis System (NFMAS), and FIREPRO used by the National Park Service.

The new Fire Program Analysis System (FPA) is a performance based program evaluation system that focuses specifically on goals, strategies, and objectives identified in the fire management plan development process. FPA will rely on measurable land management plan objectives to help formulate future Preparedness and Hazardous Fuel programs. The FPA system is scheduled for field-testing during the summer of 2004. Release and technology transfer is scheduled to start October 1, 2004 for the first module which is preparedness.

The following are key attributes of the FPA System:

- Uses land and fire management objectives as the cornerstone for planning

- Provides a common approach to fire management program planning and budgeting for all five wildland fire management bureaus

- Displays tradeoffs for meeting various fire management objectives at any given budget level, such as for protecting various natural and cultural resources, and for protecting infrastructure and property
- Helps quantify meaningful performance requirements under the National Fire Plan and the Government Performance Results Act
- Facilitates partnerships between Federal interagency planning units, and Tribal, State, and local governments

Interagency Fire Management Planning

Fire management plans are plans which identify and integrate all wildland fire management and related activities within the context of approved land/resource management plans. They define a program to manage wildland fires (wildfire, prescribed fire, and wildland fire use). The fire management plan is supplemented by operational plans, including but not limited to preparedness plans, preplanned dispatch plans, prescribed fire burn plans and prevention plans. Fire Management Plans assure that wildland fire management goals and components are coordinated.

To facilitate the implementation of FPA, the federal wildland agencies developed the Interagency Fire Management Plan (FMP) Template that standardizes fire management plan development and content. The Interagency FMP Template, signed in June of 2002 is a single, landscape scale planning process that considers:

- the goals and objectives found in land management plans, as well as
- the objectives and performance elements found within agency Strategic Plans which are a part of the Government Performance and Results Act (GPRA), and
- the performance measures developed in the Ten-Year Implementation Plan for the document "A Collaborative Approach for Reducing Wildland Fire Risks to Communities and the Environment."

The Interagency FMP Template also encourages the development of local objectives and measures that reflect the input from local government, the public, stakeholders, and other land management partners. However, these local objectives must support the goals and objectives found in federal land management plans.

Developing Measurable Objectives in Fire Management Plans

The Fire Program Analysis system also requires managers to have a set of measurable objectives that meet the needs of land management planning, and fire program implementation.

These measurable objectives need to be both outcome-based and useful for traditional accountability purposes. Previous budgeting initiatives focused on outputs because it was deemed more practical to measure agency processes and outputs rather than outcomes. FPA uses the measurable objectives found in fire management plans that are developed from land management plan direction and evaluates not only efficiency but effectiveness as well.

Fire managers have expressed dissatisfaction with current evaluation and reporting requirements. They explain that tracking and reporting costs and number of acres treated is inadequate in describing program accomplishments and measuring results. Managers are held accountable to efficiency standards with little or no reporting of whether desired results are achieved.

"We need a better system of measurement, other than treatment costs and number of acres treated. Everything focuses on efficiency; not on results. We need to measure by/for the objective of the fire management activity. We also need a fuels management strategy for fire management that speaks to outcomes. Something that helps prioritize our work."

When given the opportunity to expand on alternative forms of measurement, managers advocate for the development of a system that more clearly measures the desired outcome and goal of the strategy or activity.

Many fire managers surveyed asked for standards of measurement or acceptable ranges of change that describe conditions or changes in conditions as a result of fire management activities. Several advocate for standards or ranges that relate to interdisciplinary goals and objectives that help describe ecosystem health and sustainability, as well as community and public safety.

Most of the managers referred to the complexities of trying to find appropriate measurement for program accomplishment. Much of the meaningful measurements that will help to describe the impacts of prescribed fire are very long-term. As a result, managers acknowledge the need for interim measurable objectives, to help with short-term program accountability.

Fire managers explained that they need to do a better job of explaining the long-term, value-added benefits of prescribed fire using resource values instead of commodity driven values. This includes understanding measuring the social and cultural impacts of prescribed fire.

Lastly, several fire managers want measurements that speak to the social and cultural impacts of fire use. The National Fire Plan and the Comprehensive Strategy for Protecting Communities and the Environment highlight the protection of high-risk interface areas with special emphasis on treatments in short-interval fire adapted ecosystems. Clearly, fire managers are asking for some form of measurement that helps evaluate accomplishment and investment.

The Transition from Current Program Evaluation to Fire Program Analysis

National agency program strategies and objectives are beginning to be expressed in terms of desired outcomes. Much of this work is related to the Government Performance and Results Act (GPRA) of 1993. However, some planning, budget allocation and program implementation are still driven by efficiency measures. Upward reporting consists of costs and number of acres treated, generating an efficiency ratio that is often used in making budget allocation decisions.

Managers are still primarily held accountable for issues of cost and quantity. Questions of effectiveness become secondary in this scenario. GPRA states that program activities and measurement must be linked directly to desired outcomes, and

that they address the issue of effectiveness. Measurement information about the manner and degree to which programs impact desired conditions becomes important in several ways.

One, it allows agencies to accurately report on the effectiveness of program strategies and activities. In performance based budgeting and the GPRA, accountability reporting informs agency and congressional decision-makers and policy-makers about program successes, or where program corrections need to occur. It also informs the public about whether programs are really delivering the outcomes agencies have deemed important. At the field level, internal reporting of program effectiveness becomes a valuable tool for managers to make needed changes in field implementation, particularly if this information is available in a timely fashion.

Secondly, with measurement information in hand managers can begin to fund results rather than efficiency alone. When the impacts of activities are measured in terms of changes in conditions, funding decisions become driven by which activities are most effective in addressing desired outcomes. When efficiency information is added to this equation, managers can fund activities that show the best cost-benefit ratio rather than cost-output. This becomes useful information when designing program strategies and priorities.

Lastly, in the process of testing performance measurements and program indicators for their correlation with desired outcomes, managers are able to discard measurements and indicators that fail to provide useful information, and replace them with indicators that show a strong relationship with outcomes. This process takes time. Implementing a performance measurement process successfully will require evaluating chosen program measures periodically to incorporate lessons learned and new policy. Program measurable objectives will be added and deleted to the long list of program indicators in an attempt to fine tune which program activities have the greatest impact on desired outcomes.

Federal wildland fire specialists in all the wildland fire agencies are working toward this end. In responding to congressional concern, their efforts are focusing on mutually beneficial objectives, program strategies, accountability, measurement, and program reporting processes.

The Fire Program Analysis System

The Fire Program Analysis System (FPA) will assist federal wildland fire specialists in transitioning from measuring outputs to measuring results and outcomes. FPA is a strategic rather than tactical budget planning tool. This tool to evaluates the effectiveness of alternative fire management programs. It will provide managers with a process that helps define accountability and performance measures that track success. It is objective driven and performance based in that it incorporates measuring cost-effectiveness rather than efficiency alone. It also assists in evaluating tradeoffs in achieving objectives at different budget levels. It is an interagency program evaluation tool in that it identifies efficiencies of sharing fire resources across jurisdictions. Lastly, when completed, it will address the full scope of fire management activities.

The full project scope of FPA will analyze:

- Initial response for suppression and fire use
- Extended attack, large fire support, and national resources

- Prescribed fire and fuels mgmt
- Prevention and education
- Emergency stabilization and rehabilitation

FPA relies on agency land management plans to assess the current landscape condition and to define the desired condition. Wildland fire specialists must identify the differences between desired condition and current condition, and determine the appropriate role of wildland fire management in achieving the desired conditions.

Fire management plans bring forward descriptions of desired condition as well as resource management goals and objectives from the land management plan. FMPs represent this direction in fire management units that spatially define land management objectives, standards and guides within the context of wildland fire management. Fire management units will:

- Specify suppression goals and objectives that support the desired condition
- Specify program approaches or strategies for managing fire
- Define measures of accomplishment over a relevant time period (performance measures)
- Address public and firefighter safety in all aspects of fire management strategies
- Describe sensitive social, economic, and resource issues as they relate to fire management strategies and objectives.

A fire management unit is any land management area definable by objectives, management constraints, topographic features, access, values to be protected, political boundaries, fuel types, major fire regime groups, and so on, that set it apart from the management characteristics of an adjacent fire management unit. Fire management units may have dominant management objectives and pre-selected strategies assigned to accomplish these objectives.

Fire management unit objectives are important triggers for the Fire Program Analysis System. FMU objectives are a synthesis of federal fire policy objectives, land management plan objectives, and national performance measure objectives. They also may reflect local issues of concern that involve community protection or public safety. Most importantly, these objectives, as listed in each FMU, must not be in conflict with the direction outlined in the land management plan. The fire management unit highlights a particular fire management strategy that works toward achieving the desired landscape condition and land management objective, while also articulating key measurable objectives that will help describe the success or appropriateness of the fire management strategy.

Fundamental Elements of the Fire Program Analysis System

FPA requires a shift toward collecting program data that will aid managers and decision-makers in setting program strategies and priorities that deliver desired agency outcomes.

FPA focuses on FMU objectives and translates them into meaningful measures for the analysis model. FPA extracts, documents, and translates fire management objectives from fire management plans for each fire management unit.

The weighting process is based on specific fire management objectives as well as the values to be protected. FPA assigns weights to the objectives for each FMU based on the relative importance of such things as protecting the FMU from unwanted fire, or allowing use of wildland fire to accomplish objectives given limited initial response resources and budget. Most importantly, weighting is assigned through an interdisciplinary and/or an interagency process.

Weights are assigned to FMUs by considering such variables as time of year, and fire intensity levels. Weights indicate the relative importance of managing fire within the FMU from unwanted fire or desirable fire at different fire intensity levels and at different times of the year, assuming limited response resources. Fire intensity level is a rating index that is based on calculated flame length, as well as an indicator for fire danger that categorizes rate of fire spread. Fire Intensity level (FIL) and time of year help model the fire event in terms of the fire's potential for resource damage (See Figure 1).

Weights assigned to the objectives of one FMU are also relative to other weighted objectives found in other FMUs within the planning unit. Example 1: it is more important to suppress high intensity fires in one FMU while maintaining desirable low intensity fires that are managed for resource objectives in another FMU. Example 2: it is more urgent to suppress fire in a wildland urban interface FMU, than in a backcountry or wilderness FMU.

By assigning weights, FPA negotiates these objectives into desired (positive) weights and undesired (negative) weights that result in outcomes. For example, a planning unit may have several FMUs with strategies ranging from protecting communities in the wildland urban interface, or restoring the natural role of fire in wilderness landscapes, or restoring species and species habitat. FPA ranks these outcomes and their associated measurable objectives to produce prioritization of work and needed budget levels to accomplish those objectives (See Figure 2).

Figure 1--Relationship of Land Management Plan Direction with Fire Management Plans and Fire Program Analysis Inputs (FPA, January, 2003).

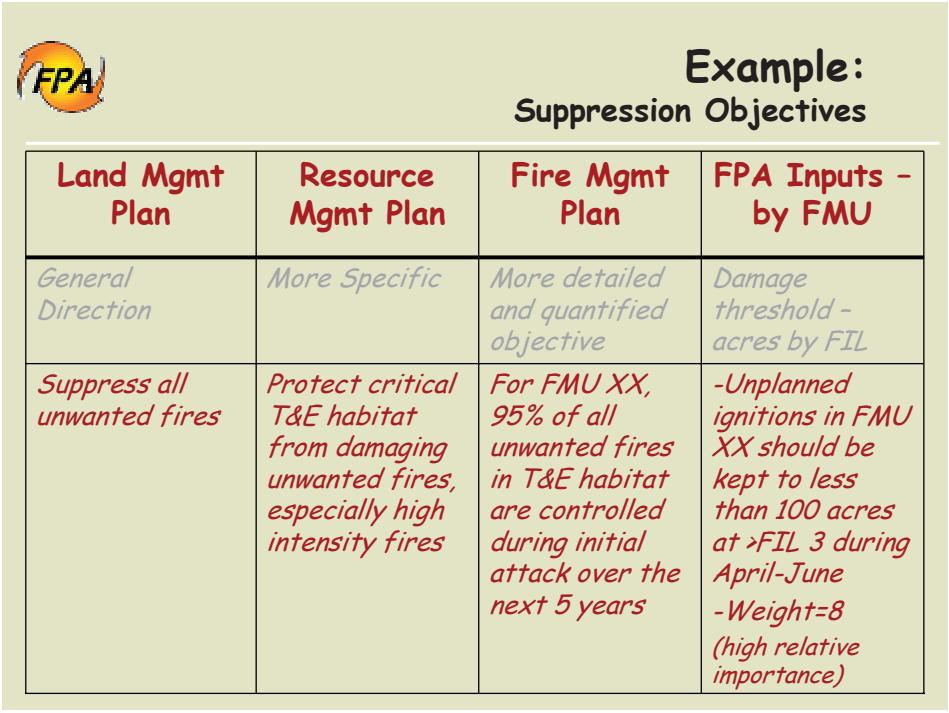
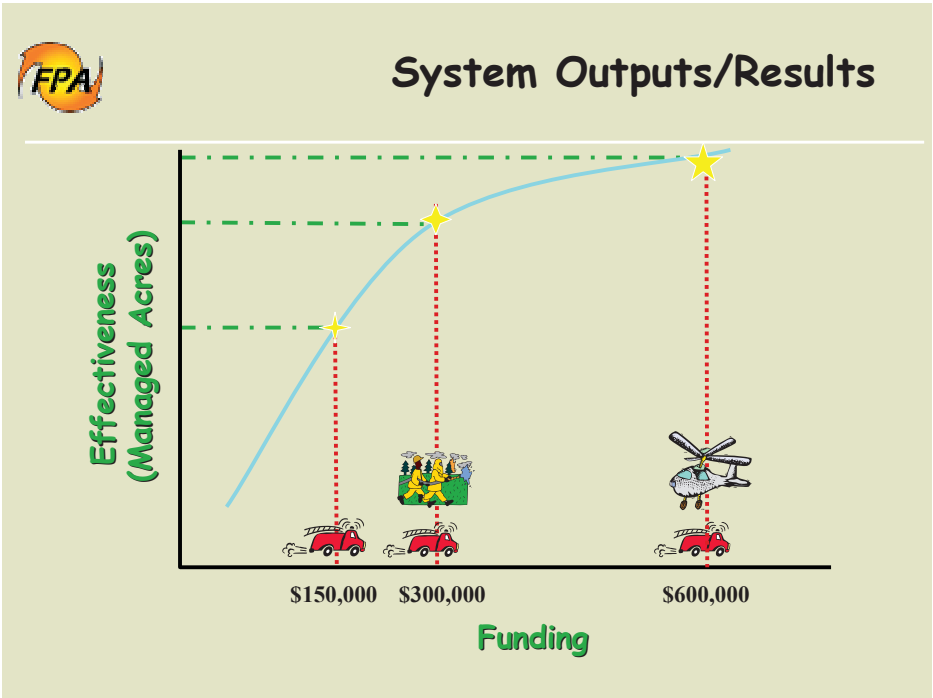


Figure 2--Example Output of Fire Program Analysis. (FPA, January, 2003).



Challenges in Developing Measurable Objectives for FPA and FMPs

The greatest challenge in implementing FPA will be the identification of meaningful measurable objectives and indicators. The key to successful performance measurement is knowing which program indicators have the most significant relationship to desired outcomes. Defining performance indicators is where science and art come together as managers link the logic and rational assumptions of policy and programs with the primary activities designed to produce results.

For every set of assumptions and activities there should be a set of indicators that test whether program logic and assumptions truly deliver intended results. Indicators provide the evidence that program activities are correlated with desired outcomes, by helping to further describe conditions associated with intended outcomes. Fire management specialists know that many of these indicators will be interdisciplinary, ecological measures of resilient and sustainable ecosystems, as well as social and economic indicators addressing the needs of public and community protection. The additional challenge will be to ensure that the aggregated summary of indicators at the national level translate into a defensible and coherent budget structure for congress. The challenge in developing measurable objectives is ensuring that indicators are meaningful to field level fire managers and high-level decision-makers alike.

Summary

Implementing the Fire Program Analysis System will take time. As mentioned, many key indicators and measurable objectives for wildland fire management are long-term outcomes that extend over decades. It will take time and exploration to put into place the short-term indicators that act as interim measures for wildland fire management outcomes. FPA, however, is an immediate important step toward increased accountability in wildland fire management. It also provides congressional decision-makers with performance data about the federal wildland fire program in a manner that considers the success our assumptions, strategies, and program activities achieve.

FPA can not be expected to eliminate conflict inherent in the political process of resource allocation, and final program decisions will need to take into account many factors, in addition to performance.

It will be significantly important for land and resource management plans to develop goals, desired conditions and resource objectives that speak to the appropriate role of wildland fire in the landscape. Stakeholders and the public must be involved in this process at the land management planning level to ensure that management objectives consider social and economic values as well. Critical processes such as activity planning, implementation, and reporting need understanding and support with partners from other government jurisdictions, special interest groups and private land owners.

The FPA process is a long-term commitment and expectations for immediate budgetary impact must be tempered with this understanding. Implementation of FPA moves the federal wildland fire program from reporting of one dimensional output data, toward outcome-based management information; management information that

fire specialists and managers now understand to be vital to making good decisions that stand the test of time in public service.

Associated Readings

USDA FS, USDI. September, 2000. Managing the impact of wildfires on communities and the environment – A report to the President in response to the wildfires of 2000.

UADA FS, USDI. August, 2001. A collaborative approach for reducing wildland fire risks to communities and the environment – 10 year comprehensive strategy. Western Governors' Association.

Western Governors' Association. May, 2002. A Collaborative Approach for Reducing Wildland Fire Risks to Communities and the Environment – 10 Year Comprehensive Strategy – Implementation Plan.

Land Management Considerations in Fire-adapted Ecosystems: Conceptual Guidelines. USFS. (1996).

Managing the Impacts of Wildland Fires on Communities and the Environment – The National Fire Plan. USDA FS, USDI. (2001). www.fireplan.gov/references.

Policy Implication of Large Fire Management: A Strategic Assessment of Factors Influencing Costs. USDA FS. (2000). www.fs.fed.us/fire/planning/Large_Fire_Mgt.pdf

Protecting People and Sustaining Resources in Fire-adapted Ecosystems – A Cohesive Strategy. USDA FS, USDI. (July, 2002). www.fs.fed.us/publications.

Blue Print for Fire Planning. Rideout, Douglas B., Botti, Stephen J. (July/August, 2002). Journal of Forestry, Vol. 100, No 5.

Designing Effective Performance Measures. National Academy of Public Administration (NAPA). Washington, DC. (1999).

Federal Wildland Fire Management Policy and Program Review Report. USDA FS, USDI. Washington, DC. (1995). www.fs.fed.us/publications.

Thirty Mile Hazard Abatement and Accident Prevention Plan. USDA FS. Washington, DC. (2002). www.fs.fed.us/publications.

Implementing the Government Performance and Results Act: Performance Measurement in the US Forest Service. Robertson, S. (1998). University of Oregon.

Fire Program Analysis System– Preparedness Module[1]

H. Roose,[2] L. Ballard,[3] J. Manley,[4] N. Saleen,[5] S. Harbert[6]

Abstract

Following the 1994 fire season in the United States of America the five federal wildland fire agencies and bureaus within the Departments of Agriculture and Interior along with the State Foresters conducted a review of the Federal Fire Policy. Lack of a common, interagency fire planning and budgeting system was identified as a weakness amongst the federal agencies. The implementation plan identified one of its action items as the development and implementation of a common, interagency fire planning and budgeting system.

The Fire Program Analysis System – Preparedness Module (FPA-PM) incorporates the use of the National Fire Danger Rating System, Energy Release Component for developing probability distributions of fuel moistures with associated probability distributions of wind speed to be used for fire behavior calculations. Weather observation data required for the distribution of wind speeds and fuel moistures is often problematic or missing, FPA-PM utilizes a GRID weather database to fulfill weather observation data when local data is unavailable.

Employing an optimization model for developing a cost effective frontier for fire planning is a key component to FPA-PM and is a new process for the five federal wildland fire agencies. The model is dependant upon land management objectives coupled with fire management strategies, reflected in weights assigned to each Fire Management Unit. Weights reflect the priority or relative importance for initial attack and wildland fire use for resource benefit one Fire Management Unit to another.

The results of the FPA-PM will be utilized for the development of the fiscal year 2007 budget request for the five federal wildland fire agencies and bureaus.

Introduction

Following the 1994 fire season in the United States of America the five federal wildland fire agencies and bureaus within the Departments of Agriculture and Interior along with the State Foresters conducted a review of the Federal Wildland Fire Policy. Lack of a common, interagency fire planning and budgeting system was

[1] An abbreviated version of this paper was presented at the second international symposium on fire economics, policy, and planning: a global view, 19–22 April, 2004, Córdoba, Spain.

[2] Bureau of Land Management, National Interagency Fire Center, 3855 South Development Avenue, Boise, Idaho 83705; hroose@blm.gov.
[3] U.S. Fish and Wildlife Service, National Interagency Fire Center, 3855 South Development Avenue, Boise, Idaho 83705; lballard@blm.gov.
[4] National Park Service, National Interagency Fire Center, 3855 South Development Avenue, Boise, Idaho 83705; jeff_manely@nps.gov.
[5] USDA Forest Service, National Interagency Fire Center, 3855 South Development Avenue, Boise, Idaho 83705; nikki_dyke@fs.fed.us.
[6] Bureau of Indian Affairs, National Interagency Fire Center, 3855 South Development Avenue, Boise, Idaho 83705; sharbert@blm.gov.

identified as a weakness amongst the federal agencies. The implementation plan for the Federal Fire Policy identified one of its action items as the development and implementation of a common, interagency, fire planning and budgeting system. At the conclusion of the 2000 fire season in the United States another review of the Federal Wildland Fire Policy was conducted. One outcome of the 2000 review was the National Fire Plan developed as part of the response to the 2000 fire season in the United States. One action item from the National Fire Plan was to evaluate the feasibility of developing a common fire planning and budget process for Local, State and Federal wildland fire agencies to use. This action item was assigned to the State Forester of Colorado, Jim Hubbard; a report entitled "Developing a Landscape-scale Fire Planning Analysis and Budget Tool" (aka Hubbard Report) followed. The report provides guidance and a conceptual framework to the Fire Program Analysis System Core Team for design and build.

Following the acceptance of the Hubbard Report by the various land management agencies, a briefing provided to United States Congress resulted in direction to design, build and implement a focused initial attack preparedness analysis, now known as the Fire Program Analysis Preparedness Module (FPA PM). The date for implementation of the Preparedness Module is October 1, 2004. Analysis results will be used to develop the Fiscal Year 2007 Preparedness Budget. Additional FPA modules are anticipated in future years to address the planning and budget needs of other elements of fire management programs (e.g. large fire and fuels management).

Organizing for Success

Upon receipt of the Congressional Direction with the accompanying implementation date, the National Fire and Aviation Management Executive Board appointed a Project Manager and Core Team Business Leader. These individuals developed a project charter containing the scope of the project, projected budget and associated organization to ensure success. This organization included a Core Team made up of representatives from each of the five federal wildland fire agencies and bureaus that make up the majority of wildland fire protection for the United States. The agencies and bureaus of the federal wildland fire agencies are the United States Department of Agriculture, United States Forest Service and United States Department of Interior, Bureau of Land Management, Bureau of Indian Affairs, Fish and Wildlife Service and National Park Service.

The Core Team is directed by a steering committee to ensure that the business requirements for initial attack preparedness and wildland fire use are represented within the Preparedness Analysis.

Preparedness Model Inputs

The Fire Planning Unit (FPU) is the geographic extent of the fire management area that will be analyzed with FPA PM. An FPU may represent one or many agencies and will have a single fire scenario assigned to it. The fire scenario is a statistically modeled representation of the ignitions within a FPU. A fire year can be subdivided into sensitivity periods. Sensitivity periods are measured in two week intervals throughout the calendar year and are used to capture seasonal variability of

resource/fire management objective. Sensitivity periods start January 1 and end December 31.

Sensitivity periods allow the user to change the relative importance of managing modeled fire events within the FPU throughout the year.

The FPU is subdivided into Fire Management Units (FMU). Fire Management Units are spatially designated polygons defined by objectives, management constraints, topographic features, access, values to be protected, political boundaries, fuel types, major fire regimes groups, and so on that set it apart from the management characteristics of an adjacent unit. Fire Management Units are the basic geographic area used in the FPA PM analysis. Modeled fire events, relative importance (weights) and fire resource arrival times from dispatch locations will be associated with each FMU.

Fire Occurrence and Fire Behavior

The Personal Computer Historical Analysis (PCHA) application will be utilized to provide historical analysis of fire occurrence and fire behavior in FPA PM. The PCHA application will develop a probabilistic fire scenario for the Fire Planning Unit and calculate fire behavior for the individual modeled fire event.

The probability of a fire occurring is calculated based upon historic fire occurrence data for the Fire Planning Unit. In the Western United States and Alaska most wildfires are caused by lightning. The weather conditions that produce lightning fires typically result in simultaneous ignitions. These fires along with those that occur individually are represented within a fire scenario. Fires that have similar fire behavior characteristics, such as those that occur at Fire Intensity Level 1 can be grouped together. Fire Intensity Levels (FIL) are representations of flame lengths that are put into categories as described in Table 1.

The fire event data with its associated fire behavior is passed to a data transformer (described later) on its way to the optimization routine.

In order for a fire frequency distribution to be calculated the location of each historical fire record must be known so that it can be assigned to a FMU. The total number of fires plotted within each FMU have associated data elements that describe them, one being discovery date. Using the discovery date a probability can be calculated of a modeled fire event and simultaneous fires could occur on any given day.

Personal Computer Historical Analysis will be used to determine fire behavior attributes of the fire scenario for use within the optimization routine. Additional fire behavior inputs into PCHA for use in FPA PM are fuel type, weather, fuel moisture, slope, elevation and aspect. FPA PM utilizes Fire Behavior Prediction System surface fuel models and associated canopy cover, stand height, crown base height and crown bulk density to model the potential of passive and active crown fire.

Weather data in terms of wind speed and relative humidity may be derived from a fire weather station that is associated with the FMU or may be retrieved from the GRID weather database. The GRID weather database utilizes all available weather

stations within an area to determine coverage for all areas of interest within the United States.

The GRID weather option interpolates weather data from known stations and applies it to points of ignition for modeled fire events. GRID weather adjusts data to account for changes in slope, aspect and elevation.

Fuel moistures used as inputs into PCHA for fire behavior calculations will be determined for all Fire Management Units within a Fire Planning Unit based upon the National Fire Danger Rating System (NFDRS) fuel model G. Fuel model G is the only fuel model within NFDRS that contains all of the size classes and categories of fuels, i.e. one-hour, ten-hour, one hundred-hour, one thousand-hour, live herbaceous and woody. Using the Energy Release Component (ERC) for fuel model G (ERCg) coupled with fire occurrence data, a regression analysis has been completed nationwide (including Alaska) to determine the probability of a fire occurring. Based upon the percentile of ERCg calculated per Fire Management Unit there are correlating fuel moistures for each of the size classes of fuels. These fuel moistures will be used with associated wind speed distributions in conjunction with each Fire Behavior Prediction System (FBPS) surface fuel model, and canopy attributes identified within a Fire Management Unit to calculate a rate of spread and flame length for every combination of fuel moisture and wind speed. Slope, elevation and aspect will be entered into PCHA by their representative proportions in preparation for using probabilistic analysis.

Outputs from PCHA that will be utilized in the FPA PM optimization routine are Rate of Spread (ROS) and Fire Intensity Level (FIL). Rate of Spread will be used to determine the amount of fireline perimeter that exists at different time periods.

Table 1— *Fire Intensity Levels*

FIL	Flame Length
1	0 - 2
2	2.1 - 4
3	4.1 – 6
4	6.1 – 8
5	8.1 – 12
6	12.1 +

Fire Intensity Levels are used to communicate the impact that the fire will have on natural and cultural resources. Fire Intensity Levels also assist in determining the effectiveness that various fire resources will have in relation to stopping the spread of the fire. As a guideline, people with hand tools alone will not be effective in stopping the spread of fires with flame lengths greater than four feet; they will need assistance from either engines, dozers, air tankers or any combination of mechanical and aerial fire resources that produce chains of fire line.

Fire Resources

The Preparedness Model requires several inputs; most of these inputs are passed to the Data Transformer and then onto the Optimization Routine, see Figure 1. Fire Resource data with their associated attributes will be characterized by their travel time, deployment cost and production rate (chains per hour) from a Dispatch Location to a Work Load Point. The initial version of FPA PM has only one Work Load point per Fire Management Unit. Workload points are used to calculate the arrival time of fire resources from their Dispatch Location to the area of concern or where the work generally occurs.

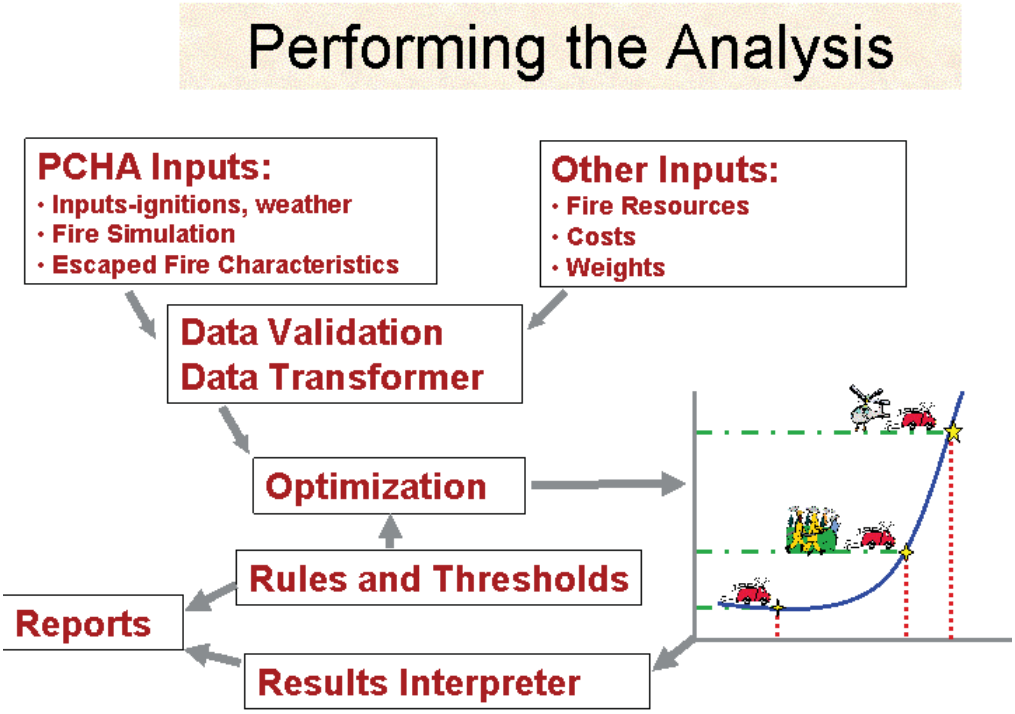


Figure 1—Performing the Analysis

The fireline production rate used for a specific fire resource is determined by Kind, Category, Type and Staffing in relation to the surface fuel model and a specific condition along with an associated percent slope. Fire resource fireline production rates are assigned to each ground based fire resource including helitack, rappelers and smokejumpers using standards developed by the National Wildfire Coordinating Group, Fire Equipment Working Team.

Weights

A critical piece of information needed by the system to translate land management objectives for initial response into the optimization formula is an indication of the relative importance to respond to unplanned ignitions under different circumstances. This will be accomplished through the application of relative weights to each fire management unit (FMU) within the fire planning unit (FPU). For ignitions that are

being modeled for aggressive initial attack, conceptually the model takes the weights applied to each fire management unit and multiplies the weight by the unburned acres for each analysis. The result is called weighted acres protected (WAP). The mathematical model strives to maximize the number of weighted acres protected across a fire season.

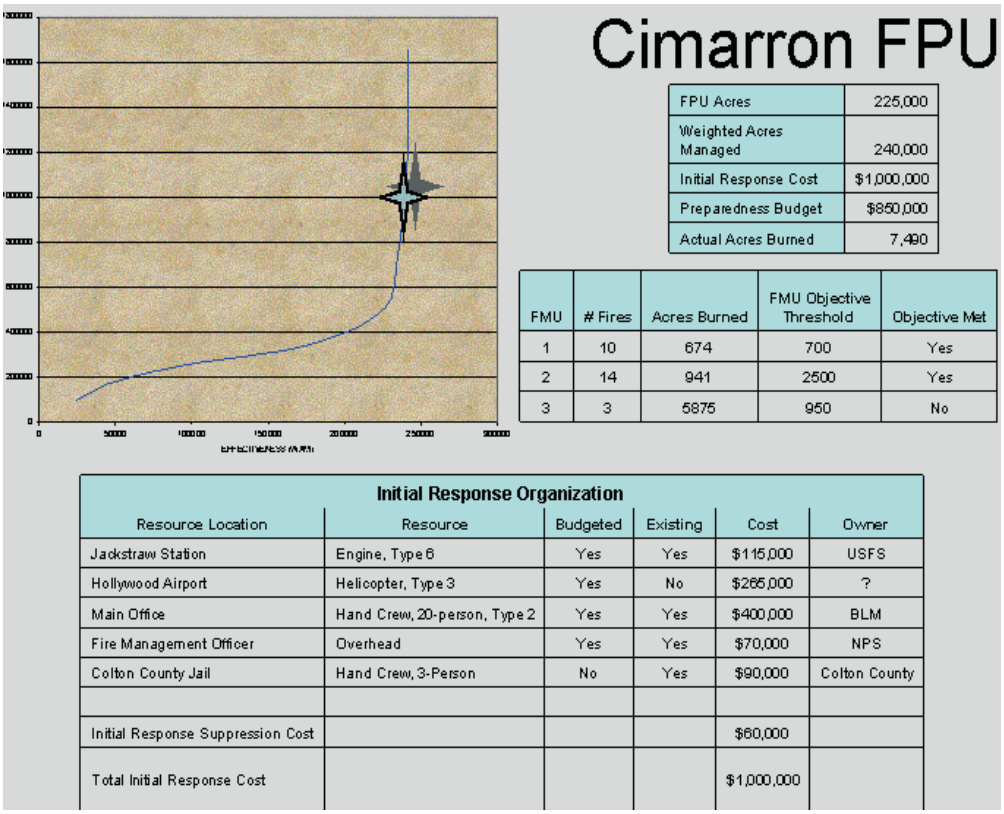
Optimization

The FPA preparedness model will utilize a linear optimization approach (integer programming) to establish the cost effectiveness frontier (See Figure 2) of weighted acres protected (WAP). The integer program will maximize weighted acres managed for a given cost level. The optimization model will then be run iteratively across a range of total cost constraints. The range of total costs will be determined by the minimum and maximum cost levels to be analyzed. The budgeted portion of total cost will also be calculated.

The integer program will model accomplishment of a set of representative wildland fires for each FIL and sensitivity period in each FMU. If the fire management objective for the ignition is suppression, containment is modeled and achieved if the sum of the fire line constructed exceeds the fire perimeter in any time period. The acres burned would result in a reduction in the total number of WAP. Each type of fire suppression resource (e.g. engines, hand crews, etc.) has an associated fire line production rate, preparedness cost and utilization cost. If the fire management objective for the ignition is Wildland Fire Use (WFU), production and cost would be estimated by the duration of the WFU event.

Expenditures and the effectiveness of wildland fire use fires will be optimized along with the suppression ignitions. Wildland Fire Use burned acres would result in an increase in weighted acres managed (WAM). The integer program will deploy fire resources to attempt to maximize the firefighting effectiveness of a given total cost.

If the model is unable to manage a fire within its cost allotment, then the fire is assumed to have escaped initial response and its size defaults to a statistically determined final fire size. All escaped fire acres result in a reduction in WAM. (Rideout and Kirsch 2002).



Cimarron FPU

FPU Acres	225,000
Weighted Acres Managed	240,000
Initial Response Cost	$1,000,000
Preparedness Budget	$850,000
Actual Acres Burned	7,490

FMU	# Fires	Acres Burned	FMU Objective Threshold	Objective Met
1	10	674	700	Yes
2	14	941	2500	Yes
3	3	5875	950	No

Initial Response Organization

Resource Location	Resource	Budgeted	Existing	Cost	Owner
Jackstraw Station	Engine, Type 6	Yes	Yes	$115,000	USFS
Hollywood Airport	Helicopter, Type 3	Yes	No	$265,000	?
Main Office	Hand Crew, 20-person, Type 2	Yes	Yes	$400,000	BLM
Fire Management Officer	Overhead	Yes	Yes	$70,000	NPS
Colton County Jail	Hand Crew, 3-Person	No	Yes	$90,000	Colton County
Initial Response Suppression Cost				$60,000	
Total Initial Response Cost				$1,000,000	

Figure 2—Example page of how to determine the cost effectiveness frontier.

Post Optimization

The Data Transformer will pass certain "Run parameters" to the Results Interpreter at the time that it initiates a call to the Optimizer. These parameters will enable the Results Interpreter to monitor the status of the Optimizer, making that status available to users who inquire about their results. If the Optimizer returns an "infeasible" message or other error, the Results Interpreter shall make the necessary notifications. Once the Results Interpreter determines that an individual Run has completed, it will begin its primary functions.

Disaggregate Optimizer Fires

The Data Transformer is allowed to take mathematically sound "shortcuts" as it prepares data for the Optimizer by grouping identical individual fire ignitions into one Optimizer Fire Event, increasing weights and costs accordingly. The Data Transformer will notify the Results Interpreter of any such allowed shortcuts it determined advantageous and implemented for each Run. Upon being notified that a Run of the Optimizer has completed, the Results Interpreter will adjust the raw Optimizer outputs to reinstate original input fire data.

In addition, the Results Interpreter will segregate dollars by Agency and Unit, and will create the capital budget indicated for dispatch locations or stations and fire resources. Where user input is needed in order to make decisions about Optimizer outputs (e.g. which Unit should an engine belong to where one or more are indicated for an inter-agency station), the Results Interpreter shall identify the required choices

for user interaction. FPA PM Users are able to specify desired Management Objectives, including acres burned by FMU, FIL, and Sensitivity Period.

The Optimizer passes to the Results Interpreter the results of each fire ignition, including acres burned. By matching the results with other available information about each fire ignition (FIL, FMU, and Sensitivity Period), the Results Interpreter can determine compliance with desired objectives.

This compliance will be stored along with the other outputs, and made available for user reports.

It should be recognized that the Fire Program Analysis System – Preparedness Module and future modules are under development while this paper and symposium are being under taken.

For the most recent, up to date information regarding this system please visit the following website:http://fpn.nifc.gov.

Summary and Conclusion

The FPA PM system will result in a consistent, common fire budget and planning tool used by five federal land management agencies. The system will use a statistical representation of historic fire events and weather data and, applying optimization, will determine the most effective fire organization to meet land management objectives at a variety of budget levels. The results will be used to develop national fire preparedness budgets and assist in budget allocations back to field units.

References

Developing an Interagency, Landscape-scale Fire Planning Analysis and Budget Tool, Report to the National Fire Plan Coordinators, 2001: U.S.D.A. Forest Service, U.S. Department of the Interior

Deeming, John E., Robert E. Burgan, and Jack D. Cohen, The National Fire Danger Rating System – 1978. US Forest Service INT – 39

Anderson Hal E., Aids to Determining Fuel Models For Estimating Fire Behavior. US Forest Service INT – 122.

Finney, Mark A. 2003. Unpublished; Process for developing the Fire Scenario for the Fire Program Analysis System – Preparedness Module.

Andrews, Patricia L. and Larry S. Bradshaw, 1997, FIRES: Fire Information Retrieval and Evaluation System – A Program for Fire Danger Rating Analysis. US Forest Service INT-GTR-367

Rideout, Douglas B. and Andrew G. Kirsch, 2002, Unpublished; Optimal Deployment for Initial Attack in Support of the Fire Program Analysis (FPA) Preparedness Module (Summary Report of Preliminary Progress).

Rothermel, Richard C. 1983. How to Predict the Spread and Intensity of Forest and Range Fires. US Forest Service, General Technical Report INT-143.

Robertson, Sarah L. and Howard Roose 2003, Fire Management Planning – Developing Strategies and Setting Measurable Objectives for Adaptive Management.

Finney, Mark A. 1998, FARSITE: Fire Area Simulator-Model Development and Evaluation. US Forest Service Research Paper RMRS-RP-4

A Model for Dynamic Programming to Back Strategic Planning for Fire Management in Chile[1]

Patricio Pedernera A., Miguel Castillo S., Guillermo Julio A.[2]

Abstract

Forest fires in Chile are a very major problem which affects both the environment and forestry work. Although Chile has a highly developed pre-suppression and fire-fighting system, over the last 15 years the effectiveness of our protection systems (measured by the average size of fires) has remained constant, while the budgets directed at protection have grown steadily, in particular in the private sector. The public sector, for its part, has been faced with difficult times, when budget assignation has been hindered by other national priorities and by the major difficulty of providing a foundation for applications for resources with no technical back-up. As a way of resolving this problem, a mathematical programming model was developed which represents the first step towards a planning scheme based on the economic analysis of fire management operations. The model determines the optimal size of the land-based fire-fighting team necessary at regional level, in order to adequately deal with fire problems which may occur within the area which the public sector protection programmes are responsible for.

This model considers the analysis of coverage by land-based fire-fighting units using a cost of access scheme, where a vehicle moves over a surface which provides friction upon displacement. The friction surface is constructed on the basis of the regional road network and average speed of displacement per road-type. A number of locations for the land-based fire-fighting units are also considered as centres providing fire protection. Following this is a dynamic programming model which evaluates the different possible combinations of locations on the basis of the coverage which each location provides to the system, maximizing the surface area under coverage. The model developed is applied to the Forest Fire Protection Programme system operated by the National Forestry Corporation in region 8 in Chile.

Introduction

Over the last 15 years the occurrence of forest fires has remained relatively constant, in spite of the many efforts made to improve the efficiency of fire-fighting operations. Although these efforts have been permanently oriented towards improving resources and the use of airborne material and resources, little or nothing has been done as regards reviewing fire protection design and the strategy which must direct fire management, in both the public and private sector.

In this respect it should be mentioned that budgets directed at forest fire protection have been constantly increased, without any real effect on the decrease in fires, or the affected surface area. This is particularly important in the private sector, where the level of

[1] An abbreviated version of this paper was presented as a poster at the second international symposium on fire economics, planning and policy: a global view, 19–22 April, 2004, Córdoba, Spain.

[2] Academics, Department of Forestry Resources Management, Faculty of Forestry Sciences, University of Chile, Casilla 9206, Santiago, Chile.

expenditure on protection is equivalent to approximately 1.5 times government investment in this area.

For its part, the public sector must compete for resources with other national priorities, so that fire protection system directors must make great efforts to justify the requests for resources to the national authorities.

The aim of this study is to provide a methodological tool to facilitate strategic fire-management planning in the public sector, by defining the right size of fire-fighting force required at regional level, in order to maximize the number of fires which may be attended to in the Bío Bío Region's National Forestry Corporation operating area of the fire management programme.

Materials and Method

This study was run in Chile's region 8 which possesses a major proportion of the natural resources of the major forestry companies and at the same time represents the region with the largest proportion of forest fires nationally over the last five years.

To undertake the study we used digital information on forest fires, the regional road network, and the coordinates of 34 locations which the region uses in the protection programme. This information was provided for the purpose on magnetic support by the National Forestry Corporation.

To handle the data, SPSS v.11 software; the geographical information systems Arcinfo, Arcview and Idrisi; and software developed for applications used for fire management by the University of Chile's Forest Fire Laboratory were all used.

The working method was to undertake three independent and successive analyses: to determine the maximum permissible response time (arrival at fire site) in the region; to calculate the areas of cover for the maximum permissible time calculated in the previous stage; and finally to run an optimising model which would identify and select the combination of locations which would maximize the number of fires which could be attended to in the region. The description of each of these stages is presented in the following pages.

Determination of response time

To determine the response times, data on fires affecting 100 hectares of surface area or less, which had occurred in the Bío Bío region between 1992/93 and 2001/2002 was taken from the data base of the National Forestry Corporation fire management statistics system. Thus, the data base consisted of 24,328 fires which underwent a verification process with the aim or ruling out any inconsistencies. In this process, 4,419 fires with some problem or other were detected and ruled out of the analysis, allowing us to obtain a definitive data base with 19,909 correctly described fires.

In addition, it should be mentioned that amongst the 19,909 fires included in the data base, there were a number of fires which recorded a discrepancy between the date and time of detection and the date and time of the first fire-fighting attack, which was given as 1, 2, 3 or 4 minutes (1,515 records), values which in our view are not sufficiently reliable. Nevertheless, given the absence of other background data, these were included in the analysis, since many of these fires may actually have been spot fires or fires which broke out very close to the position of a fire-fighting team or teams in action.

For each fire in the data base, the difference between the date and time of detection and the date and time of the first attack was calculated, in order to have an estimate of the response time for each fire. For this calculation, the response time was considered to be the time elapsed between detection and commencement of the first fire-fighting action, due to the absence of a data base field which recorded the effective response time for each fire.

This consideration is based on the fact that the dispatch of one or several fire-fighting units is only effective once notification of detection has been received, so that the calculation of the time taken for fire fighters to reach the site of the fire from their bases or stand-by positions only has true significance from the moment at which the unit is dispatched. This action is undertaken only after receiving notification and confirmation of a fire from one of the detection mechanisms used in the protection programme's operations zone.

Later, the response time calculated for each fire was converted into hours and minutes respectively, in order to facilitate later calculations. The working data base was processed using SPSS statistic software in order to obtain the respective descriptive statistics.

In order to study the existence of some direct relationship between affected surface area and response time, a dispersal graph was produced for the two variables, considering the response time as an independent variable and the surface affected as a dependent variable. This graph enables fire grouping levels to be determined, to better define the maximum values for the variables of response time and affected surface area.

Finally, a table of frequencies was constructed with average values for response time and surface area affected, in order to determine the minimum permissible response time, which could then be used in later stages of the study.

Calculation of coverage and determination of the optimal number of land-based fire-fighting units

One of the most important aspects for the success of protection against forest fires has to do with determining the coverage for each one of the operating units in the forest fire protection programme within their area of operations or competence.

In the case of the detection towers, for example, the coverage area is easily determined, as the tower's coverage concerns key protection zones which can be seen directly from the observation point. This surface area may be calculated using digital models of elevations, and tools for calculating visibility levels which are included in most of the Global Information System software.

In the case of land-based resources, a particular difficulty is come across, since the coverage area of these resources depends basically on the transit time from their bases or stand-by positions to the site of the fire they have been assigned to. This transit time depends on several factors (type of vehicle, transit conditions, accessibility to road network and others) which in fact define the time the fire-fighting teams require to reach the site of the fire.

This study used 34 land-based resource locations currently in use by the Bío Bío Region National Forestry Corporation in order to determine the current level of coverage in the region and propose locations which would contribute definitively to maximizing the number of fires which the regional protection system could attend to.

For modelling transit time and calculating coverage we used the access time where a vehicle moves over a surface producing friction on displacement (Eastman, 2000; ESRI, 1993).

This surface was constructed on the basis of the regional road network. Friction on displacement was assigned by average speed of displacement depending on type of road and road surface, following the Ministry of Public Works (MOP, 2000) road manual specifications, presented in *Table 1*.

Type of Road	Design speed (km/hr)	Speed used (Km/Hr)
Urban	60	40
Motorway	115	70
Dual carriageway	95	70
Main roads	95	60
Ring roads	80	40
Local roads	70	30

Table 1*—Speed of displacement used in the study (km/hr).*

The friction or resistance to displacement was assigned to each arc of the road network, diving the length of the arc by the speed at which the vehicle may move, as indicated in table 1.

Displacement across the arcs of the road network was modelled using the SIG Arcinfo network module (ESRI, 1992), using a supply and demand model through a distribution system, in order to identify the sectors which may be reached from each of the stand-by positions within the maximum response time determined in each study.

Movement outside the road network was modelled using SIG Idrisi software (Eastman, 2000), so that it was necessary to use the conversion tools included in the software in order to undertake the change from the vectoral data model (Arcinfo) to the raster data model (Idrisi). The conversion process produced 34 raster files, one for each of the points considered in the evaluation at 25 metre resolution.

The calculation of access time outside the road network was done using a cost of access calculation, based on the maximum ranges calculated for each location using Arcinfo. To do this the Idrisi cost analysis module was used. This takes an algorithm which produces a cost surface area where the distance is measured as the minimum cost (time, effort or expenses) of displacement over the friction surface (Eastman, 2000).

Finally, the coverage areas for each of the 34 locations were obtained using reclassification processes on the respective surfaces of costs produced, for a time equal to the response time determined earlier.

In order to determine the correct number of locations required to be part of the land-based protection system in the Bío Bío region, a dynamic programming model was produced which maximized fire coverage for the region. The model evaluates all possible location combinations, selecting the combination of 1,2,3,….34 points which maximizes overall coverage of the system.

The recursive function produced ed for this case is as follows:

$$C_n = Max \left\{ C_i + C_{n-1} \right\}$$

Where

Cn= is the number of fires covered by a combination of n locations.

Given the strong spatial connotation of the problem under study, the model was implemented to be resolved in a SIG environment, using the GRID module in the SIG Arcinfo software. The model was programmed on a automatic calculation interface, using Arcinfo AML programming language, thus obtaining the combination which maximizes total coverage of the system with each iteration.

Results

Determination of response time

The descriptive statistical analysis of the working data base is shown below in *Table 2*.

Variable	Affected Surface Area (ha)	Time of Arrival (min)
Observations	19,909	19,909
Maximum	100.00	5,125
Minimum	0.01	1.00
Mean	1.51	33.52
Variance	40.46	8,459.57

Table 2*—Descriptive statistics on the working data base*

Table 2 shows that in the case of affected surface area we see a great variability with extreme values of the order of 100 m^2 and a maximum of 100 ha, in accordance with study conditions. The average value observed for this case (1.51 ha) is fairly small, consistent with the variance observed for the population. Nevertheless, in the case of response times, a very high variability is seen in the observations, made evident by the extremely high variance calculated for the population. The same is seen with respect to the extreme values, where the difference between maximum and minimum is 5,124 minutes (85.4 hours).

In order to explore the existence of any relationship between the response time and affected surface are, a figure relating the two variables was produced without processing the information any further. The graph produced is shown below in Figure 1.

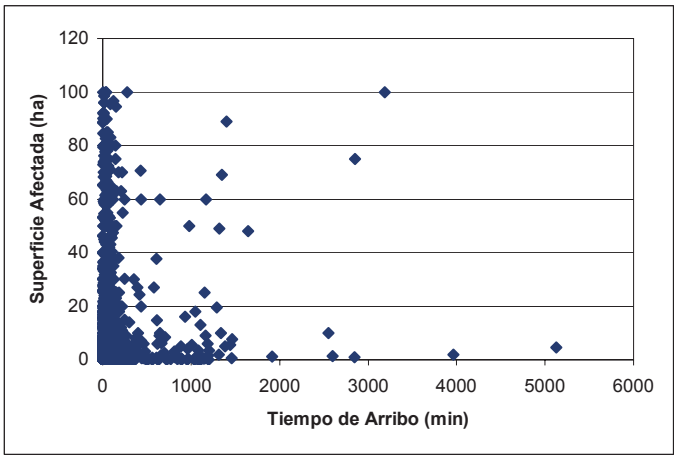


Figure 1—Response times (min) versus Affected Surface Area (ha)

Figure 1 clearly shows the grouping of fires towards categories lower than 1,000 minutes (16.6 hours) response time. Additionally, a high variability as regards surface areas affected can be seen for one same time category.

In order to explore in more detail whether there was any relationship between the data, the same graph was constructed but limiting the range of deployment for response times to values under 100 minutes (1.6 hours), as shown in *Figure 2*.

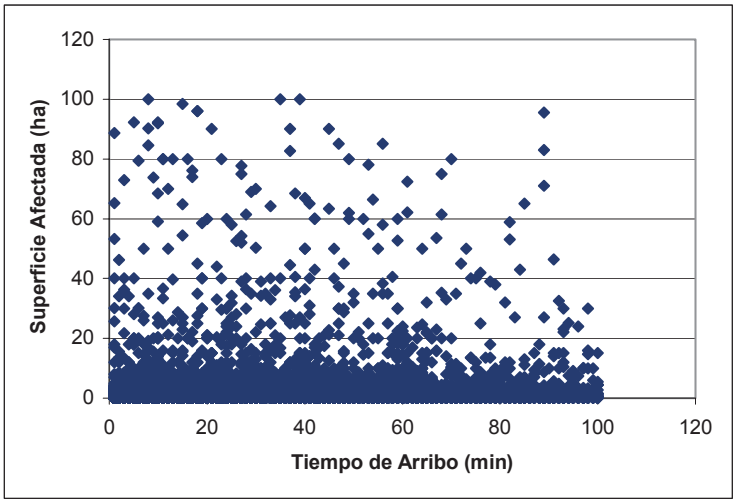


Figure 2—Response times (min) versus Affected Surface Area (ha) for a limited time of 100 minutes

Once again the same effect indicated earlier was observed i.e. for each time of arrival level, a high dispersal of affected surface areas could be seen, with no apparent direct relation between the two variables. This fact became evident on exploring each response time category in the data base, where for each level a high number of different affected surface area values were found.

In addition, when observing *figure 2* in greater detail, it is evident that a high proportion of fires are grouped within levels lower than 20 ha of affected surface area, with broad dispersal of response time values.

After establishing this affected surface area value, which was considered as a limit for improving the level of detail, a frequencies table for each surface area category was drawn up. The categories considered were defined in order to facilitate data analysis by max/min value of detail determined earlier. Thus, fires were grouped into 32 categories, where the first 20 corresponded to categories of one hectare each, and the next categories (12) were defined with variable ranges, up to 100 hectares which was defined as the limit for the study.

For each of these, the number of fires, the mean, and the maximum and minimum values were calculated for affected surface area variables and response time respectively. The usual descriptive statistics were also included for each of the variables considered. *Table 3* shows the results of this process.

Surface area Range (ha)	Number of fires	%	Affected Surface Area (ha)			Time (min.)		
			Maximum	Mean	Minimum	Maximum	Mean	Minimum
0 – 1	15,580	78.26	0.96	0.17	0.01	1,460.00	25.92	1.00
1 – 2	1,772	8.90	1.98	1.29	1.00	2,845.00	45.67	1.00
2 – 3	767	3.85	2.95	2.29	2.00	3,965.00	52.90	1.00
3 – 4	411	2.06	3.91	3.26	3.00	1,201.00	57.52	1.00
4 – 5	266	1.34	4.91	4.24	4.00	5,125.00	79.03	1.00
5 – 6	183	0.92	5.80	5.18	5.00	1,440.00	76.03	1.00
6 – 7	132	0.66	6.95	6.23	6.00	1,186.00	72.92	1.00
7 – 8	86	0.43	7.90	7.14	7.00	1,461.00	77.81	5.00
8 – 9	93	0.47	8.80	8.16	8.00	708.00	56.47	1.00
9 – 10	37	0.19	9.90	9.12	9.00	1,161.00	102.35	4.00
10 – 11	79	0.40	10.80	10.07	10.00	2,553.00	111.65	4.00
11 – 12	17	0.09	11.80	11.19	11.00	222.00	63.88	8.00
12 – 13	39	0.20	12.90	12.11	12.00	208.00	39.18	1.00
13 – 14	15	0.08	13.55	13.21	13.00	1,108.00	127.67	2.00
14 – 15	22	0.11	14.75	14.24	14.00	616.00	90.18	7.00
15 – 16	40	0.20	15.90	15.12	15.00	251.00	51.25	2.00
16 – 17	11	0.06	16.90	16.19	16.00	931.00	113.55	1.00
17 – 18	11	0.06	17.97	17.31	17.00	130.00	45.82	4.00
18 – 19	23	0.12	18.20	18.01	18.00	1,050.00	105.30	1.00
19 – 20	3	0.02	19.60	19.27	19.00	1,288.00	437.67	8.00
20 – 25	76	0.38	24.75	21.16	20.00	432.00	60.95	3.00
25 – 30	42	0.21	29.60	26.23	25.00	1,150.00	92.64	1.00
30 – 35	33	0.17	34.30	31.35	30.00	355.00	57.48	1.00
35 – 40	29	0.15	39.65	36.50	35.00	607.00	75.48	3.00
40 – 45	21	0.11	44.50	40.85	40.00	104.00	41.10	1.00
45 – 50	9	0.05	49.00	46.40	45.00	1,642.00	379.11	2.00
50 – 60	29	0.15	59.10	52.71	50.00	980.00	90.79	1.00
60 – 70	31	0.16	69.00	62.88	60.00	1,351.00	171.84	1.00
70 – 80	18	0.09	79.50	73.68	70.00	2,852.00	235.61	3.00
80 – 90	16	0.08	89.00	82.37	80.00	1,403.00	130.25	1.00
90 – 100	13	0.07	98.50	93.37	90.00	153.00	42.23	5.00
Over 100	5	0.03	100.00	100.00	100.00	3,186.00	709.00	8.00
Total	19,909	100	923.33	861.31	835.01	43,124.00	3,919.25	85.00
Mean	622.16		28.85	26.92	26.09	1,347.63	122.48	2.66
Maximum	15,580	0.78	100.00	100.00	100.00	5,125.00	709.00	8.00
Minimum	3.00	0.03	0.96	0.17	0.01	104.00	25.92	1.00
Variance	7,561,608.91		869.26	783.63	740.52	1,377,479.92	19,681.00	5.46
Deviation	2,749.84		29.48	27.99	27.21	1,173.66	140.29	2.34

***Table 3**—Grouping and ordering of data into 32 categories of Affected Surface Area*

From *Table 3* it can be seen that around 90% of fires show an affected surface area of under 5 ha, with response times under 60 minutes (one hour). Moreover, almost 80% of total

fires are concentrated within category one (less than one hectare of affected surface area) and the mean value for response time for that category is of the order of 26 minutes (25,92 min.).

It is clear that there is very high variability with regard to response times, an effect which occurs due to the dispersal of the affected surface area for the same minute of response time. This would lead one to think that there is no direct relation between these two variables. We can be sure of this, given that the final surface area affected by a forest fire depends on other factors (fuels, environmental conditions, topography, fire-fighting action) which conditions the behaviour of the fire, and consequently the propagation model and final surface area affected by fire.

However, to resolve the response time a graph was constructed which shows the surface area affected and the response times for each of the 32 categories of fire size defined in this analysis.

The data was ordered by size category and affected surface area and response times were plotted on a graph independently, with the same scale of values on the *Y* axis, in order to observe the behaviour of the two variables simultaneously. The result of this process can be seen below in *Figure 3*.

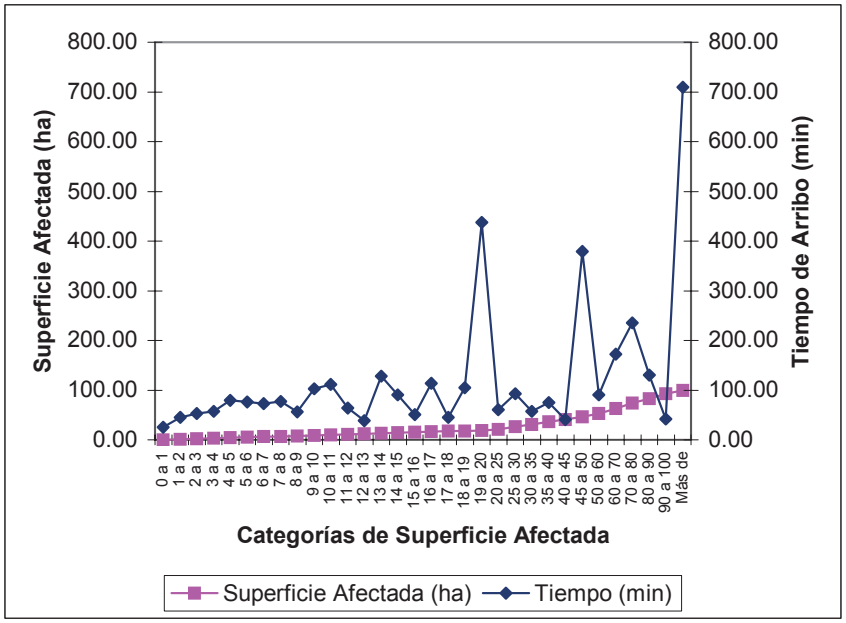


Figure 3—Distribution of the Mean Surface Area Affected and Mean Response time for 32 size categories of forest fire

In *Figure 3* one can clearly see the exponential trend shown by the affected surface area: the longer the time taken to initiate the first fire-fighting action, the greater the final surface area affected. The trend in this case shows a quadratic or exponential curve which makes the analysis consistent with the findings of Julio[3] (1999), in that the difficulty of controlling a fire (and consequently the affected surface area) increases in exponential terms with regard to the time elapsed, or delay, before initiating control.

Another interesting aspect has to do with the way in which the increase in response time (time of arrival at the site of the fire) is shown. This shows variations with no defined behaviour. In any case it is well known that as the time of arrival at the fire increases, the affected surface area also increases. In this case one cannot find a clear trend, given the high variability seen in the data.

Given the form of the curves and the frequency values calculated for each fire size category (*Table 3*), it can be concluded that "optimal" response time is in the first size category (0 to 1 hectares affected) where, on average, the fire-fighting units took 26 minutes to initiate the first attack. Coincidentally this category also groups together the major proportion (78.26 percent) of the fires recorded in the data base (*Table 3*).

Calculation of coverage and determination of the optimal number of land-based combat units

By applying algorithms to calculate routes and costs of access in the SIG environment, 34 coverage maps were produced for locations included in the analysis. Figure 4 shows an example of the result of the calculation obtained using SIG Idrisi.

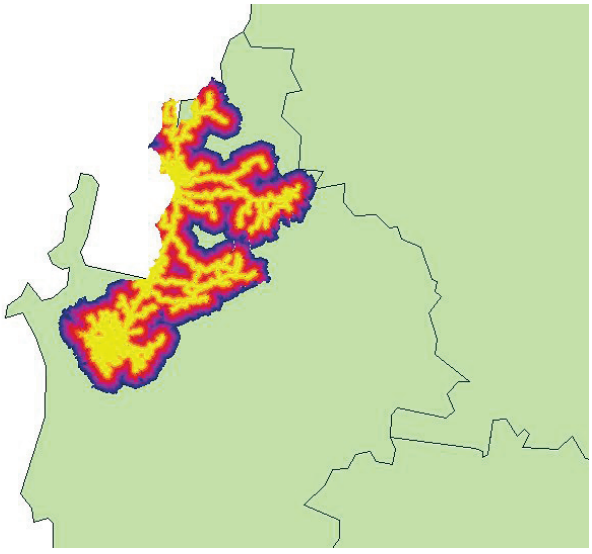


Figure 4—Costs of access for location of brigade 301. The colour bands represent the time (in minutes) taken by a vehicle to reach a pixel, up to a maximum of 26 minutes.

[3] Julio Guillermo, Basics of Fire Management, Manual of Forestry Engineering, Faculty of Forestry Sciences, University of Chile.

Figure 4 clearly shows the influence of the road network over the surface area the fire-fighting unit is able to reach within the maximum response time determined in this study.

The 34 coverage maps were subjected to a process of raster superimposition with the image corresponding to the occurrence of forest fires in the region, in order to obtain an estimate of the historical mean potential work load for each unit. The result of this process can be seen in Table 4.

Location	No. of Fires	Location	No. of Fires
1	590.4	18	170.2
2	499.8	19	372.8
3	666.0	20	264.4
4	845.8	21	385.4
5	792.8	22	276.2
6	787.8	23	290.6
7	806.6	24	442.4
8	803.2	25	250.2
9	822.0	26	445.4
10	845.8	27	255.0
11	268.2	28	882.2
12	205.6	29	1082.0
13	265.0	30	600.0
14	264.4	31	1081.0
15	287.8	32	109.2
16	329.6	33	107.4
17	290.6	34	104.4

Table 4*—Average number of fires (seasons1992/93 to 2001/02) within coverage by each of the 34 locations evaluated.*

As was expected, on superimposing the fire-fighting units' coverage areas with the occurrence of regional fires, different values were obtained for each of the locations. In this case, location number 29 stands out as the one which contributes the greatest number of fires to the total coverage of the system. This is not surprising, given that this location is in an area which historically has registered the highest number of fires in the region, the reason for which this unit is the one with the heaviest potential workload in the region. The same occurs in location 31 which is within the same zone where occurrence is concentrated.

The locations which make least contribution to the system are 33 and 34. These may have been incorrectly selected and should perhaps be removed from the system.

Using the SIG tools used in the study, an overall coverage map was constructed for all locations currently in use by the National Forestry Corporation in the Bío Bío region. This map is presented below, in Figure 5.

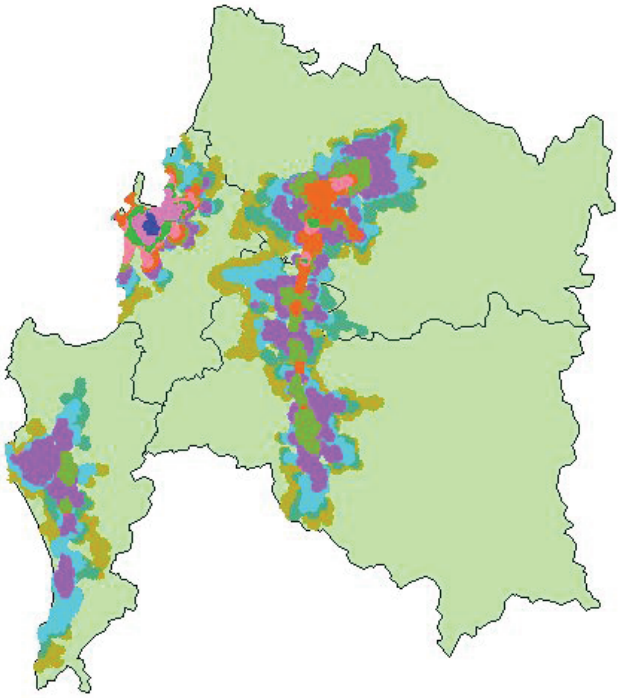


Figure 5—Current coverage of the land-based units in the Bío Bío region. The colour bands represent the amount of units which cover the same points (blue 10 units, green 1 unit)

Current coverage of the region's protection system is located more in the area close to the city of Concepción, the central valley, and the south-western area of the region, sectors which traditionally have the highest concentration of regional fires. Another interesting aspect to mention is the existence of sectors which show a level of over protection in the sense that they are covered by up to 10 different fire-fighting units at the same time.

The use of the dynamic programming model resolved the coverage problem, determining a combination which, in a first stage, maintains the same level of current cover (in terms of surface area) with fewer locations included in the system. Table 5 shows the final summary of applying the model developed for this study. This table shows the historical mean maximum number of fires covered by the protection system for each combination.

N	No. of Fires	N	No. of Fires
1	1082.0	18	3714.4
2	1992.6	19	3720.4
3	1938.4	20	3725.2
4	2383.8	21	3729.6
5	2724.6	22	3733.4
6	3048.2	23	3735.6
7	3277.2	24	3736.4
8	3384.6	25	3737.0
9	3451.6	26	3737.6
10	3508.0	27	3738.0
11	3555.6	28	3738.0
12	3587.6	29	3738.0
13	3617.6	30	3738.0
14	3647.0	31	3738.0
15	3675.8	32	3738.0
16	3691.2	33	3738.0
17	3699.2	34	3738.0

Table 5—*Mean number of fires covered by the best combination of n locations.*

From the background data in the table it can be seen that in the first iterations, the coverage contribution rises rapidly to establish itself after 27 locations. This trend may be seen more easily in Figure 6.

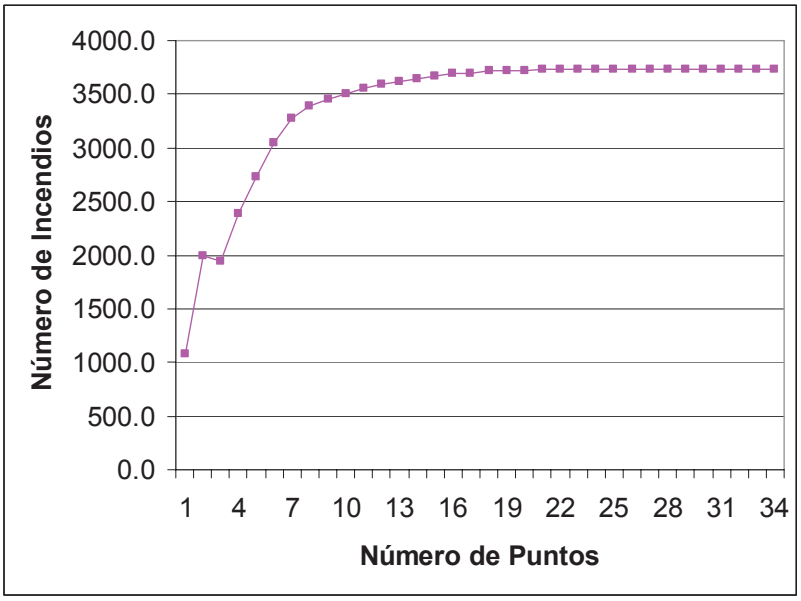


Figure 6—Evolution of the number of fires within coverage, for the best combination of locations.

The figure clearly shows the trend towards stabilization for the coverage level from 26 locations upwards, giving the maximum number of possible fires attended by the resources provided by the region for forest fire-fighting. This combination, which maximizes coverage,

corresponds to the points 29, 30, 4, 26, 6, 16, 13, 33, 27, 2, 25, 19, 17, 5, 15, 14, 18, 32, 28, 9, 24, 8, 21, 7, 20 and 22.

Conclusions

The model developed made it possible to determine the optimal number of locations which must be considered in strategic planning for forest fire protection in the Bío Bío region.

Calculation procedures for coverage areas proved to be efficient in estimating the surface area each location considered was responsible for. Nevertheless, it is especially important to consider that speeds of displacement used in this study correspond to the best possible estimate, given the absence of reliable background data on displacement speeds of vehicles in different conditions of road surface.

As a result of the background data provided by this study, the National Forestry Corporation has a new tool to justify the amount of fire-fighting units which should be used in the region in order to ensure an adequate level of protection.

Finally, it is necessary to continue running studies along these lines in order to implement an economic analysis tool for fire management in the public sector in Chile.

References

Eastman, Ronald, 2000. **Idrisi for Windows User's Manual**. Clark Labs. Massachusests, USA. 200 p.

Esri. 1993. **Network Analysis. Arc/info User's Guide**. Environmental Systems Research Institute. Redlands. California. USA. 163 p.

Esri. 1993. **Cell-based Modelling with GRID. Arc/info User's Guide**. Environmental Systems Research Institute. Redlands. California. USA. 277 p.

Julio, Guillermo. 1999. **Fundamentos de Manejo del Fuego**. Manual Docente. Facultad de Ciencias Forestales. Universidad de Chile. Santiago, Chile. 300 p.

MOP, 2000. **Manual de Carreteras vol 3**. Dirección de Vialidad, Ministerio de Obras Públicas. Santiago, Chile. 300 p-

Page left blank intentionally.

Comparison of Video and Phone Interview Survey Administration in Determining Public Support and Willingness to Pay for Prescribed Burning in California[1]

John Loomis,[2] Julie Miller,[2] Armando González-Cabán,[3] Joseph Champ[4]

ABSTRACT

This research tests whether conveying prescribed burning information and conducting survey administration via videotape is superior to phone-interviews supplemented by an informational booklet. During the phone call, the interviewer read text and referred the respondent to drawings in the mailed booklet contrasting wildfire and prescribed fire. The video administration also started with an initial phone call and then by mailing a videotape to the respondent along with an answer booklet. The announcer on the videotape verbally presented all the text that was read to respondents in the phone interview. The phone-mail booklet-phone interview resulted in support for prescribed burning increasing from 65% in the initial phone call to 91% in the follow-up interview. Preliminary results from the video survey indicate that 71% initially supported prescribed burning, with this increasing to 84% after viewing the video. There was no statistical difference between video and phone-booklet survey models in terms of response rates or reasons for refusing to pay for the prescribed burning program. Mean willingness to pay (WTP) for the prescribed burning program using the mail booklet-phone interview was $400 per household. The preliminary result from the video survey is $412. The confidence intervals for these two estimates overlap indicating they are not statistically different.

Introduction

Large scale forest fires have become more common place in the last decade, resulting in greater emphasis on fuel reduction techniques such as prescribed burning. However, a program of increasing the amount of land to be prescribed burned often engenders public opposition due to the amount of smoke generated from prescribed burning. The resulting smoke reduces visibility and creates health problems for people with respiratory conditions. Prior efforts to increase prescribed burning in states such as Florida and Washington have often been limited by citizen opposition due to smoke and health effects. The prescribed burning program is also expensive

---

[1] An abbreviated version of this paper was presented at the second international symposium on fire economics, planning and policy: a global view, 19–22 April 2004, Córdoba, Spain.

[2] Professor and Research Assistant, Department of Agricultural and Resource Economics, Colorado State University, Fort Collins, CO 80523.

[3] Economist, Forest Fire Lab, Pacific Southwest Research Station, USDA Forest Service, Riverside, CA 92507.

[4] Assistant Professor, Department of Journalism and Technical Communication, Colorado State University, Fort Collins, CO 80523.

and costs as much as $250 per acre. Thus a policy relevant issue is whether there is sufficient public support for an active prescribed burning program to occur.

The objective of this study is to determine if differences exist in survey response rates, differences in support for prescribed burning, protest refusals to pay versus non-protest refusals to pay responses, and differences in WTP estimates for using video survey administration versus a booklet with phone interview. The phone interview combined with a previously mailed informational booklet has been used in several past WTP surveys (Hanemann and others 1990) and in a past fire survey (Loomis and others 2002). However, the approach is expensive, often in the range of $50-$100 per completed interview. Mailing a videotape that presents a person that talks the respondent through the program has lower variable costs, and may have the potential to convey information in a more visual and entertaining format. This could increase survey response rates and may increase support for prescribed burning. Further, the combination of audio and visual information may result in more attention by the respondent reducing the variance of the estimate of willingness to pay. More precise estimates of willingness to pay are important to reach unambiguous conclusions regarding whether benefits of prescribed burning exceed costs.

Hypotheses Regarding Response Rate and Protest Responses

Our survey modes involve an initial random digit dialing phone call with a short initial interview. We then verify their address to mail a survey booklet and schedule a time for an in-depth (20 minute) interview. The video survey proceeds in a similar fashion except a videotape is mailed and the respondent mails back the answer booklet. Thus, the first basis of comparison is whether households respond equally to the initial phone call and follow through on answering the in depth Contingent Valuation Method (CVM) questionnaire with the two survey administration modes.

Ho: R(Video) = R(Phone-booklet)

This will be tested using separate contingency tables and χ^2 tests for both the first and second interviews.

Responses to the WTP questions elicited during the in-depth interview are the main focus of our analysis. First, phone-booklet and video survey responses are compared on reasons for refusing to pay anything for prescribed burning. Some refusals are valid expressions of zero WTP since they reflect lack of value for the good or low income (i.e., inability to pay). Other respondents that give a zero valuation or refuse to pay because they reject the scenario or rationale that citizens should have to pay for this program, are often termed protest responses (Mitchell and Carson; Halstead, Luloff and Stevens). These respondents often do not "buy into" the premise that they are responsible for paying for the solution, or are unconvinced the solution will actually work, or feel government will not spend the money collected on the specific program. Here as well, survey administration mode may result in systematically different responses.

To determine what might potentially be a protest response the following strategy was used in the voter referendum CVM question sequence. First, if a respondent indicated he or she would vote against the program at their initial bid amount, they were asked whether they would pay $1. If they said they would not pay $1, they were asked an open-ended question "Why did you vote this way?". The interviewer was

instructed to type in exactly what the respondent said. After all interviews were completed, the reasons were analyzed for content to classify answers by similar reasons given by the respondent. This open-ended response approach avoids having respondents fit themselves into pre-set protest categories or having the interviewer place them into pre-set categories.

Comparing the overall protest reasons given, we will test the null hypothesis of no difference between the two survey administration modes in terms of acceptance of the premise and credibility of the CVM survey. The null hypothesis is that the distribution of refusals to pay and protest responses to the CVM survey are independent of survey administration mode:

Ho: ProtestVideo =ProtestPhone-Booklet

This will be tested using a contingency table. The significance test will be performed using a χ^2 statistic.

WTP Model and Related Hypothesis Tests

As suggested by the NOAA panel on contingent valuation, a voter referendum willingness to pay question format was used (Arrow, et al., 1993). Hanemann (1984) and Cameron (1988) both provide motivations for how a respondent may answer a dichotomous choice CVM question. Hanemann views the respondent as evaluating the difference in utility associated with the status quo versus paying some amount ($X) to have the program. If the difference in utility is positive for the program, the individual would respond "Yes". If the difference in utility is distributed logistically, a logit model can be used to estimate the parameters and allow for calculation of WTP.

Comparisons of mean WTP estimates across survey administration mode will be used to establish if differences exist in the benefits of the public program. The null hypothesis tests whether the WTP estimate by survey administration mode are equal:

Ho: WTP(Video) = WTP(Phone-booklet)

The results are determined by whether the confidence intervals overlap or not. We will also use the confidences to compare whether the presentation of the fire and CVM scenario information in the two different modes influences of the variance of WTP. We suspect that the more visual presentation of the fire information and CVM scenario information in the video along with the more entertaining video presentation might reduce the variance as compared to the audio only with the booklet approach.

Survey Design

The survey booklet was developed in conjunction with forestry professionals in California. It described the acreage that is burned by wildfires in an average year as well as the typical number of houses lost to wildfire each year. Next, a program increasing the use of prescribed fire or controlled burning in California was described. Specifically, respondents were told that the prescribed burning fuel reduction program would reduce potential wildfire fuels through periodic controlled burning. It was acknowledged that prescribed burning does create some smoke, although far less than a wildfire. Then the survey booklet provided additional information and drawings contrasting wildfire and prescribed fire. The cost of

financing this program of prescribed burning was described as a cost-share program between the State of California and the county the individual lived in.

The WTP elicitation wording was:

" California is considering using some state revenue as matching funds to help counties finance fire prevention programs. If a majority of residents vote to pay the county share of this program, the Expanded California Prescribed Burning program would be implemented in your county on federal, state, and private forest and rangelands. Funding the Program would require that all users of California's forest and rangelands pay the additional costs of this program. ...If the Program was undertaken it is expected to reduce the number of acres of wildfires from the current average of 362,000 acres each year to about 272,500 acres, for a 25% reduction. The number of houses destroyed by wildfires is expected to be reduced from an average of 30 a year to about 12. Your share of the Expanded California Prescribed Burning program would cost your household $__ a year. If the Expanded Prescribed Burning Program were on the next ballot would you vote __In favor ___Against? "

The basic format of the survey booklet and script had previously been through several focus groups in two different states. The survey was conducted through a phone-mail-phone process. To obtain a representative sample of households, random digit dialing of the households living in a sample of California counties was performed. The counties were selected so there was a mix of counties that frequently experience wildfires, counties that occasionally experience wildfires, and counties that almost never experience wildfires. Once initial contact was established, we elicited initial attitude and knowledge of wild and prescribed fire, followed by the scheduling of appointments with individuals for detailed follow-up interviews. During the interim time period, a color survey booklet was mailed to the household.

The 15-minute video was designed to closely follow the layout of the booklet and question order of the telephone interview. First, a script was created by adhering to the exact wording of the survey booklet and interviewer script used in the first phone interview. The video is simple and includes only a headshot of the narrator, the same two graphics in the booklet, and occasional written text on the screen. In order to focus solely on the survey mode effects, the video does not deviate from the booklet or telephone script in any way. The video, like the booklet, begins by defining important fire management terms like "prescribed fire" and "wildfire." Then, the narrator continues to describe the current problem and suggested solution in detail. Ultimately, respondents were asked questions about whether or not they agree with the proposed solution and whether or not they would be willing to pay a certain dollar amount for the solution to be implemented. The script was edited and revised several times and the video was evaluated by two focus groups in two different states before the videotape was finalized.

The initial contact of potential households for the video was much like the phone-interview process. To obtain a representative sample, random digit dialing of the households was used in the same counties that were used in the telephone survey. At initial contact and after determining that the potential respondent was willing to participate in the survey, the interviewer probed the respondent about his knowledge of forest fire and forest fire management. This allowed not only the comparison of post-video questionnaires to questionnaires of the phone interviews but also provided an opportunity to analyze whether or not any changes occurred in the respondent's fire management knowledge after he watched the video. A videotape, questionnaire,

and postage-paid self-addressed envelope were mailed to those households whose residents had previously verbally agreed to participate in the survey.

Results

Comparison of Survey Response Rates

Because the survey was conducted in two waves, we compare the response rates from the initial random digit dial phone survey and the follow-up in-depth interviews separately in Table 1. We obtained 51.6% in the pre-video mailing contact and 41.3% with the pre-mail booklet contact, a response rate not statistically different at the 5% level using a chi-square test (calculated χ^2 of 2.4 versus critical of 3.84 with one degree of freedom). However, response rates to the follow-up were higher for the mail booklet at nearly 73% as compared to the 53.2% for the video. The direction of the difference is surprising as one would have expected the more novel video survey would have yielded a higher response rate for the video, although the difference is not statistically significant at the 5% level (calculated χ^2 is 2.41). Perhaps, having the phone interviewer calling back and recording responses, with nothing for the respondent to have to initiate or mail back is an advantage to the phone-survey booklet approach over the video. The video mail back rate is similar to most other CVM mail back survey response rates.

Table 1 Response Rates and Chi-Square Tests

	Video	**Phone**	**Total**
First Wave-Screener			
Total Initial Sample Contacted	178	794	1,283
Completed Initial	92	328	420
1st Wave Response Rate	**51.6%**	**41.3%**	
Chi-Square			**2.40**
Second Wave-In-Depth Interview	**Video**	**Phone**	**Total**
Refusal	86	4	90
Phone disc, moved, not avail	100	16	116
Not called by end	211	51	262
Net Sample for 2nd	**92**	**257**	**435**
Completed	49	187	236
2nd Wave Response Rate	**53.2%**	**72.8%**	
Chi-Square			**2.41**

Comparison of Support for Prescribed Burning

The phone-mail booklet-phone interview resulted in support for prescribed burning increasing from 65% in the initial phone call to 91% in the follow-up interview after the booklet had been read and interviewer read the script. Preliminary results from the video survey indicate that 71% initially supported prescribed burning, with this increasing to 84% after viewing the video.

Reasons Why Households Would Not Pay for the Program

Table 2 presents the analysis of refusals to pay, i.e., individuals that indicated they were in favor of the prescribed burning program at no cost, but then would neither pay their initial bid amount nor pay $1 in the follow-up willingness to pay question. These individuals appear to favor the program but essentially have a zero WTP. Table 2 lists the reasons why a person would not pay the $1. The first four reasons listed in Table 2 are not considered protest responses because having no value for the program or receiving no benefits from the program, as well as not being able to afford to pay, are valid reasons for zero WTP. However, the other three categories of responses (italicized in Table 2) are considered protests because they were frequently prefaced with, "I am in favor of program" or "I'm all for it, but I think the program should be paid for by those living in the forests or with existing taxes."

Because of the frequency of zero cell entries for specific protest responses, only an overall chi-square of protest refusals to pay versus non-protest refusals to pay can be computed. The calculated chi-square of .289 indicates no statistically significant difference in the pattern of protest and non-protest reasons for refusing to pay for video and phone surveys.

Table 2 Why Respondents Would Not Pay $1

Reason	Video	Phone	Total
Non-Protest Refusals to Pay			
No Value/No Benefits	0	1	1
Cannot Afford	5	3	8
Taxes Already too High	3	2	5
Other	3	0	3
Sub Total	11	6	17
Protest Responses			
Should be Paid for with Existing Taxes	*2*	*4*	*6*
Those that Live in Forest Should Pay	*2*	*0*	*2*
Other	*2*	*1*	*3*
Sub Total Protest Refusals	*6*	*5*	*11*
Total	17	11	28

*Italicized considered protest responses for purposes of the chi-square analysis

Results of Logit Regressions

Due to the small sample size for the video survey (n=42), we conserved degrees of freedom and only estimated a simple logit model with the bid amount as the sole explanatory variable. This will not affect the calculation of WTP between the two models, since the non-bid variable coefficients are multiplied by their respective means prior to calculating WTP. This can be seen in the formula for calculating mean WTP:

Mean WTP = (ln(1+expBo))/B1

Where Bo is either the constant term (as in the videotape survey logit model) or the other non bid variable multiplied by their mean and added to the constant term. In either case, this is subsumed into the Bo term, for purposes of calculating mean WTP.

As can be seen in Table 3, the bid slope coefficients are statistically different from zero at conventional levels (0.01) for both types of survey administration.

Table 3 Logit Regressions Used to Calculate WTP

	Phone			Video Survey		
Variable	Coef.	T-stats	Prob.	Coef.	T-Stats	Prob.
Constant	1.9659	1.585	0.112	1.8547	3.211	.0013
Bid	-0.0055	-3.667	0.000	-.00485	-2.031	.0423
RX Health Problem	-0.7147	-0.813	0.416			
Income	.000006	1.354	0.175			
Gender	-0.844	-1.899	0.057			
Age	.00889	.6249	0.532			
# in Household	-.05845	-.3460	0.729			
Education	-.02990	-.3526	0.724			
Mean Dependent	0.7482			0.738		
Log likelihood	-70.91			-21.98		
Restr. Log likelihood	-80.68			-24.15		
LR statistic	19.55			4.34		
Probability (LR stat)	0.006			.037		
McFadden R^2	0.1211			.0898		
Sample Size	143			42		

Comparison of Mean WTP

Mean WTP in reported in Table 4, is computed using the coefficients in Table 3. The confidence intervals were calculated using the approach of Park et al. (1991) that involves an adaptation of the Krinsky-Robb method to dichotomous choice CVM. Since the 90% confidence interval of overlap there is no statistical difference between the mean WTP of $400 per year using the phone-booklet approach and $412 per year using the videotape. Note the confidence intervals do not suggest much difference in precision in WTP, although this comparison is hampered by the sample size for the video survey being one-third that of the phone-booklet approach. It appears that with larger sample sizes for the video, its variance might fall to below that of the phone-booklet survey.

Table 4 Mean WTP and 90% Confidence Intervals for Prescribed Burning Program in California

	Mean	90% Confidence Interval
Phone-booklet	$399	$312-$608
Video	$412	$272-$1229

Conclusions

Using a univariate test (chi-square), we did not find a statistical difference in survey response rates between the two survey administration modes for both the initial random digit dialed interviews and the scheduled follow-up CVM phone interviews. Reasons for not being willing to pay for the prescribed burning program were similar as well for the survey administered via videotape and via phone-booklet approaches. There was also no statistical difference in mean WTP between the two approaches, with both annual WTP estimates being nearly identical ($400 for the phone-booklet approach and $412 for the video survey approach).

Thus the results of this comparison were not what might be expected. The good news is that the innovative survey administration mode via videotape yielded results comparable to the more conventional mixed mode phone-booklet approach. However, we had hoped that the novelty of the videotape would increase the response rate in the follow-up phase. This did not happen, perhaps because the video survey format still relies upon respondent initiative as compared to being called back by an interviewer and led through the booklet. We had hoped that respondents would have paid more attention to the video survey presentation of the information than perhaps they would have with the phone interview with the booklet. This would have translated into a reduced variance on mean WTP, and perhaps a higher mean WTP. There is no statistical difference in mean WTP. The comparison of the variance in WTP is confounded by the much smaller sample size in the video survey (n=42) which tends to increase the variance, relative to the large sample size 143 in the phone-booklet survey. Nonetheless, the equivalency of results between the two methods is encouraging. The video survey costs more for the initial production, but is less expensive than the follow-up phone interviews. The videotape technology also offers the potential to present actual fire footage and more dynamic images, something we did not undertake in this study to maintain consistency with the booklet. However, the phone-booklet approach offers a live interviewer, which may result in a more engaged respondent even if the interaction is only audio. Further

research sorting out the advantages and disadvantages of these two methods versus mail and in-person interviews is clearly warranted.

Acknowledgement

Funding for this study was provided by the Joint Fire Sciences Program. The analysis of this data was supported by the W1133 Regional Research project of the Colorado Agricultural Experiment Station.

References

Arrow, K., R. Solow, P. Portney, E. Leamer, R. Radner and H. Schuman. Report of the NOAA Panel on Contingent Valuation. U.S. Department of Commerce, Federal Register

Cameron, T. "A New Paradigm for Valuing Non-Market Goods Using Referendum Data." Journal of Environmental Economics and Management 15(4), 1988, 355-79

Halstead, J., Luloff, A., and Stevens, T. "Protest Bidders in Contingent Valuation." Northeastern Journal of Agricultural and Resource Economics 21, 1992, 160-169.

Hanemann, M. Welfare Evaluations in Contingent Valuation Experiments with Discrete Responses." American Journal of Agricultural Economics 67(3), 1984, 332-341

Hanemann, M., J. Loomis and B. Kanninen. Statistical Efficiency of Double-Bounded Dichotomous Choice Contingent Valuation. American Journal of Agricultural Economics 73(1): 1225-1263. 1991.

Loomis, John, Lucas Bair and Armando Gonzalez-Caban. Language Related Differences in a Contingent Valuation Study: English Versus Spanish. American Journal of Agricultural Economics. 84(4), 2002, 1091-1102.

Mitchell, R., and Carson, R. Using Surveys to Value Public Goods: The Contingent Valuation Method. Ed. Washington D.C.: Resources for the Future. 1989.

Park, T., Loomis, J., and Creel, M. Confidence Intervals for Evaluating Benefit Estimates from Dichotomous Choice Contingent Valuation Studies." Land Economics 67(1), 1991,64-73.

Page left blank intentionally.

Forest Fire Spreading[1]

Joseph Romanovsky,[2] Vassili Shikin,[3] Yuri Shur[4]

Abstract

Forest fire problem is very present-day problem for Russia. Forest fires become disasters in 2 or 3 regions of Russia every year, especially in regions of Siberia and Far East. Due to that, the problem of effective management of forest fire control system in Russia is one of the most important problems of conservancy. The model that is suggested helps to estimate the shape of ground fire, taking in consideration type of soil cover, current fire danger class, wind speed and direction and unburnable objects on the map. The result of the research work is a program that models forest fire spreading. The program is made on Delphi 6.0.

Introduction

Forest fire spreading modeling will help to solve several important problems for forest fire management.

The first is to develop the optimal plan of suppression forest fire in real time. The optimal plan of suppression forest fire assumes finding the most effective tactics of its suppression.

The second important problem, based on forest fire spreading modeling is estimation of the activity of fire departments after the end of fire season. It is important to determine the potential area of a forest fire that might have been occupied by the fire without suppression.

Approaches to forest fire spreading modeling

There are several approaches to forest fire spreading modeling.

The first is based on modeling physical and chemical processes of burning and composing analytical models and systems of differential equations. An example of such model is suggested by A. M. Girshim. This model describes 3D processes of temperature exchange. It implies systems of differential equations. Another example is approach, suggested by U. A. Gostinzev and A. A. Suchanov. These models describe processes of temperature exchange, chemical changes and the movement of gas streams. These models require a number of parameters of forest information that

---

[1] An abbreviated version of this paper was presented at the second international symposium on fire economics, policy, and planning: a global view, 19–22 April, 2004, Córdoba, Spain.

[2] Professor, St.-Petersburg State University, Mathematical department, St.-Petersburg State University, University embankment 7/9 St.-Petersburg 199034

[3] Bachelor, St.-Petersburg State University, Gagarin st. 21 flat 284, St.-Petersburg 196135.

[4] Head of fire management group, doctor of economics, St.-Petersburg Forestry Research Institute, Institute pr. 21, St.-Petersburg 194021.

change rapidly and interact with each other. That makes practical application of these methods quite difficult.

The second approach implies rough estimates on the shape of the fire.

The third approach is based on simulation of the forest fire without making rough estimates on the shape of the fire.

The approach given in this report belongs to the third group. Map is divided into horizontal stripes of equal width. In each stripe zones with similar burning properties are picked out. This data representation helps to improve the speed of working with the map. During the modeling wind speed, wind direction, type of soil cover and current fire danger class are taken into consideration. What is more, special attention is paid on the unburnable objects.

Program Overview

The main task of forest fire modeling is to determine the location of fire border at each point of time. Due to the difficulty modeling, the program concerns only ground fires. When modeling on a large territory, the program considers both the type of soil cover and weather conditions, and there changes during modeling.

After the launch of the program the main window appears (fig. 1).

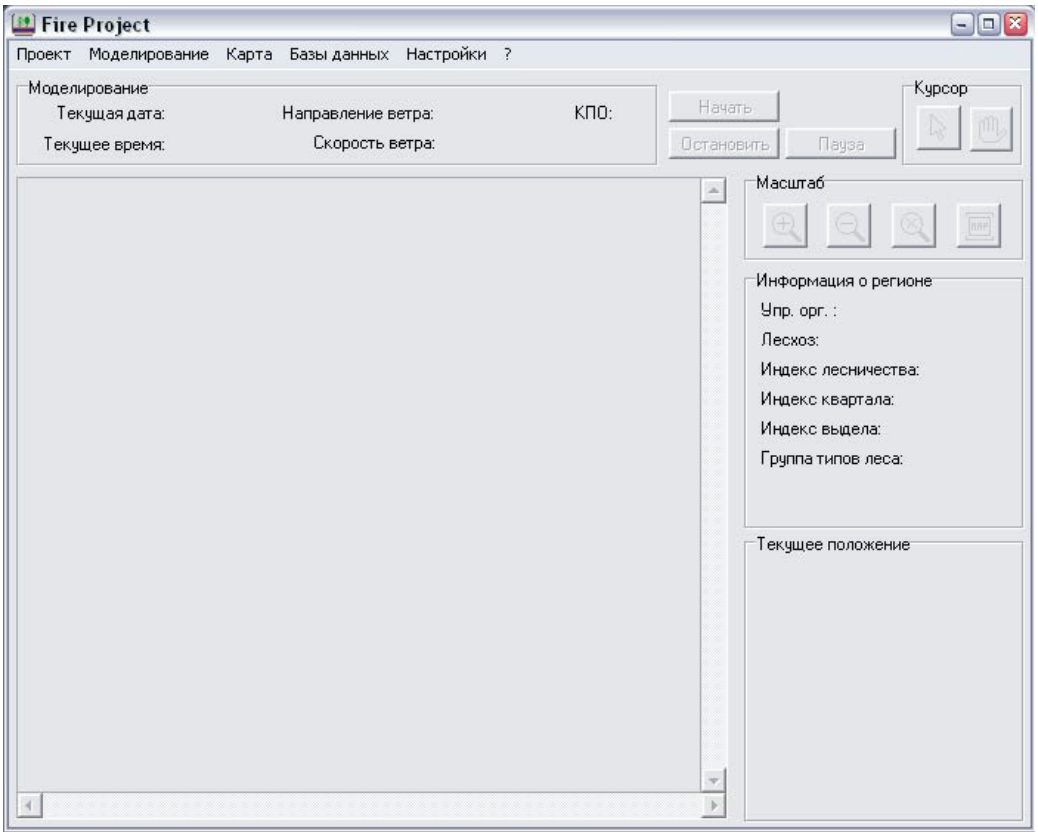


Figure 1—Program main window

In order to create a new project one should choose "Project → Create". Then follow the instructions of the new project wizard. On the first page (fig. 2) data source is chosen: one can either work with database of forestry information or use his own files.

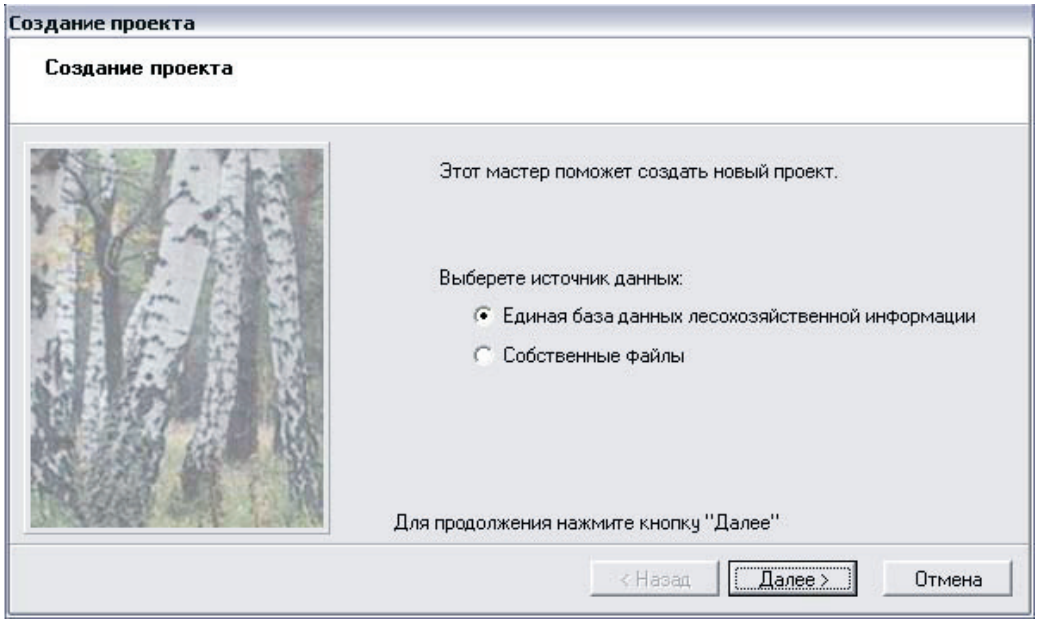


Figure 2—Data source

If the first source is chosen next pages (fig. 3-9) help to choose regions for modeling.

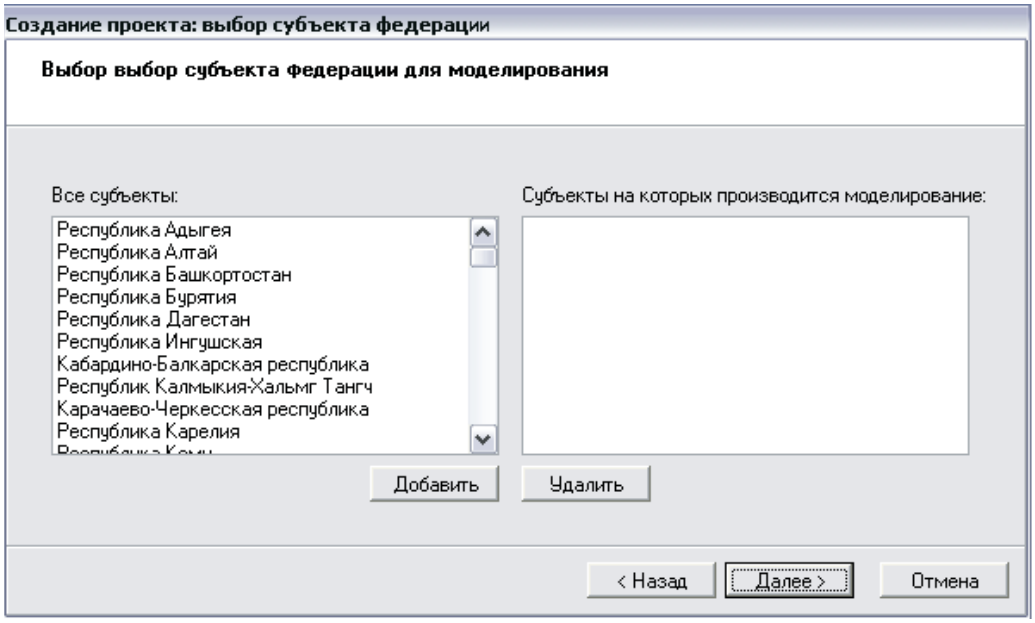


Figure 3—Wizard page 1

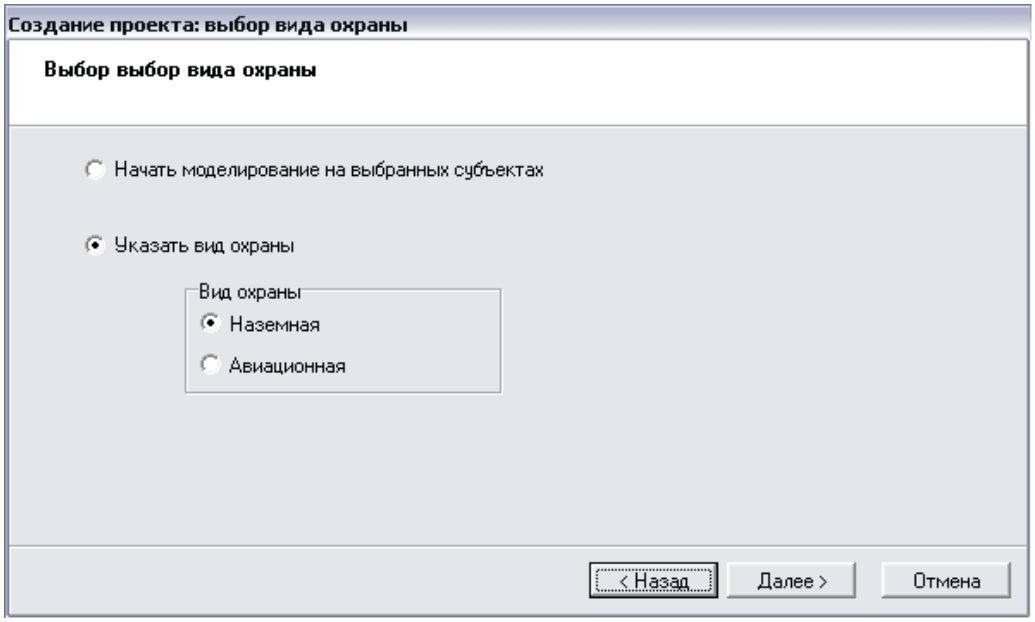


Figure 4—Wizard page 2

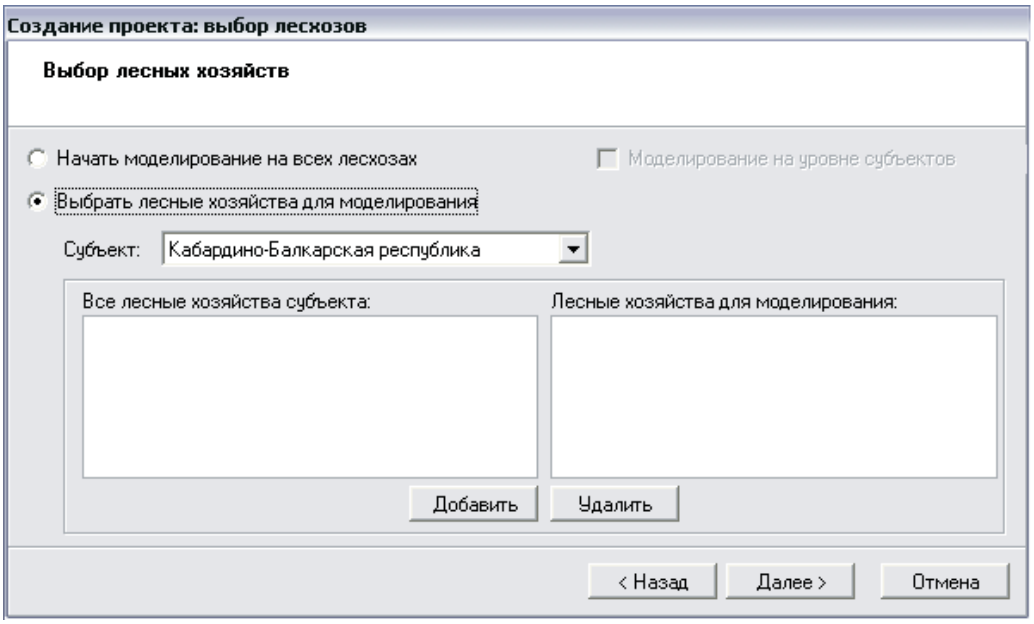


Figure 5—Wizard page 3

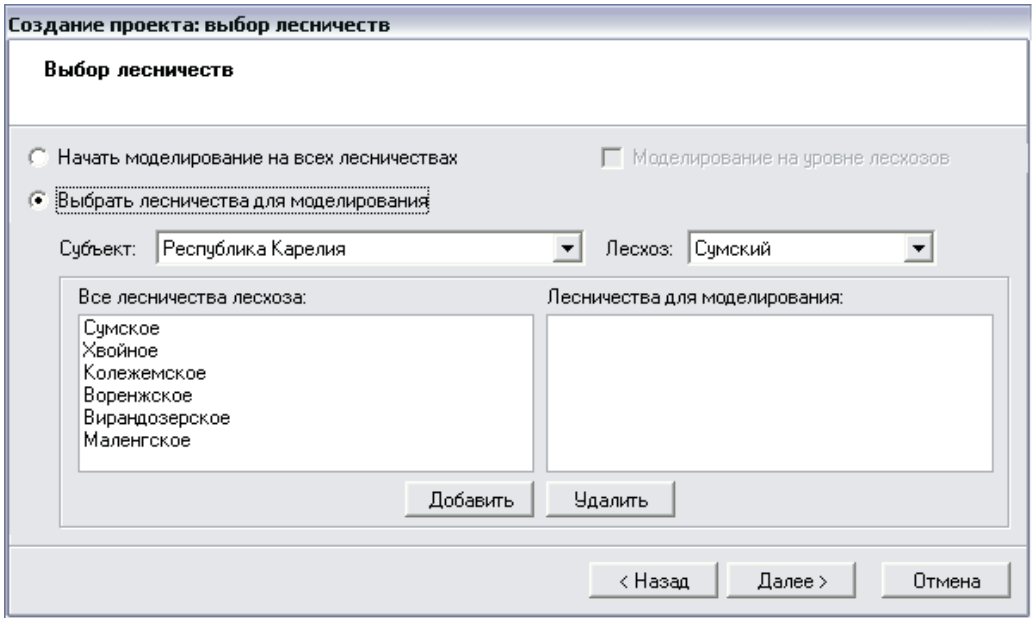


Figure 6—Wizard page 4

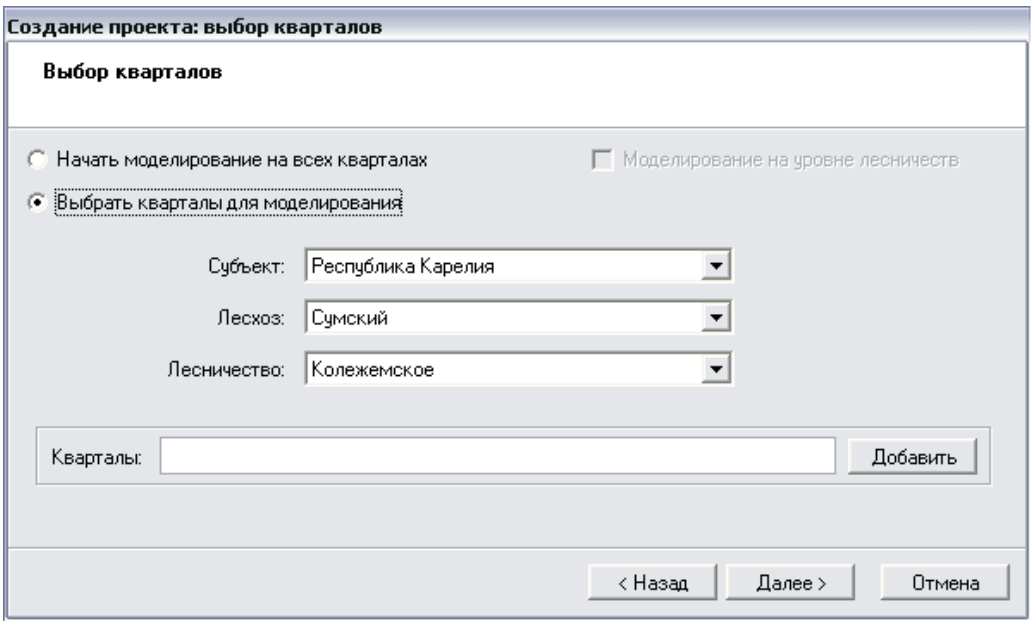


Figure 7—Wizard page 5

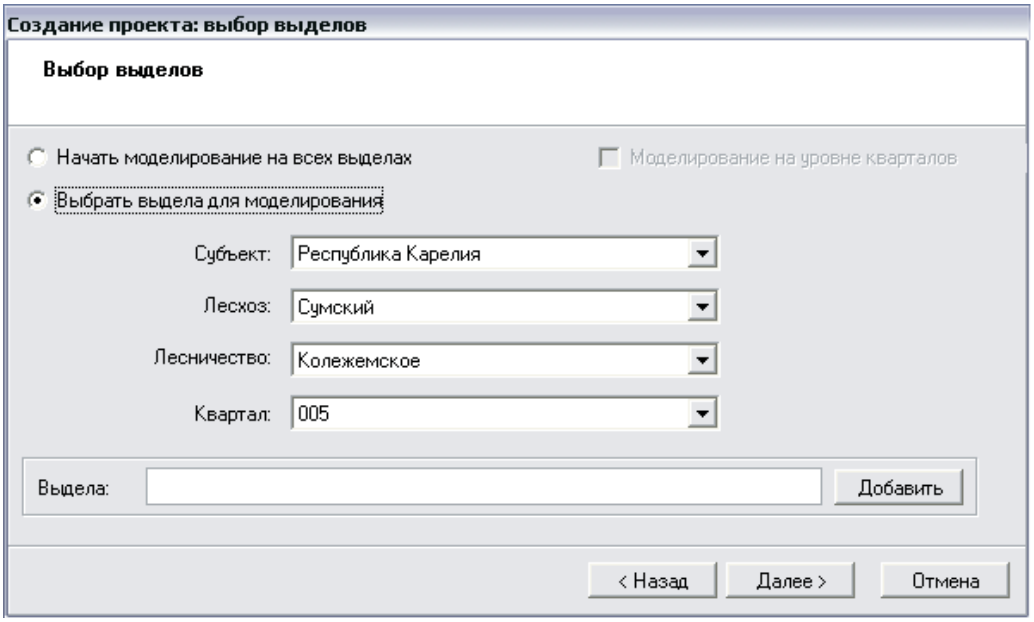


Figure 8—Wizard page 6

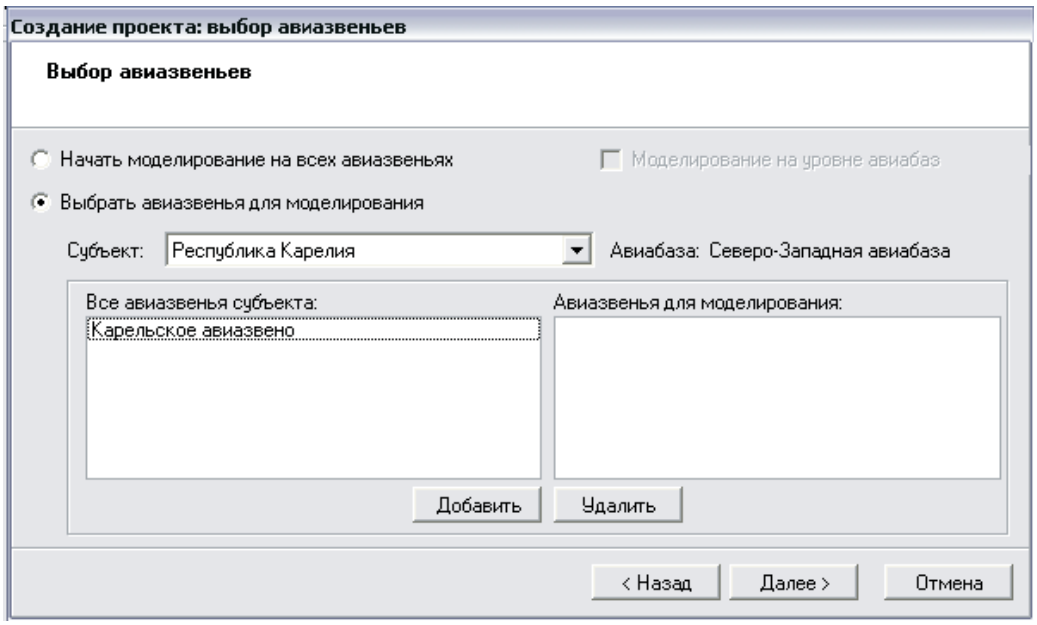


Figure 9—Wizard page 7

If the second source is chosen, program requires files with the map layers of the region for modeling and databases with land and weather information (fig. 10, 11).

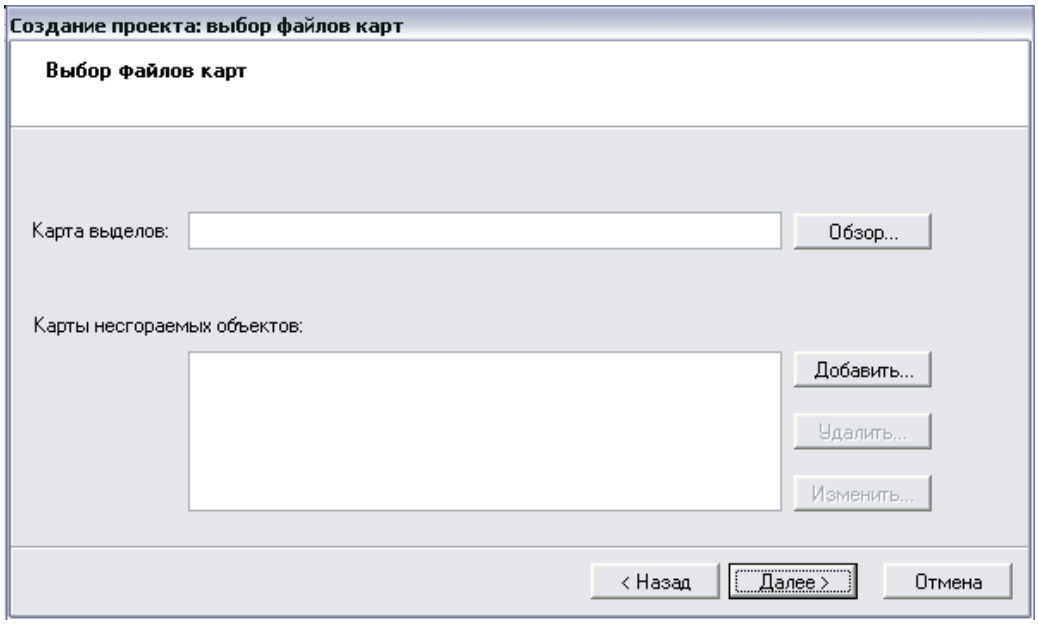


Figure 10—Maps layers

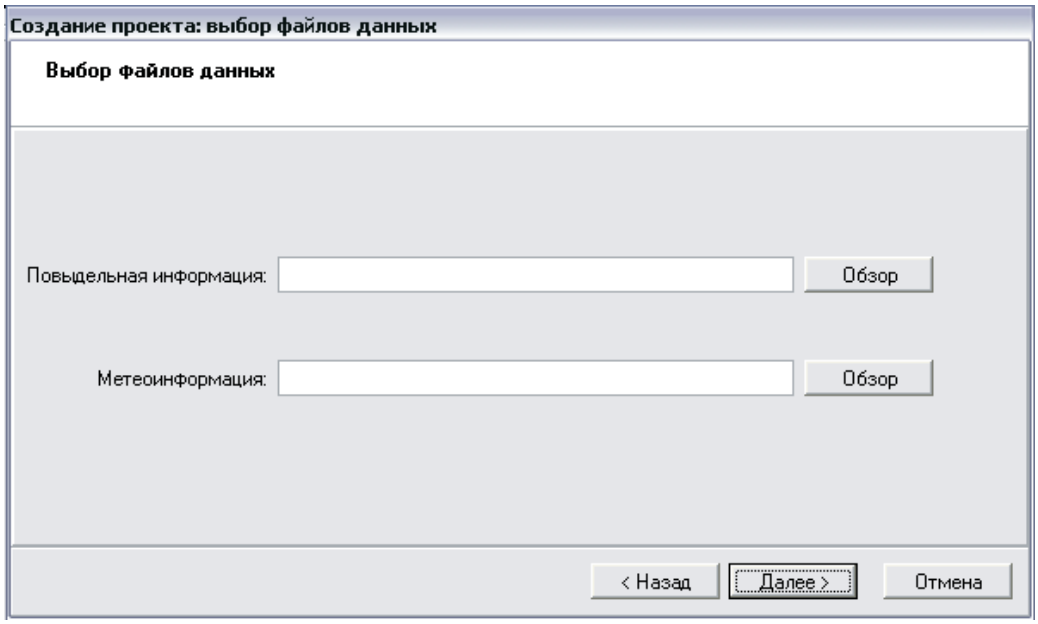


Figure 11—Land and weather databases

After processing input data the program is ready for modeling.

To begin modeling one should press button "Begin" (fig. 1). In the appeared window (fig.12) date and time of the beginning and the end of modeling, source of weather information should be chosen.

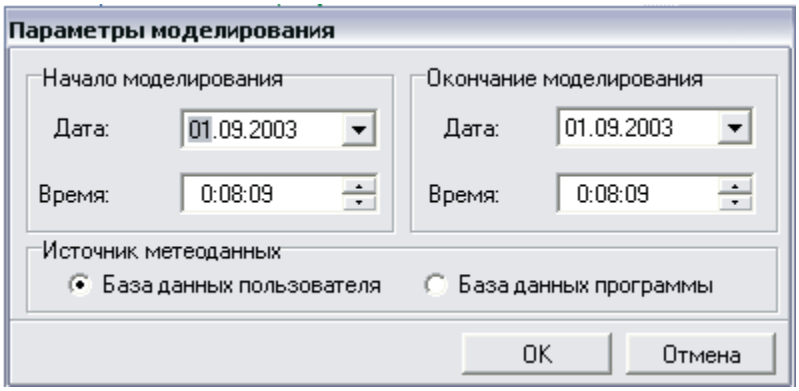


Figure 12—Begin modeling window

In order to enter new weather information during the modeling "Modeling → Weather Info" is used. Here (fig. 13) one may enter current wind speed, wind direction and fire danger class.

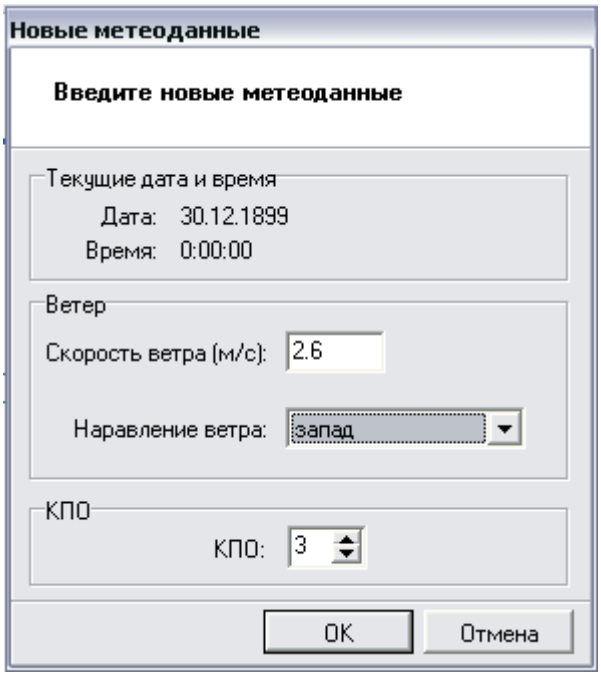


Figure 13—New weather information

Using buttons in "Zoom" group one may zoom in, zoom out, view whole map and get back to initial zoom (fig. 14,15).

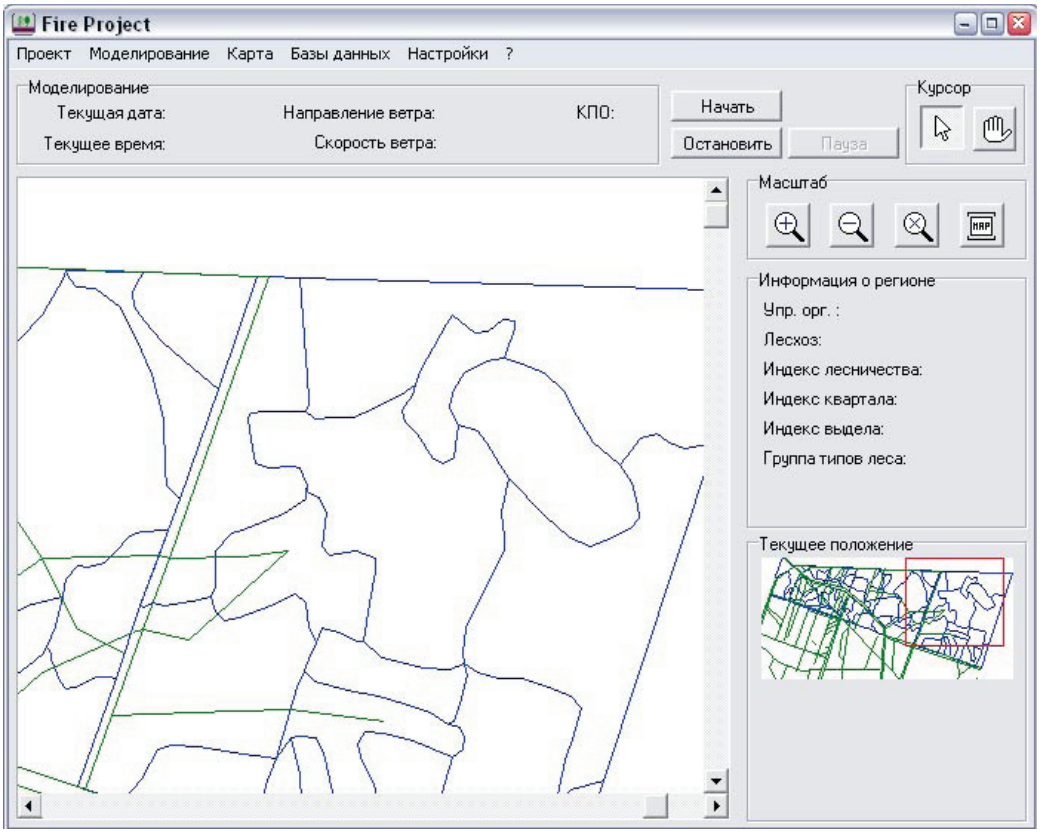


Figure 14—Zooming out

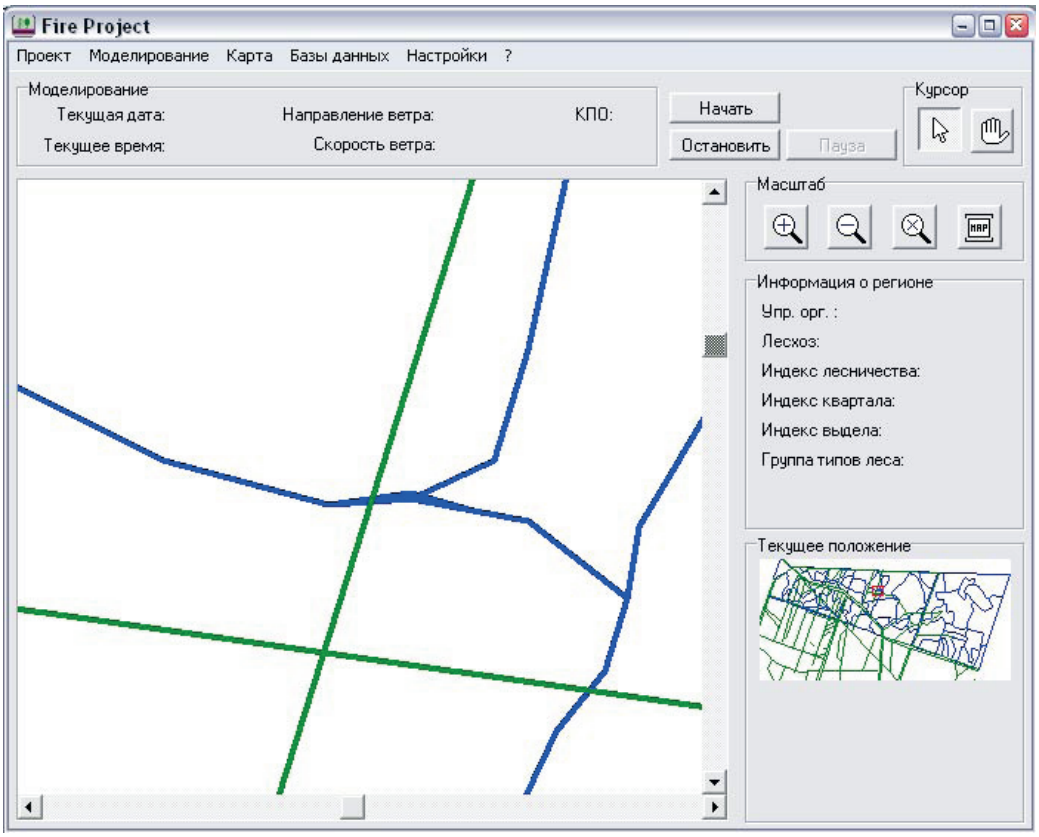


Figure 15—Zooming in

Items that could be found in the main menu in "Databases → …" (fig. 16) are help to view and edit databases, used by the program.

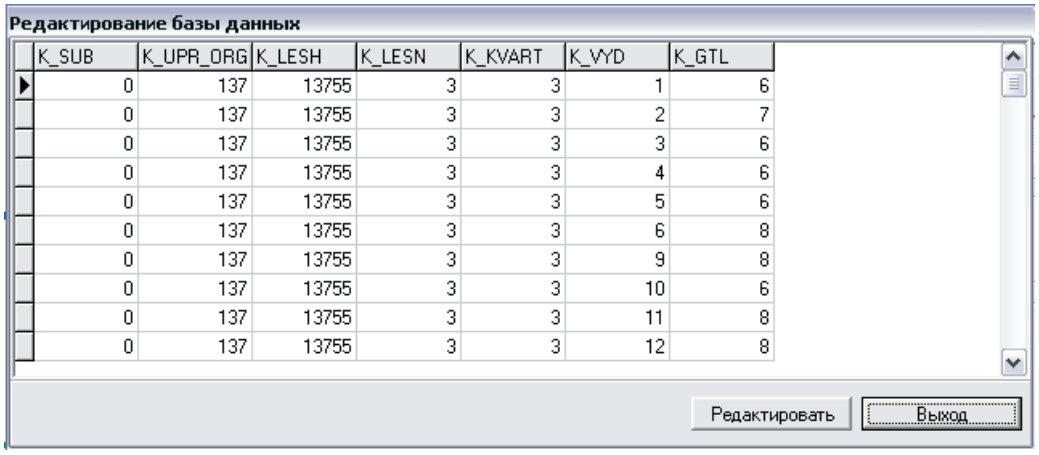


Figure 16—Viewing and editing databases

Main menu items in "Settings → Paths" open the window (fig. 17), where basic databases, used by the program are to be entered.

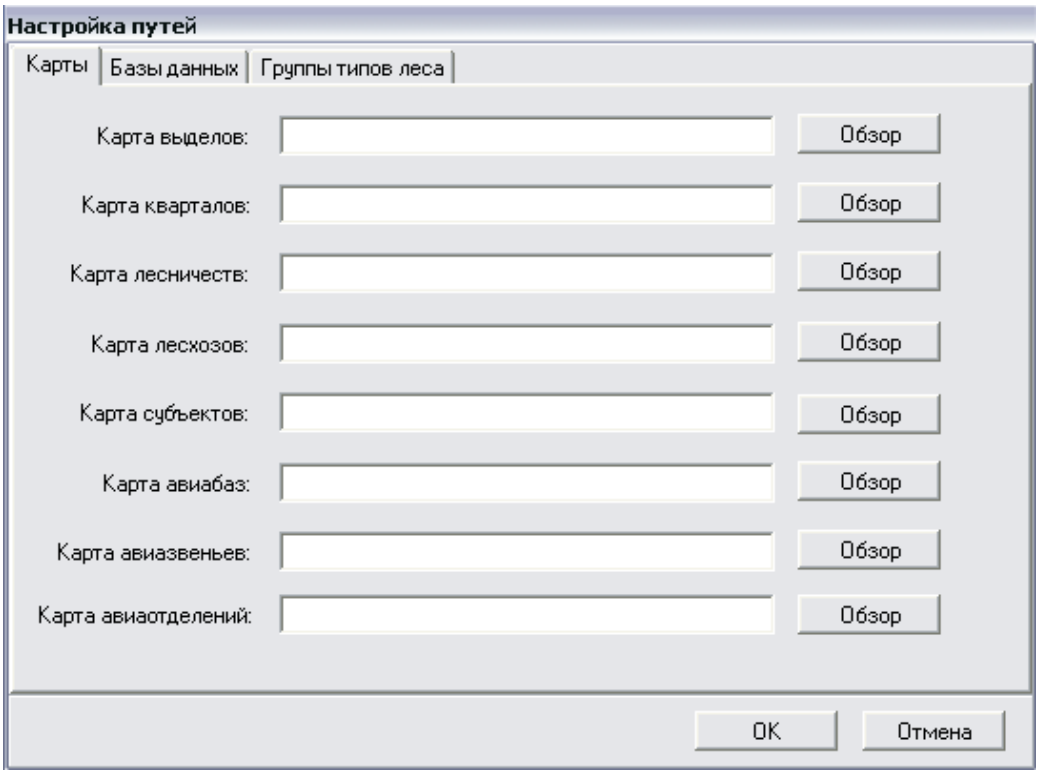


Figure 17—Editing paths

Main menu items in "Modeling → Statistics" open the window (fig. 18) with total square of the map, square of the region on fire and fire perimeter.

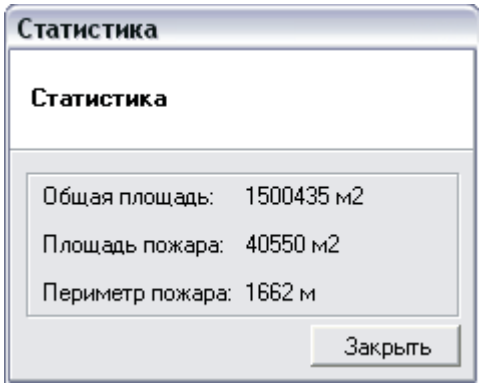


Figure 17—Statistics

When modeling the region on fire is marked with red lines, right side of the main window contains information about selected region, such as type of soil

cover and name. In the top part of the main window current date, time, wind speed, wind direction and current fire danger class are displayed (fig. 19).

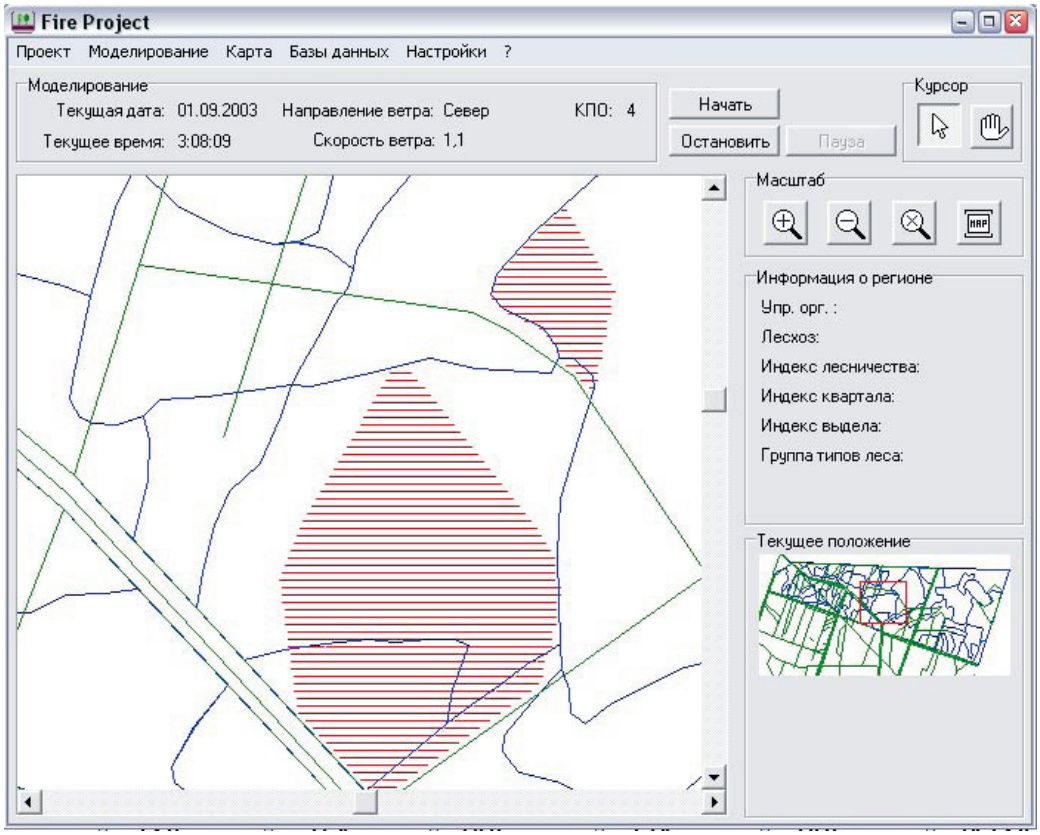


Figure 19—Modeling

Result

Developed algorithm and the program may be useful in forest services and the management of its activities. It may also be used for teaching the staff of forest services.

References

Korovin G. N. Methods of evaluation of some parameters of ground forest fires, LenNIILX, 1969

Gostinciv U. A., Suchanob L. A. Aerodynamics of the environment in big fires. Linear fire, 1997

Optimal Maneuvering of Forest Fire Protection Resources[1]

Joseph Romanovsky,[2] Vladimir Sapronov,[3] Yuri Shur[4]

Abstract

Resources that are used in forest fire fights may vary. They imply different types of machinery, chemical means of fire fighting, explosives, and some others.

We may distinguish two types of maneuvering: maneuvering, induced before the start of fire season, for example, aircraft transfer to their base location; maneuvering, induced in real time during the fire season.

The forest fire resources decision-maker should have optimal plan of transfer of resources from the places of their availability to the places, where they are needed. What is more, this transfer should be fulfilled according to some criterion, for example, transfer expenses. We should remark that the means of transferring resources from the places of their availability to the places, where they are needed vary a lot. This might be airplanes, helicopters, cars, etc. The difficulty of solving the problem of optimal maneuvering also depends on variety of packages, used for resources transfer. For example, chemical substances may be delivered in bags that weigh 25, 50 and 100 kilograms.

One of the ways of solving the problem of optimal maneuvering of forest fire resources is mixed integer linear programming that implies some modification of simplex-method of linear programming.

In order to solve this program a complex of programs was developed. It provides the user with convenient form of getting information about the availability and needs of resources. Current information, organized in different data bases. Information about the means of transfer and transfer expenses is used to determine the optimal plan for solving the transport problem. The complex is made with the help of Delphi 6.0.

Functionality of the program

The program should process data base of efficient information about forest fires that is formed by regional forestry geographical informational systems for air and land fire prevention services.

In this case fire fighting supposes both preventing maneuvering of the available resources before fire season and detection and extinguishing fires during the fire season.

---

[1] An abbreviated version of this paper was presented at the second international symposium on fire economics, policy, and planning: a global view, 19–22 April, 2004, Córdoba, Spain.

[2] Professor, St.-Petersburg State University, Mathematical Department, St.-Petersburg State University, University Embankment 7/9 St.-Petersburg 199034.

[3] Bachelor, St.-Petersburg State University, Chudnovskogo Str., 9 Flat 1, St.-Petersburg 193231.

[4] Head of Fire Management Group, Doctor of Economics, St.-Petersburg Forestry Research Institute, Institute pr. 21, St.-Petersburg 194021.

Resources imply all that is necessary for detection and extinguishing forest fires: technical units, chemical substances, explosives, etc.

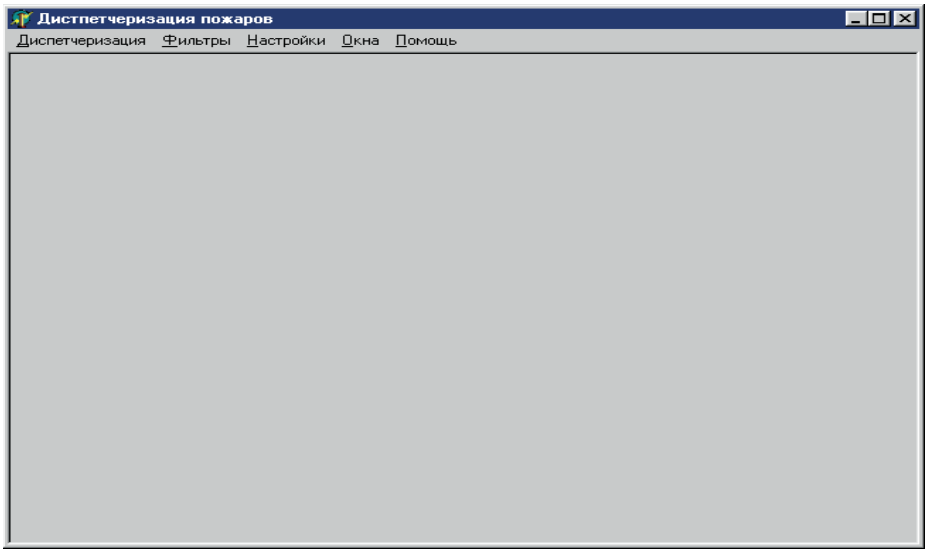
Identifier characteristics of objects, that may require resources and objects that have free resources (like geographical coordinates of forest fires and air bases) are stored in forms, tables and files. What is more, they contain information about availability of free resources that are out of the zone of forest fires. It includes geographical names, coordinates and expenses on transpiration of particular resource. After this work is finished there is full information for solving the problem of optimal maneuvering with the abilities of forest fire services at the dispatcher base.

t is taken in consideration, that now there are no one dispatcher bases that monitor both air fire protection and land fire protection in the regions. There is also no department, other then MPR of Russian Federation, that are engaged forest fire fighting. The program can be used for separate work with air and land fire protection.

Description of the work of the program

At first the main window appears. It contains main menu with following items:

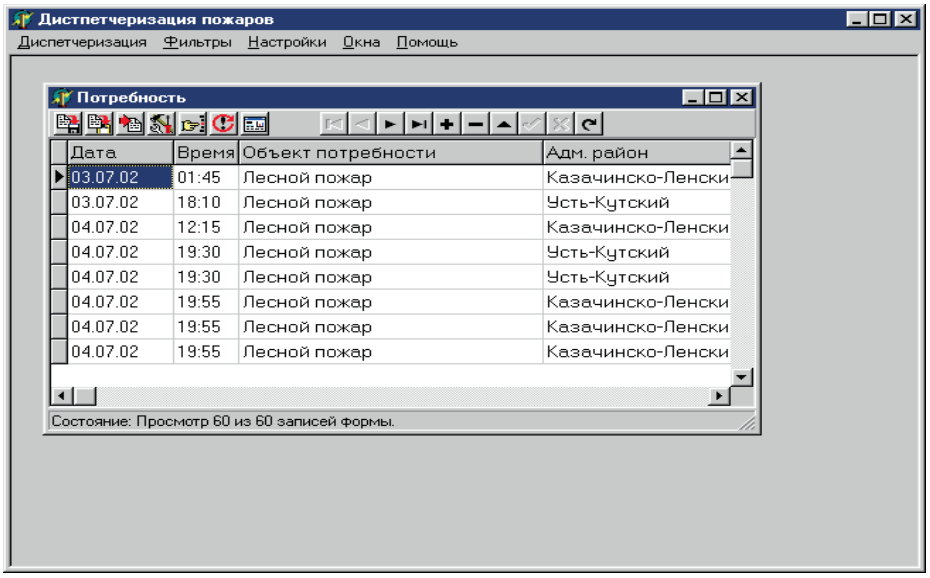
- dispatching
- filters
- settings
- windows
- help



After choosing dispatching one can see a menu, that contains following items:

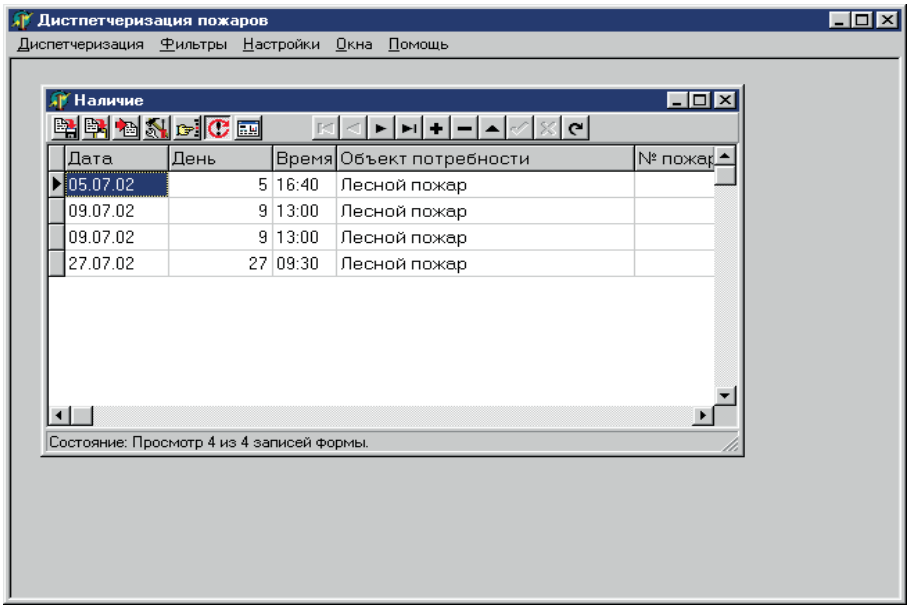
- need
- availability
- expenses

After choosing 'need' one can see window like that:



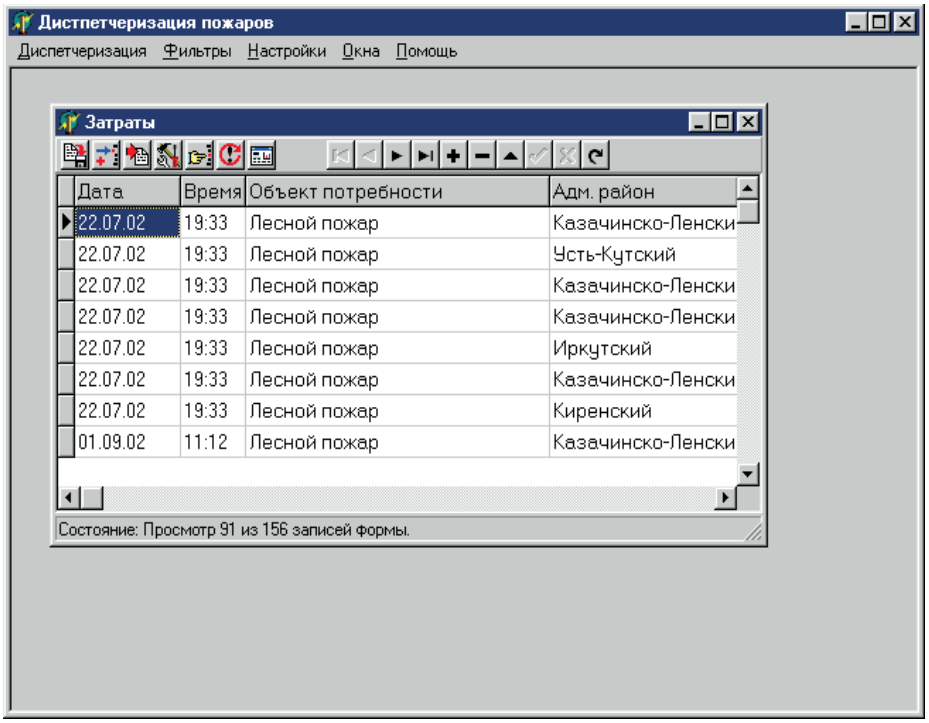
Tables and forms are either shown automatically or are entered manually. These forms contain information about needs of resources at current moment.

After choosing ' availability ' one can see window like that:



These windows contain information about the availability of resources. They could also be entered manually.

After choosing 'expenses ' one can see window like that:



There one may manually enter data about expenses on the delivery of different resources form the places of availability to the places of need.

After choosing 'filters' in the main menu one will see following items:

- filter management
- need
- availability
- expenses

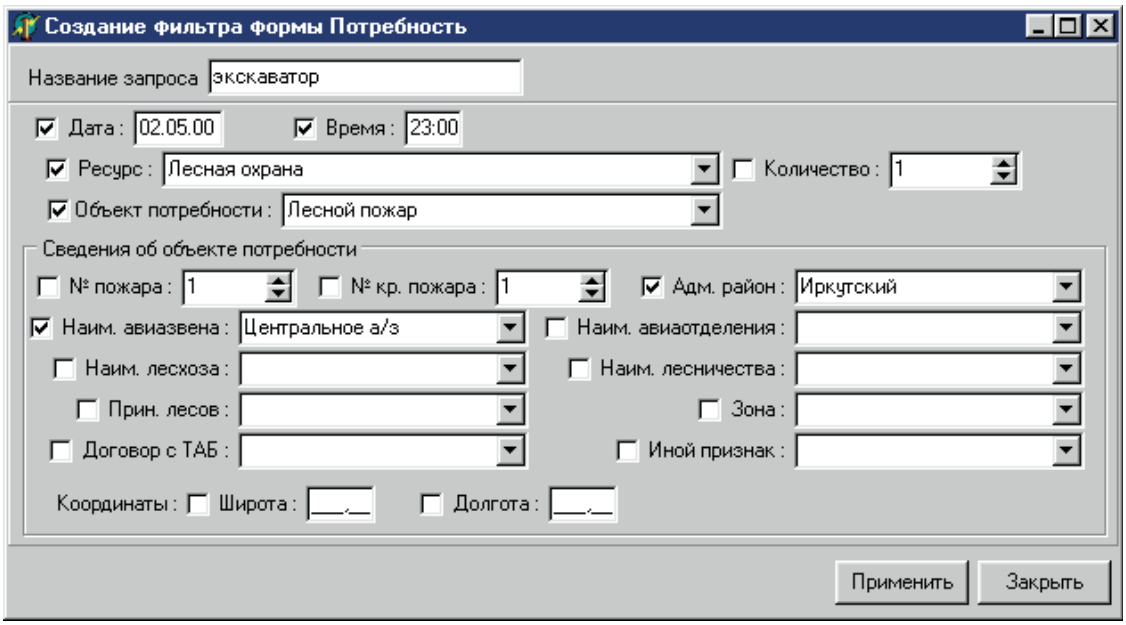
After choosing 'need' a user get the opportunity to create an inquiry on need of particular type of resource. In order to create an inquiry a user should do following actions.

Choosing an inquiry from existing.

In this case a user should mark necessary inquiry. In the field 'inquiry' he can view an inquiry. After making sure that the content of an inquiry fulfills the requirements, a user check a checkbox to the left of the name of the inquiry and clicks 'apply' button/ The result of the inquiry may be seen after choosing 'Dispatching->Need' menu item.

Changing the content of an inquiry.

In this case a user, after choosing one of the existing inquiries may activate 'Change' button. Then a window will appear.



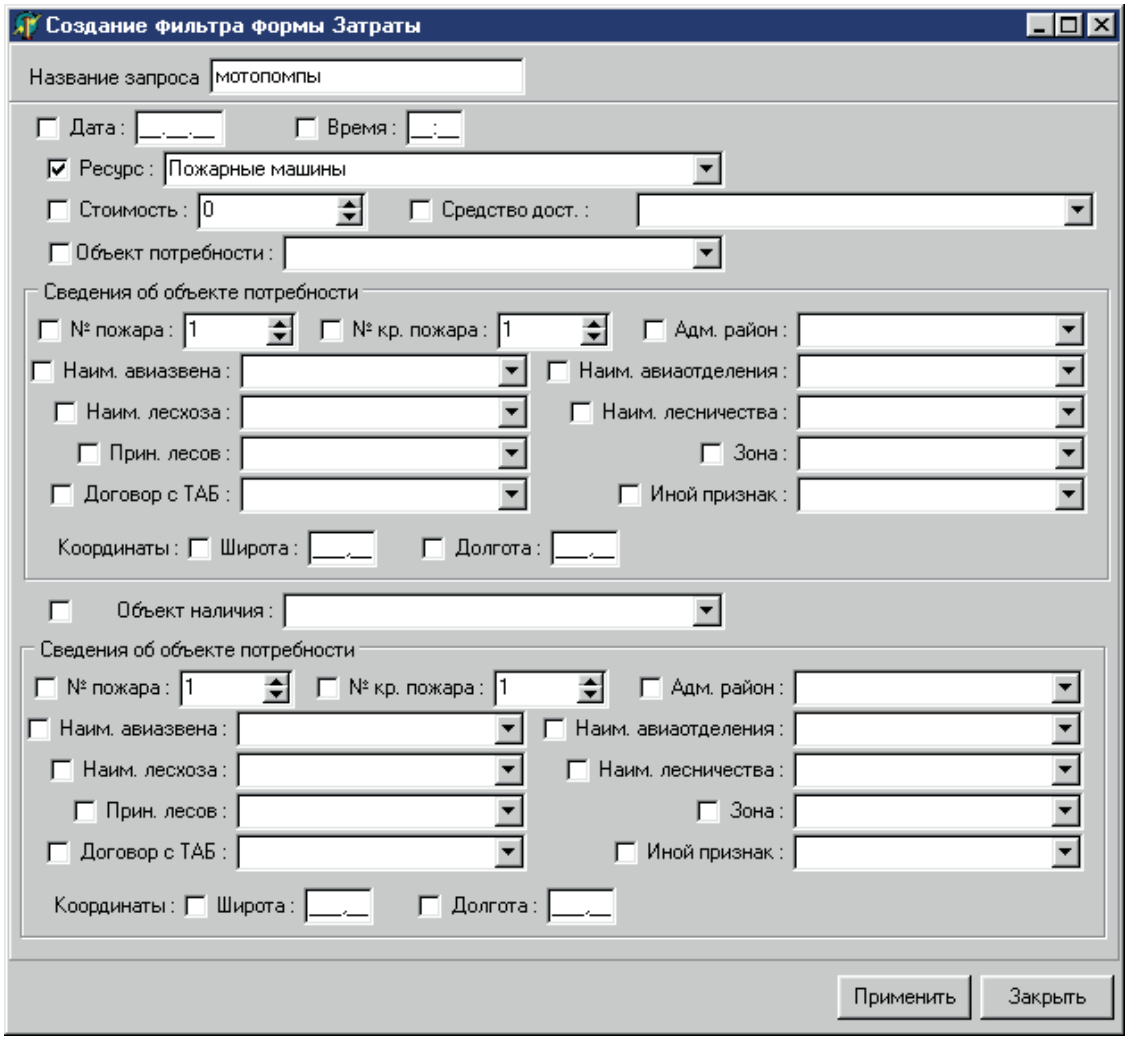
In it the content of the fields may be changed. The change is accepted if a checkbox to the left of the field is checked. After then one should push 'Accept' button. The changed inquiry a user may see in a previous window. The next actions look much like the previous point.

Adding a new inquiry.

A user should open 'Filter management' window. After activation 'Add' button a user gets to the window 'New Filter' of 'Need' form. In this window all the fields are empty and the user may for inquiry to add. Next actions are like in the previous point.

Adding to all above, a user may delete one or several inquiries by clicking 'Delete' button.

Same may be done by the user for filtering the table form 'Availability' and 'Expenses'. Window 'Create' of the filter form 'Expenses' looks like:



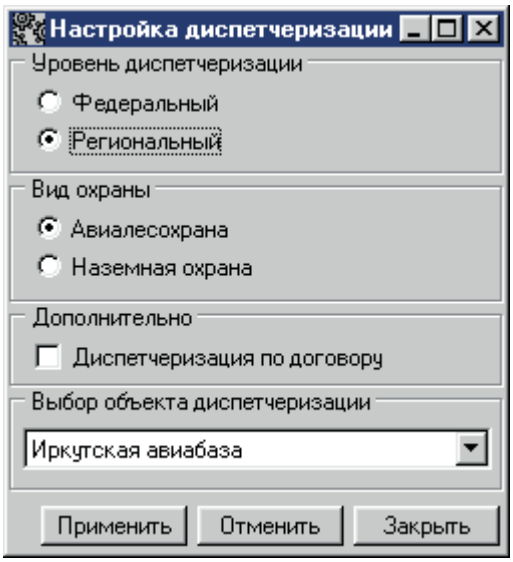
Submenus 'Need', 'Availability' and 'Expenses' of 'Filter' menu are needed to form only one inquiry to 'Need', 'Availability' and 'Expenses' tables. Forming an inquiry is done through menu item 'Set'. If 'Clear' menu item is selected, all filters, connected to this forms and tables, are cleared.

The language of inquires can be also implemented when forms and windows of 'Dispatching' menu item are open.

When selecting 'Settings' menu one has following options:

- 'Dispatching'
- 'Paths'
- 'Forms'

After activating 'Dispatching' menu item a user may see following window:

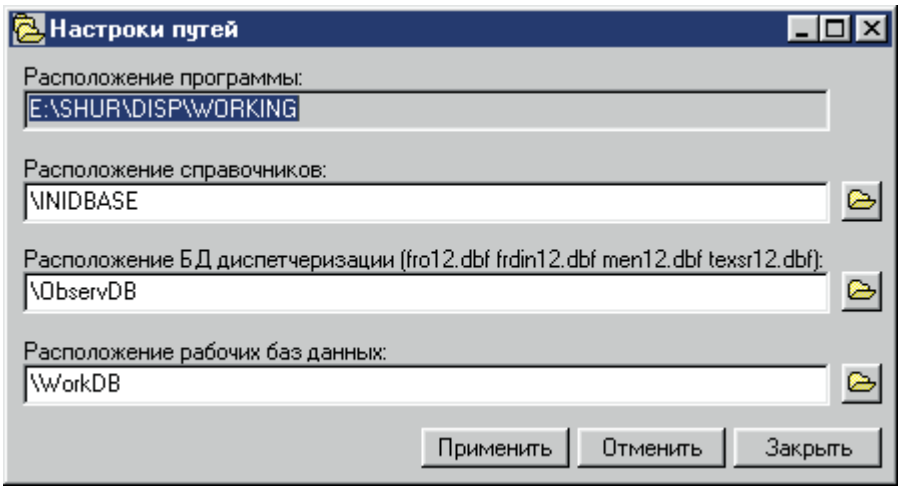


Here one may choose:

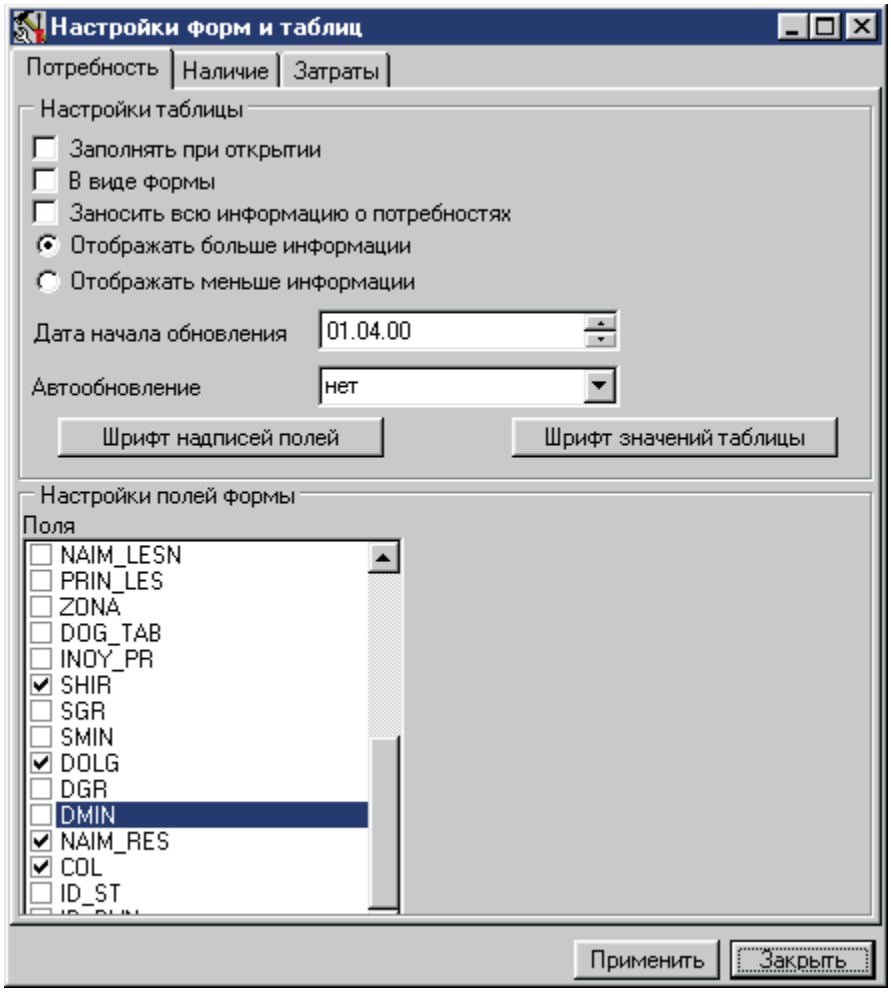
- the level of dispatching (regional or federal)
- type of fire protection (land or air)
- type of relationships between management nodes (contract or not)
- object of dispatching

This option is considered accepted after clicking 'Accept' button.

After choosing 'Paths' a user may define paths to the location of the program, and different data bases, used by the program. It is done in the following window:



After choosing menu item 'Form' one may see a window:



Here a user may define settings for 'Availability', 'Need', 'Expenses' forms and tables.

There are two groups of settings:

- table settings
- form settings

In the first group a user can

- fill in when entered or not
- enter information as a table or not
- enter all information about the need or not
- show all the information or not (the latter supposes that a user needs only some fields)
- enter the date of update out of the databases (this means that a user may set some date, after which the information of particular databases will be output)
- setting in automatic mode the time interval, starting with which the information from databases will be output
- set fonts for names and content.

In the second group a user can:

- choose form fields that will be shown and could be changed. To do this a user should check a checkbox to the left of the field name

After choosing 'Windows' menu a user can set the window locations. Menu item 'Help' shows help content for the program.

Programming tools

The complex of the programs is written on Delphi 6.01 and can work under Windows 98, Windows NT and Windows 2000.

Page left blank intentionally.

Followup to Large-Scale Forest Fires to Aid in Evaluating Economic Losses[1]

Miguel Castillo S., Patricio Pedernera A., Guillermo Julio A.[2]

Abstract

The KITRAL System Forest Fire Expansion Simulator was used to recreate the conditions of the large fires that affected a forest company in February 1999 in the Octava Region in Chile. The objective of the study was to determine which events affected a specific land plot and at what exact moment, in order to quantify the direct economic damages and to facilitate the decision-making process for a Safety System. In that regard, it was determined that the plot in question was affected by three of the seven fires that touched the area of study.

Introduction

The Octava Region in Chile was severely affected by the ignition and spread of forest fires from February 7 to 11, 1999. According to estimates released by the National Forestry Corporation (CONAF), these fires caused damage to more than 40,000 ha. The problematic situation, which chiefly affected the costal area of the Concepción Province, was mainly produced by the extreme weather conditions present prior to and during said time period. In addition, the cumulative effects of an ongoing drought in the area played an important role. Among the many losses caused by the fires, the losses suffered in the large radiata pine plantations belonging to several forest companies were especially noteworthy. The direct resulting losses of this resource were numerous and unprecedented in the region in the last 30 years, or at least since official statistics regarding forest fires have been kept.

Naturally, the economic, social and environmental implications of such a serious situation called for a detailed analysis of the facts. Indisputably, the forest companies affected needed to know exactly how the problem occurred, and in what way and in what circumstances their plots were damaged. However, it was not possible to clearly identify the fire's spread patterns by visually examining the burned areas. Likewise, the information registered in the operations centres was not sufficient for precisely determining the spread as it devastated the forest plantations. Therefore, in order to know the origin of the damages in each of the affected areas, a study determining the spread models of the different disasters occurred on February 7 and 8th was proposed. The particular plot of interest for the study was deemed to be the Trinitarias plot, property of the forest company Bío Bío S.A.

In carrying out the study, the KITRAL System fire simulator was used. The results of the simulation clearly reveal the spread models of the fires analysed, the

[1] An abbreviated version of this paper was presented at the second international symposium on fire economics, planning, and policy: a global view, 19–22 April, 2004, Córdoba, Spain.

[2] Académicos, Departamento Manejo de Recursos Forestales, Facultad de Ciencias Forestales, Universidad de Chile, Casilla 9206, Santiago, Chile. (Professors, Forest Resources Management Department, School of Forestry Science).

plots which were affected as the fire advanced, and at what moment the damages occurred.

In accordance with the above, the following objectives were set: to define the spread models of the forest fires that occurred on the dates mentioned above by using the KITRAL System fire simulator, to gather information on the behaviour of the forest fires that affected the Trinitarias plot and other areas belonging to the forest company Bío Bío S.A., and to determine the surface area burned by each of the fires that affected the subject plot.

Methods

The study was carried out through the sequential execution of the following steps: the update of the Digital Information on Forest Fuels, the securing of Environmental Parameters simulating the fires considered in the study and, lastly, application of the KITRAL System fire simulator, the results of which were processed in a GIS.

The KITRAL System

The KITRAL System, which operates by computational means, was completely designed in Chile. The system is based on the construction of diverse independent and interconnected modules allowing the user to easily perform the most frequent activities of an operations centre. The main characteristics of the system, among others, are the ability to predict fire spread at different points in time and the capacity to reconstruct past events and evaluate them in terms of surface area, type of damage, and quantification of the fuels affected (Julio et al 1995).

When simulating a fire—that is, representing in advance the characteristics that a fire will acquire following its ignition or after a given moment in its development—it is possible to obtain an enormous quantity of useful data, such as spread model and spread rate, the amount of energy released, flame length, effects of vertical radiation, extension of the perimeter and effort required for control, just to mention a few of the most relevant data available.

The key factor in simulating fire behaviour is to determine the spread rate and the spread model. Accordingly, if the prevailing environmental conditions in the affected area are known, then from these two variables it is possible to estimate the effect of the other components present in the expansion of a fire (Julio 1999).

The variables that influence the spread model of a forest fire are innumerable, as are those that affect the way in which heart of fire develops horizontally from the moment of ignition onwards. Nevertheless, experience shows that the spread rate depends essentially on four factors regarding the behaviour of the fire: fuel type, fuel moisture, slope, and wind speed (Brown and Davis 1973, Albini 1976).

Several different research studies have shown that although both fuel type and fuel moisture affect the spread rate, they do not influence spread model. That is, for different levels of values or conditions of the above-mentioned factors, different sizes of fires will be produced, but the geometric figure generated by the heart of the fire will remain the same if the other factors (slope and wind speed) are constant. In addition, variations of fuel type and fuel moisture are not present in small surface areas (Anderson, 1983).

The situation is different, however, as regards slope of the land and wind intensity. The relationship of these factors with the speed with which the fire advances is not lineal, and thus variations of their levels will affect the fire's spread model, even if fuel type and fuel moisture remain constant. In addition, the fluctuations in wind (direction and intensity) and in slope (grade of slope and aspect) are very high even in small land areas. Furthermore, significant changes can be observed in their effects depending on the course of the spread (Andrews 1986).

The fire simulator was tested under real conditions by compiling complete and reliable information from more than 120 forest fires of different sizes. The results indicate that KITRAL is capable of providing 90%-correct forecasts for fires where more than 60 ha were affected. However, in fires affecting less than 2 ha, the level of reliability is decreased by approximately 58%. From a technical point of view, this decline is within reason if we bear in mind that the minimum information unit present in the geographic databases of the system is composed of 25 square meter cells for all levels of information (Castillo 1998).

These findings demonstrate the high level of reliability of the simulator, especially in the case of large fires. Together with the processing speed of the system (projection of 12 hours in the future in three minutes), this can be considered a very good standard, given the complexity of the issue and the high number of variables with their respective functions that are involved in the process.

Update of Digital Information regarding Forest Fuels

This stage involved adjusting the fuel maps in the KITRAL system by introducing into the geographic database of the system the data provided by the forest company Bío Bío S.A. regarding the fuels present in their various plots. In that respect, data on the vegetation and tree populations provided by the company was introduced in the database, and the vegetation formations existing within the plots were categorized by fuel types in line with the Fuel Type Classification developed for the KITRAL System.

As a result, a digital map of the fuel covering the total area of study was obtained. This map was then used to carry out the forest fire simulation.

Securing of Environmental Parameters for the Simulation

This stage involved the analysis of the data gathered on the weather conditions observed in the area of study during the days of interest. On the basis of the analysis of the data gathered, the feasibility of using the KITRAL System Wind Field Simulator was evaluated. In line with the data studied, the situation observed for February 7, 8, 9 and 10 clearly shows the existence of favourable conditions for extreme fire behaviour, which is very difficult to control. The existence of high temperatures, together with the presence of a high-speed wind and an ongoing drought (various months), made it difficult to control the spread of the fires throughout the 7th of February. Given the duration of the period of study considered, as a way of equating the value of the simulated environmental variables with the real conditions present in the area, in each of the simulations the value of each was adjusted to truly represent the different day and night-time conditions.

Use of the KITRAL System Fire Simulator

The simulation process was carried out for each fire independently, thu obtaining a map of free spread (not including fire suppression actions) for the perio from the starting time of each event to 10:00 a.m. the next morning. Time wa expressed in minutes and was measured from the moment of ignition of the fir (Minute Zero). Once the ignition points were located geographically, the simulation for each event were conducted until the spread model of the simulated fire mirrore that of the real fire. As a result of this stage, seven maps of spread times wer generated, one for each of the fires considered in the study. These maps covere approximately the same surface area and the same spatial resolution. Subsequently these maps were transferred to a Geographic Information System for the fina analysis.

Processing of the Simulated Fires in GIS

The KITRAL System contains instruments that allow the simulated fires to b displayed on a screen. The different colour bands used in the display identify th positions of the fire fronts in intervals defined by the user (which in this case wer 60-minute intervals). However, the system does not have the necessary tools t achieve the desired analysis (intergeneration of all the spread models) and thus th entire final processing had to be completed by using the geographic informatio systems Idrisi for Windows and ARC/INFO for Unix.

The processes involved in this stage were: 1) classifying the time maps obtaine into intervals of a common start time and 2) generating all-inclusive maps showin the integrated development of all the fires in one map. For this, time zero (or the sta time for all the simulations) was considered to be the time the Huidanqui fire wa ignited (11:00 a.m. on 7 February 1999), as this was the first of all the fires analysec This process was carried out by adding the necessary amount of minutes to shift th start time in the KITRAL simulation to the real-life start time in relation to the sta time of the Huidanqui fire. Thus, the number of minutes listed in the table below wa added to the initiation time of each fire.

Table 1— Real start times and those used in the KITRAL System Simulator

Fire	Time of real ignition in the simulation	Minute of initiation in the KITRAL simulation	Minutes to be added i the simulation
Huidanqui	11:00	0	0
Hualqui	13:00	0	120
Puente 5	13:10	0	130
Quebrada Honda	14:40	0	220
San Lorenzo	15:50	0	290
Santo Domingo	19:50	0	530
Coihueco	22:20	0	680

After obtaining the adjusted time maps, the time interval (11:00 a.m. on February to 10:00 a.m. on 8 February) was divided further to secure a cleare illustration of how the fires spread overall. For this, the period considered wa divided into five irregular intervals in line with the ignition times of eacl considering that each of the fires should show some spread. The spread was the shown on maps reflecting the situation at 14:00, 17:00, 21:00 and 24:00 on February, and at 03:00, 07:00 and 10:00 on 8 February.

The final step was to estimate the exact area affected by each fire. Due to the fact that for this case the system delivered information on each fire independently, without taking into account its interaction with the other fires, it was necessary to develop a program to analyse the ignition time for each unit of analysis, considering the overall spread of those fires that merged at some point during the analysis period. The program created for this purpose uses an algorithm that examines all the pixels in each of the time plans generated per fire and identifies the first fire to reach said pixel in its spread. This process was necessary to identify the areas within the Trinitarias plot that were affected by each of the fires in question. In this part of the study, only the fires that could have had an effect on the subject plot were taken into account, namely Huidanqui, Hualqui, Puente 5, Quebrada Honda and Coihueco. The San Lorenzo and Santo Domingo fires were discarded, as it was clear that they had had no affect on the subject plot. Thus, a map of the areas burned by each fire within the Trinitarias plot was obtained.

Results

Fire Simulation

With respect to the simulations carried out with the system, the following figures illustrate the spread of the individual fires. Each colour represents the position of the fire front every 60 minutes from the moment of ignition to the time stated as the maximum simulation time (10:00 a.m.).

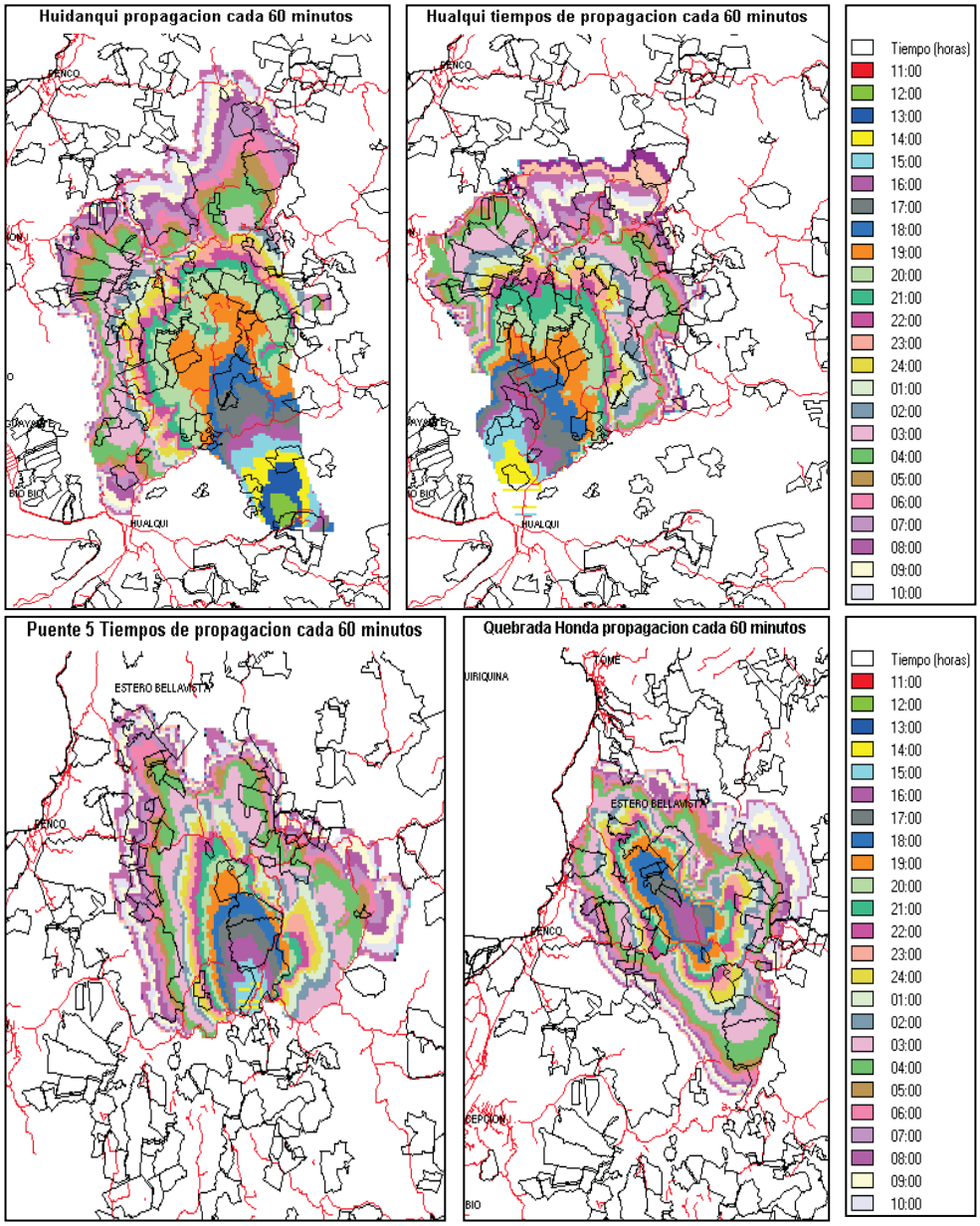


Figure 1— Simulation of forest fires in a 24-hour period using the KITRAL System. The different colours represent the borders of the fire spread every 60 minutes.

All the cases show the violent advance of the fires during the hours immediately following ignition. However, they also show the effects of the environmental conditions of temperature and relative humidity, which acted to slow the fire spread during the night.

Processing the Simulated Fires in GIS

A more general idea of the events surrounding the fires of 7 February was obtained by generating a map showing the global situation at the different time periods following the ignition of the fires.

In that respect, it is important to note that in order to show this situation, time intervals allowing for a relatively clear vision of the fire spread were selected. Care was taken to show some spread time for each fire. Figure 2 shows the global situation three hours after the ignition of the Huidanqui fire and one hour after the ignition of the Hualqui fire.

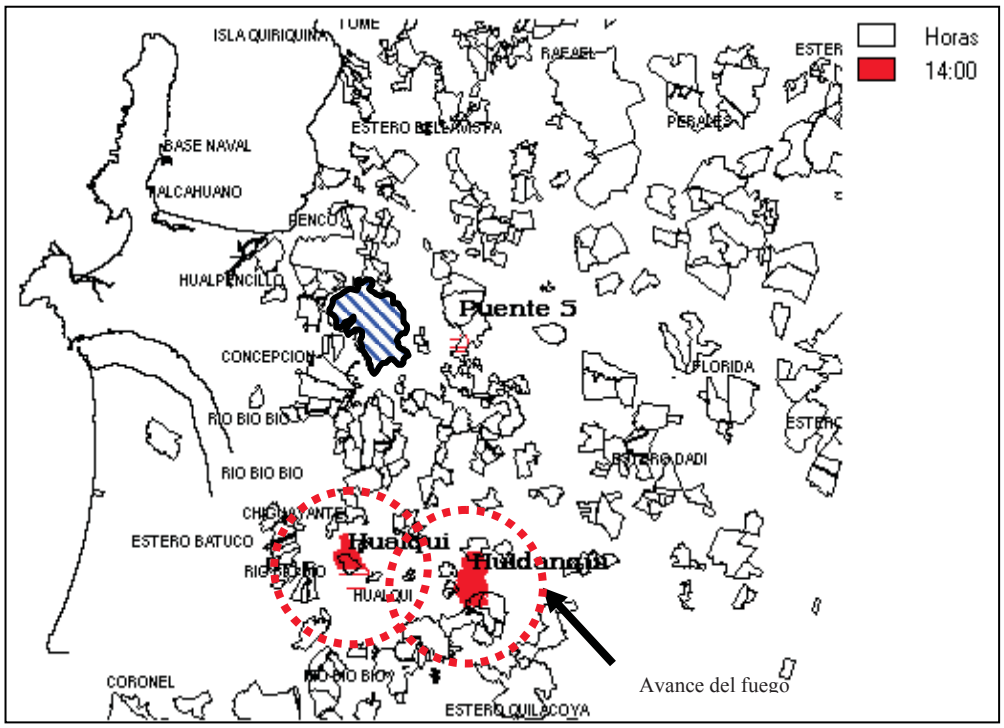


Figure 2—Global Situation at 14:00 on 7 February. The striped area is the zone of interest for the study (Trinitarias). The circles mark the main hearts of the fires, with a N-NE spread.

The figure clearly shows that the Huidanqui fire advanced quickly toward the Northwest, affecting 776 ha, a large portion of which was private land. The case was similar for the Hualqui fire, which advanced in the same direction and affected an approximate area of 423 ha..

Figure 3 depicts the situation in the area six hours later (at 17:00) and shows that the fires continued expanding in the same direction, consuming land belonging to company in question and to the forest company Forestal Celco.

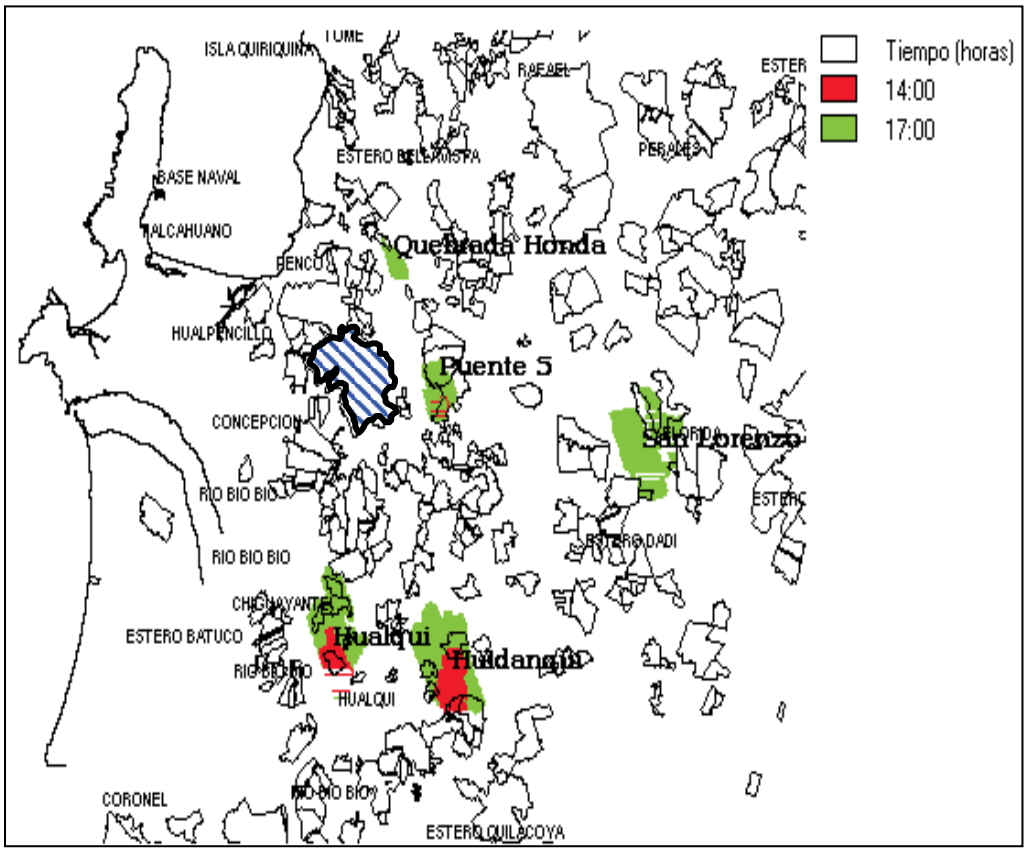


Figure 3—Global Situation at 17:00 on 7 February

In the case of the Huidanqui fire, by 17:00 the fire had affected 2,440 ha. The Hualqui fire had touched 1,780 ha, a large part of which belonged to the company and to Forestal Celco. By this time, the following fires had also been ignited: Puente 5 (736 ha burned), Quebrada Honda (280 ha burned) and San Lorenzo (1999 ha burned). In general, the fires were spreading toward the Northwest.

In addition, the speed with which the San Lorenzo fire advanced its expansion in the Florida area in the simulation was noteworthy. In only 70 minutes the surface area affected was much greater than in the other centres of fire activity. This points to possible problems in the values assigned to the variables determining fire spread in the simulation process.

In the case of the Puente 5 fire, it was possible to note that by this time the fire had already reached the Camarico 1 plot of Forestal Celco, advancing directly toward the adjacent Camarico 2 plot. In the case of the Quebrada Honda fire, the fire advanced directly toward the plot of the same name, accumulating a burned surface area of approximately 280 ha. Figure 4 shows the global situation observed at 21:00 on 7 February.

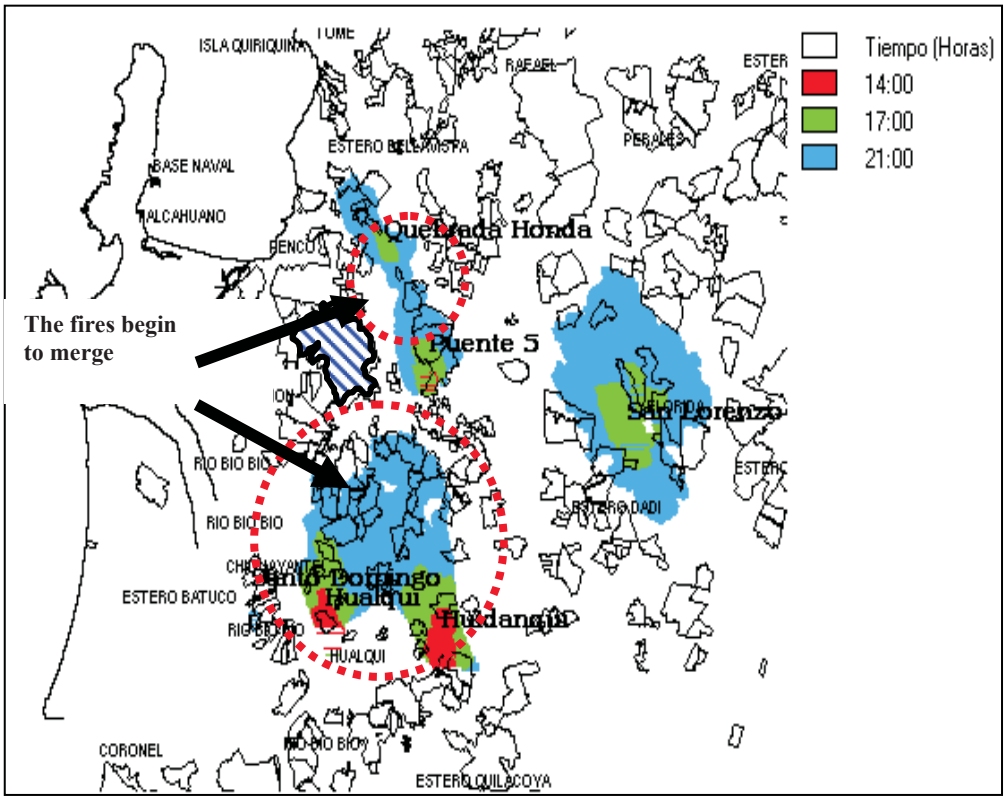


Figure 4— Global Situation at 21:00 on 7 February

Figure 4 shows that by 21:00 Huidanqui and Hualqui, the two main fires, had merged, affecting an overall surface area of 11,500 ha and damaging a large number of plots. The fire continued advancing toward the north, toward Forestal Bio Bio's Trinitarias plot, with a fire front that originated from the Huidanqui fire.

Near the Northern part, the Puente 5 and Quebrada Honda fires also merged, covering an approximate area of 4,700 ha, part of which corresponded to the already completely consumed Camarico 1 plot. As in the Huidanqui-Hualqui fire, the fire continued advancing due northwest. At the same time, the Santo Domingo fire was initiated, affecting an area of 55 ha.

At 24:00 on 7 February, the situation was similar to the previous period, with the fires advancing northwest. However, in the north section of the area the Coihueco fire had ignited and by this time had affected 117 ha of private land. Figure 5 depicts the global situation at this time.

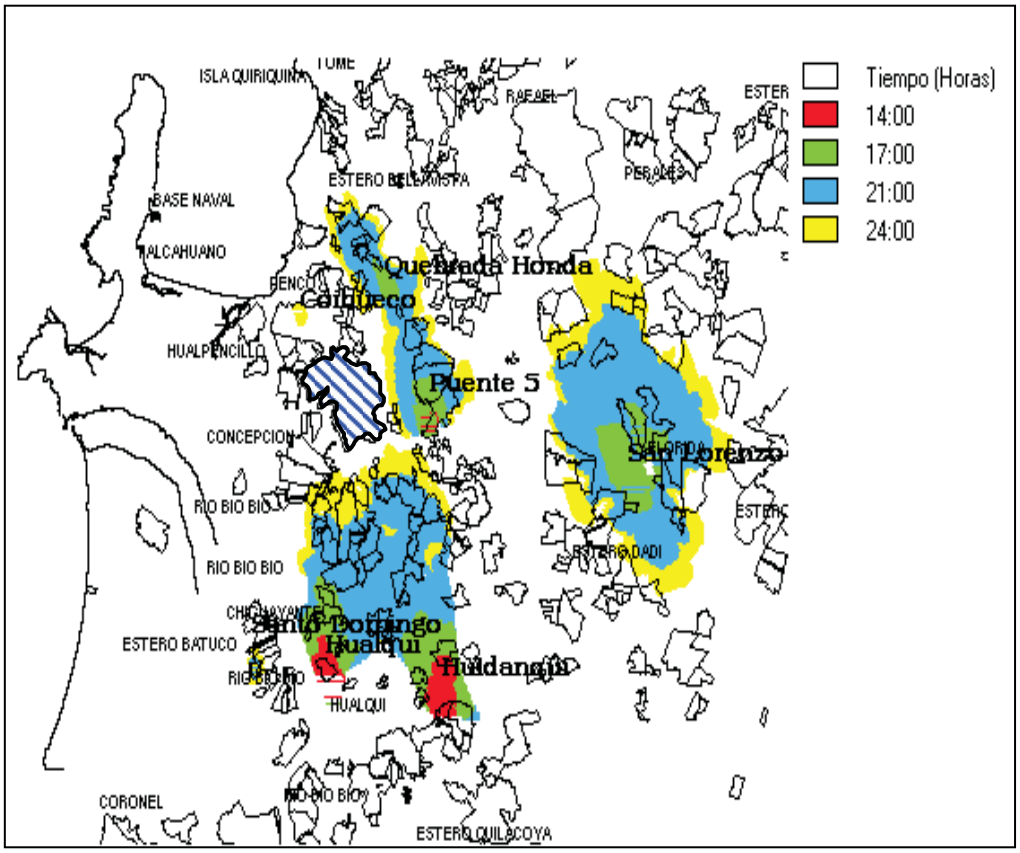


Figure 5— Global Situation at 24:00 on 7 February

By this time, the Huidanqui-Hualqui fire had already consumed approximately 15,400 ha and was nearing the Concepción-Bulnes road. The Puente 5—Quebrada Honda fire had consumed 7,200 ha and was beginning to expand outward. In the following period this would cause these fires to merge with the fire front coming from the south (Huidanqui-Hualqui).

In the case of the San Lorenzo fire, the spread was rather explosive (17,400 ha), which confirmed that there were problems with the parameters introduced in the simulation system.

The graphic clearly shows that by this time the Trinitarias plot was beginning to be threatened by two fire fronts: the Huidanqui-Hualqui fire to the south and the Puente 5- Quebrada Honda fire to the east. The global situation at 03:00 on 8 February is represented in the following graphic.

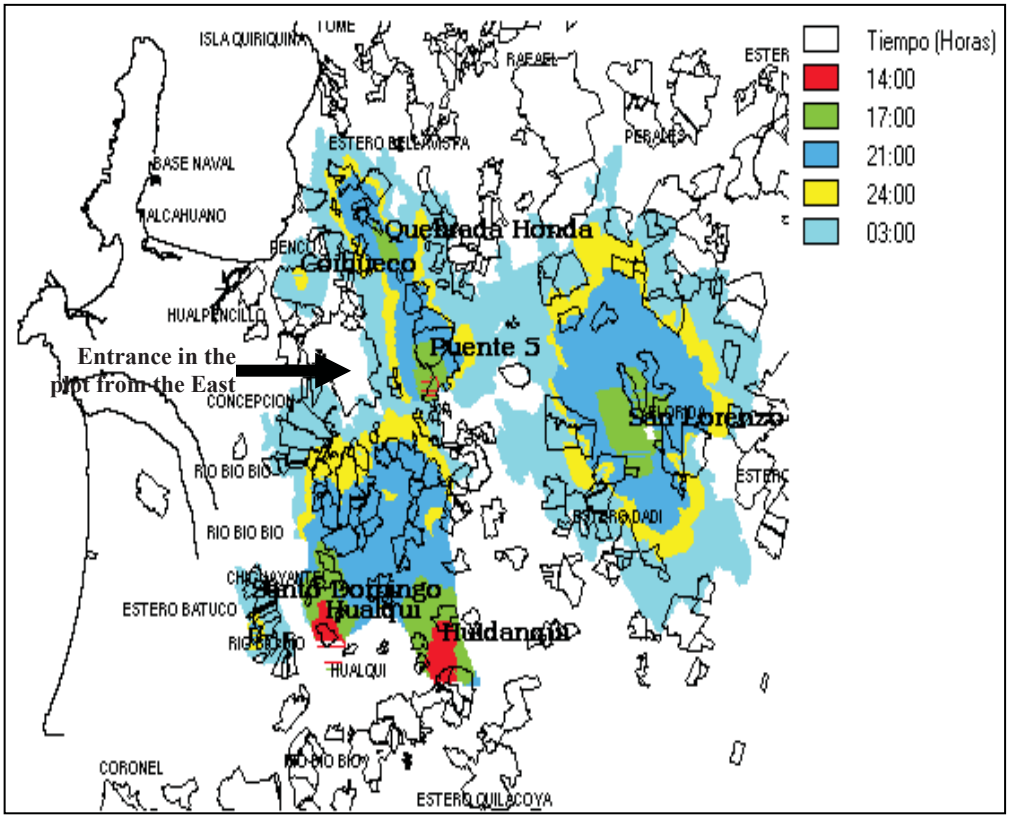


Figure 6—Global Situation at 03:00 on 8 February. The fire begins to enter the Trinitarias plot from the east section.

Figure 6 shows that at this time the fire fronts approaching from the south (Huidanqui-Hualqui) and from the east (Puente 5- Quebrada Honda) were entering the Trinitarias plot. In addition, the two fires were merging to the east and continuing their expansion outward. Upon observing this data and bearing in mind the part of the plot in which the fire entered, the fires that affected the plot at this time correspond to the fire fronts originated by the Huidanqui and Puente 5 fires. The advance of the Hualqui fire was halted by the presence of a watercourse and the Concepción-Bulnes road. In the north sector, at this time the Coihueco fire was not yet more than a threat to the Trinitarias plot, even though the fire front was quite close to the plot boundary. In the south, the Santo Domingo fire continued to expand, affecting 1440 ha. Figure 7, below, shows the situation at 07:00.

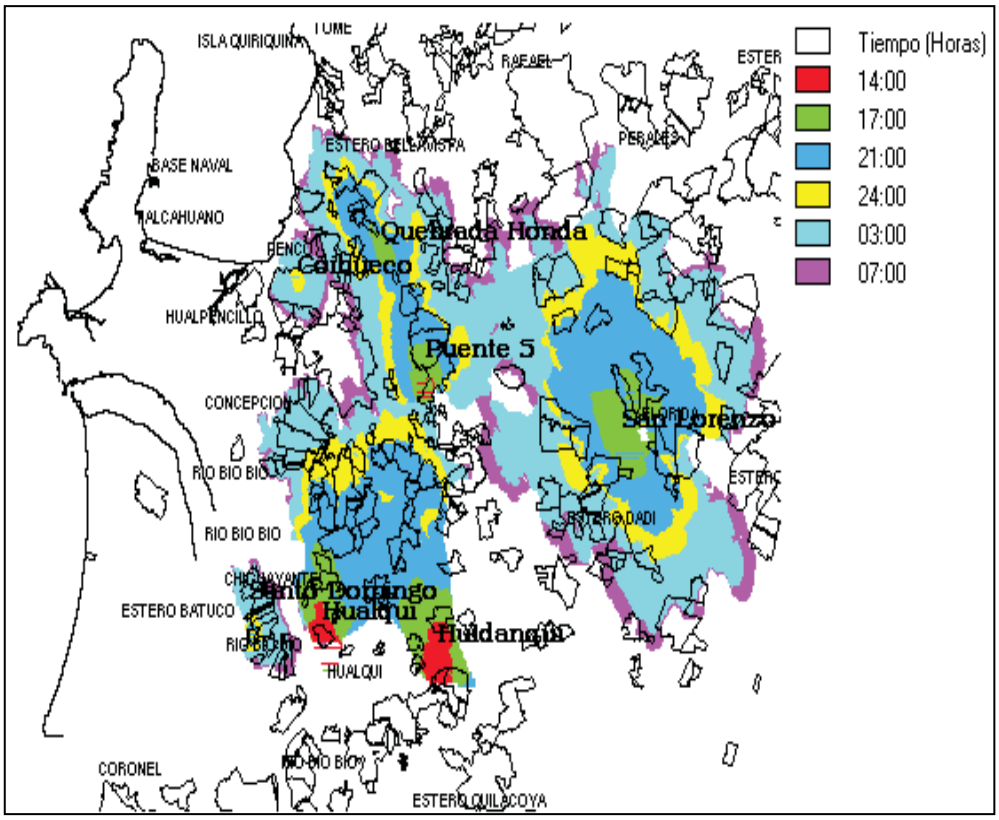


Figure 7— Global Situation at 07:00 on 8 February

During this period, the Huidanqui-Hualqui and the Puente 5-Quebrada Honda fires continued advancing within the Trinitarias plot, and the fire front originating in the Coihueco fire entered the subject plot from the north. In all cases, the fires expanded from the sides outwards. There are no other relevant aspects worth mentioning. The final situation is depicted in Figure 8.

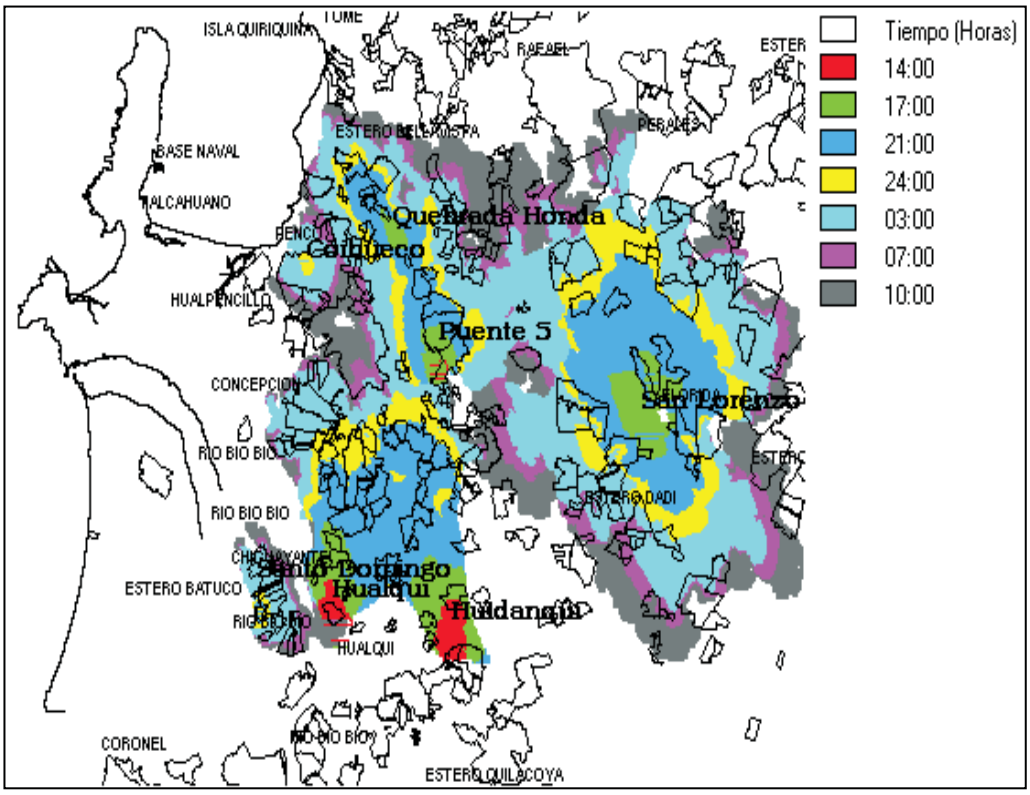


Figure 8— Global Situation at 10:00 on 8 February

The graphic shows that by 10:00 the fires had completely consumed the Trinitarias plot, leaving only a small interior section unaffected. With respect to the other fires in the area, by this time they had merged with the main fires and thus it is rather difficult to clearly evaluate the resulting image.

The project also called for the elaboration of a map showing the surface area affected by each of the fires, especially for the interior of the Trinitarias plot. This map made it possible to evaluate the final situation at the end of the simulation period, specifically to answer the question of how many fires affected the subject plot. The results of this evaluation are shown in Figure 9.

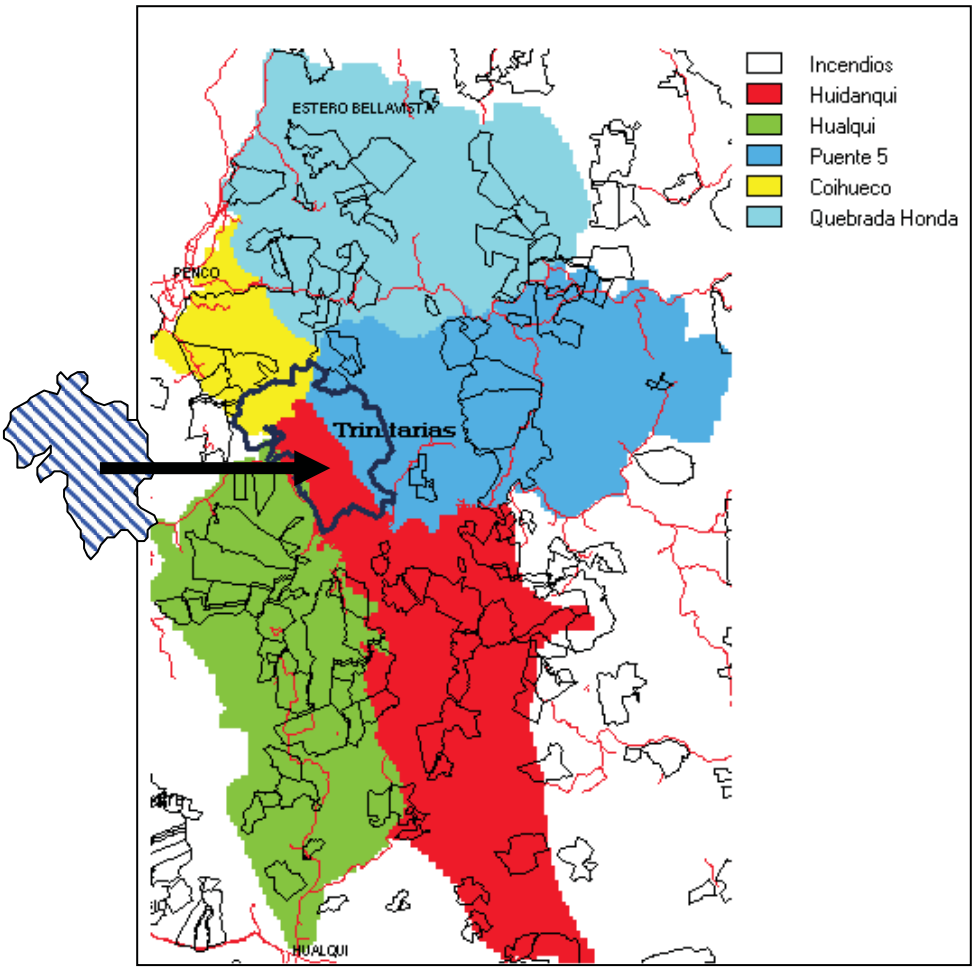


Figure 9—Areas burned by the fires affecting the Trinitarias plot. Each colour represents the area burned by each fire.

The figure, which was obtained by applying a calculation and assignment algorithm, shows that the Trinitarias plot was affected by three fires: Huidanqui in the south, Puente 5 in the east and Coihueco in the north, with 938, 735 and 441 ha of burned area respectively. Toward the southwest, a small sector of approximately 43 ha was left unharmed.

Final comments

From the data provided by the simulation it was possible to reconstruct the events in the Concepción area on 7 and 8 February 1999.

The San Lorenzo fire behaved inconsistently in the simulation, and therefore it was not possible to reach conclusions regarding its true behaviour. This situation could be explained by the lack of reliable data to introduce in the fire simulator, in particular regarding fuels.

Nevertheless, when the information entered is reliable, the post-fire simulation process does make it possible to confirm the observations registered in the field regarding the time the fires reached the subject plot. It was ultimately concluded that

for this case study, the Trinitarias plot was affected by three fires, Huidanqui, Puente 5 and Coihueco, which caused damage in 938, 735 and 441 ha respectively.

Lastly, it is necessary to emphasize the performance of the KITRAL system forest fire expansion simulator, whose functional design is highly effective both for predicting how a fire will advance and for recreating true-life situations, as was done in the reconstruction of these large fires. Thanks to the speed with which the simulator provides results and the high degree of reliability, especially for large fires, the system represents an effective contribution to the quantification of damages caused by fire.

Bibliography

Albini, F. 1976. **Estimating Wildfire Behavior and Effects**. USDA Forest Service. Gen.Techn.Rep. INT-30, Ogden. 92p.

Anderson, H. 1983. **Predicting Wind-Driven Wild Land Fire Size and Shape**. USDA Forest Service, RES.pap. INT-305, Ogden.

Andrews, P. 1986. BEHAVE: **Fire Behavior Prediction and Fuel Modeling System**. Burn Subsystem. Part I. USDA Forest Service, Gen.Tech.Rep. INT-260, Ogden.

Brown, A.; Davis, K. 1973**. Forest Fire. Control and Use**. Second Edition, Mc.Graw-Hill, N.York. 686p.

Castillo, M. 1998. **Método de Validación para el Simulador de Expansión de Incendios Forestales del Sistema KITRAL**. Universidad de Chile. Facultad de Ciencias Forestales. Santiago. 123p.

Julio,G.; Pedernera, P.; Castillo, E. 1995. **Diseño funcional de simulador de incendios forestales**. En: Actas Taller Internacional. Proyecto FONDEF FI-13. Santiago; 182-204.

Julio, G. 1999. **Apuntes de Manejo del Fuego**. Universidad de Chile. Facultad de Ciencias Forestales. 313p.

Page left blank intentionally.

Fire Management Plan at Regional Scale in an Alpine Fire-Prone Area (Valle d'Aosta Region - Italy)[1]

Giovanni Bovio,[2] Elisa Guglielmet,[3] Andrea Camia[4]

Abstract

In this contribution the methodology for the development of the fire management plan at regional scale based on the new Italian regulation on wildland fire protection (L.353/2000) is presented. In particular the main features of the recent regional fire management plan finalized for Valle d'Aosta region according to the mentioned regulation are described, with a specific focus on the criteria used to define and spatially distribute protection priorities.

Located in the extreme Northwestern part of Italy, Valle d'Aosta is the smallest and the most mountainous of the Italian regions, characterized by an Alpine environment, a main central valley East-West oriented and a total area of about 3262 km2. In this region, as in general in Northern Italy, wildfires are concentrated in the winter-early spring season, in agreement with the driest period of the year. Spatial analysis techniques made with a GIS to derive land zoning from fire related variables in order to support the development of the fire management plan are reported, together with the criteria followed to define the protection priorities at regional scale.

Introduction

The protection of forests against wildfires can be successfully realized only with the support of a wildfire management plan.

In Italy forest fire management plans at regional scale are based on the wildland fire protection national law L. 353/2000. This regulation establishes new rules to reduce burned areas, enhancing fire prevention and wildfire danger rating systems. Italian regulation on wildland fire protection and its guidelines define the main arguments that must be analyzed in regional plans.

According to the prescriptions of the general policy forest fire general law, the fire management plan of Valle d'Aosta Region, one of the 20 Italian regions, was accomplished. The present contribution shows the main phases of the work realized

---

1 An abbreviated version of this paper was presented at the second international symposium on fire economics, planning and policy: a global view, 19–22 April 2004, Cordoba, Spain.

2 Full Professor, Dept. Agroselviter, University of Turin, Via Leonardo da Vinci 44, 10095 Grugliasco (TO) Italy. email: giovanni.bovio@unito.it.

3 Forest Engineer, Dep. Agroselviter, University of Turin, Via Leonardo da Vinci 44, 10095 Grugliasco (TO) Italy. email: elisa.guglielmet@unito.it.

4 Doctor in Forestry, Dep. Agroselviter, University of Turin, Via Leonardo da Vinci 44, 10095 Grugliasco (TO) Italy. (Current affiliation: Joint Research Centre, Institute for Environment and Sustainability - TP 261, I-21020 Ispra (VA) Italy. email: andrea.camia@jrc.it).

to produce this fire management plan, with particular attention to the criteria used to define and spatially distribute protection priorities.

Objectives

The objective of the present work is to describe a methodology for setting up wildfire management plans at regional scale. In particular the first objective is to provide the regional fire managers with an operative plan to address fire planning procedures and operative services, linking together different sectors of fire management activities. The attention is pointed out on the modalities to spatially distribute protection priorities and, in general, to define fire risk mapping process at regional scale in an Alpine area, in which wildfires season is concentrated in the winter-early spring months. For this reason we have chosen to describe the methodology followed for the wildfires management plan of Valle d'Aosta region.

Study area

Valle d'Aosta Region is located in the North-Western extremity of Italy, bordering on Switzerland to the North, on France to the West, on Piedmont to the South and East. It is characterized by a total surface of about 3,262 km^2, 1,080 km^2 of which covered by forests. The territory is mainly mountainous and the average altitude is 2,100 meters, with a range that goes from about 295 m to 4,800 m a.s.l.. Considering the administrative divisions, Valle d'Aosta Region presents only one province, divided into 74 municipalities. For its collocation and its climatic conditions, Valle d'Aosta forest fire distribution during the year is the typical one of the Regions of the Alpine range, with a fire season that extends from November to April and with few summer fires. The following figure shows the location of Valle d'Aosta Region *(fig.1)*.

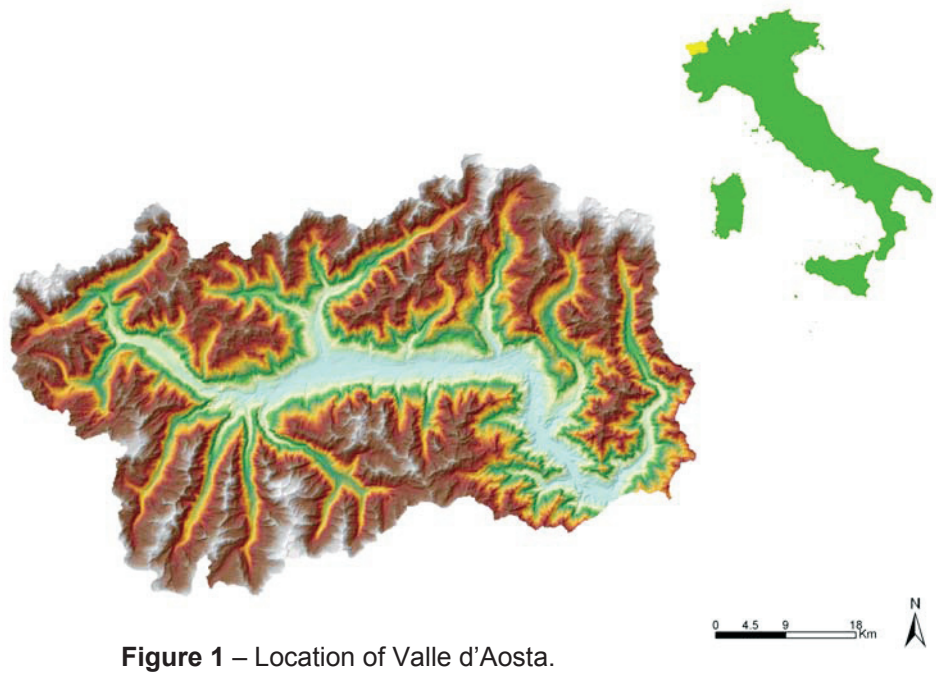


Figure 1 – Location of Valle d'Aosta.

Methodology

Statistics on forest fires

For the redaction of a wildfire management plan a preliminary issue is to give an historical summary of the wildfire situation of the study area. A database of wildfires and the basic cartography are required to make landscape analysis and statistical elaboration. The period considered in the study area is made of 17 years, from 1986 to 2002. The data were obtained from the Forest Service of Valle d'Aosta. In the following table a summery of the historical wildfire data is given *(table 1)*.

Table 1– *Main statistical variables for the considered historical series (1986 – 2002)*

	Total	Annual average
# Fires	366	22
Total burned area	2,785 ha	164 ha
Forest burned area	1,666 ha	98 ha
Non forest burned area	1,119 ha	66 ha
Average burned area by fire	-	7.6 ha

Fire Risk Zoning

Fire risk zoning is meant as the definition for wildfire protection purposes of homogeneous areas having similar fire risk level.

In the present study the basic geographical unit to which information on fire events has to be referred is the municipality. For each municipality many parameters were calculated and analysed to define risk classes and their spatial distribution. A set of variables related in particular to fire frequency and fire characteristics has been selected to describe the pirological situation of each municipality. These variables together are able to define a "fire history profile" of each municipality.

The variables considered for each municipality are the following:

- *Number of forest fires per unit area (10 km^2) per year.* This feature expresses a measure of the average concentration of wildfires in the territory.
- *Number of "large fires" per unit area (10 km^2) per year.* This expression of concentration is limited to events that for their size have been considered exceptional for the whole regional territory. The surface threshold for discriminating "large fires" was derived from statistical analysis that considers the frequency distribution of area burned by forest fires. For Valle d'Aosta Region "large fires" correspond to fires with a surface burned of almost 8 hectares. They are the 10 percent of the total fires occurred in the Region during the historical period considered, corresponding to a surface of about the 80 percent of the total burned area in the same period.
- *Number of "small fires" occurred per unit (10 km^2) area per year.* This variable expresses the mean concentration of fires whose area burned is less than 0.5 hectares. This extent threshold of "small fires" is defined by Valle d'Aosta Forest Service and is used to define the potential susceptibility to fires of the Region considered.
- *Number of years with least one event during the period considered in percentage.* This variable estimates the time continuity of the phenomenon.
- *Mean area burned by a single event.* This variable synthesizes average fires dimension for each municipality, but it is influenced by the extreme values of the distribution, which is typically strongly asymmetric.
- *Median area burned by a single event.* This is the value of burned area that divides the area burned sorted values of into two equal parts. Below and above this value 50 percent of occurrences of fires in a municipality are found. Median area burned by a single fire represents the area burned by the so-called "typical fire".
- *Maximum area burned by a single event.* It is the area burned by the largest fire occurred during the historical period for each municipality.

From the analysis of the previous variables, history profiles of the municipalities were calculated. Then, through hierarchical cluster analysis applied with Ward method (Ward 1963), it was possible to define 5 municipality groups for Valle d'Aosta Region. Each group defines a risk class, which is synthetically described by the centroid value of the profile variables, i.e. the mean value computed for each variable of all the municipalities that belong to a risk class. In the following table *(table 2)* the centroids of the 5 risk classes of the 74 Valle d'Aosta municipalities derived from classification applied are showed.

Table 2 - *Centroids of fire risk classes*

	Municipality fire risk classes				
	1	*2*	*3*	*4*	*5*
Number of municipalities	12	44	10	3	5
Number of fires per year per 10 km2	0.0	0.1	0.3	0.2	0.8
Number of fires > 8 ha (large fires) per year per 10 km2	0.00	0.01	0.02	0.05	0.11
Number of "small fires" per year per10 km2	0.3	0.4	2.1	1.1	2.7
Years with fires (pct)	0.0	15.4	37.6	41.2	54.1
Mean area burned by one fire (ha)	0.0	6.1	3.4	31.4	7.7
Median area burned by one fire (ha)	0.0	4.9	1.1	3.7	2.2
Maximum area burned by one fire (ha)	0.0	12.4	23.0	266.3	60.4
Number of fires per year	0.0	0.2	0.7	0.6	1.3
Number of fires > 8 ha per year	0.00	0.02	0.05	0.16	0.20
Number of "small fires" per year	0.6	1.0	4.7	3.9	4.0
Burned area per year (ha)	0	0.9	2.5	18.4	8.5

The fire risk zoning allows to define and characterized homogenous areas and to put municipalities in ordinal scale in order to distribute protection resources at Regional scale. In the following figure municipalities classified into the fire risk classes are represented *(fig.2)*.

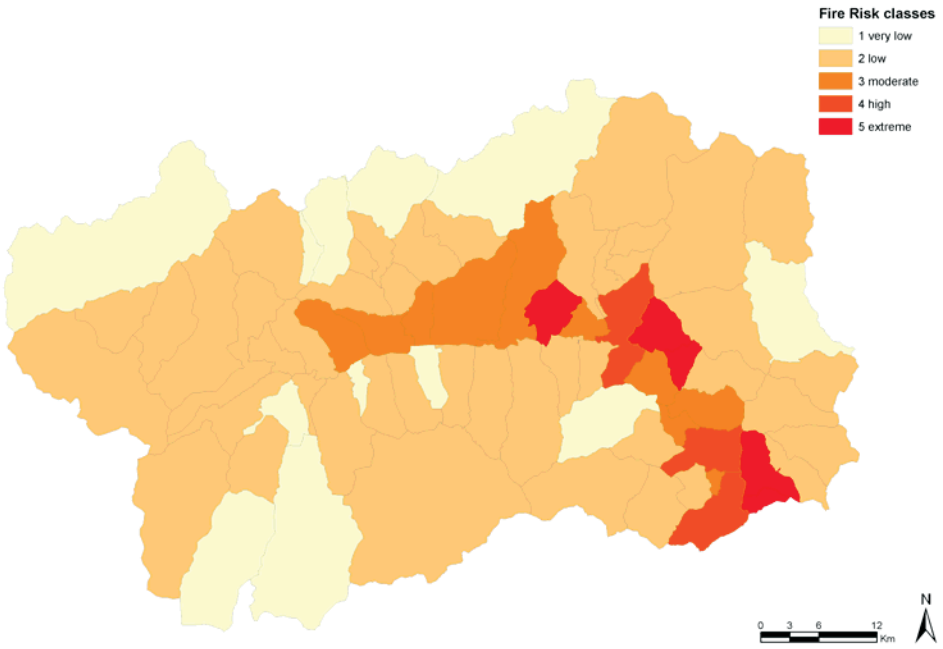


Figure 2 - Map of fire risk classes in Valle d'Aosta Region.

Aims zoning

Results obtained from zoning process are used to define different planning objectives that are established according to criteria, such as acceptable fire impact and its distribution within the homogeneous areas previously defined.

Through a more detailed analysis, within each municipality the areas where fire protection activities have a priority importance were defined. To define these areas and to give them a protection priority level, spatial analysis with Geographical Information System (GIS) techniques were made. GIS can provide useful tools for wildfires management, through their capability of handling in an integrated environment multi-source and multi-resolution spatial data (Burrough and McDonnel, 1998).

The following spatial data layer were integrated using ARC-GIS 8.3 by ESRI:

- Elevation: derived from Digital Elevation Model (DEM).
- Aspect: derived from Digital Elevation Model (DEM).
- Forest types: a value based on the inflammability of the species was given to each forest type.
- "Large fires" location: the perimeter of all forest fires with a burned area greater than 8 hectares was digitalized.

Through GIS analysis the different layers were overlayed and merged deriving 5 different protection priority levels in the study area. The following figure shows the spatial distribution of the protection priorities at regional scale (fig.3).

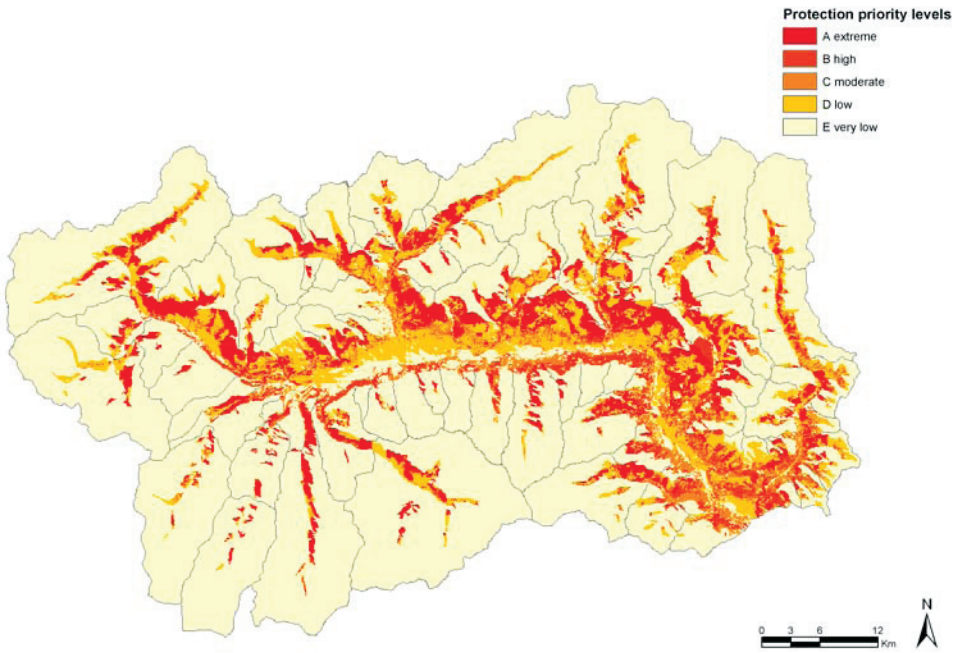


Figure 3 - Map of protection priorities.

The protection priority classification of the regional territory has to be used together with the fire risk classification. The fire risk classes define the priority rank of the municipalities. Then the protection activities will be planned starting from the municipalities with the higher risk and then considering, for each municipality, the protection priority levels.

Interventions zoning

This part of the fire management plan has the objective to describe prevention and extinction activities that have to be realized and distribute them in the regional territory. In the present work these activities are not presented in detail, but only the main categories of interventions foreseen are briefly described.

The interventions zoning concerns the following activities:

- Meteorological Fire Danger Rating. At the moment in Valle d'Aosta Region the *Canadian Fire Weather Index* (Van Wagner 1987) is operationally used. For the computation of FWI daily meteorological data are used. Within the fire management plan the index was calibrated with the method described by Van Wagner (1987) applied on a monthly basis. The daily fire danger classes are meant to be linked to the real time operational activities.
- Direct Prevention activities. This category of interventions includes different activities:
  - Preventive Silviculture
  - Firebreaks
  - Prescribed fire
  - Forest and operative viability
  - Watering
  - Helicopters
- Indirect Prevention activities. The main actions of this category are educational activities, turned in particular to students. The main purpose is to reduce fire ignition causes and to give suggestions concerning the correct behaviour to adopt in case of wildfire.
- Extinction activities.
- Restoration.
- Decision support Systems and Control Center
- Firefighters Training.

Discussion and Conclusions

Planning activities are fundamental to reduce forest fires and the consequent burned area.

The methodology followed to set up the fire management plan of, a typical Alpine fire-prone area located in Italy (Valle d'Aosta Region), is presented. Planning choices suitable at a regional scale are outlined, describing variables to be selected and the way to join them in order to define homogeneous areas where a protection

level and priorities can be defined. The main steps and criteria followed for the zoning process are presented and the results obtained from the zoning task are showed. These have been used in the fire management plan to define different planning objectives.

Fire management planning at regional scale is a complex process in which different items and purposes have to be integrated and considered with a global perspective. Taking into account Italian fire management requirements, the research has shown that the most appropriate approach for regional fire management planning has at first to consider the area interested by the plan as a whole and then to proceed with the analyses at a more refined detail.

Acknowledgments

This research was funded by the Regione Valle d'Aosta, Assessorato Agricoltura, Risorse Naturali e Protezione Civile, Dipartimento Risorse naturali, Corpo Forestale, Protezione Civile e Antincendi, Direzione Foreste.

References

Bovio, Giovanni 1990. **La pianificazione antincendi per la difesa del patrimonio boschivo.** Accademia Italiana di Scienze Forestali 38: 431-458.

Bovio, Giovanni 2001. **La Pianificazione antincendi boschivi alla luce della Legge 353/2000.** L'Italia Forestale e Montana 6/2001: 441-454.

Bovio, Giovanni; Camia, Andrea 1994. **Fire danger zoning using multivariate analysis.** In: Domingos Xavier Viegas, Proceedings of 2nd International Conference on Forest Fire Research, 1994 November 21-24, Coimbra, Portugal, 733-745.

Burrough, P.A.; McDonnell, R. A. 1998. **Principles of Geographical Information Systems.** Spatial Information Systems and Geostatistics. Oxford University Press, pp. 333.

Canadian Forestry Service, 1987. **Canadian Forest Fire Danger Rating System. Users' Guide.** Canadian Forestry Service Fire Danger Group. Three-ring binder (unnumbered publication).

Van Wagner, C.E. 1987. **Development and structure of the Canadian Forest Fire Weather Index System.** Canadian Forestry Service, Technical Report 35, pp 37.

Ward, J.H.1963. **Hierarchical grouping to optimize an objective function.** Journal of the American Statistical Association 58 (301): 236-244.

Comparative Analysis Between the Forest Fire Prevention Systems in Sicily (Italy) and Andalusia (Spain)[1]

Clara Quesada Fernández[2]

Abstract

The Sicilian Region, as it is located in the south of Italy, shares common geographical and climatic characteristics with Andalusia, as well as those concerning vegetation. To these features we may also add the high demographic pressure Sicily is subjected to, making it a region susceptible and vulnerable to attack by forest fires. Moreover, the 2003 Regional Plan for Sicily actually corresponds to 1994. Since then a number of laws have been passed in which the Italian regions have been required to draft and/or update their forest fire forecast, prevention and active fire-fighting plans, such as the Regional Sicilian Law 16/96, the Italian national law 353/2000 and the European Regulation of 1997. Due to problems of a bureaucratic, administrative, economic and political nature these directives have not yet been implemented. In accordance with this legislation, a new Regional Sicilian Plan is being drafted but the budget estimates for each of the sections of forecasting, prevention and fire-fighting, extinction and supplementary action have still to be designated.

In order to undertake the comparative analysis, we have used the INFOCA Regional Plan and the organisational models currently existing in Andalusia, a region which is a pioneer in forest fire-fighting, as these elements are reasonably effective as regards planning the strategy for effective fire prevention management.

We should underline that there is great difficulty in collecting certain key information on forest fires but that there is a growing awareness on the part of the Sicilian government, which is currently updating its data bases and setting up the Special Services Offices. Nevertheless, the effort made to date is still insufficient and more investment in economic, material and human resources is needed. The comparative analysis which we have undertaken may therefore help to establish a common direction for work, improving both our forest fire-fighting systems.

Introduction

The profound climatic change recorded in Italy in recent years has led to a reduction in humidity which has increased the exposure of Italian forestland to the work of arsonists, a problem which is accentuated by the spread of fires which, as can be seen by the statistics, are largely the fault of man. Thus, we should always be conscious of the context in which these occur, when analysing the regions under study.

---

[1] An abbreviated version of this paper was presented at the second international symposium on fire economics, planning and policy: a global view, 19–22 April, 2004, Córdoba, Spain.

[2] Forestry engineer, University of Córdoba (Spain).

Comparisons made

In a regional context, Italy is under huge demographic pressure, a fact accentuated in some of the southern regions of Italy, such as the case of Sicily (*tables 1 and 2)*.

Region	Regional surface area (ha)	Woodland surface area (ha)	Woodland rate (%)	Population (Inhab)	Population density (inhab/km^2)	Woodland surface area per inhabitant
Sicily	2,570,856	266,400	10.4	5,108,067	197.8	0.05
Southern Italy	10,781,405	1,819,443	16.9	19,337,785	179.3	0.095
Andalusia	8,759,968	4,325,378	49,4	7,236,459	83	0.6
Italy	30,127,761	8,675,100	28.8	57,563,354	191	0.15
Spain	50,949,139	25,984,061	51	39,975,479	78.5	0.65

Table 1-- *General data on the southern regions of Italy, Andalusia, Italy and Spain.*

The administrative structure in Andalusia and Sicily is similar, with regions divided into provinces and municipalities. The areas comprise 8 and 9 provinces and 770 and 390 municipalities respectively.

Characteristic	Andalusia	Sicily
Woodland surface area (Ha)	4,325,378	266,400
Conifers	611,551	45,293
Greenwoods	530,136	111,259.44
High level woodland	1,141,687	156,543.44
Mid-level woodland	42,696	63,409.72
Low-level woodland	37,592	63,126.84
Woodland rate (%)	49.4	10.4
Woodland surface area per inhabitant (Ha)	0.6	0.05

Table 2-- *Main woodland characteristics in the regions of Sicily and Andalusia.*

A striking fact in the region of Sicily is the non-existence of any differentiation between fires of different sizes, with all incidents appearing as “forest fire”, with no reference to the surface area affected, whether or not this was an abortive fire, or a major forest fire. This makes studies and comparisons difficult. The differences in statistics enable a more exhaustive study to be made of the effectiveness of the Fire prevention plan “*table 3”*.

Characteristic	Andalusia	Sicily
Abortive fires (< 1 ha)	6,321	7,460
Fires (> 1 ha)	10,944	
Percentage of fires nationally 93-02 (%)	5.74	5.40
Hectares burnt 93-02	105,928.96	166,800.3
Percentage of hectares burnt nationally (%)	7.7	11.65
Affected woodland surface area (Ha)	44,616 Ha	71,957.88 Ha
Affected woodland surface area (%)	42.12	43.14
Mean ha/fire 93-02	9.68	21.52

Table 3-- *Data and statistics on forest fires in the Sicilian Region and Andalusia.*

In the period 1993-2002 the average surface area per fire in the Sicilian region was 21.52 ha, the main reason for this comparative study being carried out *(table 3)*. Moreover, it should be borne in mind that in both regions there is major legislation on forest fire prevention and fire-fighting: in Andalusia, law 5/1999 and in Sicily, Law 353/2000.

Another fact to be underlined is the existence of Forestry Defence Associations (ADFs in Spanish) in Andalusia. These were set up within the INFOCA Plan, amongst forestry land owners, both public and private, who joined forces to protect the natural heritage of forestry, with the common aims of conservation. In the Sicilian Region we do not find similar groupings and the existing agricultural associations do not concern themselves too much with forestry concerns. Similarly, the organisation of the Sicilian region does not cover official protocols for collaboration over forest fire-fighting between the different provinces which make up the region - a normal procedure at both provincial and municipal level in the self-governing region (Autonomous Community) of Andalusia.

It is important to emphasize that the economic data for forest fire prevention campaigns for 2003 and earlier are not available for consultation. In the case of data for 2004, the Sicilian region is finalising the drafting of budget items to be assigned to each of the sections in the future Fire Prevention Plan.

The Fire Prevention Plans in Andalusia and the Sicilian Region have very different philosophies and organisations. The INFOCA plan centres more on prevention and the Sicilian plan on extinction, although the same objectives of improving forest fire-fighting are met (*table 4)*. This has been defined by the importance the respective communities attribute to the rural environment and is observed in Andalusia through the Autonomous Community Forestry Plan, one of the first to be passed, and the great amount of legislation existing on fire prevention and extinction in that region. On Sicily's part, this general legislation on forestry is insignificant.

Characteristic	Andalusia	Sicily
Activation of Fire Prevention Plan	All year round	Only during risk period
Scope of Fire Prevention Plan	Regional	Regional
Philosophy of Plan	To deal with all forest fires and consequent emergencies	To optimise resources in order to avoid risks
Importance of prevention	Fundamental, assigning major resources	Fundamental, but sufficient resources not provided
System used	Stand-by crew	Use of Civil Protection Services, assisted by volunteers and hired stand-by crew

Table 4--*Philosophy and organisational structures of the INFOCA Plan and the Sicilian Plan.*

The INFOCA Plan is strictly forestry based, seeking a decrease in fire sites, and therefore attributes major importance to prevention through preventive silviculture, public awareness and the use of new technologies and working methods in the rural environment. The plan is considered by forest fire-fighting professionals as one of the best available plans in the Spanish state over all. The Sicilian Plan is based on the philosophy that fire is inevitable and seeks the least possible damage from this, with few preventive measures for silviculture, due to the fact that this is conceived from the viewpoint of the emergency services and not the forestry environment.

The INFOCA Plan involves a change in organisation depending on the Provincial Operating Division. The CEDEFOs only remain open when there are stand-by crew in the period devoted to extinction tasks. Changes in the uniformity of procedures and organisation may cause small problems of coordination when resources are moved from one province to another. In addition, according to the INFOCA Plan, some functions of the CEDEFO, which are fundamental for improving the level of prevention amongst the inhabitants of rural areas, should be undertaken outside the period of maximum risk, when these are in fact closed. For this reason, in most cases these tasks are not undertaken, as no fire-fighters remain at the CEDEFOs outside the period of maximum danger. It would therefore be recommendable to maintain a minimum structure all year round with a number of specialist stand-by crew. This would also lead to greater professionalisation. As an advantage it would also reduce a certain lack of motivation observed amongst the hired staff, which affects the work done during the season, since many of these employees use working days as time off and do not wish to do training courses or equipment maintenance.

As regards the resources and funds assigned, in some cases deficient maintenance of equipment used for forest fire-fighting has a close relation with the use of the CEDEFOs, closed down for part of the year, without any monitoring of material or maintenance. This is left for the start of the next season and deficiencies are carried over during the vital period of total availability of resources.

With regard to the Sicilian Plan, intensive use of Civil Protection volunteers is made for all tasks, since these volunteers are present in surveillance and extinction. The problem lies in the fact that many of them do not have the necessary physical or

mental capacities for these posts and lack technical, theoretical and practical knowledge regarding behaviour in a forest fire. Another interesting feature is the almost exclusive use of water-based fire-fighting systems due to the provision of self-pumping vehicles and limited experience of fire fighters' forest fire-fighting systems. This dictates to a large extent the procedures to be used in fire-fighting.

The definitive characteristic of both Plans is the existence of one single controller. This corresponds to the government department in charge of forestry and the environment, based in the Andalusia government's Department of the Environment and the Sicilian Regional authority. The Plans are the responsibility of the Andalusia government's Counsellor for the Environment and the President of the Sicilian region. Under them are the respective regions and regional structures including similar organisational and planning structures (*table 5).*.

Comparison made	INFOCA Plan	SICILY Plan
Structure at regional level	COR with an Advisory Committee and an Information Office	COR
Provincial structure	Network of 8 COPs, with an Advisory Committee in each one.	Network of 9 COP
Regional structure	21 regional units, each with a CEDEFO	-

Table 5-- *Existing power structure.*

Fire-fighting resources are automatically dispatched from the CEDEFO in Andalusia, however in Sicily this situation is only possible in very exceptional cases, with strictly special bureaucratic authorisation from the Airborne Centres, slowing down the process considerably (*Table 6)*. This highlights the INFOCA Plan's theoretically greater speed in arriving at the fire, as well as its control and total extinction, preventing propagation.

Comparison made	INFOCA Plan	SICILY Plan
Responsibility for extinction on woodland	The Forestry Dept. is in charge of technically directing extinction.	The technical direction of extinction is under the Dept. of Agriculture and Woodland (Forestry Dept.)
Automatic dispatch of airborne resources	Yes, at the CEDEFO.	No, only in very exceptional cases
Organisation of first attack	Forestry department	Forestry Dept.
Advance Command Point Directorate	COP Director	
Structure of the Advance Command Point	Planning, operations and logistics sections	Advanced Command Point does not exist as a definition
Fire structure	SMEIF action groups	
Support infrastructure to Advance Command Point	UMMT and UNASIF	

Table 6--*Action, responsibilities for extinction and organisation.*

As regards operating capacity, the largest number of units are concentrated within the high risk period. The Sicilian Region does not differentiate between different risk periods, so that it only assigns resources during the summer months when it is active, leaving other periods unattended (*table 7)*.

Comparison made		INFOCA Plan	SICILY Plan
High risk	1 July - 30 Sept. Full team and resources	Full team and resources	
Average risk	1st May - 30 June 1st Oct –31st Oct Some specialist stand-by crews and airborne resources remain	Some specialist stand-by crews and airborne resources remain.	15th June - 15th Oct.
Low risk	1st Nov-30th April There are no units	There are no units	
Period active		All year.	Summer months

Table 7--*Comparison of resources by danger period.*

Each region has a number of infrastructures and resources for the tasks of forest fire detection, surveillance and extinction in its areas. The assignation of infrastructure resources is fairly similar in general terms (*table 8)*. The numerical differences in absolute and relative terms are explained by the different conception of the two Plans which assign their resources differently.

Comparison made	INFOCA Plan	SICILY Plan
Fire Brigade HQ	-	-
Helicopter Bases	4	6 + 2 support
Main runways own planes	8	-
Own secondary runways	12	-
Watchtowers	231	250
Mobile patrols	345 mobile patrol members	86, one per Forestry detachment
Own medical teams	17	-
Forestry crews	267	-
Heli-transportable crews	4	-
Extinction Vehicles	96	81
Transport Planes on land	6	3
Amphibious Planes	2	1
Coordination Planes	3	1
Fire-fighting helicopters	2	6
Transport Helicopters	1	2
Transport and fire-fighting helicopters	18	6

Table 8--*Infrastructures and detection, surveillance and fire-fighting resources.*

Nevertheless it can be seen that the Sicilian Plan has some shortfalls in its extinction structure: it does not have runways exclusively for Fire Prevention Plan units, most of them having to depend principally on those granted by the official bodies of conventional airports, thus considerably slowing down the operations. Moreover, the non-existence of helicopter-transportable fire-fighters and highly specialised squads means these cannot be used in highly labour-intensive tasks.

The effectiveness of a Fire Prevention Plan is measured by the way in which the available resources - mainly economic - are managed, whether many or few, and the results obtained. Economic resources assigned to the Plans are insufficient for existing requirements in both cases. In the case of the Sicilian Region, these resources are totally insufficient, added to the fact that assignation of all available funds has not yet been determined (*Table 9)*.

Element	Andalusia	Sicily
Euros allotted to regional plan	104 million	3.5 million
Euros allotted to prevention	57.2 million	-
Euros allotted to extinction	41.3 million	-
Euros allotted to restoration	5.2 million	-

Table 9--*Available economic resources in the Sicilian Region and Andalusia.*

In the case of Andalusia, available resources are reasonably sufficient for the tasks undertaken, however many aspects of their management could be improved in order to optimise final results. Thus, the result obtained is relatively optimistic, bearing in mind the above premises.

The Sicilian region does not provide a great deal of information on the resources it has, so that the resulting effectiveness cannot be analysed in sufficient depth. Information provided refers to fairly scantly fire-fighting resources which prove totally insufficient for the needs the Fire Prevention Plan aims to cover. These needs, at the end of the day, are not met or are met insufficiently, placing a greater burden upon the already deteriorated and weakened forestry of Sicily.

Future improvements and recommendations

In order to achieve the objectives of improving prevention, protection and the active forest fire-fighting system in Sicily, a number of measures must be taken, taking Andalusia as an example, with future action which is either already going ahead in the Sicilian fire prevention organisation, or which should be considered.

In the Plan's organisational structure, it must set down procedures for action by teams and services which come under the Sicilian region and by those assigned by other government departments and official bodies. For this purpose independent Forest Fire Investigation Brigades will be set up which shall determine and investigate the cause of all the fires in the region over the course of the year, given the very high degree of actionable fires.

According to the Plan's operations, the human and material resources envisaged will gradually come into service in a staggered manner, depending on the risk indicated by weather conditions. These resources should be fully operational during the period from 1st June to 15th October, save cases of *force majeure*, with a skeleton staff and minimum resources remaining available till the end of the season. If applicable, the Advance Command Post (PAIF in Spanish), the stand-by areas and the base camp may be defined and created to direct and monitor the suppression work.

The greater or lesser density of surveillance resources for each zone is directly related to the number of fires, the information provided by the statistics, and the value of the area to be protected. From the distribution of the quality-risk maps on forest systems and considering the current resources the region has available, a minimum provision of resources is proposed which provides total protection of greater quality systems and minimum protection for lower quality areas, as well as capability in the case of fires of average proportions.

In order to improve on shortfalls, a specific municipal register of burnt zones was produced, as required by the Italian Law 353/2000 - the only measure to stop later speculations after many fires. Correct and preventive information campaigns, with greater awareness and sensitisation, also help to prevent anthropic fires: "Those who love, do not burn" is a call to ignite passion and extinguish indifference.

Measures which give incentive to the right behaviour, with tax deductions for landowners who show concern for their woodland, continue the initiatives of 2002 in the Italian financial law. This is of notable importance as 60% of the national woodland surface area is in private hands.

A "permanent structure" will be set up, adequately provided with human, structural and financial resources, which will independently draw up the planning document and proceed to the Plan's annual review; map-making of the areas affected by fire; acquisition of any element in digital format involved in drafting the Plan; and the verification of action taken to achieve the envisaged objectives. This also involves taking specific political initiatives to reorganise, improve, potentiate and adapt forest-fire prevention measures. Similarly, the creation and strengthening of Forestry Defence Associations amongst forestry land owners will give incentive to the care of potentially endangered areas in the Sicilian region.

The main prevention measure, as well as preventive silviculture, will be to continue collaboration with the Forecasting Services for danger of forest fires" in order to coordinate and include resources which are common to other sectors of public administration

In the active fight, it is recommended that the radio network and anti-fire resources be revised and modernised, and the aerial tele-detection system be activated, extending this to areas of particular environmental and natural interest and to areas of greater fire risk, building upon the growing attention paid by regional policy to defence and conservation of the area, and civil protection and restructuring of the regional administration itself. It is proposed that regional and local anti-fire systems be strengthened, creating their own regional air-borne forest fire protection service, since the suppression of forest fires is done at present with helicopters rented by the Regional Forestry Administration. Special attention should also be devoted to the airborne resources' early warning system, coordinated by the Civil Protection Dept.

The action and participation of the municipalities in the fight against forest fires formulates its own anti-forest fire policy, an integral part of a policy for land management and reclassification. Within this sphere is found specifically designated action, such as compiling regional information essential for the implementation of the remaining action, and the existence of coordination structures with the other bodies within the anti-forest fire system, in order to manage regional resources with the maximum efficiency and effectiveness.

Administration and logistics assigned for this purpose provide functionality for the system, reducing the occurrence of contretemps in a possible emergency situation. For this purpose, the efficiency and effectiveness of the system is evaluated through an audit to provide improvements, render accounts to authorities, assign merit and responsibility, and compare the mechanisms with those adopted in similar situations.

Final Consideration

Qualifications and professionalisation for all personnel in the forest fire prevention service requires to be given an impulse through training courses for both hired personnel and civil servants, as well as voluntary staff, placing special emphasis on the safety of personnel and self-protection in fire suppression tasks. Moreover, it is recommended that wherever possible, activities which include prevention should be promoted, since, apart from reducing the number and effects of the fires, in parallel, effort and human risk may be decreased and contribute positively to the local economy and social conditions.

Any task which supports efficient and speedy decision-making with the use and application of computing and the SIGs should be systematised, since these are essential tools in achieving increasingly effective results, and moreover intensifying collaboration with Italian police surveillance (Corpo Forestale della Regione Siciliana, Carabinieri, Guardia di Finanza).

References

Abbate, R. 2002. **Valutazione statistica del livello di rischio da incendi boschivi in Sicily**. ISTAT-Ufficio Regionale per la Sicily. Progetto "Determinazione di metodologie statistiche per la prevenzione di incendi boschivi in Sicily". Dipartimento di Economia e Territorio. Catania.

Arrigo, M. 2002. **Nuovo programma di vigilanza finalizzato alla prevenzione degli incendi dolosi**. Ufficio Speciale Servizio Antincendi Boschivi, Assessorato Agricoltura e Foreste, Regione Siciliana. Palermo.

Bovio, G. 2002. **La situazione attuale della protezione incendi boschivi in Italia.** En: "Atti del XXXIX Corso di Coltura in Ecologia: Il fuoco in foresta, ecologia e controllo", San Vito di Cadore, 2-6 settembre 2002, Padova.

Bovio, G.; Camia, A . 2002. **Piano Regionale per la programmazione delle attività di previsione, prevenzione e lotta attiva contro gli incendi boschivi 2003-2006**. Regione Piemonte Settore Antincendi Boschivi e Rapporti con il Corpo Forestale dello Stato. Torino.

Consejería de Medio Ambiente. 2003. **Plan INFOCA. Presentación año 2003**. Junta de Andalucía. Sevilla.

Quesada Fernández, C. 2003. **Análisis comparativo entre los sistemas antifires forestales en Italia meridional y Andalusia**. Trabajo Profesional Fin de Carrera. Universidad de Córdoba. Córdoba. Inédito.

Regione Siciliana. Assessorato Agricoltura e Foreste, Direzione Foreste. 1994. **Nuovo Piano di Difesa dei Boschi e delle Aree Protette dagli incendi**. Palermo.

Rodríguez y Silva, F. 2000. **Ejemplos de Planes de Defensa en España: Andalusia.** En: Vélez, R. "La Defensa contra Fuegos Forestales: fundamentos y experiencias*",* pp 11.17-11.56. McGraw Hill; Madrid., España

Effects of Forest Fire Protection on Plant Diversity in a Tropical Deciduous Dipterocarp-Oak Forest, Thailand[1]

Shesh Kanta Kafle[2]

Abstract

A two-hectare plot of a deciduous dipterocarp-oak forest of Doi Suthep-Pui National park of northern Thailand protected against fire for 28 years was compared with a similar, but frequently burnt forest nearby with respect to changes in plant diversity. The objective of was to find out the effects of forest fire protection on plant diversity. To survey the tree communities, six meter wide transects with a total length of 650m in each site were laid out across the slope of the mountain following a bearing of 60. To survey the ground flora, quadrats of 2 2 m^2 area were placed in each site covering 2.3 percent of the total transect area. The importance value percentage (IP) of trees > 10 cm DBH, species composition and diversity for both tree and ground flora communities were calculated. The species richness of both the ground flora and tree species was higher in the protected areas. The occurrence of evergreen or tropophyllous trees was greater in the protected area than in the burnt area.

Introduction

Thailand has suffered a rapid decline in forest cover over the past three decades, loosing more than one half of its forested area. With a total forest cover of 60 percent in 1953, Thailand has only about 27 percent now (Poffenberger & McGean 1993). Recent satellite images indicate much less than this (SPOT, Landsat and ERS). This rampant destruction of forest cover in the past was due to logging concessions, encroachment and development of infrastructure such as roads, hydropower plants and mining. Nevertheless, the practices of shifting cultivation and intentional forest fires are still common in northern Thailand where forest are estimated to cover more than 40 percent of the land area.

Forest fire has increasingly become a frequent and problematic phenomenon in Thailand. Fires have a major impact on National Parks in particular where protection of the flora and fauna and their habitats is the primary aim. Since plant variety and abundance, flowering, fruiting, and leafing phenologies of trees and soil nutrients status are essential features for ecological niches of wild animals, studies on impacts of forest fire on these factors are essential to properly manage the bio-diversity in such areas.

---

[1] An abbreviated version of this paper was presented at the second international symposium on fire economics, policy, and planning: a global view, 19–22 April, 2004, Córdoba, Spain.

[2] Agro-Farm Foresters' Association Nepal (AFFAN), GPO Box: 8365, Kathmandu, Nepal, email: skkafle@hotmail.com.

Hypothesis

This study examined the following hypotheses:

- Prolonged protection of a forest from fire changes the species composition of the ground flora to be more characteristic of a mixed deciduous forest.
- There will be less disturbance effects after protection from fire, therefore, there will be higher plant diversity in protected areas.

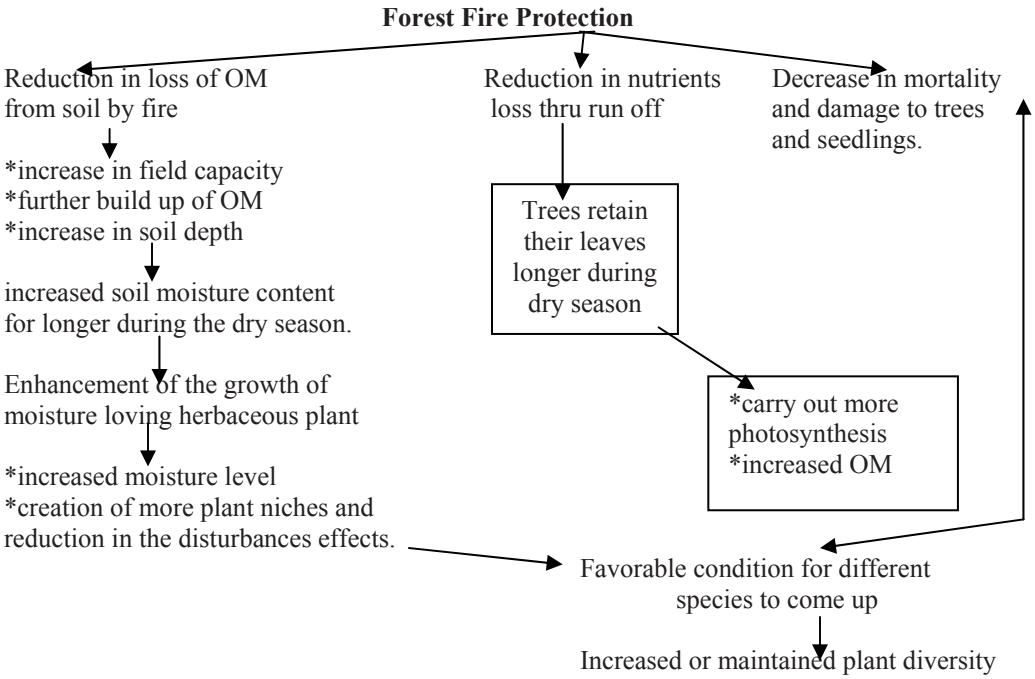


Figure 1—A hypothesized mechanism of the effects of fire protection in a deciduous dipterocarp-oak forest

Objectives

1. To find out the effects of forest fire protection on plant diversity.
2. To identify the potential uses of satellite images in monitoring plant diversity.

Methodology

Study area

This study was carried out in deciduous dipterocarp-oak forest (DOF) in Doi Suthep-Pui National park in northern Thailand. The area lies a few kilometers west of Chiang Mai City at approximately 18°50'E longitude. The forest was designated as a National Park in 1981 and covers an area of 261km2. The DOF is situated from the eastern base at 350 m to 950m elevation whereas the highest point of the park Doi Pui, is at an elevation of 1685 m.

Two sites were selected, one protected against fire for 28 years and the other left unprotected. When selecting the burnt are, besides similar vegetation composition and soil type, much attention was given to other site factors such as aspect, distance from water sources, rocks and elevation. Prior to the final selection, possible sites nearby were reconnoitered and site factors closely examined. GPS was used to locate

the exact position of the site. In the protected area three-meter-wide firebreaks had been maintained to prevent fire spreading into the area. The elevations of both sites ranged from 500 to 650m. The bedrock was granite (Maxwell 1988). In most of the places, soils are shallow, highly weathered, and exposed to soil erosion.

Sampling

Six meter wide transects were laid out across the slope of the mountain, following a bearing of 60°. There were 4 transects in the protected area (PA) and 5 in the burnt area (BA) laid out with varying length. However, the total length of transects in each area was 650m covering 5 percent of the total area.

Data collection and Analysis

All trees greater than 10 cm diameter at breast height (DBH) were labelled and identified. Similarly, ground flora community was monitored using percent cover of each species with the help of Domin Scale (*table 1*). The area over shadowed by tree seedlings and saplings was also recorded. The ground flora community was surveyed at the beginning of rainy season (June), during the rainy season (September) and at the end of rainy season (November).

Table 1—*Domino scale*

Category	Score
+	Single individual
1	1-2 individual
2	<1 % cover
3	1-4% cover
4	5-10% cover
5	11-25% cover
6	26-33% cover
7	34-50% cover
8	51-75 cover
9	>75%< 100% cover
10	100% complete cover

Most of the vegetation data were analyzed statistically using ECOSTAT and SPSS computer programs.

Results

Species Composition and Diversity

A total of 130 plant species, with 29 trees and 101 ground flora species, was recorded from the sampled area (*table 2*). The protected area supported a richer ground flora community than the burnt area although the species richness of tree community was very similar in both areas. The PA also contained slightly more unique species, found only there, than the burnt area. *Dipterocarpus obtusifolius* var. *obtusifolius* was the most abundant species followed by *Shorea siamensis* var. s*iamensis* in both sites. Two deciduous trees namely *Dipterocarpus tuberculatus* var. *tuberculatus* and *Tristaniopsis burmanica* var. *rufescens* had a greater occurrence in the BA compared to PA, even though their percentage contribution was comparatively low. In the PA, *Lithocarpus elegans, Lithocarpus sootepensis, Buchanania lanzan and Quercus kerrii var. Kerrii* were more abundant.

Table 2—*Species composition in the sampled area*[1].

Composition	Number of species [2]				
	Total	PA	BA	% (PA)	% (BA)
Tree spp. (>10cm dbh)	29	22 (8)	21 (7)	76	72
woody climbers	3	3 (2)	1 (0)	100	33.3
Shrubs	14	10 (3)	11 (4)	71	79
Vines	10	9 (2)	8 (1)	90	80
Herbs	74	52 (27)	47 (22)	70	64
Total	131	96 (42)	88 (34)	74	68

1.The number of tree species is based on transect survey whereas ground flora is based on the quadrat made along transects.
2.Figures in parentheses indicate the number of species only found in that site.

Dipterocarpaceae was the dominant family of trees (*table 3*). The percentage composition of individuals of this family was higher in the burnt area (63.58 percent) than in protected area (56.8 percent).

Table 3—*Composition of major tree species >10 cm dbh in the burnt and protected areas*

Species	Number of individuals1	
	Protected site	Burnt site
Diptercocarpus obtusifolius var. obtusifolius	100 (37.45%)	58(35.80%)
Shorea Siamensis	30 (11.24%)	22 (13.58%)
Buchanania lanzan	27 (10.11%)	9 (5.56%)
Shorea obtusa	22 (8.24%)	15 (9.26%)
Quercus kerrii var. kerrii	26 (9.74%)	15 (9.26%)
Lithocarpus sootepensis	15 (5.62%)	4 (2.47%)
Lithocarpus elegans	10(3.75%)	3(1.85%)
Craibiodendron stellatum	9 (3.37%)	5 (3.09%)
Tristaniopsis burmanica var. rufescens	2 (0.75%)	8 (4.94%)
Dipterc\ocarpus tuberculatus var. tuberculatus	0 (0.00%)	8 (4.94%)
Miscellaneous	26 (9.74%)	15 (9.26%)
Total	267 (100.0%)	162 (100.0%)

[1]Percentage figures in parentheses indicate relative dominance of the species.

Basal Area, Tree Density and Community Dominance

Basal area and tree density (p>10 cm DBH) were both higher in the PA than in the BA. (*table 4*). However, average basal area of trees in aggregate was similar in both sites. McNaughton's community dominance index (CD) was practically the same in both sites. This indicates the higher relative dominance values of two most dominant species.

Table 4—*Percentage and total basal area, tree density and community dominance of protected and burnt sites*

Community statistic	Unit	Sites	
		PA	BA
Basal Area Ha^{-1}	M^2	22.67	13.95
Tree Density (>10 cm dbh)	no./ha.	685	415
Community Dominance	%	48.7	49.4

Importance Value of major tree species

More than 50 percent of the importance percentage, calculated from relative basal area (RBA), relative frequency (RF) and relative density (RD), was contributed by Dipterocarpaceae in both sites (*table 5*).

Table 5—*Importance value (iv) of major tree species in the PA and BA*

Species	Protected Area					Burnt Area				
	RBA	RF	RD	IV	IP	RBA	RF	RD	IV	IP
Diptrocarpus obtusifolius	0.48	0.07	0.37	0.92	30.7	0.47	.09	.36	.92	30.7
Shorea siamensis	0.19	0.07	0.11	0.37	12.3	0.16	.09	.14	.39	13
Buchanania lanzan	0.06	0.07	0.10	0.23	7.7	0.03	0.7	.06	.16	5.3
Quercus kerrii	0.08	0.07	0.10	0.25	8.3	0.08	.07	.09	.24	8.0
Shorea obtusa	0.08	0.07	0.08	0.23	7.7	0.07	.07	.09	.23	7.7
Lithocarpus sootepensis	0.03	0.07	0.05	0.16	5.3	0.01	.07	.03	.11	3.7
Lithocarpus elegans	0.02	0.07	0.04	0.13	4.3	0.04	.06	.02	.12	4.0
Craibiodendron stellatum	0.02	0.07	0.03	0.12	4.0	0.01	.07	.03	.11	3.7
Tristaniopsis burmanica	0.034	0.04	0.01	0.05	1.7	0.02	.06	.05	.13	4.3
Diptrocarpus tuberculatus	0	0	0	0	0	0.04	.06	.05	.15	5.0

(RBA = relative basal area; RF = relative frequency; RD = relative density; IV =importance value; IP =importance percentage).

Species Richness Diversity, and Evenness

Computed values of different community statistics are given in *table 6.* The results failed to show a clear distinction between the protected and burnt sites. In PA irrespective of high species abundance and richness, the diversity indices (H') was slightly lower than in BA. However, the values were not statistically different. Also, individuals were more evenly distributed in the burnt area.

Table 6—*Species richness, species diversity and evenness indices of trees in the burnt and protected areas*

Community statistic		Protected Area	Burnt Area
Species richness	No	22	21
Diversity	λ	0.18	0.17
	H'	2.18a	2.24a
	N1	8.81	9.43
	N2	5.46	5.90
Evenness	E5	0.57	0.58

[a] Values of diversity indices of two sites are not statistically different (Using t-test).

Size class Distribution

Fiure. 2 shows a larger amount of regeneration in the PA than in the BA. Around 73 percent of the tree individuals found in the PA was 10-20 cm DBH. It further reveals that very young trees were quite abundant in this site. In the BA, however, only 64 percent of individuals were in this category. There was no marked difference in the distribution of tree individuals in other categories.

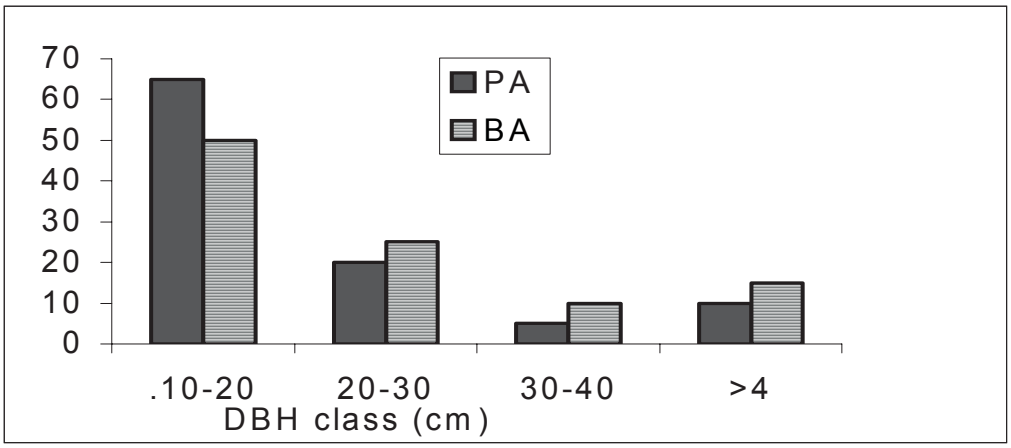


Figure 2— *Size class distribution of tress >10 cm category.*

Ground flora diversity

Regardless of the significantly lower percentage cover, based on the total Domin score (t-tast, p>0.05), the protected area supported a greater number of ground flora species (Table 7). However, the burnt area contained higher species diversity and evenness indices than the protected area. Nevertheless, the species diversity index was not significantly different (t-test, p>0.05)

Table 7—*Ground flora diversity, richness and evenness in the protected and burnt areas*

Community statistic		Protected area	Burnt area
Species richness	No	74	67
	R1	12.49	10.298
	R2	3.98	2.91
Diversity	λ	0.812	0.553
	H'	3.401a	3.477a
	N1	30.207	32.37
	N2	12.316	18.080
Evenness	E5	0.387	0.544
Total Domin Score`	TDS	349.5	505.0

T-test (p>0.05).

Frequency and Abundance score

In both sites, very few species were dominant in terms of their frequency and abundance scores. *Themeda triandra* Forssk. (Gramineae) was the most frequent and highly abundant in both sites followed by *Globba schomburgkii* Hk.f. (Zingiberaceae) in the BA and *Scleria lithosperma var. lithosperma* (Cyperaceae) in the PA. The most frequent and highly abundant species in both sites are given in *table 8*.

Table 8—*Ground flora species with high abundance and frequency scores in the study areas*

Species	Av. Domin score1		% Frequency	
	PA	BA	PA	BA
Themeda triandra	83	72	81	86
Uraria lacei	-	15	-	20
Scleria lithosperm var. lithosperma	14	18	33	48
Scleria levis	-	19	-	43
Abrus precatorius	10	10	52	43
Globba schombergkii	-	32	-	52
Globba reflexa	8	12	24	33
Dunbaria longeracemosa	-	22	-	57
Aristolochia kerrii	7	-	33	-
Curcuma zedoaria	-	18	-	52
Lygodium flexuosum	9	-	29	-
Scutellaria glanduolosa	10	-	48	-
Murdania loureirii	8	-	24	-
Desmodium laxiflorum ssp. Laxiflorum	8	-	29	-

[1]Average of Total Domin Score of July, Spetember and November. The blank (-) does not mean that the species is absent in the site. It indicates the species does not fall within the nine maximum abundant species.

Discussion

The greater tree population density in the protected area was a direct consequence of fire protection. The protected area contained 25% more individual trees than the burnt area. Also, it has more young trees of DBH 10-20 cm category than in the burnt area. This suggests that forest fire protection decreased the killing or damaging of trees, which ultimately leads to increased productivity and organic matter in soil, thus more favorable conditions for growing. This result also supports the findings made by Naidu and Sribasuki (1994) that young plants are more badly affected by fires than mature ones.

Another striking feature noticed during the study was that no individuals of *Dipterocarpus tuberculatus* var. *tuberculatus* greater than 10 cm DBH were found in the PA. However, a few emerging coppicing shoots were seen. This observation agrees with a statement made by Barrington (1931) in a study of forest in Burma that "… protection encourages evergreen undergrowth which prevents the reproductions of *Dipterocarpus tuberculatus* var. *tuberculatus* and would obviously change the vegetation type to a moister type".

Fire protection seemed to have more impact on the herbaceous community than trees. Almost half of the ground flora species recorded were specific to each site. The majority of herbaceous species in the PA were typical of moist condition and some species found in the burnt area are fire resistant . *Phoenix humilis Roy. var. humilis (Palmae)* and *Pennisetum pedicellatum* Trin. (Gramineae) are typical examples. Although the total Domin score in the BA is much higher than in the PA, there was no significant difference in the species diversity index. This was probably due to the dominance of a few species rather than the even distribution of species. *Themeda triandra* Forssk. (Gramineae, and *Globba schomburgkii* (Zingiberaceae), *Scleria lithosperma* (L.)Sw.spp. *lithosperma*(Cyperaceae)were among the dominant ground flora species in both areas.

Conclusions and recommendations

The greater influence of evergreen or tropophyllous trees and the presence of some shade-loving herbaceous flora in the protected area suggest that the forest environment in the protected area was favored by plant associated with a mixed evergreen and deciduous forest. However, no distinct differentiation was observed. Hence, the hypothesis that prolonged protection of forest from fire changes the species composition of the plant community to be more characteristic of a mixed evergreen and deciduous forest was only partially proved. In order to know whether the presence of certain shade demanders was due to changes in the local environment or chance detailed studies in different physiographic conditions are needed.

The higher tree density and more young trees of 10-20 cm DBH category in the protected area adds supports to the idea that the fire protection decreased mortality and damage to trees which ultimately leads to more favorable conditions for different species to grow.

References

Naidu, C.V. and K.P. Srivasuki. Effect of Forest fire on Tree Spices on different areas of Aeshachalam Hills. Journal of Tropical Forestry. July-September 10 (III), 1994.

Proffenberger, M and B. Mc Geen Community Allies : Forest co-management in Thailand, South east Asia Sustainable forest Management Network, Centre for Asia Studies, University of California, 1993.

Maxwell, J.F. The vegetation of Doi Suthep Pui National Park, Chiang Mai Pnvinu, Thailand Tiger paper 15 (4), 6-14.

Barrington, A.H.M. 1931. Forest soil and vegetation in the Hlaing forest circle Burma. Burma Forest Bulletin 25, Ecology series No.1. Rangoon, 1988.

Wildland-Urban Interface Fire Risk Management: WARM Project[1]

David Caballero[2]

Abstract

Forest fires in the wildland-urban interface are a growing problem in Europe as well as in the rest of the world. In the frame of WARM project (Wildland-Urban Area Fire Risk Management), a research activity of the 5th Framework Programme of the European Commission, the scales of the problem and factors identified are presented. According to the experience of past years, a consistent and comprehensive framework is explained in which several research activities are presented. Among them, the characterization of different house-vegetation patterns, the description of interface fuels, the modeling of fire behavior and the participation of water runoff and landslides are considered in the computing of settlement risk and vulnerability.

Introduction

Most of the attention of natural resources protection management goes to the preservation of natural life, ensuring a sustainable and beneficial use for the society. Recently, there exists a growing demand for wildland as places where to live or to spend pleasant vacation periods. This phenomenon is more evident in the nearby of large urban agglomerations and cities. It is expected growing rates of occupation for the next years in wildland.

This situation leads to consider a new scenario of natural resources planning and management, that is where urban areas mixes with wildland grounds. This specific situation is commonly known as Wildland-Urban Interface (W-UI). It is defined as the line, area, or zone where structures and other human developments meet or intermingle with undeveloped wildland or vegetative fuels (United States Department of the Interior, 1995).

Wildland fire experts believe that the threat of massive fire damage to human lives, private property, and natural resources is increasing (Fischer and Arno, 1988) and the reasons for this are: 1. Human activity patterns have changed the landscapes over the past three decades. 2. Natural resources are too valuable to let fires burn uncontrolled. 3. Wildland fire fighting budgets are shrinking. 4. More people are escaping the cities into the wildland. 5. Wildland fire fighters are untrained and/or ill-equipped to fight structure fires. 6. Climatic conditions such as drought are like a match to volatile fuels (Chuvieco et.al, 1994).

W-UI areas present typical problems of cities management together with those found in wildland management. Besides, a specific set of problems arise as synergy and interaction between the two land uses. One of the most prominent problems

[1] An abbreviated version of this paper was presented at the second international symposium on fire economics, policy, and planning: a global view, 19–22 April, 2004, Córdoba, Spain.

[2] TECNOMA S.A. - TYPSA Group, Spain, davidcaballero@tecnoma.es.

found in W-UI areas is the occurrence of wildfires. People inhabiting urban areas and residences amid the forests are barely aware about the destruction potential of forest fires, until they have been stroked by previous experiences (Cortner et al., 1990). Forest fires is something that citizens are not used to, but something that they are exposed to when populating W-UI areas. Foreign people (immigrants and tourists) usually do not care about wildland-urban forest fire risk (Goldammer, 1992; Thomas 1994)

It has been found that wildland-urban fire contingency is frequently associated to large fires and, in most of cases, to crown fires development (Alexander, 1988), as recent regrettable examples show (USA-Oakland Hill, 1991; Greece-Mt. Penteli, Athens 1995, 1998; Spain-Tarragona province 1994; South East France, 1995). In the other side, the presence of agglomerations of people, that frequently are tourists, do represent a potential risk itself in the probability of fire occurrence. Thus, urban areas are, frequently, sources of new wildland fires (Alcázar 1998).

Houses and structures are generally poorly protected against wildfires intensities and behavior, as forest fires strike structures from the outside. The production of flying embers is particularly dangerous as they fall in roofs and ignite accumulated dead biomass.

Post-fire effects, such as erosion, landslides and rainfall runoff, actually threaten structures. In some cases surface flow is multiplied several times because hydrophobic reaction of burned grounds. This entails great risk to structures placed downstream. Smoke is also a serious side-effect in cities and towns near wildland where recurrent fires occur (Eftichidis, 1990). Power lines are also affected and can collapse power distribution. Sometimes, power lines are origin of new fires and they difficult aerial traffic of fighting forces.

Protecting structures against fire in wildland is not an easy task, fire fighters must apply techniques to control forest fires, in such conditions all homes and structures can't be actively protected from fire. In case of active fire fighting, difficult decisions must be taken in the case that human lives, properties and wildland areas are at risk simultaneously (Goldammer 1992). Fire fighting techniques in structures are different from wildfire fighting. Specific dangerous situations are found in both cases (blow-out in forest fires and flash-over in buildings). This demands specific training, techniques and tools (Thomas, 1994). In W-UI areas, water supply is not always available in quantity as required for fighting purposes, as it happens in cities. Besides, access to structures in W-UI areas is difficult. Fighting forces spend too much time in accessing houses located in mid-slope in wildland (mountainous) areas. Frequently people has a one-way escape route

Forest fires in W-UI areas affects a variety of key actors, either as people suffering consequences or personnel implied in the prevention and fighting of wildfires. It has been identified the following key actors: Protection Agencies, home owners, land owners, government and banks and insurance companies. All of them have a role in the planning and management of W-UI areas under fire threat. It is well known that techniques aimed at controlling forest fuels in or around urban areas is not regularly applied in time, place and quantity as required to protect structures from wild fire intensity that such fuels generate.

Hence, the responsibility of fuel control practices and other passive defense techniques must be shared and coordinated between land managers and house owners. Within commuting distance of metropolitan areas, development point to erect relative expensive residences on medium-to large lots. House builders tend to leave as much native vegetation as possible to maintain and promote the rural effect that buyers seek. Also, building materials are commonly non fire-resistant and access roads are narrow and forming dangerous cul-de-sac. Implication of developers and homeowners is critical, which is why population in W-UI places must be aware of actual forest fire risks and of its consequences in their areas.

Wildland-urban fire protection must be planned at regional scale, but it has to be implemented locally. Currently number of information systems are apply to, either, urban planning and forest and wildland planning and management. This includes techniques of data capture using remote sensors, data geo-referencing, analysis and report. There exist a number of models to predict land uses changes, vegetation growth, forest fire progression and, also, detection and estimation of urban areas expansion.

In light of the above, defense planning against forest fires in W-UI areas is a multi-faceted challenge which requires a coordinated effort in identifying, measuring, analyzing and solving the different problems presented.

Wildland-urban interface defense assessment

Framework of the problem

In light of the experience during 2003 fire campaign in Europe and according to the needs identified, several points have to be considered to provide a common understanding of the problem and a common working frame for the planning and management of this problem. Also, this will identify the research lines involved in the W-UI realm, left open for future research projects.

First, it is the need to have a common understanding of the geographical scope and meaning of "settlement". In this point, it should be clarified that the subject deals with groups of houses which could be defined as W-UI units. These not necessarily have to match with the classical definition of settlement, namely, a group of houses forming an structure with common services; instead, a broader definition has to be given and a preliminary classification of types.

In fact "settlement", or what hereafter will be referred also as W-UI Unit, is the geographical area of interest that include a group of houses which have spatial relationship with the existing vegetation, susceptible to burn.

A preliminary classification of these W-UI units can be given according to their house-vegetation structure. Thus, considering vegetation and house density and in the other hand the degree of clustering of both components, the following table is obtained:

Table 1—Wildland-urban interfaces according to house-vegetation patterns

			VEGETATION			
			SPARSE		DENSE	
			Uniform	Clustered	Uniform	Clustered
HOUSE	SPARSE	Uniform	Not Considered	Not Considered	Sparse Intermix	Sparse Intermix
		Clustered	Not Considered	Not Considered	Clustered Intermix	Clustered Intermix
	DENSE	Uniform	Urban	Urban	Intermix	Occluded Urban Interface
		Clustered	Urban	Urban	Urban Interface	Clustered Urban Interface

0. Urban - Dominated by housing occupation. Not considered.
1. Sparse Intermix - Typical structures in rural areas, self-protection plans are needed.
2. Clustered Intermix - Same as (1). Small clusters of few houses, isolated.
3. Intermix - Typical structure in high-value, tourist areas, physical plan, emergency plan and also self-defense plans are needed.
4. Urban Interface - A well-defined boundary exists between house-dominated and vegetation- dominated areas. Physical plan and emergency plan are needed.
5. Internal Urban Interface - Typical structure of large wildland parks inside cities, physical plan is needed to isolate fire and minimize effects on the surrounding houses.
6. Clustered Urban Interface - Same as (4). Urban Interface but in continuous groups.

The assessment for planning will be focusing in the elaboration of:

- Physical plans, oriented to the execution of works
- Emergency plans, oriented to Civil Protection
- Self-protection plans, a tailored version of physical and emergency plans for isolated houses

W-UI Units are located in the landscape which has specific conditions and factors. A first analysis has to be done at landscape level, to provide planning strategies aimed at the prioritization of actions and quantification of the W-UI problem. Thus the assessment should include:

1. Identification of W-UI types, quantification
2. Potential causes of fires, fire origins
3. Fire fighting resources and infrastructures
4. Erosion, landslides and flood risk potential
5. Fire potential (intensity, spread rate)
6. Meteorological and wind most frequent, most adverse conditions
7. Ground accessibility through road network

For the point 1, a tool/method is needed to almost-automatically identify and quantify the different W-UI Unit classes in a certain territorial working area (TWA)

according to the density of vegetation and houses and taking into account the cluster degree of houses an vegetation.

It has been observed that in the destruction of a house participate, first, the probability of fire reaching the house and, second, the probability that the fire destroys the house. To this it has to be considered a third probability or fact, the fire reaching and entering the settlement from the exterior.

Thus, it is required consider three scenarios:

EXT (X)	Fire propagating from outside the settlement and then entering it
SET (S)	Fire propagating inside the settlement
HOU (H)	Fire behavior in the lot and around the house, destroying properties

To this a new scenario has to be added, that specific of the Interface Zone (IFZ), which corresponds to the area of vegetation surrounding the settlement which potentially can drive fire to the vicinity of houses and evenly transport fire inside the settlement. This zone, which is a boundary between EXT and SET scenarios, is not present in all W-UI Unit types.

EXT (X) The fire external to the front is conditioned by the propagating factors, namely, forest fuel, topography and wind which corresponds to the immediate exterior of the settlement ("near zone", or 500 m. buffer around settlement boundary).

The fire can reach the settlement in two ways:

- A fire front approaching settlement boundary
- By firebrands flying inside settlement

Both phenomena do not automatically entail the propagation of the fire within the settlement and the destruction of houses.

SET (S) The fire propagates in the settlement thanks to the existing fuel, topography and wind conditions. To this we must add the unburnable structures which could act as barriers. But in the other hand we must consider again fire front propagation and firebrand production. The propagation inside the settlement is expected to occur through a non-uniform fuel pattern in a non-continuous flame front.

HOU (H) Fire behavior in the vicinity of the house is conditioned, mostly, by the presence of fuels and the wind. Radiation and convection are both related to the heating and destruction of the exterior house and properties outside, particularly when this entails flame contact. Also, sometimes this behaviors entails the fire entering or breaking into the house and destroying the house inside.

The above mentioned fire scenarios must be coupled with:

- Effective fire fighting operations, at the three levels (X, S and H)
- Civil protection (evacuation, confinement) and human behavior

The efficiency of these two set of operations can be helped or impeded by the infrastructures and local conditions at the three levels (X, S and H). In the end, our assessment has to point to the identification of:

- Potential destruction of settlement values
- Risk to human lives
- Destruction of properties in the lot, external to the house
- Destruction of the interior of the house, and thus the house itself

This assessment, that is the identification and quantification of factors that drive to these events, will have as outcome the measurement of vulnerability and risk associated to a settlement.

It is interesting to observe that these three scenarios, (X, S and H) happen normally in sequence one after the other, but in a real fire all of them can happen simultaneously in different points. Individual vulnerability of houses can be typified and sums to the total computation of settlement vulnerability and risk.

In light of this, in order to give a reasonably complete assessment, it is required to approach and solve the following questions:

In the EXT scenario:

- X1 Which meteorological and wind conditions are in average the most adverse for this settlement?
- X2 Which are the location and type the most likely sources of fire (starting points) or expected approaching fire fronts reaching this settlement?
- X3 How much is this settlement covered by nearby ground and aerial fire fighting forces?

In the SET scenario

- S1 How fire will reach and enter the settlement?
- S2 How fire could be effective and safely suppressed or controlled?
- S3 How fire will destroy settlement values (vegetation, infrastructures etc.)?
- S4 How fire should entail putting people at risk?

In the HOU scenario

- H1 How fire will behave in the lot and around the house?
- H2 Will the fire destroy properties outside and exterior of the house?
- H3 Will the fire enter the house and destroy it from inside?
- H4 Could the house constitute a safe shelter for people?
- H5 Which effective and safe fire fighting operations could be applied?

The assessment will be given in the form of maps and recommendations. The maps will be derived from the spatial analysis at settlement scale of the points mentioned above. Recommendations will be technical reports and protocols, and will point at:

In the EXT scenario

- Effective fuel management and vegetation structures in the exterior of the settlement

- Effective fire fighting operations (to avoid the fire entering the settlement)
- External accessibility and structures to help effective and safe fire fighting

In the SET scenario

- Fuel design and management to avoid adverse, sustained fire propagation
- Internal accessibility and structures to help fire fighting and Civil Protection operations
- Effective and safe fire fighting operations, to minimize fire propagation in the settlement
- Effective Civil Protection operations, to keep people safe in every moment

In the HOU scenario

- Fuel (gardening) design and management to provide a safe place and minimize effect of fire on properties and house
- Design, location and protection of properties exposed outside the house
- Material, elements and their position/defense relative to potential sources of fire
- Identification and adaptation of house's weak points, through which fire could enter
- Effective and safe fire fighting operations
- Structure and infrastructure to help fire fighting safe and effectively
- Classification of house as "fire shelter", or identification and adaptation of the required elements to be classified as it.

All the recommendations and the maps mentioned will constitute a preventive physical plan for settlement protection against forest fires. This should be complemented with an emergency plan oriented specifically to the protocols to follow in case of fire emergency, and should be directly pointing at the people inhabiting the settlement in such moment. Both documents, preventive physical plan and emergency plan, will constitute the General Plan of the settlement for its protection against forest fires.



Settlement vulnerability, risk and value loss assessment

At settlement scale, defense planning assessment has to touch the following factors and considerations:

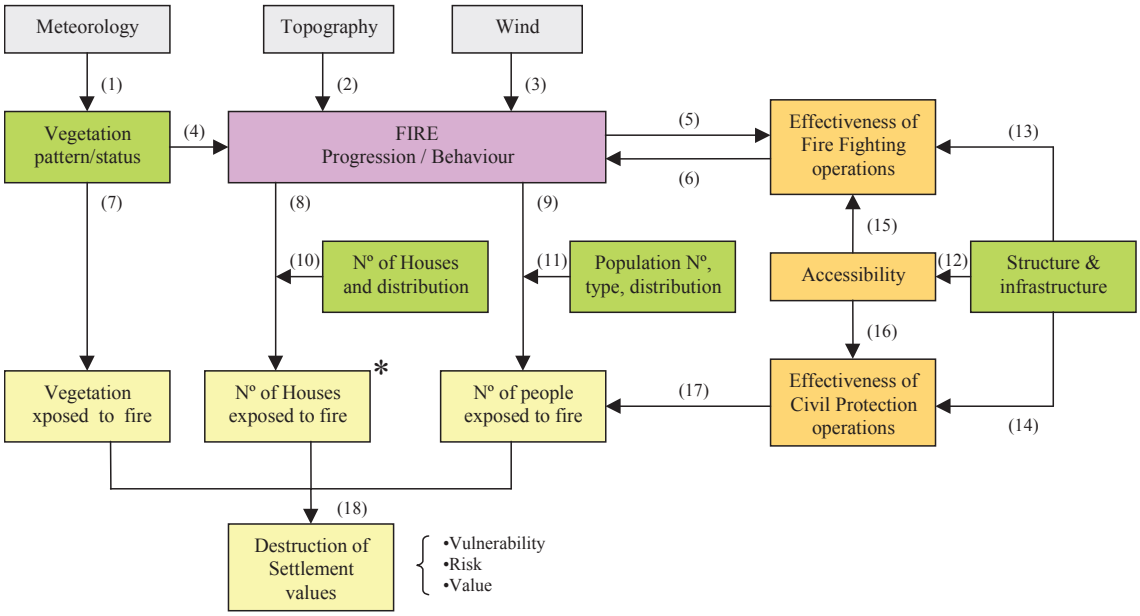


Figure 1—Assessment scheme at settlement level

- Vegetation patterns, understood as spatial distribution of burnable and non-burnable material, affecting fire behavior thus conditioning fire ignition and propagation inside the settlement. This accounts also for firebrand and smoke production and intrinsic properties, such as heat content, flammability or bulk load per volume unit. To the existing wildland fuels, specific to settlement fuel species have (4)
- Vegetation inside settlement as an intrinsic value (aesthetics, shadow etc.), with an associated monetary value, that could lead to destruction due to the fire front passing (7)
- The number and type of houses and the distribution within the settlement forms a pattern itself. When coupled with the fire front passing, a computation of the total house exposition to fire can be obtained. The evaluation of vulnerability, risk and values affected is done in more detail in the house vulnerability assessment (10)
- The people still present in the settlement while fire is progressing inside the settlement, can be coupled with the expected fire progression to compute the exposition of such people to fire and smoke. Number and type of people (mainly mobility) and human behavior has to be taken into account (11).

- The presence of specific infrastructures (such as, helispots, safe areas and shelters, including the houses that can be classified as such) can contribute to the effectiveness and safety of civil protection operations, such as evacuation, confinement and rescue (14).
- Civil protection operations will lead to the movement and/or protection of people potentially exposed to fire. This does not ensure, however, that all the people in the settlement will be kept under safe conditions. The remaining, exposing themselves (voluntarily or not) will account to the potential loss due to fire progression (threat to human lives) (17).
- Total accounting of vegetation loss, house and property loss (as comes from house level analysis) and threat to human lives will be synthesized in an unique, unified measurement of settlement vulnerability, risk and value at risk (18).

Lot and house vulnerability, risk and value loss assessment

At house-lot level the following points must be taken into consideration:

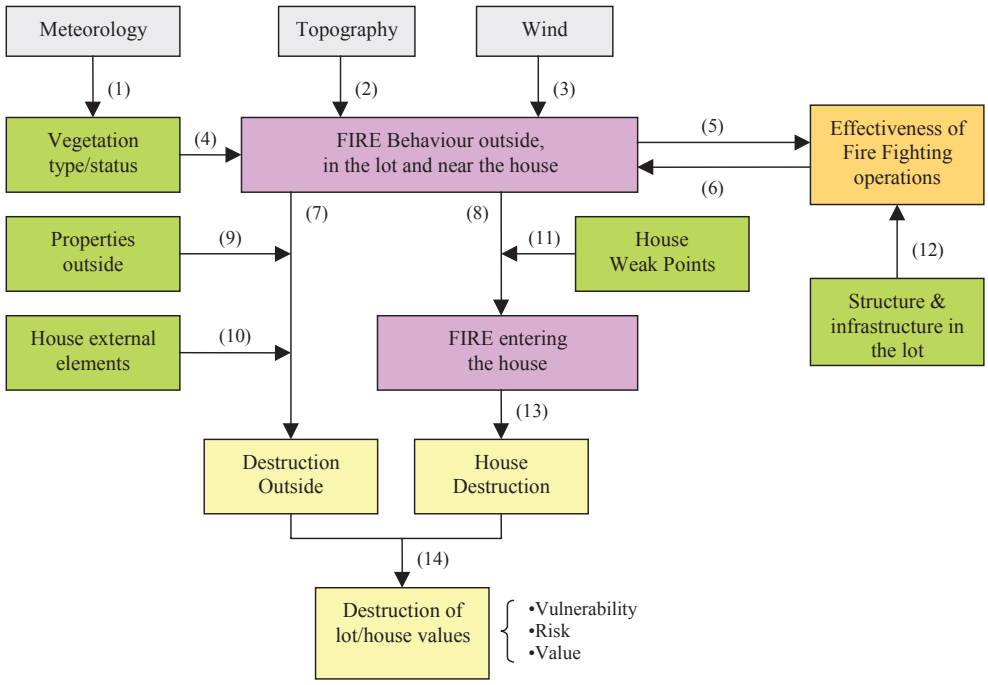


Figure 2—Assessment scheme at house-lot level

- Vegetation components in the lot, such as hedges, ornamental bushes and trees, affecting fire behavior thus conditioning fire ignition, propagation and heat release inside the lot. Intrinsic properties, such as heat content, flammability or bulk load per volume unit, of specific settlement fuel species has to be considered. 3D position, space occupation and species (characterized as mentioned before) will be inputs for the assessment. Besides, vegetation inside

the lot as an intrinsic value, with an associated monetary value, which has to be accounted in the total value of the lot (4).

- Locally developed fire behavior (radiation, convection, smoke) conditions fire fighting operations locally. Burning of other components and the house must be considered as well (5).
- Fire behavior inside the lot has destructive effects on the vegetation, understood as a value of the lot, the properties located outside the house, normally in the garden, and the external parts of the house (7).
- Fire behavior threatening house can derive, under certain circumstances, into the fire entering or breaking-through into the house (8).
- Properties outside the house, normally are exposed to the heat sources, hence entailing destruction and accounting for the total value loss of the lot (9).
- House external elements are commonly directly exposed to fire, such entailing different degrees of destruction, which derives into house value loss. Materials and their ease to be destroyed, 3D position relative to heat sources and value of such elements have to be considered (10).
- Weak points are those spots in the house structure that, according experience, fire enters or breaks through into the house, thus exposing interior to the ignition and destruction of properties inside or the house itself. Type and their relative 3D position to heat source has to be considered (11).
- Once fire is entering the house, it could entail the ignition and propagation of fire inside the house, even the total destruction of the building. This part fall in the domain of structural fires. Valuation of losses accounts here for the properties inside and the house itself (13).
- Total accounting of the lot and house vulnerability, risk and potential loss of values at risk is obtained by summing the losses in the exterior and interior of the house. This should be an input to the assessment at settlement level, thus accounting the total vulnerability, risk and values at risk of the settlement. To proceed, houses can be typified in a number of cases for which detailed assessment can be provided, and then extrapolate to the rest of the houses of the same type within the settlement (14).

WARM project

Description and objectives

Fires in the W-UI/RA have been studied for decades in USA, Canada and Australia, among other countries. Looking at this experience, a number of research projects, co-funded by the European Commission, are now focusing into the reality of W-UI/RA fire management in Europe. Among them is WARM project (Wildland-Urban Area Fire Risk Management).

Within the context of WARM project, a scientific approach is proposed to complete a series of studies, experimentation activities and developments which will end up in a methodology and a computer-based Decision Support System in the aim that the resulting tool and protocols will assist wildland and urban planners to identify and solve forest fire risks to minimize losses and costs.

General objective of WARM project is to characterize direct and indirect risks due to fires in the wildland-urban interface (W-UI) in Europe and to provide a methodology and an information system to minimize losses of residences and other structures, while reducing social and environmental impact, throughout the assistance in the elaboration of rationalized, encompassed wildfire defense plans.

In this project, six countries participate with their experience and study cases, namely Spain, France, Italy, Greece, Slovak Republic and Czech Republic. These represent a significant number of cases hence a good sample of W-UI problem in Europe.

Conclusions

In light of our activity in WARM project, a number of conclusions can be derived in regards to Wildland-Urban Interface in Europe:

- Forest fires in the W-UI in Europe are an emerging and growing problem, with social and economical consequences. In Europe, especially in Mediterranean countries, forest fires affect people, properties and natural environment. However, houses are affected but frequently they are not destroyed.
- W-UI problems have, at least, three different scales which must be approached in different ways, but consistently between them: landscape, settlement and house levels.
- Assessing settlement vulnerability to forest fires is a complex task that can be approached through the identification, measurement and spatial analysis of particular variables
- Settlement can be understood as a structure itself
- Settlement vulnerability is strongly based on house vulnerability, but also on fire progression within the settlement, accessibility and house exposition to fire
- House / vegetation densities and clustering degree are variables related to the progression of fire within the settlements. Each type demands different defense approaches.
- RS and GIS techniques can be applied to identify and measure relationships between vegetation and house distribution
- It is proposed to elaborate a danger index associated to such vegetation/house distributions
- Spatial integration of all the observed variables in synthetic maps help to identify which components have to be modified and which are the areas of higher vulnerability within a settlement.
- For each of the identified cases of settlement vulnerability, a set of good-practices and guide for self protection has to be produced and handled to people living in the settlement.

References

Alexandrin, D. (1996). A new method of fire danger mapping in the forest urban interface. Workshop on Wildfire Management-Systems, Models and Techniques Fire Prevention Planning Session, June 3-4, 1996, Athens, Greece.

Caballero, D. Martinez-Millán, F.J. Martos, J. Vignote, S. (1994). CARDIN 3.0, A Model for Forest Fire Spread and Fire Fighting Simulation. Vol.1: 501. In proc. of 2nd Intl. Conf. on Forest Fire Research. Coimbra, Portugal.

Cohen J., and J. Saveland. (1997). Structure ignition assessment can help reduce fire damages in the W-UI. Fire Management Notes. 57(4): 19-23.

Cohen, J. D., R. A. Chase, S. L. LeVan, and H. C. Tran. (1991). A model for assessing potential structure ignitions in the wildland/urban interface. Pp. 50-57. In proceedings of the 11th Conference on Fire and Forest Meteorology, April 16-19, 1991, Missoula, Montana. Andrews, P.L., and D. F. Potts, editors. Society of American Foresters, Bethesda, MD, USA. 616 p.

Cortner H. J., and T. Lorensen. (1997). Resources versus structures: Fire suppression priorities in the wildland/urban interface. Wildfire. 6(5):23-33..

DeGrosky, M. T. (1997). A fire professional's strategy for influencing wildland-urban interface development. Wildfire. 6(5):16-20.

Foote, E., Martin, R., Gilless, J.K. (1991). The defensible space factor study: a survey instrument for post-fire structure loss analysis. In Proceedings of the 11th Conference on Fire and Forest Meteorology, April 16-19, 1991, Missoula, Montana.

Franklin, S.E. (1987). Urban-Wildland Fire Defence Strategy, Precision Prescribed Fire: The Los Angeles County Approach. In Proceedings of the Symposium on Wildland Fire 2000, April 27-30, 1987, South Lake Tahoe, California.

Harris, J. P. (1998). LCES in the interface - learn it, remember it, use it every time. Wildfire. 7(9): 10-16.

Otto, G. (1998). Building smarter in Urban/Wildland areas - the case for RASTRATM. Wildfire. 7(11): 16-18.

Packham, D. R. (1995). Evacuation in wildfires: The Australian experience. Wildfire. 4(2):24-30

Perry, D.G., (1990). Wildland Fire-fighting. pp.275-284. Fire Publications Press.

Queen, P. L. (1993). Fighting fire in the wildland/urban interface. Fire Publications Inc. Bellflower, California, USA. 119 p.

Queen. P. L. (1995). Evacuation at a Wildland/Urban Interface Fire. Wildfire. 4(2):22-23

Teie, W.C. (1994). Fire-fighter's Handbook on Wildland Fire-fighting. pp.53, 195-220. Deer Valley Press (Rescue, California).

Trelles, J. (1998). Modelling fire-induced winds in the 20 October 1991 Oakland Hills fire. Wildfire. 7(4):15-17.

Vélez, R. 1995. Planning for wildfire and evacuation in Spain's wildland/urban interface. Wildfire. 4(2):37-38.

Waggoner, E., and M. Terwilliger. (1998). Fighting fire in the I-Zone: "Safe to Stay". Wildfire. 7(10):17-22.

Xanthopoulos, G. (1994). Development of a decision support system for water bomber dispatching in Greece. pp. 139-149. In proceedings of the 2nd International Conference on Forest Fire Research, November pp. 21-24, 1994, Coimbra, Portugal. Domingos Xavier Viegas, Univ. of Coimbra, Portugal. 1275 p.

Evaluating Tradeoffs Between Wildfires and Fuel Treatments[1]

Philip N. Omi[2]

Abstract

Wildfires continue to burn in the US despite rising concerns for the costs and losses associated with recurrent fire episodes. Prescribed fire and other fuel treatments have been proposed as potential solutions to US fire problems, though fire hazard reduction through fuels management can be controversial. Evaluating tradeoffs between wildfires and fuel treatments for a geographic area may sound straightforward, especially with a growing body of evidence showing fuel treatment effectiveness in reducing wildfire severity within a stand. However analytical problems in assessing treatment productivity are considerable, and may be compounded by deficiencies in the type of data typically collected by public agencies. Other problems are rooted by the relatively scant information available on treatments applied on a landscape scale. Further, public agency proxies for minimizing wildfire cost and net value changes may not link directly with societal values.

Introduction

The US has experienced episodic wildfire seasons in 1988, 1994, 1996, 2000, 2002, and 2003, with significant fire incidents occurring annually. Over the years, policy makers, scientists, and various publics have labored long and hard to develop different alternatives to these recurrent outbreaks. The usual conclusion reached is that solutions involve a systematic approach to fire management, including a combination of fire prevention, fire suppression, fuels management, ecological restoration, and other activities. Traditionally, fire suppression has received the most focus by far. More recently, fuel treatments such as prescribed fire and mechanical thinning are often seen as a critical part of hazard reduction and resource management plans, though tradeoffs between wildfires and fuel treatment alternatives have proven elusive and difficult to establish.

The number and size of fires varies considerably from year to year in the US, with a variety of causative agents (i.e., human activities vs. lightning) and contributory influences, e.g., climate, weather, fuels, topography, and cultural activities. The same variability characterizes fire activities in geographic regions both inside and outside the US, with episodic peaks and followed by lulls in fire activity, with some years near average. Thus, isolating the effects of fuel treatments on future wildfire occurrence, size, and/or effects presents numerous analytical difficulties.

Purpose

Recent US initiatives call for dramatic increases in fuel modification in the nation's forests. However, little information is available for assessing the success of fuel treatments, such as prescribed fire, in reducing wildfire cost and damages. The

[1] An abbreviated version of this paper was presented at the second symposium on fire economics, policy, and planning: a global view, 19–22 April 2004, Córdoba, Spain.

[2] Professor, Colorado State University, Department of Forest, Rangeland, and Watershed Stewardship, 131 Forestry, Fort Collins, CO 80523-1472, USA.

purpose of this paper is to examine information currently available from accessible public sources and ascertain their usefulness, if any, for establishing tradeoffs between wildfires and fuel treatments. A case example comparing wildfire and prescribed fire unit costs ($/ha) is presented, using available information from reliable worldwide web sources. A case is then made for considering the plausibility that, at least in the short-term, wildfires may reduce fuels over a much larger area than can be achieved through planned fuel treatments. Longer-term implications also are discussed.

Background

The literature on fuel treatment effectiveness is quite limited (Martinson and Omi, in review). However, to date most studies stop short of evaluating tradeoffs between wildfires and treatments, due to analytical difficulties first identified by investigators such as Davis (1965) and Simard (1976). These and other investigators identify the difficulties associated with establishing the productivity of fuel treatments in terms of effecting subsequent reductions in wildfire costs and losses. Analytically, a major problem lies in determining a production function for fuel treatments. Other difficulties lie in determining rates of technical substitution between various treatment alternatives, or production possibilities for wildfire protection in the urban interface versus ecological restoration of more remote wildland ecosystems. Further, data typically are neither collected nor reported in formats that allow inferences about the relative returns from different types of treatments.

For example, the US federal government only recently has started posting summaries of annual frequency and wildfire area burned, agency wildfire suppression costs, areas treated by prescribed fire, and agency prescribed fire expenditures (i.e., see http: www.nifc.gov/stats). With the exception of area burned, the length of record is quite short for these summaries. However, more critically, there appears to be no way to connect prescribed fire (or any other treatments) to eventual alterations in area burned.

Fuel treatments in advance of wildfires have a long and controversial history in the US, dating back to the so-called “light burning controversy” of the early 20th century. At that time a loose coalition of scientists and timber companies in northern California proposed that periodic surface burning of forests with low intensity fires could reduce the potential for catastrophic wildfires. Although eventually discredited by agency scientists, proponents for light burning periodically questioned the wisdom of agency fire exclusion policies throughout the 20th century and to this day. Only recently have fuel treatments such as prescribed fire and mechanical thinning become mainstream forestry activities, spurred mostly by the recognition of the futility of fire exclusionary policies promulgated by agencies for most of the past 100 years.

Fuels management involves the deliberate manipulation (reduction, removal, and/or rearrangement) of flammable biomass to achieve fire protection and land management objectives (Omi, in prep.). Methods include a variety of mechanical thinning and prescribed fire alternatives, but also include biological, chemical, and natural controls.

Fuel treatments generally manipulate the structure of forests to reduce fire hazards at stand and landscape scales. Structural changes occur in the fuel loadings, horizontal and vertical continuity, age class distributions, and species composition

that characterize ecosystems, for example. As a result, wildfire severity is reduced, suppression costs and effectiveness are optimized, and firefighter safety is improved.

Recent proposals for expanding fuel treatments include an interagency strategies for treating 161 million hectares at risk from wildland fires (Williams 2003) and the 2003 Healthy Forests Restoration Act (P.L. 108-148), signed by President G.W. Bush. These initiatives will increase dramatically the magnitude of future areas treated in the US, primarily in the western US.

Federal agency land bases

To visualize some of the analytical difficulties, we will start with a simplified example comparing wildfire suppression and prescribed fire costs on federal lands within the US. Table 1 provides a context for making this comparison by comparing respective land bases managed by the different federal land management agencies.

Table 1— *Differences in federal agency, land bases, and primary management units help explain some, but not all, variability in annual outlays for fire and fuels management.*

Federal agency	Land base, in million ha	Primary management units
USDA Forest Service	77.3	155 national forests and 20 national grasslands
USDI Bureau of Land Management	109.3	Multiple use areas within 50 states
USDI National Park Service	32.4	166 national parks, monuments, preserves, and seashores
USDI Fish and Wildlife Service	38.5	540 National wildlife refuges and thousands of small wetlands and special management areas.
USDI Bureau of Indian Affairs	22.7	Tribal and Indian Trust lands

US federal agencies protect and manage vastly different pieces of real estate, and costs would be expected to vary substantially across timbered national forests of the USDA Forest Service, as compared to the predominant shrublands of the BLM, scenic vistas in national parks and monuments, wetlands in wildlife refuges, or traditional native uses on Indian trust lands. In addition to differences in the values protected, fire behavior and effects will vary widely among the various fuel types represented within each agency's jurisdiction. Differences in expenditures may also reflect agency missions and management practices--and the extent to which agencies have come to grips with managing fire problems in the past.

Wildfire area burned and suppression costs on federal lands

US frequency and area burned summaries go back to the early-mid 20th century. By contrast, cost data are difficult to resurrect and analyze. Although most fires remain small and result in relatively insignificant impacts, occasionally fires grow large and cause significant damages, including loss of life. In some years, climate and fuel conditions will contribute to numerous large fires regionally. Thus a plot of fire frequency against size shows a high fraction of fires in the small size classes, decreasing proportions of mid-sized fires, and an even smaller ratio of large fires (to

the total number of fires), as shown in Holmes and others (2003). The relatively few large fires (say in excess of 1,000 hectares) cause the bulk of natural resource damage and housing losses.

Generally, larger fires are more costly, with so called mega fires accounting for as much as 80-90 percent of annual suppression expenditures. However, as might be expected, area burned at best provides an incomplete proxy for the costs, damages, and ecological impacts of forest fires. Data are not collected routinely on fire damages and ecological impacts, so we can only speculate on the magnitude of these outcomes. However, some of the costs can be monitored relatively easily, although suppression expenditures alone will be a poor reflection of all costs associated with wildfires and their management.

Figure 1 shows US federal wildfire suppression costs over time, in this case for the period 1994-2000. Clearly the USDA Forest Service expends more than other federal agencies combined from year to year, followed by the Bureau of Land Management. These agencies protect more public land than the other federal agencies so we would expect higher total expenditures. However these estimates may be misleading since suppression costs will only reflect spending on large fires—spending prior to a fire for staffing, equipment, or other preparedness measures may not be included. Further, spending by state, local, and private entities will not be reflected.

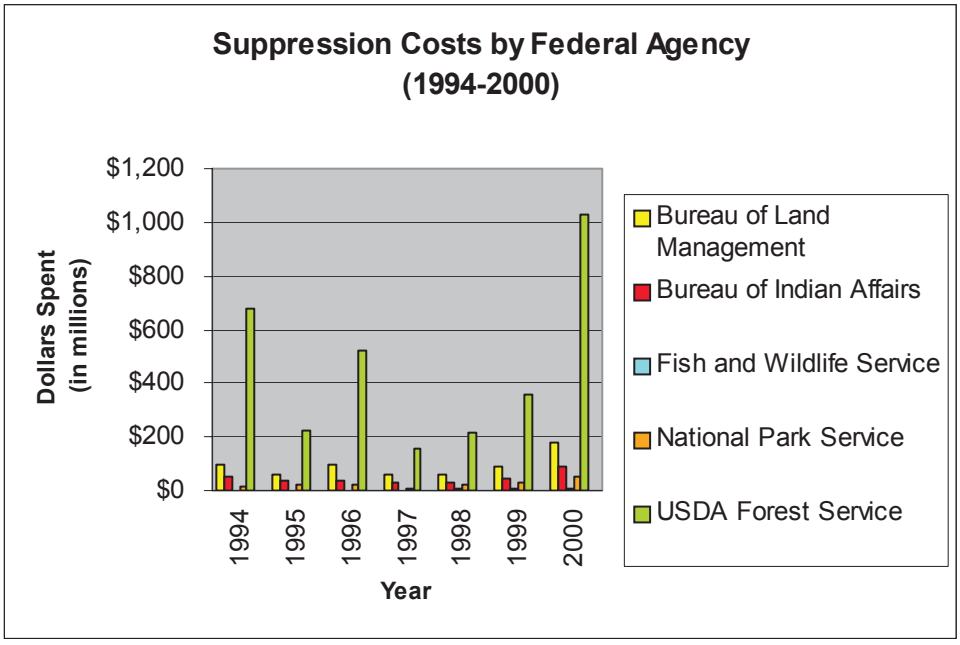


Figure 1— Total suppression expenditures by federal agency, 1994-2000. Estimates are unadjusted by inflation (source: http://www.nifc.gov/stats)

Variation in expenditures can be explained by differences in agency missions, land base, fire loads, and recording standards, as well as numerous other considerations. In this paper I focus on federal agencies, because of their general primacy in US fire and fuels management. Table 1 provides a sense for differences in

federal agency mission and land base, but differential fire loads are difficult to assess because a large fire may involve multiple jurisdictions and cross numerous property boundaries as it spreads across a landscape. Typically, expenditures will be assigned to the responsible agency at the location of the fire's origin, but eventually costs may be shared among many other organizations, depending on how the fire spreads and cooperative arrangements among participating entities. Sometimes cost assignments and reimbursements among agencies will require months and even years to resolve, depending on fire complexity and spread patterns. For example, if state and private lands are involved the process could drag on even longer, especially if disaster insurance claims are involved. Thus cost estimates probably need to be viewed with considerable caution.

Table 2 provides an estimate for suppression costs per hectare burned on federal lands during 2000-2002, across all federal agencies in Table 1. Based on area burned, 2000 and 2002 were severe fire years in the US, while 2001 was relatively quiet. During these three years, suppression costs ranged from a low of $375 per hectare in 2001 to $571 per hectare in 2002.

Table 2— *US wildfire burned area and suppression costs can be used to estimate costs per hectare during 2000-2002.*

Year	US wildfire burned area (ha)	US estimated wildfire suppression costs	Estimated costs per ha burned by wildfire	Source
2000	3,409,813	$1.3 billion	$380	http://www.nifc.gov/fireinfo/2000/index.html
2001	1,445,713	$542 million	$375	http://www.nifc.gov/fireinfo/2001/index.html
2002	2,808,738	$1.6 billion	$571	http://www.nifc.gov/fireinfo/2002/index.html

Prescribed fire area burned and costs on federal lands

Information on fuel treatment area and costs is harder to come by than wildfire burned area and costs since agency fuel programs are relatively new and good record-keeping hasn't always been standard practice. In the US, federal agencies have been under increasing pressure to increase usage of prescribed fire and other fuel treatments (such as mechanical thinning), especially after the bad fire years in 2000, 2002, and 2003. Table 3 shows prescribed fire area treated by federal agencies recently. Compared to the agency land bases in Table 1, the annual prescribed fire accomplishment is pretty low considering the total area under each agency's jurisdiction. In fact, the annual area burned by both wild and prescribed fire on federal lands constitutes about one percent or less of total agency land bases.

Table 4 provides estimates for federal agency prescribed fire annual expenditures. As with wildfire costs (Figure 1) the differences between agencies reflects a variety of factors, including type and size of land base, agency mission, workforce expertise and experience, among others. Further, prescribed fire cost estimates reflect expenditures for execution but not necessarily planning, preparation, and data collection costs—or costs associated with escapes, which would show up as wildfire expenditures.

Table 3— *Annual area (ha) treated using prescribed fire by federal agencies during 1995-2000, including 6-year averages and standard deviation (Std). (source: http://www.nifc.gov/stats)*

Agency	1995	1996	1997	1998	1999	2000	Ave (Std)
USDA Forest Service	230,891	249,864	444,396	602,953	558,688	294,833	396,937 (161,546)
Bureau of Indian Affairs	8,502	6,478	14,980	19,549	33,957	1,357	14,137 (11,633)
Bureau of Land Management	22,672	20,243	29,352	81,062	124,696	50,850	54,813 (41,145)
National Park Service	25,101	21,053	28,340	34,869	54,834	7,721	28,653 (15,702)
U.S. Fish and Wildlife Service	84,615	72,874	131,174	115,691	121,663	81,398	101,236 (24,481)
Total	371,781	370,511	648,242	765,006	906,925	436,160	583,104 (225,228)

Table 4— *Federal agency annual prescribed fire expenditures, 1995-1999, unadjusted for inflation (source http://www.nifc.gov/stats). Expenditures will likely increase even more as public agencies commit to expanded prescribed fire programs.*

Year	Bureau of Land Management	Bureau of Indian Affairs	Fish and Wildlife Service	National Park Service	USDA Forest Service
1995	NA	$840,000	NA	$3,200,000	$16,406,000
1996	$1,200,000	$650,000	NA	$3,200,000	$24,500,000
1997	$1,600,000	$800,000	NA	$4,600,000	$29,146,000
1998	$6,700,000	$2,268,000	$4,825,000	$7,000,000	$50,000,000
1999	$10,600,000	$6,300,000	$7,404,000	$9,800,000	$65,000,000

Based on the agency estimates for annual area treated in Table 3 and annual costs (Table 4) for prescribed fire, a rough estimate of agency prescribed fire unit costs (per hectare) can be computed (Table 5). Estimates vary from a low of $41.69/ha for the Fish and Wildlife Service in 1998 to a high of $200.76/ha for the National Park Service in 1998, with an average $96/ha across all agencies during the years of record. Rideout and Omi (1995) have described reasons for the variability in unit cost estimates for prescribed burning, including size of the burn project, objectives, complexity of project, and fuel types. Generally speaking, the larger the prescribed burn project area, the lower the unit costs of treatment execution.

Table 5— *Estimates for prescribed fire costs per hectare, based on agency estimates for costs (Table 3) and area treated (Table 4).*

Year	Bureau of Land Management	Bureau of Indian Affairs	Fish and Wildlife Service	National Park Service	USDA Forest Service
1995	NA	$76.45	NA	$127.48	$71.06
1996	$59.28	$100.36	NA	$152.00	$98.06
1997	$54.51	$53.40	NA	$162.30	$65.58
1998	$82.65	$116.02	$41.69	$200.76	$82.92
1999	$85.02	$185.52	$60.86	$178.73	$116.34

The average prescribed fire unit costs ($96/ha, with a range of $42/ha to $201/ha) can be roughly compared with the average suppression cost ($442/ha) presented in Table 2, ranging from a low of $375/ha in 2001 to $571/ha in 2002. Prescribed fire and fire suppression are not substitutes for one another, so this comparison is not totally meaningful. However, these limited data confirm the conventional wisdom that fire suppression is much more costly than prescribed fire on a unit cost basis.

Discussion

Research has shown that most north American wildlands will eventually burn. Wildfires generally burn with uncontrolled intensity, and attendant high costs and losses. Although significant exceptions occur, e.g., Cerro Grande (2000), prescribed fires generally burn with controllable severities, lower costs, and even produce benefits if applied correctly. So managers (and society) confront a fairly clear choice regarding the type of fire that would be preferred in wild areas, i.e., uncontrollable wildfires vs. managed prescribed fires (or substitute treatments).

The presumed advantage to prescribed fires over other treatment alternatives (such as mechanical thinning) is its low cost. Generally the marginal rate of technical substitution between prescribed fire and thinning would seem to favor prescribed fire except where revenues can be derived from thinning products and/or where smoke and risk of prescribed fire escape are high. A significant exception may occur where the fire treatment confers ecosystem benefits not included in normal calculations, such as nutrient recycling, or fireproofing a stand against future wildfire outbreaks. However the tradeoff between prescribed fire and other treatments, such as mechanical thinning may be less relevant, especially given the analytical difficulties of determining the productivity of each treatment, or substitutability of treatments.

Given the analytical problems associated with evaluating fuel treatment tradeoffs, in the short term we might consider a different tradeoff, that is, between prescribed and wild fires. Prescribed fires not only cost considerably less than wildfires, but recent evidence seems to suggest that wildfires may be far more effective in reducing fuel biomass and landscape flammability than any current fuel treatment alternative. The problem with wildfires is their uncontrollability under extreme burning conditions, although they certainly can be managed under favorable weather conditions or when they run out of fuel.

Wildfires and prescribed fires both consume living and dead biomass, but prescribed fires generally cause less damage to organisms and ecosystems—in fact,

depending on burning conditions and objectives, prescribed fires may be beneficial and perhaps required for restoring the health of some ecosystems. The question remains whether enough area can be treated by prescribed fire and other treatments, such as mechanical thinning, to reduce costs and losses by wildfires significantly across the landscape. Though lower in cost than other treatment alternatives, the main problems with prescribed fire are smoke and risk of escape. The main problems with mechanical thinning include high cost and suspicions that it provides a pretext for increased logging on public lands.

In the US we are learning that in order to protect forests and grasslands from fire, we need to use fire, not attempt to exclude it (Williams 2003). In fact, wildfires probably have reduced fuel loads on more areas in recent years than likely could have been achieved by intentional hazard reduction treatments. Since prescribed fires can be used to reduce fuel hazards and the severity of eventual wildfires, society has a fairly clear cut choice to make regarding fire management on public lands—that is, application of fuel treatments such as prescribed fire at relatively low costs versus massive expenditures and damaging wildfires (which coincidentally result in reduced fuel hazards in burned areas), as witnessed every year but especially in bad fire years such as 2000, 2002, and 2003. These years were widely acknowledged as some of the worst to date in terms of costs and losses due to US wildfires, but also they resulted in a great deal of fuel hazard reduction. Arguably, certain sectors of even the worst wildfires also support improved habitat for some wildlife species or improve recreation opportunities.

That wildfires may actually produce benefits may be counter-intuitive and defy current policy mandates, but does have scientific precedent. In particular, fuel consumption theories would suggest that wildfire burned areas, once extinguished, provide important opportunities for managing future fuel hazards and preparing for the next generation of wildfire incidents on the landscape. In fact, a common wildfire control strategy calls for herding fire spread toward or into recently burned areas, where lower fuel levels may result in a more controllable incident.

Moreover, the pattern of recent severe fire seasons and recurrent large incidents suggest that extreme wildfires defy most management efforts, especially in the midst of prolonged droughts. So rather than expending enormous sums of money in fruitless attempts to suppress mega-fires that defy control efforts, perhaps it is time to consider a more nuanced approach toward fire suppression. Such an approach could reduce useless financial commitments that often accompany large fire suppression efforts that are mostly controlled by weather changes—and moreover acknowledge the role that wildfire burned areas can play in the strategic management of landscapes.

The restoration of fire-adapted ecosystems is a growing area of interest in the US, especially when perceived as a plausible solution to the catastrophic wildfires of the late 20th and early 21st centuries. Accordingly, scientists and managers suggest that ecosystems can and should be restored structurally to resemble forests and wildlands prior to European settlement in north America, i.e., with sustainable levels of surface fuels, reduced ladder fuels, few large trees, and relatively open canopies. A forest thus restored should be less prone to devastating crown fires but also able to withstand periodic surface fires. The rationale behind its appeal relies on a combination of scientific studies (mostly dating of historic fire-scars using tree rings and temporally-paired photographs) and informed speculation about the structure (size distribution and species composition) of forests prior to European settlement

times. The scientific studies indicate the unequivocal disparity between the low numbers of contemporary ignitions versus the historic higher frequencies of lightning and native firings (most often indistinguishable from each other). Journals of early explorers, news articles, and oral histories reinforce the findings from photo comparisons, suggesting that many of today's forests are choked with dense thickets of small-diameter, shade-tolerant trees compared to yesteryear's open, park-like stands. Devastating wildfire episodes only reinforce the comparisons and emphasize the need for forest restoration.

Over the long-term, forests that are restored ecologically will offer many advantages over the current situation, including safety, aesthetics, and reduced fire hazards. Further, a restored forest is preferable to the devastated aftermath that usually accompanies today's wildfires.

Treatments spread across numerous landscapes over many years may be needed in order to reduce the severity of fuel hazards across the US. As public agencies embark on expanded fuel management programs, an interested public will want assurance that treatments are progressing in accordance with an overall plan for fuel hazard reduction, including treatment of high priority areas. Urban interface and long-needled forests characterized by non-lethal understory fire regimes (Brown 2000) are often cited as high initial priorities, as they should be.

At the same time, agencies will need to develop comprehensive plans that reduce the overall risk of wildfire across the landscape. Annual area (hectares) treated by mechanical and/or prescribed fire may inaccurately represent the accomplishments achieved, especially if treatments are occurring in low-hazard areas mostly easily manipulated or if multiple treatments over several years will be required to reduce wildfire hazards (GAO 2003). Thus current reporting standards (annual area treated and costs) may provide misleading information regarding actual accomplishments. Further, improved reporting of current baselines and annual progress may be required.

Conclusions

Fuel treatments can reduce wildfire severity, but overall effects on landscapes are poorly understood. Evaluation of tradeoffs among treatments is confounded by analytical difficulties associated with understanding fuel management production functions, but also by current reporting practices.

For the foreseeable future, wildfires will continue to burn, sometimes with excessive damages, even as fuel treatment programs are expanded by recent government initiatives. Overall, these damages will recur although the wildfires themselves will in effect reduce fuel hazards within the burn perimeter. Unacceptable wildfire costs and losses will continue until such time as urban interface development can be managed and wildland ecosystems are restored to survive both wild and prescribed fires.

The US experience is coming around to the idea that healthy, resilient forests (that are safe for wild and prescribed fires) are important for protecting people and private property in wildland areas. Firefighting will always be needed in certain areas, such as the urban interface; but in other areas, e.g., historic low severity fire regimes, complete fire exclusion has created unanticipated and unmanageable fuel

conditions. Unless fuels are managed in these areas, future fires may become even costlier and deadlier.

Acknowledgements

The study reported here relied on support from the Joint Fire Science Program, USDA Southern Forest Experiment Station, and McIntire-Stennis Cooperative Forestry Program. Jermiah Sisneros provided assistance with graphics.

Literature Cited

Brown, J.K. 2000. Chapter 1: Introduction and fire regimes. Pp 1-6 *In*: Brown, J.K. and J.K. Smith (eds.) 2000. Wildland fire in ecosystems. Effects of fire on flora. USDA Forest Serv. Gen. Tech. Rep. RMRS-GTR-42, vol. 2, 257 p.

GAO. 2003. Wildland fire management. Additional actions required to better identify and prioritize lands needing fuels reduction. United States General Accounting Office. Report GAO-03-805. 67 p.

Davis, L.S. 1965. The economics of wildfire protection with emphasis on fuel break systems. Calif. Div. For., Sacramento. 166 p.

Rideout, D.B. and P.N. Omi. 1995. Estimating the cost of fuels treatment. For. Sci. 41:664-674.

Simard, A.J. 1976. Wildland fire management: the economics of policy alternatives. Can. For. Serv. Tech. Rep. 15. For. Fire Res. Instit., Ottawa, Ont. 52 p.

Williams, J. 2003. Values, tradeoffs, and context: A call for a public lands policy debate on the management of fire-dependent ecosystems.

An Examination of State and Local Fire Protection Programs in the Wildland-Urban Interface [1]

Margaret Reams,[2] Terry Haines,[3] Cheryl Renner[3]

Abstract

Recent years have brought dramatic expansion of residential development into the Wildland-Urban-Interface (WUI). This rapid development places property, natural assets and human life at risk from wildfire destruction. The U.S. National Fire Plan encourages communities to formulate and implement regulatory and outreach programs for pre-fire planning to mitigate the risk to area residents. During 2003, researchers surveyed the administrators of regulatory and voluntary wildfire risk reduction programs in 25 U.S. states. These state and local programs are listed on the USDA Forest Service's National Wildfire Programs website and are concerned with vegetation management on private lands. Empirical analyses of the administrators' responses suggest several new insights about these sub-federal risk mitigation efforts concerning how they are organized and what they are trying to accomplish. First, certain types of program activities - public education, assistance to property owners, and conducting area-wide risk assessments – are highly related, suggesting a common "bundle" of services offered by many of these programs. Second, desirable management activities – including forging collaborative associations with other stakeholder groups and measuring progress toward program goals – are associated with more "comprehensive" programs, those conducting numerous public education activities and offering a variety of services to property owners. Third, many program managers are facing significant obstacles as they attempt to meet the goals and objectives of their programs. These tend to fall into three categories: shortcomings within the broader policy context, such as inadequate scientific knowledge about fire risk; negative attitudes among the public, including resistance from property owners toward vegetation removal; and budgetary constraints. Finally, respondents offer the activities they believe to be most effective along with "measurable changes" in risk conditions they expect to see as direct results of their efforts. This suggests potential indicators of program effectiveness that may be useful in future research, shedding light on which approaches and activities may work best in reducing risk to WUI communities from catastrophic wildfire.

Introduction

Recent years have brought dramatic expansion of residential development into the Wildland-Urban-Interface (WUI), placing property, natural assets and human life at risk from wildfire destruction. The U.S. National Fire Plan encourages communities to formulate and implement regulatory and outreach programs for pre-fire planning to mitigate the risk to area residents. These programs are important because to reduce wildfire threat requires well-designed, coordinated efforts among various levels of

[1] An abbreviated version of this paper was presented at the second international symposium on fire economics, policy and planning: a global view, April 19–22, Córdoba, Spain.

[2] Department of Environmental Studies, Louisiana State University, Baton Rouge, LA

[3] USDA Forest Service, Southern Research Station, Forest Resource Law and Socio-Economics, New Orleans, LA.

government, stakeholder groups, and private property owners. Moreover, effective efforts will be those that can change the attitudes and behaviors of residents, encouraging them to create defensible space and practice smarter management of the vegetation on their properties. Thus, a systematic review of these efforts is needed to better understand the complexities of their missions, how they are being implemented, and, ultimately, how well they are working.

During 2003, researchers surveyed the administrators of regulatory and voluntary wildfire risk reduction programs in 25 U.S. states. These are listed on the USDA Forest Service's National Database of State and Local Wildfire Hazard Mitigation Programs website, www.wildfireprograms.usda.gov, and are concerned with encouraging vegetation management on private lands. The objectives of this research are to examine these sub-federal risk mitigation efforts to determine what they are trying to accomplish, the major obstacles they are facing and how these obstacles may work as constraints on the programs, and how managers are attempting to gauge the effectiveness of their efforts.

Public Attitudes and Wildfire Risk Mitigation

One of the major challenges facing decision makers as they formulate sub-federal risk mitigation programs is how to change the behaviors of private property owners regarding vegetation management. While there is substantial scientific research concerning components of wildfire risks, such as the relative influences of climate, topography, and fuel loadings, there is far less research concerning related human behavior and the types of programs most likely to lead to desirable changes in that behavior. At the level of program theory, the strategies employed by risk reduction programs targeted to private property owners remain largely untested.

Public risk perceptions concerning wildfire appear to affect residents' support for policy alternatives to mitigate the risk. For example, Bradshaw (1987) and Loeher (1985) reported that many residents within WUI communities had had no direct experience with the devastating effects of wildfire and, as a result, tended to underestimate the risk. Over a decade later, Winter and Fried (2000) found that focus groups in Michigan perceived wildfire to be inherently uncontrollable, with random patterns of damage, a perception that tended to discourage individual property owners from engaging in unilateral removal of vegetation. Further, some expressed a negative view of direct regulations for vegetation management on private lands as a potential infringement on property rights.

Similarly, Smith and Rebori (2001) cited several persistent attitudes among residents that may discourage vegetation management. These include: property owners may not want to believe they are at risk (McCaffrey 1999); they may not believe that vegetation removal only on their land will not stop a wildfire in the community; or that it is simply not their responsibility to protect themselves from wildfire risk (Loeher 1985). Further, some residents may not support vegetation management because they fear that removal of trees and shrubs will negatively affect the aesthetics and ecological functions of a natural landscape (Alan Bible Center for Applied Research 1998; Hodgson 1995; Davis 1990).

Winter and Fried (2000) findings suggest that public support may be strongest for educational-type programs that raise the awareness of the wildfire threat, teach

specific methods for fuel reduction, and encourage a more coordinated set of mitigation actions among community residents.

Given the various constraints on residents' willingness to implement vegetation management strategies, a clear role exists for effective risk reduction programs. Existing efforts tend to take the form of direct regulations at the state, county or municipal levels or more voluntary, public-outreach type programs. This research is an initial step in gaining insight into what these programs are attempting to accomplish, how they are going about furthering their goals, and the obstacles their administrators are encountering as they attempt to reduce risk to WUI communities from catastrophic wildfire.

Data and Methods

Researchers developed and administered a survey of program administrators in an effort to gather additional information about the wildfire risk reduction programs listed on the U.S. Forest Service website, "National Database of State and Local Wildfire Hazard Mitigation Programs" at www.wildfireprograms.usda.gov. The survey represents a first attempt at gathering detailed information about the objectives, activities and experiences of managers of state, county, and local risk mitigation efforts. Throughout the summer of 2003, researchers sent surveys via email to administrators or officials of as many of the risk reduction programs as possible. In some cases, such as a state statute or local ordinance, there were no apparent "contact" individuals to answer questions about the implementation of the law. We sent surveys to 100 administrators and received 56 completed responses. The researchers are continuing to add programs to the national data base weekly, as this phase of the project focused on wildfire risk reduction programs in only 25 U.S. states. Researchers used descriptive statistics, a series of bi-variate correlation and factor analyses in SPSS version 11.0 to answer the research questions.

Major Themes of Wildfire Risk Mitigation Efforts

Survey respondents were asked to indicate the major goals and objectives of their programs. Fifty-five are working toward "public education and outreach"; 46 are involved in assessing the wildfire risk at the community level; 44 are offering assistance to property owners for vegetation removal; and 26 of the programs in the survey are implementing legal standards and regulations.

Since many programs are pursuing more than one of these objectives, to what extent are these program objectives associated with each other? For example, are most of the programs that are actively pursuing "education" as a stated objective also implementing numerous "area-wide risk assessment" activities? And, are programs that oversee the implementation of regulations also involved in helping property owners clear dangerous vegetation from their land? To answer these questions, we constructed several variables from the survey responses. These are the reported total number of activities undertaken for: 1) public outreach and education (such as websites, demonstration projects, and workshops); 2) assessing general risk levels for the community (for example, creating GIS hazard maps and using fire behavior models); 3) assisting homeowners with hazard reduction (through individual property evaluations, treatment, chipping, and slash disposal), and; 4) the number of regulations or guidelines implemented by each program (such as requirements for new developments and/or existing residences). These four quantitative variables

indicate the level of program activity in the pursuit of the four distinct goals or objectives. We used a Pearson's correlation matrix to estimate the associations between these four quantitative variables.

We found that programs with more activities for public outreach and education also are more likely to be using multiple tools in conducting area-wide risk assessments, including GIS and technical risk assessment models (Pearson's r = .382; p=.004; n=56). Also, more active public education programs tend to offer more services to help residents clear dangerous vegetation from their properties (Pearson r = .589; p< .001; n=56). Similarly, programs that are more active in conducting risk assessments for the surrounding area tend to offer more assistance to property owners (Pearson r = .400; p=.002; n=56). Finally, we found that programs implementing more regulations were also likely to be offering more activities to assist private property owners (Pearson r = .388; p=.003; n=56). We found no significant associations between implementing more regulations and investing in more educational services or being more active in assessing general levels of wildfire risk within a community or county.

These findings suggest that several of the four program goals appear to be significantly associated, suggesting a tendency among program decision makers to offer a similar "bundle" of services to WUI residents that may transcend, to some extent, geographic location. The similarities among the programs in this survey suggest that efforts of national and regional organizations such as the Firewise Program and California's Fire Safe Council are effective in encouraging risk-reduction programs at the local levels.

Pre-fire Collaborative Planning

In addition to examining program objectives and activities, the researchers were interested in the extent to which program managers are engaging in collaborative pre-fire planning with other stakeholder groups. The managers were asked whether they participate in such collaboration and, if so, how many partner groups they work with. These responses led to two variables measuring participation in collaborative planning and a rough estimation of the size or extent of their collaborations. Fifty of the respondents indicated that they are participating in pre-fire collaborative planning with other stakeholder agencies or organizations. The median number of partners in these collaboration is 4 and 43 of these managers expect to see tangible reductions in risk as a result of collaborative planning. The most widely expected results include the creation of more effective risk reduction plans and an increase in public support for defensible space and vegetation management.

Risk Reduction Programs and Systematic Evaluations

The second management activity the researchers were interested in was whether administrators attempt to measure progress toward stated goals and objectives in some systematic manner. In addition, the managers were asked to indicate how they measure progress and for what purposes. This is important information for the building of an evaluation framework for these programs in that it indicates the extent to which evaluation of the effectiveness of risk reduction efforts may already be taking place. Further, it identifies performance indicators that may be useful in more formal evaluations of the effectiveness of these risk mitigation programs. The

number of respondents reporting that they attempt some type of systematic review of "progress toward stated program objectives" is 44 out of the 56 total respondents.

How do the Program Managers Measure the Effectiveness of Risk Reduction Programs?

We asked respondents to list the performance indicators they have assembled for the purpose of estimating progress toward program objectives. Their responses were:

1) Increase in number of properties where fuel reduction is achieved (24)
2) Compare results to goals (20)
3) Number of meetings or participants (17)
4) Make regular progress reports (13)
5) Number of communities participating (9)
6) Number of signups for programs (5)
7) Interviews with homeowners (4)

Most of the respondents attempt to measure progress toward reducing wildfire risk by keeping records of the number of treated properties within their community during a specified period of time.

Major Obstacles to Effective Risk Reduction Programs

We were interested in the obstacles faced by program managers as they attempt to meet their programs' goals and objectives. Respondents examined a list of potential obstacles such as budgetary constraints, inadequate cooperation among relevant public and/or private agencies, and public apathy and were asked to indicate on a scale of 1 – 5, the extent to which the item is an obstacle. If an item is not an obstacle at all, the respondents were asked to leave a blank space beside the potential impediment or put a "0" in the blank. The obstacles receiving the highest mean scores, indicating more significant problems are: budgetary constraints, public apathy, owner resistance to vegetation management, and a lack of qualified staff (Table 1).

Factor Analysis of Reported Program Obstacles

The researchers conducted a factor analysis of these responses and found that the obstacles cluster into three "dimensions" or types of problems. These are: 1) problems occurring mostly beyond the managers' control and external to the program, within the larger "policy context"; 2) negative public attitudes, and; 3) inadequate funding for the program itself. For these 3 types of obstacles, a factor score was constructed for each case to indicate the extent to which administrators perceive them to be impediments to program effectiveness.

Table 1—*What Obstacles Are Program Managers Facing in Meeting Program Goals?*

	N	Minimum	Maximum	Mean	Std. Deviation
budget is obstacle	56	.00	5.00	3.3214	1.44105
lack of qualified staff	56	.00	5.00	2.4643	1.68377
need technical help	56	.00	5.00	1.8393	1.46196
public apathy	56	.00	10.00	3.1429	1.71017
owners resist veg. mgt.	56	.00	10.00	2.8393	1.55828
unclear program goals	56	.00	5.00	1.5357	1.26440
scientific uncertainty of risk	56	.00	4.00	1.5714	1.23373
inadequate com. risk assess.	56	.00	5.00	1.8036	1.49447
inadequate help for owners	56	.00	12.00	1.8929	1.94168
inad. enforcement of regs.	56	.00	5.00	1.7679	1.62918
inad. cooperation among stakeholders	56	.00	5.00	1.7321	1.47082
inad. public input into fire policy	56	.00	5.00	1.3929	1.43563
other obstacles to program success	56	.00	5.00	.8393	1.77638
Valid N (listwise)	56				

Note: Responses could range from "0" (not an obstacle) to "5" (a very significant obstacle).

Dimension 1 – Obstacles Relating to the Broader "Policy Context":

1) Lack of qualified staff
2) Need for technical help
3) Unclear program goals
4) Scientific uncertainty of risk
5) Inadequate community risk assessments
6) Inadequate help for property owners
7) Inadequate enforcement of regulations
8) Inadequate cooperation among stakeholders
9) Inadequate public input into wildfire policy

Dimension 2 – Obstacles Relating to Public Attitudes:

1) Public apathy
2) Property owners resist vegetation management

Dimension 3 – Obstacle Relating to Program Funding:

1) Inadequate program budget

Do These Obstacles Limit Managers' Choices?

Several research questions can be answered by determining whether a statistical association exists between various program components, management activities and the reported obstacles facing program administrators. These questions are presented below:

1) **Is there an association between reported budgetary constraints and the number of program objectives implemented by administrators?**

   Yes, a bivariate Pearson Correlation analysis revealed that the more severe the budgetary constraints, the fewer program goals and objectives were being attempted (Pearson r = -.295; p=.029; n = 55.). Conversely, managers of those programs attempting to achieve more objectives are less likely to report budgetary constraints. Thus, more highly developed, more comprehensive risk reduction programs appear to benefit from adequate and stable levels of funding. However, we found no evidence that programs that attempted certain objectives or "bundles" of objectives were more or less likely to experience funding constraints. For example, programs implementing regulations reported no fewer budgetary problems than those with public outreach and education as their primary objectives.

2) **Are more serious reported problems within the broader "policy context" of wildfire risk reduction associated with certain management choices?**

   Yes, researchers found that more serious perceived problems beyond the control of program managers, such as scientific uncertainty pertaining to risk levels and a program's need for technical help, are associated with a disinclination to measure progress toward program goals (Pearson r = -.272; p=.043; n=56). Interestingly, the other types of obstacles – budget constraints and negative public attitudes – do not appear to be associated with willingness to evaluate the effectiveness of the risk reduction program. Apparently, significant problems within the broader policy context, outside the control of program administrators, may serve to undercut faith in the program's ability to gain "traction" and affect meaningful reduction in risk.

3) **What other factors may affect managers' decisions to attempt to measure progress toward stated goals and objectives?**

   Researchers found a significant correlation between those programs that offer more types of activities in the service of either educating the public, assessing the risk within the community, assisting property owners with vegetation management, or implementing specific standards or regulations -- and a tendency to conduct systematic evaluations of program effectiveness (Pearson r = .282; p=.035; n=56.). Thus, managers and administrators who are implementing more specific activities to further program goals are also more likely to try and measure the effectiveness of their efforts.

4) **What factors may influence managers' decisions whether to participate in collaborative pre-fire planning with public and private stakeholder groups?**

Researchers found a significant association between greater reported problems with public apathy and resistance from property owners concerning vegetation removal and a reluctance to enter into collaborative partnerships and associations ((Pearson r = -.249; p =.052 , one-tailed; n = 56) It appears that program officials facing a more hostile or, even, merely an uninformed group of property owners within their community are less likely to participate in pre-fire planning for risk reduction. Managers of programs in areas with a more supportive group of residents appear to be more likely to forge relationships for collaborative planning. This is logical given that stakeholder groups – likely partners in collaborative planning -- may not be well-organized in areas where property owners do not perceived wildfire risks to be of high importanc. However, other factors may influence the degree of collaboration including the severity of wildfire risk, population density, and the proximity and availability of agencies and organizations to work with.

What Measurable Changes Can Program Managers Expect to See As They Progress Toward Specific Objectives?

The following is a list of measurable changes in risk conditions that program managers report they would expect to see if specific program objectives are met. These tangible improvements are useful as potential indicators of program success.

1) Expected Effects of Education and Public Outreach: For the program goal "Education and Public Outreach", the most offered potential indicator of effectiveness is a measurable "increase in general public awareness of Fire Wise concept." Such a change in public awareness could be determined through a regular survey of the property owners within communities.

2) Expected Effects of Conducting Area-Wide Risk Assessments: For the program goal "conducting area-wide risk assessments", the potential indicators most often mentioned are "targeting high risk areas" and "prioritizing projects". Also, "increasing defensible space" was suggested. Each of these measures could be developed into performance indicators if records of program activities are maintained carefully.

3) Expected Effects of Assistance to Property Owners: For the program goal "assistance to property owners", more respondents suggested simply keeping records of the number of properties treated during a designated period of time.

4) Expected Effects of Implementing Regulations: For the program goal "implementing regulations", the potential indicator most often suggested is similar to the outcome expected after offering assistance to property owners – an increase in treated lands. Again, keeping records regarding these activities is a logical step toward developing these suggestions into indicators of program effectiveness.

Most Effective Program Activities for Creation of Defensible Space

The program managers were asked to list the specific activity they believed to be most effective in encouraging private property owners within their communities to

engage in vegetation management and implement defensible space on their properties (Table 2).

Table 2— *Most Effective Program Activities as Reported by Managers*

Program Activities as Reported by Managers	**Frequency** (Total Response)
Public Education (Including K-12 and Teacher Training)	14
Mapping of Risk Areas (GIS)	1
Individual Risk Assessments	13
Prescriptions for Defensible Space for Individual Properties	10
Free Vegetation Removal and/or Treatment	8
Cost/Share Vegetation Removal and/or Treatment	14
Free Disposal of Slash Material (Plant Debris)	11
Chipping Service for Slash Material (Plant Debris)	10
Scheduled Community Clean-up Days	3
Law Requiring Vegetation Removal and Management	10
Distributing "How-To" Guides for Property Owners	2
Demonstration Properties	4

Note: The question was open-ended, respondents were not selecting from a list of "suggested" most effective program activities. Most respondents gave only one answer. In cases where more than one answer was given, both responses were recorded.

The respondents indicated a general preference for "hands-on", practical assistance to private property owners. While many respondents listed "public education – including K-12 student and teacher outreach" as valuable, even more voiced support for the pragmatic type of assistance that encourages residents to get out into their yards and make the changes that will reduce the wildfire risks to their communities. Thus, those programs that are more active in offering these types of aid to home owners are engaged in some of the most effective methods to reduce risk, according to program managers – themselves, grappling with how best to invest their time and resources.

Conclusions

The examination of sub-federal wildfire risk mitigation programs is a recent area of inquiry and this survey of program officials is a first step toward a systematic review of these efforts. First, we clarified the stated objectives of the programs, important because future estimations of how well these programs are working must be based on progress toward specific program goals. Further, identification of goals allows for an organizational typology whereby programs with similar goals and objectives may be placed into similar categories. Then, managers of programs within each category may choose from a common pool of potential indicators of program effectiveness. Second, these findings shed light on the types of impediments that managers believe are hindering progress toward program objectives. We discovered that these obstacles tend to fall into 3 distinct categories: 1) problems associated with the broader "policy context"; 2) negative public attitudes, and; 3) budgetary constraints. Further, these obstacles appear to affect the choices made by program managers, as

suggested by the finding that problems within the broader policy context of the programs, including scientific uncertainty as to actual risk levels and risk components, may discourage program managers from attempting to evaluate the effectiveness of their efforts. Similarly, participation in collaborative pre-fire planning becomes less likely in the face of apathy or resistance from community residents. Finally, using input from managers, we assembled a list of potential indicators of program effectiveness that may be applied to programs with similar goals to help administrators plan more systematic reviews of their activities. This information should be useful to decision makers, community stakeholders, and researchers as they begin to consider the effectiveness of these important sub-federal wildfire risk mitigation efforts.

References

Alan Bible Center for Applied Research. 1998. **Report of the living with fire survey results.** Under contract to Nevada Cooperative Extension, University of Nevada, Reno. (unpublished)

Bradshaw, W.G. 1987. **The Urban/Wildland Interface Fire Problem. Can Social Science Play a Role?** People and Fire at the Wildland/Urban Interface (A Source Book). USDA Forest Service, Washington, D.C. ed: R.D. Gole and H.J.Cortner.

Davis, I. **B.** 1990. **The wildland/urban interface. Paradise or battleground?** Journal of Forest**r**y, January: 26-31.

Hodgson, R.W. 1996. **Community programs.** In: R. Slaughter, ed., California's I-zone urban/wildland fire prevention and mitigation. California Department of Forestry and Fire Protection, Sacr**a**mento**, CA:** 242-258

Loeher, L.L. 1985. Fire hazard: **The dimension of resident's attitude.** In: K. Radtke (ed.), Conference Proceedings Living in the Chaparral of Southern California. National Foundation for Environmental Safety and USDI National Park Service. Santa Monica, CA; 51-55.

McCaffrey, S. 1999. **Preliminary results: Incline village fire survey**. University of California, Berkeley. (Unpublished)

Smith, Ed**;** Rebori**,** Marlene. 2001. **Factors affecting property owner decisions about defensible space**. Assisting Forest Owner, Farmer and Stakeholder Decision-Making, International Union of Forestry Research, Proceedings of the Extension Working Par**t**y (S6.06-03) Symposium 2001.

Winter, Greg; Fried**,** Jeremy**.** S. 2000. **Homeowner perspectives on fire hazard, responsibility, and management strategies at the wildland urban interface**. Society and Natural Resources 13(1); 33-49.

The National Wildfire Mitigation Programs Database: State, County, and Local Efforts to Reduce Wildfire Risk[1]

Terry Haines,[2] Cheryl Renner,[3] Margaret Reams,[2] and James Granskog[2]

Abstract

States, counties and local governments in the United States have dramatically increased their wildfire mitigation efforts in recent years. Policymakers and fire officials are employing a wide range of regulatory and voluntary wildfire risk reduction programs to protect residents, communities, and natural resources. We researched these sub-federal wildfire hazard mitigation efforts and established the website, www.wildfireprograms.usda.gov, as a clearinghouse of information to assist fire officials, public officials, planners, and land managers in the development and expansion of effective programs. The website currently describes over 184 programs in 27 states, and includes information about the purpose, features, and accomplishments of wildfire hazard mitigation programs; as well as links to pertinent websites and program managers' contact information. The types of programs that fire officials are using in their wildfire risk reduction efforts include public outreach and education, assessment of wildfire risk and designation of high-risk areas, homeowner assistance, community recognition, and regulatory programs. These classifications are identified in the website search option, along with options to select programs by administrative jurisdiction and by specific states. By using the website, community officials can find successful programs currently at work in other communities, and get ideas of how to structure their program for greatest effectiveness.

Introduction

A century of wildfire suppression coupled with the rapid expansion of human developments into fire-prone wildlands has greatly increased wildfire risk to people and their communities. Wildfires in 2000, and 2002, were particularly devastating, with a total of more than 15 million acres burned and nearly 1700 homes destroyed (National Interagency Fire Center 2004). Furthermore, California suffered its worst wildfire season in modern times in 2003 with more than 739,000 acres burned and 3,600 homes lost (U.S. Department of Agriculture 2004). The escalating losses and wildfire risk exposure in the wildland urban interface has prompted policy makers and fire managers at all governmental levels to take action. Federal efforts focus primarily on the treatment of fuels on federal lands adjacent to high-fire risk communities; while states, counties, and local governments face a more complex

[1] An abbreviated version of this paper was presented at the second international symposium on fire economics, policy, and planning: a global view, 19–22 April, 2004, Córdoba, Spain.

[2] USDA Forest Service, Southern Research Station, Forest Resource Law and Socio-Economics, New Orleans, LA.

[3] Louisiana State University, Department of Environmental Studies, Baton Rouge, LA.

challenge—creating effective wildfire mitigation strategies to protect lives, property, and resources within developed communities and private holdings in wildland intermix areas.

State, county, and local governments are implementing a wide-range of approaches to achieve their wildfire risk management objectives. Programs vary in complexity and scope, from programs that focus on a single purpose, such as educational campaigns to multi-faceted wildfire risk management plans. Complex programs may include a mix of public outreach and educational programs, wildfire hazard assessments, homeowner assistance, and regulatory policies. Federal funding provided through National Fire Plan grants has enabled states and communities to undertake many wildfire mitigation efforts. Funding is usually in the form of cost-share grants that are often used to purchase equipment, undertake studies to identify areas of highest risk, and to support operations that remove hazardous fuels around homes.

Procedures

Several approaches were used to identify and obtain information about state, county, and local wildfire risk management programs. Initially, a list of contacts was developed that included state fire protection officials (identified from state's forestry and fire protection agency websites), wildfire protection managers of county and local programs (identified by the national Firewise organization), and National Fire Plan grant recipients (provided by USDA Forest Service National Fire Plan regional coordinators). The most successful approach for obtaining information was through personal communication with these contacts and referrals from the initial contacts to fire managers in other localities. Fire protection officials included copies of grant proposals and accomplishments reports; wildfire hazard assessment reports; regulations and guidelines; educational materials including publications, Powerpoint presentations and videos used in workshops; and personal assessments of programs successes and obstacles encountered.

In addition to identifying pertinent laws and regulations through the state and local fire protection officials, we conducted legal searches of state statutes and county codes of three states—Florida, California, and Colorado. With the exception of the California Fire Marshal's Office website, which offers a database specific to the State's fire laws, there is no single source of fire-related laws and regulations.

Results

In our analysis of sub-federal wildfire risk management efforts, we identified a number of common program components. We organized common elements under the broad categories of education, demonstration projects, wildfire hazard assessment and mapping, homeowner services and public/private mitigation projects, and regulatory programs. We constructed a matrix using all responses to determine the frequency of these components.

Education

We found that a component for education was universal in the 121 localities. The most common focus of education was public outreach. Managers use a number of methods to educate the public about the dangers of living in wildfire-prone areas, and the importance of creating defensible space around their homes. Publications that promote hazard reduction, fire protection and safety, as well as landscaping and defensible space guidelines specific to the geographic area have been developed and distributed through mailings, public events, and on websites. Lists of recommended fire-resistant plant species have been developed to a lesser extent but are valuable, particularly in new developments. Publicity in newspapers, on radio, television and through video rentals which discuss wildfire protection, hazard reduction planning, and thinning projects are another way residents are being informed.

Classroom resources and teacher education are part of the overall education component in about 35 percent of the jurisdictions with wildfire risk mitigation programs. In several states, a fire science component has been added to the science curriculum. Software and media firms have been contracted to create the curricula for educating students about wildfire ecology, safety and protection. The curricula often include the use of interactive cd-roms and videos.

Fire protection officials have developed their own classroom programs in many areas. These efforts have included "hands on" defensible space and fire safety programs for grade school students. Those targeting high school students have involved fuels removal around schools and field exercises, such as assessment and mapping of high fire-risk areas in the community.

In about 70 percent of the wildfire protection programs, fire officials conduct community and neighborhood meetings. In these meetings a dialogue between residents and fire officials is established and issues related to wildfire protection measures for the area are explored. Wildfire management officials are also promoting firewise workshops for volunteer and career firefighters, planners, developers, and policy makers. The workshops generally focus on developing a wildfire risk management plan for the town/community. About 25 percent of the localities we researched had provided at least one workshop as part of their education efforts.

Demonstration projects

Demonstration projects provide examples of fuels treatment for homes or small forests. They give landowners the opportunity to see the recommended fuels treatments in a landscape similar to their own, and to reduce anxiety over tree removal or recommended residential landscape design. Demonstration homes, gardens, trails, or forests which show firesafe landscape design, plantings of fire-resistant species suitable to the local climate and soils, and thinning options were a component of about 50 percent of the programs. Two notable examples of demonstration projects are the High Desert Museum in Bend, Oregon which features a nature trail showing conditions before and after thinnings, prescribed burns, and uncontrolled burns; and the Fire Safe Garden at the University of California at Berkeley, which demonstrates recommended species and planting arrangements around typical building components.

Wildfire Risk Assessments and Mapping

State-level wildfire risk assessments and mapping projects were underway, or had been completed, in most of the state programs, and in about 50 percent of the county and localities with wildfire risk management programs. Designation of high-risk areas is accomplished by studying the interaction of individual risk factors such as fuel loading, topography, fire history, climate, housing density, and infrastructure for fire fighting. These factors are ranked and mapped individually, and then overlaid to find areas where factors combine to define areas of highest risk. Assessments at the regional, state and county level are used to target high-risk areas for intervention based on GIS data using remote sensing and fire behavior models. This information is then supplemented at the county, municipal, and subdivision levels through inspections by trained personnel using a wildfire hazard severity rating system to determine risk for individual homes and subdivisions. Hazard severity rating systems used are often based on a model developed by the National Fire Protection Association. The model assigns a rating for individual components of wildfire risk related to vegetation, home construction materials, road design and access, water availability, signage, and other factors. From these ratings, a composite hazard severity score is assigned (NFPA 1997).

Homeowner Assistance

Direct assistance to homeowners was provided in about 65 percent of the areas researched. Homeowner assistance includes the evaluation of the individual home's wildfire risk, prescriptions for fuels reduction, free or cost-share treatment of fuels, chipping of debris, and slash disposal. Despite the high cost of land treatment for homeowners, 75% of all jurisdictions providing assistance to homeowners offered either free or cost-sharing treatment. More than 60% of those offering assistance offered either chipping of slash or debris disposal, with many instituting regular curbside pickup or establishing community disposal sites. Public/private partnerships to create fuelbreaks around wildland urban interface communities were a common program element; most often, managers of government-owned lands treated fuels beyond the boundaries of public holdings, such as thinning adjacent private property to reduce the fire threat to homes and communities.

Regulatory Programs

Six of the 27 states and about 40 percent of county and municipal governments have adopted laws, ordinances, or regulations pertaining to wildfire planning, fuels treatment, and other wildfire mitigation practices. To date, only the State of California has adopted and enforces defensible space regulations for all structures in high wildfire risk areas; however, direct regulation by the State does not apply to incorporated towns.

Most regulations exist at the county level, and address risk reduction for new construction or substantial remodeling of existing structures. Falling under the police powers to protect public health, safety and welfare, regulations are often incorporated in a jurisdiction's Zoning Ordinance, Subdivision Regulations, or Building and Fire

Codes. Jurisdictions that have completed mapping projects usually designate high hazard areas on an overlay map, and restrictions apply only to those areas. In many locations, developers are required to submit detailed development plans prepared by a professional forester and create a plan to mitigate wildfire risk before either subdivision approval or a building permit is issued. Regulations requiring existing homes to comply with standards to create and maintain defensible space are less common. Many administrators have been relying on education efforts or other aspects of their mitigation programs to motivate homeowners to reduce fuels around homes, but expressed a hope that regulations for existing homes might be passed in the future.

Wildfire hazard mitigation programs' database

As officials develop wildfire mitigation strategies, a knowledge base of existing programs, and what has been successful in similar communities, can greatly enhance planning efforts, while reducing time and cost in implementing new wildfire mitigation strategies. To date, only limited information has been compiled about the programs, policies and tools being used across the country to mitigate wildfire risk in the wildland-urban interface. Some agencies and organizations have websites with information about successful mitigation efforts on a limited scale (California Fire Alliance 2004, National Wildfire Coordinating Group 2004, and Wildland Fire Leadership Council 2004). Particularly lacking is information about regulatory programs.

To facilitate the broader dissemination of ideas among fire protection officials, community leaders, policy makers, planners, educators, and homeowners we have developed a central clearinghouse describing the wildfire mitigation programs that sub-federal governments across the country have implemented -- the website www.wildfireprograms.usda.gov. The website currently describes 184 programs that are being implemented in 125 areas in 27 states and the database continues to be expanded.

Because website users may be interested in specific approaches to wildfire mitigation, we have designated categories for programs in the database search feature. These categories include education, designation of high-risk areas, homeowner assistance, regulatory, and community recognition programs. Website search options also include selecting programs for each individual state and by administrative jurisdiction, – i.e. state, county, city/town, or fire district; or, users may use multiple selections from the search features. Program descriptions include background information, key features, and highlights of the most significant activities. Program profiles also include the program manager's contact information and links to pertinent websites.

Discussion

National Fire Plan grants have provided much needed funding to offset the cost of state and local wildfire mitigation programs. In 2001, communities received $28 million for wildfire hazard mitigation projects through federal State Fire Assistance (SFA) Program grants. Funding for the SFA community grants increased to $51 million in 2002 (U.S. Departments of Agriculture and Interior 2003). In addition, the

Healthy Forests Restoration Act of 2003 points to increased federal emphasis on reducing wildfire hazards on federal lands and promoting actions to protect WUI communities. Given these factors, and the continuing trend of human development in fire-prone ecosystems, it is likely additional high-risk areas will be adopting wildfire risk management strategies and that existing programs will be expanded.

In the future, regulatory mechanisms may be an increasingly common component of wildfire mitigation programs. Many of the regulations and ordinances we identified had been adopted in recent years, and a number of fire officials indicated that regulatory programs were being formulated or considered for adoption.

Insurance programs also may play an increasingly important role in shaping homeowners' wildfire mitigation efforts in the future. Insurance companies have experienced large losses due to wildfires in recent years. For example, a single fire event, the Colorado Hayman fire, cost insurance companies $38.7 million, accounting for more than half of the state's $70.3 million in total insured losses for wildfires in for 2002 (Reese 2003). As a result of an increase in perceived risk, State Farm Insurance Company initiated a home inspection program to evaluate defensible space and wildfire hazards around homes in the summer of 2003. Over 20,000 homes in six Rocky Mountain States are slated for inspection. After evaluation, insurance officials will make recommendations for treatments to homeowners in writing. Homeowners will then have two years to make the recommended modifications. Although the inclusion of wildfire risk in insurance evaluations is new, some properties in very high-risk areas of California have been subject to a "brush surcharge" on premiums for several years

Conclusions

Through the use of the national wildfire programs database website, fire protection officials, community leaders, policymakers, planners, and educators can learn about the strategies communities are employing to reduce wildfire risk and how these programs have been funded, administered, and implemented. The website can facilitate the development of effective state and local wildfire risk mitigation programs while reducing time and cost in planning and implementing new wildfire mitigation strategies. Continued development of the website database will include wildfire risk management programs in more states and will update information about existing programs.

References

California Fire Alliance, 2004. **Success stories**. www.cafirealliance.org.

National Fire Protection Association. 1997. **NFPA 299, Standard for protection of life and property from wildfire**. Quincy, MA: 16p.

National Interagency Fire Center. 2004. **National Fire News**. www.nife.gov/fireinfo.

National Wildfire Coordinating Group. 2004. **Firewisecommunities/USA.** www.firewise.org/usa.

National Wildland Leadership Council. 2004. **Success stories.** www.fireplan.gov.

Reese, April. 2003. **Wildfire risk prompts insurance companies, communities to take action.** Land Letter 22(11):7-8.

U.S. Department of agriculture and Interior. 2002. **FY2001 Performance Report, National Fire Plan.** www.fireplan.gov; 84p.

U.S. Department of agriculture and Interior. 2003. **FY2002 Performance Report, National Fire Plan.** www.fireplan.gov; 56p.

U.S. Department of agriculture and Interior. 2004. **Implementation of the Healthy Forest Initiative.** Fact Sheet. 3p.

Page left blank intentionally.

An Evaluation of the Economic Tradeoffs of Fuel Treatment and Fire Suppression on the Angeles National Forest Using the Fire Effects Tradeoff Model[1]

Mark D. Schaaf,[2] Marc A. Wiitala,[3] Maarten D. Schreuder,[4] David R. Weise[5]

Abstract

In this study, the Fire Effects Tradeoff Model (FETM) was used to evaluate the economic tradeoffs between fuels treatment and fire suppression on the Angeles National Forest located in southern California of the United States. FETM uses historical weather data, fire history data, current vegetation maps, prescribed-fire planning data, fuels treatment and wildfire costs and benefits, and surface and stand composition data to simulate the future annual wildland fire area burned, landscape composition, smoke emissions, and the present net value of fire suppression and fuels treatment over any time period. Five fire suppression and fuels treatment alternatives were evaluated, combining one of two fire suppression program options with five prescribed-fire intensities ranging from 0 to 52 percent of the available chaparral area per decade. Our results show that maintaining a larger suppression program with a low level of fuels treatment substantially reduces the wildfire area burned. However, the increased costs associated with this program are not met with a commensurate reduction in resource loss and suppression costs. Similarly, our results show that a smaller fire suppression program coupled with an aggressive prescribed-fire treatment option substantially reduces the wildfire area burned, but the increased costs of treatment are likewise not met with a commensurate reduction in resource loss and suppression costs. We found instead that a smaller and less costly fire suppression program, matched with a moderate intensity fuels treatment program targeting only the highest loading classes of chaparral, provides the most cost-beneficial fire protection strategy for the study area.

Introduction

In the United States today, an estimated 79 million hectares of state and federal forests and rangelands, an area twice the size of California, face high risk of large-scale wildfire and are in need of ecosystem restoration. Effective fire suppression and prevention over the past decades has resulted in the present accumulation of dense undergrowth, brush, and dead-and-down woody debris uncharacteristic of fire-adapted forest and rangeland ecosystems (GAO 1999). This unhealthy ecosystem condition, combined with recent drought conditions, disease and insect infestations,

---

[1] An abbreviated version of this paper was presented at the second international symposium on fire economics, policy and planning: a global view, April 19–22, 2004, Córdoba, Spain.

[2] Principal Scientist, Air Sciences Inc., 421 SW 6th Avenue, Suite 1400, Portland, Oregon 97204.

[3] Operations Research Analyst, Pacific Southwest Research Station, USDA Forest Service, 620 SW Main, Suite 400, Portland, Oregon 97205.

[4] Forest Ecologist, Air Sciences Inc., 421 SW 6th Avenue, Suite 1400, Portland, Oregon 97204.

[5] Supervisory Research Forester, Pacific Southwest Research Station, USDA Forest Service, 4955 Canyon Crest Drive, Riverside, California 92507.

and invasion by exotic species, makes the forests and rangelands in many areas of the country vulnerable to costly and environmentally disruptive wildfires. A major effort is currently underway to identify and treat areas with fuels buildups posing the greatest risk of catastrophic wildland fire (USDA Forest Service 2000).

The chaparral-covered mountainous slopes of southern California are among the most hazardous and fire prone in all of the United States. Chaparral is a vegetation community composed largely of broadleaf evergreen shrubs between 1 and 4 meters tall. These communities typically occupy the steepest slopes and most skeletal soils in the mountainous areas of southern California below 2,000 meters in elevation. The leaves of the chaparral species are sclerophyllous and aromatic, and resist decay upon falling from the twigs. As the plants age, the ratio between dead wood and active stems and twigs increases dramatically, setting the stage for large-scale brush fires (Minnich 1988; Schoenherr 1992). The longer the period between fires, the greater the magnitude and intensity of the subsequent fire.

Throughout the United States, but especially in southern California, it is increasingly common to see new homes and other types of structures constructed in wildland environments (Minnich 1988). This has created an expansion of the wildland-urban interface area in which structures are located adjacent to highly flammable vegetation. Because of their location, these structures are highly vulnerable to fire should one occur in the surrounding area. In 1999, nearly 750 structures were lost in nine fires in California. One particularly devastating event was the Jones fire near Redding, California, in which 428 structures were lost in a single 10,500-hectare blaze. The tragic Oakland fire in 1988, and the wildfires of October 2003, focused national attention on the recurrent natural hazard of wildfires around California's urban areas.

Land managers and fire personnel in southern California have long sought to reduce the wildfire hazard through a combination of methods, including: education, building standards that require the use of fire-resistant materials, enhanced fire suppression capabilities, and fuels treatment programs on federal lands and in the wildland-urban interface. One lingering question for the public and land managers is the overall effectiveness of large-scale fuel reduction programs aimed principally at reducing the size and intensity of wildfires before they grow into more populated areas.

Landscape simulation modeling of disturbance processes provides an objective framework for weighing the short-term risks against the long-term benefits of fuels treatment and other restoration programs on high priority lands. In this investigation, we use the Fire Effects Tradeoff Model (FETM) to explore the economic consequences of five prescribed-fire and fire suppression program alternatives on the Angeles National Forest (ANF) in southern California. The short- and long-term consequences of these management actions are also measured in terms of the reduction in wildfire area and smoke emissions.

Methods

Study Area and Vegetation

The study area is a 234,061-hectare portion of the ANF, administered by the United States Department of Agriculture (USDA) Forest Service. The ANF is located in the San Gabriel Mountains northeast of Los Angeles, California, U.S.A, (*fig. 1*). The vegetation of the area is largely chaparral (Ottmar and others 2000), consisting of

four separate species groups: northern mixed chaparral, semi-desert chaparral, chamise chaparral, and montane chaparral (*table 1*). Roughly one-half of the remaining vegetation (23 percent) is conifer woodlands (primarily *Juniperus* spp. and *Pinus* spp.), and the remainder (21 percent) is composed of hardwoods and sagebrush, or is non-vegetated.



Figure 1—Vicinity map of the Angeles National Forest in the San Gabriel Mountains of southern California, U.S.A. The study area comprises all of the Los Angeles River and San Gabriel River Ranger Districts, and that portion of the Santa Clara/Mojave Rivers Ranger District lying southeast of Highway 14. Note: 10 miles = 16 km.

Table 1—*Vegetation composition of the Angeles National Forest study area.*

Vegetation type	Area (hectares)	Percent of total area
Northern mixed chaparral	92,972	40
Semi-desert chaparral	21,741	9
Chamise chaparral	8,206	4
Montane chaparral	7,393	3
Conifer woodland	54,424	23
Hardwoods	19,958	9
Sagebrush	15,044	6
Grass	333	0.1
Non-vegetated	13,990	6
Total	234,061	100

Chaparral is highly adapted to fire disturbance. Because of its ability to stump-sprout, chaparral quickly restores its coverage of a site following fire. Many

chaparral species are dependent on frequent fire for reproduction and renewal (Vankat 1979). Frequent fires have led to a mosaic of different stand ages, which vary in species composition, vegetation height, and biomass.

For purposes of this analysis, the area in each of the four main chaparral groups was sub-divided into five fuel loading classes. For northern mixed chaparral and semi-desert chaparral, the loading classes were: I—less than 2.2 metric tons hectare^{-1}, II—2.2 to 22 metric tons hectare^{-1}, III—23 to 40 metric tons hectare^{-1}, IV—41 to 54 metric tons hectare^{-1}, and V—55 to 72 metric tons hectare^{-1}. For chamise chaparral and montane chaparral, the loading classes were: I—less than 2.2 metric tons hectare^{-1}, II—2.2 to 16 metric tons hectare^{-1}, III—17 to 29 metric tons hectare^{-1}, IV—30 to 38 metric tons hectare^{-1}, and V—39 to 45 metric tons hectare^{-1}. These loading classes were used to establish priorities for prescribed-fire treatment.

Fire Frequency and Magnitude

During the 29-year period from 1970 through 1998 (USDA Forest Service 1997), a total of 4,439 fires consumed 142,379 hectares of chaparral and other vegetation within the ANF. This yields an annual average of 153 fires and 4,910 hectares (±2,450 hectares standard deviation) consumed. The median fire size was 0.04 hectares. The maximum fire size was 19,179 hectares (*fig. 2*).

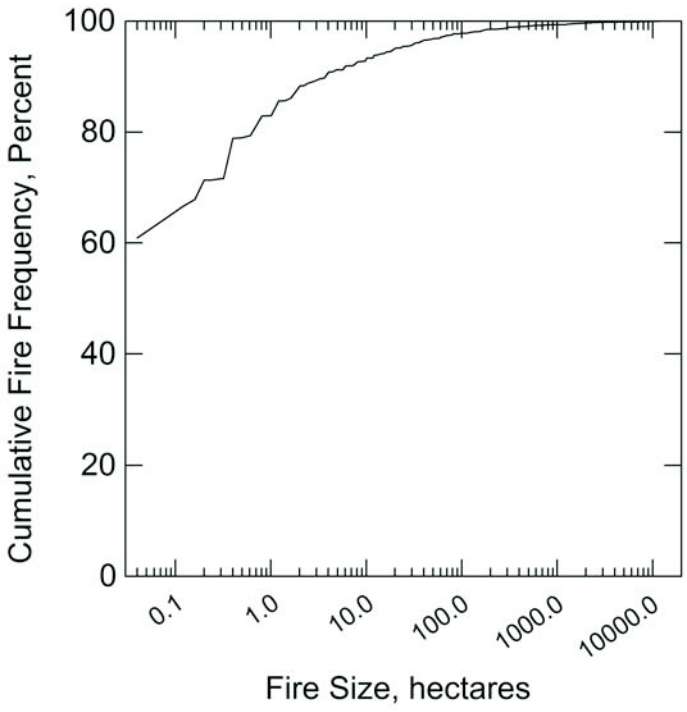


Figure 2—Cumulative fire frequency distribution for the Angeles National Forest for the period from 1970 through 1998 (USDA Forest Service 1997).

Prescribed-Fire and Fire Suppression Alternatives

Five alternatives were evaluated, each involving a different level of prescribed- fire treatment in combination with one of two fire suppression program options (*table 2*). Alternative 1 contains the larger of the two fire suppression programs (C20) coupled

with the smallest prescribed-fire treatment area (zero hectares annually). Alternative 3 contains the smaller of the two suppression programs (M30) coupled with the largest prescribed-fire treatment area (12,141 hectares annually). The other three alternatives match the C20 or M30 suppression program with intermediate levels of prescribed-fire treatment.

Table 2- *Fuel treatment and suppression program alternatives for Angeles National Forest*

Alternative	Annual prescribed fire treatment area (hectares)[†]	Suppression program option (annual program cost)
1 – Larger C20 suppression program / No prescribed fire	0	C20: Current + 20 percent ($14.4 million)
2 – Larger C20 suppression program / Smallest prescribed-fire treatment area	3,035	C20: Current + 20 percent ($14.4 million)
3 – Smaller M30 suppression program / Largest prescribed-fire treatment area	12,141	M30: Most efficient level - 30 percent ($10.3 million)
4 – Smaller M30 suppression program / Intermediate prescribed-fire treatment area	6,070	M30: Most efficient level - 30 percent ($10.3 million)
5 – Smaller M30 suppression program / Variable prescribed-fire treatment area	<6,070	M30: Most efficient level - 30 percent ($10.3 million)

[†]Targets chaparral only.

The two candidate fire suppression programs (C20 and M30) were selected by ANF staff from a list of 32 available options. The two options differ in the number of hand crews, engines, and aerial firefighting resources available to respond to fires.

Chaparral was the only vegetation category targeted for prescribed-fire treatment. Each of the four chaparral groups was targeted in rough proportion to the proportion of the total chaparral area that each occupies (*table 1*). Northern mixed chaparral, with the largest initial area (92,972 hectares, or 71 percent of the total chaparral area), received the largest area of prescribed-fire treatment (8,855 hectares annually, or 73 percent of the total under Alternative 3). Montane chaparral, with the smallest initial area (7,393 hectares, or 5.7 percent of the total chaparral area), received the smallest area of prescribed-fire treatment (650 hectares annually, or 5.4 percent of the total under Alternative 3).

The fuel treatments were prioritized from the highest to the lowest fuel loading class. The highest class (V) was treated first, followed by the second highest class (IV) and so forth until the treated area equaled the planned annual area. In the case of Alternative 5, only the highest two loading classes (IV and V) were targeted for treatment in each species group. Over time, this treatment exhausted the available area in the highest chaparral loading classes, which caused the actual prescribed-fire area to drop below the 6,070-hectare planned area. Successional processes were insufficient to make up the shortfall in the area available for treatment.

Each model simulation was run for a period of 100 years and with 200 iterations for each year. The results therefore represent the "expected" outcome of fuels treatment and fire suppression at each time step.

Fire Effects Tradeoff Model

FETM[6] version 4.8.8 was used to simulate the short- and long-term effects of the five prescribed-fire treatment and fire suppression program alternatives (Schaaf and others 2004). FETM is a landscape-scale disturbance effects model designed to simulate the relative effects of alternative land management practices over long periods of time and under diverse environmental conditions, natural fire regimes, and fuel and fire management strategies. The model is based on a classical stationary Markov formulation (Feller 1968). Stationary Markov models are mathematical models that utilize matrices of empirically determined probabilities to predict vegetation class replacement, and therefore composition, over time. The transition probabilities in a stationary Markov model are analogous to the flow coefficients in a Stock and Flow simulation model (Forrester 1961). More specifically, one could interpret FETM as representing an ecosystem as a system of first-order, homogeneous, linear difference equations with constant coefficients (Luenberger 1979).

The first-order difference equation used in FETM to describe landscape change over time is:

$$\tilde{a}_{t,p} = \mathbf{S}\left\{\left(\tilde{a}_{t-1,p} + \sum_{r=1}^{8} \tilde{s}_{t,p,r}\left(\mathbf{M}_r - \mathbf{I}\right)\right) + \tilde{w}_{t,p}\right\} \quad (1)$$

where $a_{t,p}$ is an area vector (~) of fuel characteristic classes (FCC) (Sandberg and others 2001) in simulation year t for prescribed-fire treatment level p, **S** is a natural succession matrix, $s_{t,p,r}$ is a vector of area scheduled for treatment by FCC, $\mathbf{M}_r$ is an effects matrix for disturbance r (range 1 to 8), **I** is the identity matrix, and $w_{t,p}$ is a wildland fire acreage net-change vector, given by:

$$\tilde{w}_{t,p} = \sum_{i=1}^{4}\left(\mathbf{W}_i - \mathbf{I}\right)\tilde{F}_{t,p,i} \quad (2)$$

where $\mathbf{W}_i$ is a wildland fire effects matrix for fire weather severity class i (range 1 to 4), and $F_{t,p,i}$ is a column-vector of expected FCC area burned for year t, prescribed-fire treatment level p, and fire weather class i. FETM calculates the $F_{t,p,i}$ vector each year on the basis of the current landscape composition, number of fire starts, and predicted single-event wildfire sizes for a set of weather conditions and associated fire behaviors.

FETM is dynamic, predicting annual changes in landscape composition and effects over any time period ranging from one to 300 years. For each independent run, the starting composition in any year of simulation is linked to the previous year's results. The model is stochastic; random variables include wildfire frequencies in each of the four National Fire Danger Rating System (NFDRS; Bradshaw and others 1983) weather classes, and the potential wildfire size in the event that fuel loadings exceed the range of historical variability. FETM is a non-spatial model, capable of predicting disturbance effects within an area by vegetation class, but not capable of

[6] FETM website: www.fs.fed.us/r6/aq/fetm

predicting where those impacts will occur on the landscape or whether the impacts are contiguous or dispersed.

One feature that differentiates FETM from other landscape models is its use of fire behavior algorithms to determine the size and intensity of fire events. Rather than relying exclusively on historical fire data as the basis for determining future fire sizes and effects, FETM integrates aspects of physical fire behavior modeling into its simulations. This integration of classical fire behavior modeling into landscape simulation modeling allows FETM users to evaluate the consequences of changes in the fire environment (e.g., fuel loading, canopy structure, weather, topography) on wildfire area and other fire effects. For example, FETM can evaluate the effect of a change in surface fuel loading or stand configuration on the potential for crown fires. Integration of fire behavior modeling also offers an opportunity to quantify the level of fuel consumption and smoke emissions over time, which is an increasingly important factor in implementing management activities across the landscape.

Economic Analysis

In this investigation, the primary measure of economic efficiency is the present net value (PNV) of costs and benefits, annualized over the simulation period. More specifically, PNV is the 100-year sum of future annual fire suppression costs (FSC), annual fuel treatment costs (FTC), and monetary and non-monetary net value change (NVC) values discounted at a 4-percent real discount rate (Forest Service Handbook, FSH 1909.17). ANF staff provided the economic cost and natural resource value inputs used in this analysis.

Following the accounting procedure in the USDA Forest Service National Fire Management Assessment System (USDA Forest Service 1999), wildland fire suppression costs were calculated on the basis of two component costs: the average acre cost (AAC), and the unit mission cost (UMC). AAC is the average per-acre cost incurred during active fire suppression. UMC is the fixed cost associated with dispatching a suppression resource to a fire irrespective of whether the suppression resource engages in fire line building. The unit (that is, per hectare) costs for each vary by fire size class. Typically, the smallest fires have the highest unit FSC, and the largest fires have the lowest unit FSC.

The FTC values were computed based on user-provided per-acre fuel treatment costs, which typically vary by treatment activity and vegetative class. The ANF provided an average prescribed-fire treatment cost of $555 per hectare.

The NVC resulting from fire disturbance is the algebraic sum of the economic effects of fire on the value of natural resource outputs, both positive and negative. Here, a positive NVC represents an economic loss or cost, and a negative NVC represents an economic gain or benefit. NVC varies directly with the area burned by fire intensity level (FIL). The higher the FIL, the higher the unit NVC. The FIL is a measure of the resistance to suppression, and corresponds to different flame length ranges: FIL 1, 0- to 2-foot flame lengths; FIL 2, 2- to 4-foot flame lengths; FIL 3, 4- to 6-foot flame lengths; FIL 4, 6- to 8-foot flame lengths; FIL 5, 8- to 12-foot flame lengths; and FIL 6, 12+-foot flame lengths. Net value change is computed for both monetary resources (timber and range resources) and non-monetary resources (e.g., recreation, water storage, wildlife, and fish) on National Forest System lands only. The NVC values used in this analysis do not account for resource benefits or losses associated with fires that burn outside the ANF; that is, off-site resource impacts are

not included in this assessment of economic tradeoffs. Off-site property losses are likewise not included.

Results

Fire Area and Emissions

Under Alternative 1, the mean annual wildfire area increases from ~3,900 hectares in year 1 to 4,300 hectares by year 40 (fig. 3a). Combining the larger fire suppression program with the smallest prescribed-fire treatment area, Alternative 2, results in a steady decrease in wildfire area over the first three decades to a relative stabilization after year 35 (fig. 3b). A similar pattern can be observed for the smaller fire suppression program coupled with largest prescribed-fire treatment area, Alternative 3 (fig. 3c). Under this alternative the wildfire acreage decreases rapidly over the first decade, followed by an increase in wildfire area over the next four decades and a relative stabilization by year 50. The increase in wildfire area over time is attributed to the high level of prescribed-fire treatment, which converts the predominantly chaparral vegetation to grass. Grass is slightly more flammable than chaparral (that is, produces larger fires) in the moderate fire weather class under which the majority of the fire starts occur each year.

In Alternative 4, the combination of a smaller suppression program with an intermediate level of prescribed-fire treatment (6,070 hectares per year) results in a rapid decline in wildfire area over the first two decades followed by a relative stabilization at the lowest level of any of the alternatives: 2,600 hectares per year (*fig. 3d*).

In Alternative 5, targeting only the highest two chaparral loading classes for treatment results in a rapid decline in wildfire area over the first two decades. This is followed by a small but steady increase in the annual wildfire area, from a mean of 2,600 hectares in year 20 to 2,900 hectares in year 100 (*fig. 3e*). In year 20, 4,166 hectares are treated by prescribed fire compared to 6,070 hectares in Alternative 4 (*table 3*).

In general, the greater the wildfire and prescribed fire area, the higher the $PM_{2.5}$ emissions (*table 3*). This pattern holds for all the alternatives except one, Alternative 3. In this alternative, FETM shows that the most aggressive prescribed-fire treatment rapidly converts the predominantly chaparral vegetation to grass, which has lower loading and lower consumption than chaparral, and therefore produces fewer emissions per hectare consumed.

Table 3-*FETM-predicted wildfire area, prescribed fire area, and $PM_{2.5}$ emissions in year 20.*

Alternative	Wildfire area (hectares)	Prescribed fire area (hectares)	$PM_{2.5}$ emissions (tons)
1	4,027	0	939
2	3,040	3,035	1,473
3	2,806	12,141	1,703
4	2,594	6,070	1,826
5	2,651	4,166	1,518

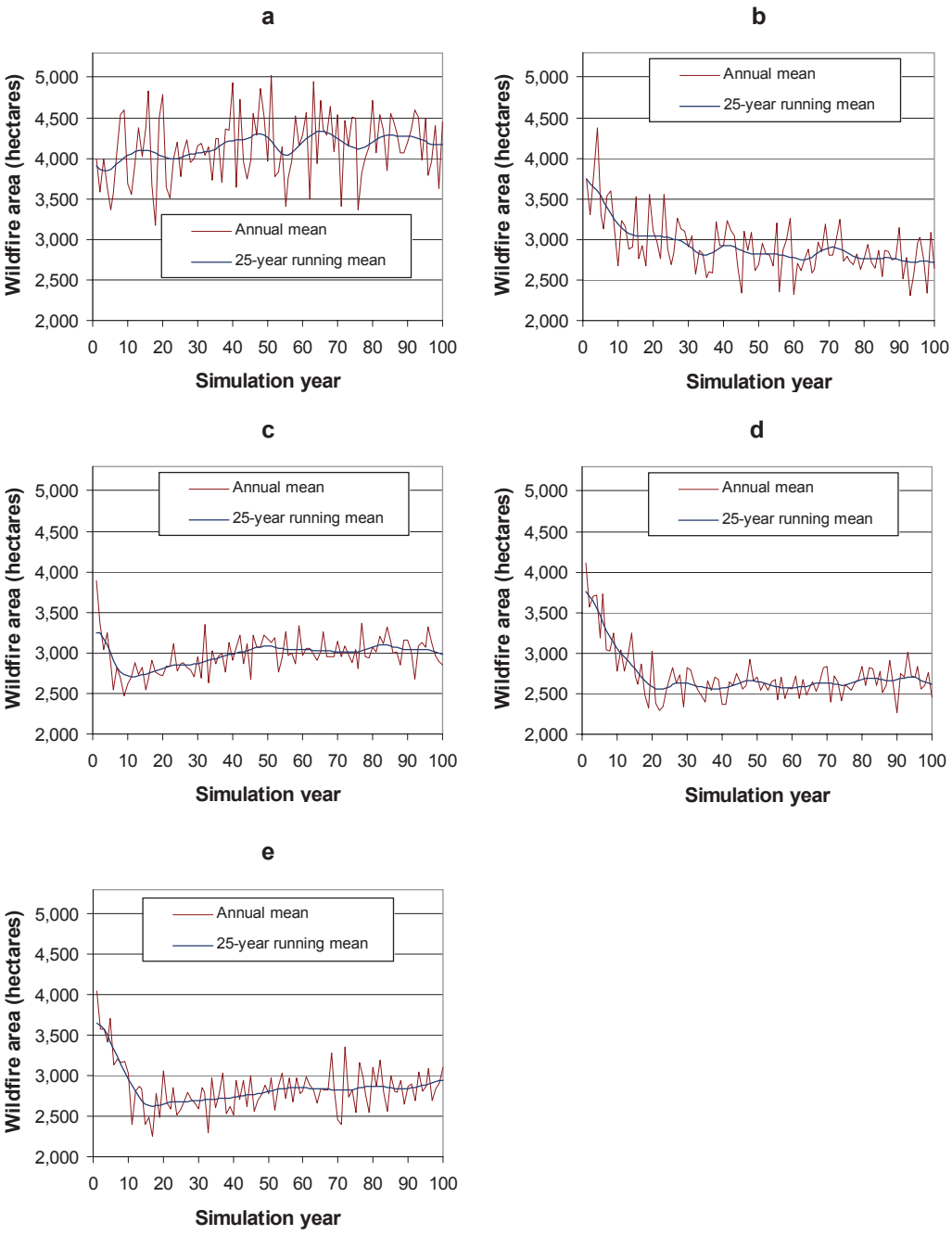


Figure 3—Time series plot of annual-average wildfire area burned for (a) Alternative 1 – Larger C20 suppression program with no prescribed fire, (b) Alternative 2 – Larger C20 suppression program with 3,035 hectares of prescribed fire annually, (c) Alternative 3 – Smaller M30 suppression program with 12,141 hectares of prescribed fire annually, (d) Alternative 4 – Smaller M30 suppression program with 6,070 hectares of prescribed fire annually, and (e) Alternative 5 – Smaller M30 suppression program with < 6,070 hectares of prescribed fire annually.

Annualized Present Net Value

The annualized PNV values for the five alternatives range from $21.3 million to $24.9 million (*table 4*). Forty to 60 percent of the annualized PNV is in program costs, depending on the alternative (*tables 2 and 4*). The C20 suppression program in Alternatives 1 and 2 has substantially higher annualized program costs than the M30 program in Alternatives 3 through 5.

Table 4-*Annualized present net value (PNV) of future costs and revenues ($1,000s of dollars).*

Alternative	Program cost	FSC	FTC	NVC wildfire	NVC prescribed fire	Total PNV
1	15,019	7,089	0	2,268	0	24,376
2	15,019	5,645	1,758	1,455	994	24,871
3	10,744	5,447	7,033	572	997	24,793
4	10,744	5,558	3,517	926	1,056	21,802
5	10,744	5,643	2,821	999	1,159	21,336

Fire suppression costs vary in direct proportion to the wildfire area consumed by fire size class. Alternative 1 contains no prescribed-fire treatment and consequently has the greatest annual wildfire area and the highest FSC. Alternative 3 has the lowest annualized FSC in spite of the fact that it has a larger annual wildfire area than Alternatives 4 and 5 because most of the wildfire area is in smaller size classes with concomitantly lower unit FSC values (*tables 3 and 4*).

Fuel treatment costs vary in direct proportion to the prescribed-fire area. Alternative 1 has no prescribed-fire area and no FTC. Alternative 3 has the largest area of prescribed-fire treatment and the highest FTC (*tables 3 and 4*).

The net value change associated with wildfire varies in direct proportion with the wildfire area. Alternative 1 has the largest wildfire area and also the highest annualized NVC for wildfire (*N.B*. Alternative 1 contains the larger suppression program but no prescribed-fire treatment). Alternative 3 has the lowest annualized NVC even though its wildfire area is larger than the area burned under either Alternatives 4 or 5. This is because most of the wildfire area in Alternative 3 is in grass vegetation, which burns at lower FIL than chaparral and with concomitantly lower unit NVC values (*tables 3 and 4*).

The net value change for prescribed fire varies in direct proportion with the prescribed-fire area. Alternative 1 has no prescribed-fire treatment program and therefore no prescribed-fire NVC. Alternatives 2 and 3 have similar prescribed-fire NVC, despite the fact that the latter has four times more prescribed-fire area than the former. The reason for this is that over time the more aggressive prescribed-fire treatment program in Alternative 3 produces a lower average FIL, as well as a lower NVC, than the less aggressive treatment program in Alternative 2. The same explanation can be applied to a comparison of Alternatives 3, 4, and 5 (*table 4*).

The total PNV of Alternatives 1 through 3 are similar and within two percent of each other (*table 4*). This is due to tradeoffs in program and fuel treatment costs. For

example, in Alternative 1 the savings in fuel treatments costs are entirely offset by the higher cost of wildfire suppression (*table 4*). Similarly, Alternative 3 has substantially lower program costs than the previous two alternatives, but these savings are offset by higher fuel treatment costs. With the two larger suppression (C20) alternatives, total NVC costs are similar, but differ in their wildfire and prescribed fire contributions.

Alternative 4 has substantially lower annualized PNV than Alternative 3 due to the lower combined FTC and NVC.

Alternative 5 has a lower annualized PNV than Alternative 4 because the lower combined FTC and NVC more than offsets the higher FSC (*table 4*). Alternative 5 has the lowest annualized PNV of all the alternatives.

Conclusions

This study's examination of economic tradeoffs between fuels treatment and fire suppression on the ANF found that substantial economic benefits in reduced overall fire protection program costs and natural resource loss can be achieved with a smaller fire suppression program coupled with a moderate fuels treatment program targeting only the highest loading classes of chaparral. These results are based on the evaluation of five fire suppression and fuels treatment alternatives and combine one of two fire suppression programs (annualized program costs of $14.4 and $10.3 million, respectively) with five prescribed-fire treatment intensities, ranging from 0 to 52 percent of the available chaparral acreage per decade.

More specifically, our results show that the larger C20 suppression program coupled with a small prescribed-fire treatment program (Alternative 2) substantially reduces the wildfire area compared to the no-prescribed-fire alternative (Alternative 1). However, the increased cost associated with this fuels treatment program is not met with a commensurate reduction in natural resource loss and suppression cost. In examining the smaller M30 fire suppression program coupled with an aggressive prescribed-fire treatment program (Alternative 3), our results show a slight increase in protection benefits over Alternative 2. However, the increased cost associated with this fuel treatment program is still not met with a commensurate reduction in natural resource loss and suppression cost. We found, instead, that a smaller and less costly fire suppression program, matched with a moderate intensity fuels treatment program targeting only the highest loading classes of chaparral (Alternative 5), provides the most cost-beneficial fire protection strategy for the ANF. Based on the USDA Forest Service's historical budgeting process, which does not consider off-site resource impacts, there appears to be little or no economic advantage in adopting alternatives with the larger of the two fire suppression programs. However, recent experience in Southern California shows that off-site property losses can be overwhelming. Including the risk of off-site impacts and associated economic losses would very likely alter the conclusions of this analysis.

Acknowledgements

This study was performed as part of a U.S. Joint Fire Science Program sponsored study entitled "A Risk-Based Comparison of Potential Fuel Treatment Tradeoff Models," conducted by the USDA Forest Service Pacific Southwest Research Station, Riverside, California (David Weise, Principal Investigator). FETM was

developed in part by a grant from the U.S. Joint Fire Science Program and in partnership with the USDA Forest Service, Pacific Northwest Region, and the Oregon State Office of the Bureau of Land Management, U.S. Department of the Interior.

References

Bradshaw, Larry S.; John E. Deeming; Robert E. Burgan; and Jack D. Cohen (compilers). 1983. The 1978 national fire-danger rating system: technical documentation. General Technical Report INT-169. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 44 p.

Feller, W. 1968. An introduction to probability theory and its applications. Volume 1, 3rd edition, New York NY: Wiley.

Forrester, Jay W. 1961. Stock and flow concepts are usually associated with system dynamics modeling. Industrial Dynamics. The MIT Press, Cambridge. 290 p.

GAO (U.S. Government Accounting Office). 1999. Western national forests: a cohesive strategy is needed to address catastrophic wildfire threats. Report to the Subcommittee on Forests and Forest Health, Committee on Resources, House of Representatives, GAO/RCED-99-65, 60 pp.

Luenberger, David G. 1979. Introduction to dynamic systems: theory, models, and applications. 435 p.

Minnich, Richard A. 1988. The Biogeography of Fire in the San Bernardino Mountains of California: A Historical Study. Berkeley, Los Angeles, and London: University of California Press. Publications in Geography No. 28.

Ottmar, Roger D.; Robert E. Vihnanek; Jon C. Regelbrugge. 2000. Stereo photo series for quantifying natural fuels. Volume IV: pinyon-juniper, sagebrush, and chaparral types in the Southwestern United States. PMS 833. Boise, ID: National Wildfire Coordinating Group, National Interagency Fire Center. 97 p.

Sandberg, David V.; Roger D. Ottmar; Geoffrey H. Cushon. 2001. Characterizing fuels in the 21st century. International Journal of Wildland Fire. 10: 381-387. (http://www.fs.fed.us/pnw/fera/jfsp/fcc/index.html).

Schaaf, Mark D.; Marc A. Wiitala; Donald Carlton, Roger Ottmar; and Maarten D. Schreuder. 2004. Fire Effects Tradeoff Model (FETM): A Landscape-Scale Disturbance and Succession Model for Land Management Planning (manuscript in progress).

Schoenherr, Allan A. 1992. A natural history of California. Berkeley, Los Angeles, and London: University of California Press. California Natural History Guides No. 56.

USDA Forest Service. 2000. Protecting people and sustaining resource in fire-adapted ecosystems: a cohesive strategy. General Accounting Office Report GAO/RCED-99-65. 85 p.

USDA Forest Service. 1999. FSH 5109.18: Wildland fire prevention handbook, WO amendment 5109.18-99-1, effective 06/10/1999, Chapter 10 - wildland fire prevention planning. (http://www.fs.fed.us/im/directives/fsh/5109.18/5109.18_10.txt)

USDA Forest Service. 1997. National interagency fire management integrated database (NIFMID). USDA National Information Technology Center, Kansas City, MO.

Vankat, John L. 1979. The natural vegetation of North America: an introduction. New York and other places: Wiley.

Forest Harvest Can Increase Subsequent Forest Fire Severity[1]

Carter Stone,[2] Andrew Hudak,[3] Penelope Morgan[4]

Abstract

The USDA Forest Service is progressing from a land management strategy oriented around timber extraction towards one oriented around maintaining healthy forested lands. The healthy Forest Initiative promotes the idea of broadscale forest thinning and fuel treatments as an effective means for mitigating hazardous fuel conditions and, by extension, fire risk. Fuels mitigation is proactive while fire suppression is reactive and expensive. Costs associated with suppressing large wildfires, as occur in the western USA with annual regularity, are astronomical and routinely exceed fire suppression budgets. It is not difficult to demonstrate that treating forest fuels is more cost effective than suppressing forest fires on untreated lands. In addition, forest thinning is potentially profitable, or at least can recoup the cost of thinning, and may also produce safer conditions for those living in the wildland-urban interface zones. Thinning practices also facilitate wildland firefighting efforts for monitoring and controlling future fire incidents as well as for forest health management practices by state and federal forestry agencies. However, forest thinning and other fuel treatment strategies can take many different forms, some of which can do more harm than good when considered with other factors that influence wildfire behavior, such as weather and terrain. One example of this issue can be seen in Montana during the 2003 fires. At the Cooney Ridge fire complex, an extensively and homogeneously logged watershed burned severely and uniformly due to remaining ground slash (which had attained low fuel moisture after overstory removal) and severe fire weather (low relative humidity and strong upslope winds). This contrasted with a mosaic of burn severities in an adjacent watershed with higher fuel loads yet greater heterogeneity in fuel distribution at the stand and landscape levels. Harvesting timber does not translate simply into reducing fire risk. Given the stochastic nature of fire weather events, and the complex terrain of most forested landscapes in the western USA, applying a variety of forest thinning and fuel treatment operations towards the goal of maintaining a diverse forest habitat mosaic, also constitutes a sensible fire risk mitigation strategy.

Introduction

In recent decades, fires have burned an increasingly larger area in the western US. The many large fires experienced in the western US have been variously attributed to effective fire suppression that has allowed fuels to accumulate, to land use including logging that has removed larger trees but not always thinned the smaller tress that remain, and to climate change (Morgan and others 2003). In some drier forest types,

---

[1] An abbreviated version of this paper was presented at the second international symposium of fire economics, policy, and planning: a global view, 19–22 April, 2004, Córdoba, Spain.

[2] GIS Analyst, University of Idaho Department of Forest Resources, Moscow, ID, USA.

[3] Research Forester, USDA Forest Service Rocky Mountain Research Station, Moscow, ID, USA.

[4] Professor, University of Idaho Department of Forest Resources, Moscow, ID, USA.

such as the semi-arid ponderosa pine ecosystems, tree density far exceeds historical norms and these can fuel unusually intense fires (Covington and others 2000). Elsewhere, however, many forests, such as sub-alpine forests at high elevations, naturally contain abundant surface and canopy fuels. There, intense and severe fires were the historical norm. The increasing number of people living in and using forests and rangelands have greatly increased both the chances of fires starting and the degree to which fires threaten people and their property when wildfires do occur. Dense thickets of younger trees now abound, and human and ecological communities are increasingly vulnerable to destructive crown fires. A consensus has emerged that it is urgent to restore more natural conditions to these forests (Allen and others 2002). Large, severe fire events account for a majority of the total area burned over time (Strauss and others 1989), as well as threats to people and their property (Maciliwain 1994).

The US responded to increased cost and extent of western wildfires with the National Fire Plan (http://www.fireplan.gov/content/home/) in 2000 and more recently with The Healthy Forest Initiative (http://www.whitehouse.gov/infocus/healthyforests/). Both the National Fire Plan and the Healthy Forest Initiative seek to reduce fire hazard through active fuels management via logging and prescribed burning. Efforts are designed to complement continued fire suppression, assistance to local communities, and rehabilitation. Both efforts build on recent concern over declining forest health in the western US as a result of fire exclusion, land use change, and climate change. Past emphases in fire management have been on wildfire suppression and prescribed fire to reduce hazardous fuels following timber harvest and improve wildlife habitat. On the other hand, lightning fires have been allowed to burn in wilderness areas to restore natural process for over thirty years. It is only in the last five or six years that fire management has extensively used prescribed burning and mechanical fuel treatments to reduce hazardous fuel accumulations in non-wilderness areas (Long 2003). The degree to which mechanical treatments such as thinning will reduce the intensity and severity of subsequent fires is a subject of lively debate (Morrison and others 2000). Relatively few studies exist, and these mostly have focused on dry forests.

Burn Severity

Burn severity is broadly defined as the degree of ecosystem change induced by fire (Ryan and Noste 1985). Severe fires are those that result in great ecological changes (Rowe 1983, Ryan and Noste 1985, Moreno and Oeschel 1989, Schimmel and Granstrom 1996, De Bano and others 1998, Ryan 2002). Compared to low severity fires, vegetation recovery is slower, nutrient cycles are more altered, invasive species are more abundant, tree mortality is higher, and soil erosion is more likely to follow severe fires. Burn severity encompasses fire effects on both vegetation and surface soils (Ryan 2002, Ryan and Noste 1985, Key and Benson 2001).

Burn severity is usually mapped from remote sensing data, to assess ecological effects and the degree to which post-fire rehabilitation is needed to reduce soil erosion and speed vegetation recovery (Parsons and Orlemann 2002). The US Forest Service (USFS) and other land management agencies employ remote sensing tools in an effort to efficiently and effectively manage fire-adapted ecosystems. Fire perimeter data for this paper came from Incident Command Geographic Information Systems (GIS) during and immediately after the fire. Fire severity classes came from

a Burned Area Reflectance Classification (BARC) map provided by the USFS Remote Sensing Applications Center (RSAC).

Cooney Ridge Fire

Cooney Ridge is one of several large wildfire events that occurred during the active 2003 fire season in western Montana (Fig. 1). A prolonged drought of four years preceded a very dry summer, and the weather in late August was hot, dry and windy. On August 8, 2003, lightning ignited a fire on Cooney Ridge, located approximately 18 miles east of Missoula, Montana (Fig. 2). Despite intensive suppression efforts (www.fs.fed.us/r1/fire/2003fires), the Cooney Ridge fire burned 8589 ha before it was contained on October 15, 2003. Many people who lived in small towns and scattered homes in nearby valleys feared that this fire would spread toward them. The fire threatened industrial power lines serving eastern Washington, northern Idaho and western Montana. A world-famous trout fishing stream, Rock Creek, directly to the east (and downwind) of the fire, was another resource fire fighters sought to protect.



Figure 1 — Aerial Photo of the Cooney Ridge Fire.

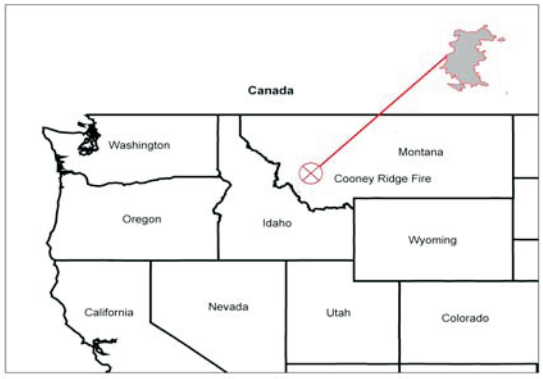


Figure 2—Location of the Cooney Ridge Fire.

The Cooney Ridge fire perimeter (Fig. 3) includes both public (54%) and private (46%) land. Most of the public land is managed by the USFS for multiple uses including timber extraction, recreation, and wildlife habitat, while only 177 ha (4%)

is managed by the Montana Department of Fish and Game. Private land is mostly industrial forestland belonging to Plum Creek Timber Company, while only 48 ha (1%) is under other private ownership.

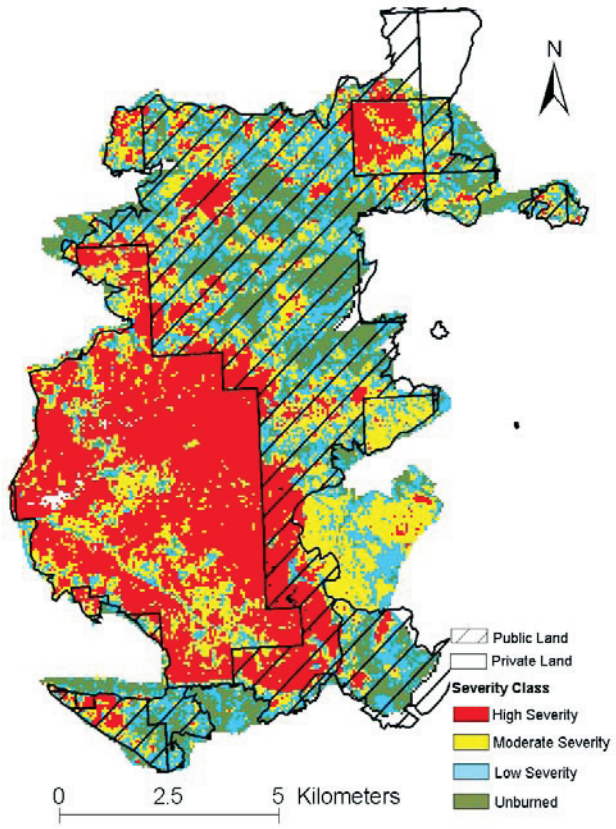


Fig. 3. Burned Area Remote Classification (BARC) Map

Results

Overall, 88% of the area within the final fire perimeter burned. More than 98% of private land burned, while 79% of public land burned. The areas that contain the most unburned vegetation are on the public lands portion (Table 1).

Table 1—*Area Burned on Public and Private Land in the 2003 Cooney Ridge Fire, Montana, USA.*

	Private		Public	
Class	Hectares	Percent (%)	Hectares	Percent (%)
Un-Burned	**83**	**2**	**984**	**21**
Burned	**3899**	**98**	**3622**	**79**
Low	*228*	*6*	*1347*	*29*
Moderate	*1704*	*43*	*1594*	*35*
High	*1967*	*49*	*681*	*15*
Total	**3982**	**100%**	**4607**	**100%**

Much more private land burned severely compared to public land (Fig. 4). Heavily logged areas and tree plantations have been known to burn more extensively than intact forests (Brown 2002). Much of the private land within the fire perimeter had been recently heavily logged for timber extraction, not for the purpose of fire hazard reduction

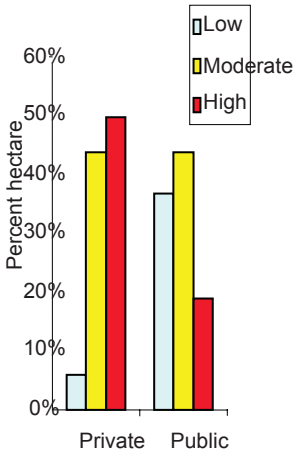


Figure 4—Proportional Area % burned in the Cooney Ridge Fire by ownership. Each column represents the burn severity classes illustrated in Fig. 3.

Daily fire perimeter maps showed that the largest fire expansion at the Cooney Ridge fire occurred between Aug 13 and Aug 17 (Fig. 5). The area burned during this time, and throughout the Cooney Ridge fire, was fairly evenly balanced between public and private lands (Fig. 6).

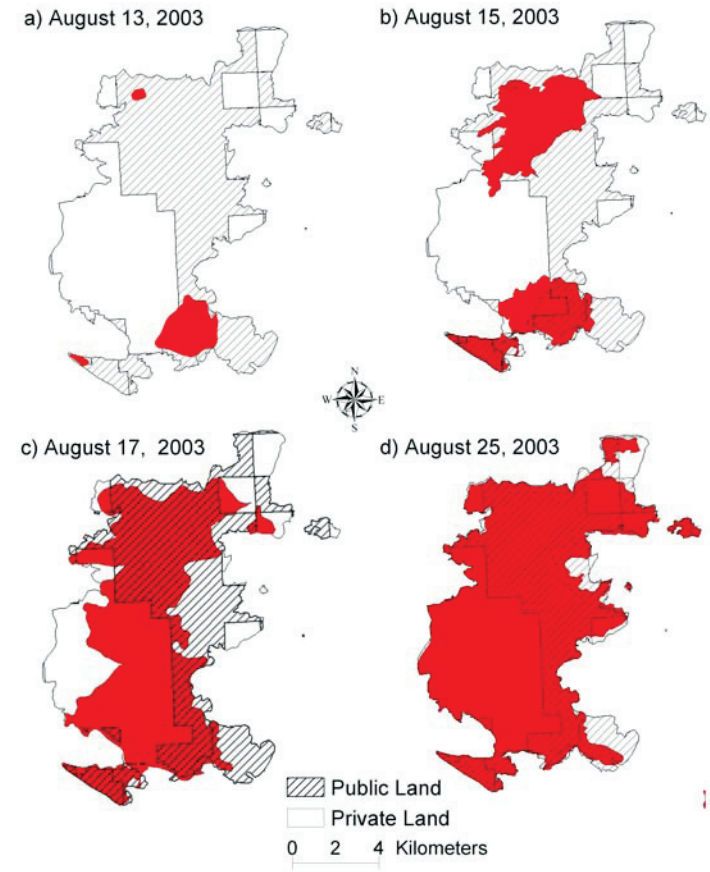


Fig. 5. Cooney Rige Fire Progression by date.

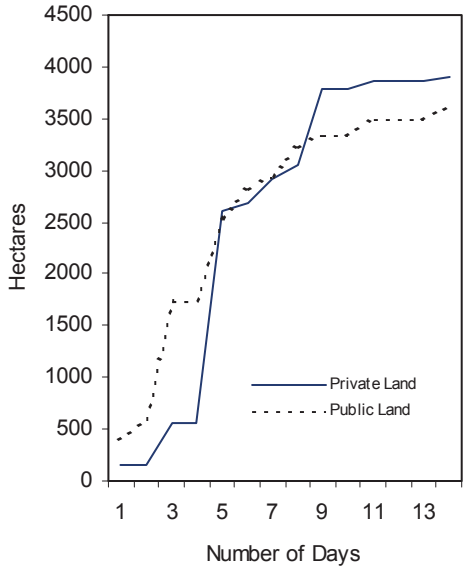


Fig. 6. Number of hectares burned per day of the Cooney Ridge Fire between the dates of August 13 to August 26, 2003.

Discussion

Private lands in this area were recently harvested with large clear cuts. Remaining vegetation and slash debris burned in the Cooney Ridge Fire. A much lower proportion of the public land had been recently harvested. Cut patches on the private land were much smaller, reflecting restrictions on the size of clear cuts and other harvesting units on public lands. The USFS manages federal lands for multiple uses besides timber production: wildlife habitat, recreation, and protecting water quality. As timber supply from federal lands has fallen over the last three decades, harvesting rates on private timberlands have increased to meet demand.

Pollet and Omi (2002), mention that fire severity refers to fire effects on the ecosystem and is directly related to post-fire vegetation survival. Their findings indicate that fuel treatments do mitigate fire severity. Fuel treatments provide a window of opportunity for effective fire suppression and protecting high-value areas. They go on to state that topography and weather may play more important roles than fuels in governing fire behavior. Of course, topography and weather cannot realistically be manipulated to reduce fire severity.

Hot, dry and windy weather made fire suppression efforts difficult, despite the many roads providing access for fire fighting crews. Daily fire perimeter maps showed that the largest blowup at the Cooney Ridge fire occurred between Aug 13 and Aug 17 (Fig. 5). The area burned during this time, and throughout the Cooney Ridge fire, was fairly evenly balanced between public and private lands (Fig. 6). Although local weather conditions may have differed slightly when public and private lands burned, these similar fire progression trajectories suggest more similarity than difference.

The Healthy Forest Initiative promotes the idea of broadscale forest thinning and fuel treatments as an effective means for mitigating hazardous fuel conditions. This is based on the sensible assumption that treating forest fuels is more cost effective than suppressing forest fires on untreated lands. In addition, forest thinning is potentially profitable, or at least can recoup the cost of thinning, and may also produce safer conditions for those living in the wildland-urban interface zones. However, as the Cooney Ridge fire suggests, timber harvesting does not always reduce the intensity or severity of subsequent fires. At Cooney Ridge, much of the extensively and homogeneously logged private lands burned with uniform high severity (Figs. 3-4, Table 1). Presumably, this is due to residual fuel, which had dried to very low fuel moisture.

The western United States is a fire environment (Morgan and others 2003). Fires will occur in the future, and some will occur when weather conditions are very dry, hot and windy. Given this ecological reality, the stochastic nature of fire weather events and the complex terrain of most forested landscapes in the western USA, applying a variety of forest thinning and fuel treatment operations towards the goal of maintaining a diverse forest habitat mosaic constitutes a sensible fire hazard mitigation strategy. An understanding of where fires are more likely to be severe would help to strategically locate and design fuel management treatments where they will be most effective. Such an understanding would also be helpful in fire suppression, fire mitigation and post-fire rehabilitation decisions.

Several challenges exist for fuels management. First, there is no single prescription that will be appropriate to all the conditions possible in diverse ecosystems. Second, thinning has very different economic and ecological effects depending on whether large trees are removed or remain behind. Third, the effects of logging include roads and sometimes, the damage to residual trees. Lastly, the costs of treatments must include long-term maintenance and monitoring. If practical alternatives to prescribed fire for reducing hazardous fuels can be found, resource managers will have a wider choice of methods to reduce risk of damaging wildfires at the urban interface (Brose and Wade, 2002).

In extreme years, especially after prolonged drought (Swetnam and Betancourt 1990, 1998), extensive areas burn across the western US. Such years account for the majority of the area burned (Strauss and others 1989) and the greatest threats to people and property (Maciliwain 1994). Thus fuels management through logging or other means will be less effective when weather conditions are extreme. Pollet and Omi (2002) suggest that funding for fuels management be directed towards the urban interface, tree plantations, critical watersheds, and habitat for threatened and endangered species.

Conclusion

One the clearest lesson from history is that fires have always occurred and that they will continue to occur despite our efforts to detect and suppress them (Morgan, 2003). In many forest ecosystems biomass production exceeds decomposition; this accumulated biomass fuels fires when lightning or people ignite fires in hot, dry, windy conditions. Fire and other disturbances have played important ecological roles in these ecosystems, thus complicating management decisions.

More research is needed to understand the relationship between ownership practices and severity. At the Cooney Ridge fire, patches of unburned vegetation and low severity remained after the fire, while much more of the private land burned uniformly with high severity. These results indicate that more diversified public lands management helped produce a much more diverse fire mosaic, thus better protecting this forested landscape. By comparison most private forested land burned with moderate to high severity, under likely similar weather conditions as on the public land.

Our results show that, perhaps counter intuitively, heavy harvest can increase subsequent fire severity. Costs associated with wildfire suppression far outweigh the costs of fuel treatment. Given the damages in both dollar and acreage, it would seem to be in the best interest of timber companies to implement thinning treatments and/or prescribed burning programs, rather than clear cutting. While there is much to be learned about the current status of forested ecosystems on the national Forest Lands, and about efficacy of thinning and prescribed fire to make these forests more sustainable, it appears clear that action must be taken to reverse trends of degradation. Since 1) thinning is a form of logging, and 2) prescribed fire can produce excessive smoke, runs the risk of escape, and appears to contradict decades of misinformation about the evils of forest fire, both techniques will be controversial among some portions of the public. Every effort should be made to apply these tools in manners that reduce the possibility of unintended consequences (Brown, 2002).

Cooney Ridge is not unique. Extensive amounts of untreated logging slash contributed to the devastating fires during the late 1800s and 1900s in inland Pacific

Northwest forests (Graham and others 1999). Logging doesn't always result in severe fires; it depends on which trees are harvested and the fuels left behind (Graham et al 1997, Pollet and Omi 2002.) Logging at Cooney Ridge was not designed to reduce hazard, and clearly it did not. Carefully designed harvesting practices, including those that retain smaller trees and/or thin dense stands, can reduce fire hazard (Pollet and Omi 2002, Graham et al 1999). Logging geared only towards large tree removal, since it does not manage surface fuels, will increase fire hazard and subsequent fire severity (Morgan and others 2003).

References

Allen, C., Savage, M., Falk, D., Suckling, K., Swetnam,T., Shulke, T., Stacey, P., Morgan, P., Hoffman, M., and Klingel, J. (2002) Ecological Restoration of Southwestern Ponderosa Pine Ecosystems: A broad perspective. Ecological Applications 12(5): 1418–1433.

Brose, P. and D. Wade. 2002. Potential fire behavior in pine flatwood forests following three different fuel reduction techniques. Forest Ecology and Management 163: 71-84.

Brown, Rick. 2000. Thinning Fire and Forest Restoration: A Science-Based approach for National Forests in the Interior Northwest. Defenders of Wildlife, Washington D.C.-USA. 1 p.

De Bano, LF, DG Neary, and PF Ffolliott. 1998. Fire's effects on ecosystems. John Wiley and Sons, NY. 333 p.

Graham, R.T., A.E. Harvey, T.B. Jain and J.R. Tonn 1999. The effects of thinning and similar stand treatments on fire behavior in Western forests, USDA Forest Service, Pacific Northwest Research Station and USDI Bureau of Land Management. PNW-GTR-463.

Hann, W.J.; Bunnell,D.L.; 2001 Fire and land management planning and implementation across multiple scales. International Journal of Wildland Fire, 10, 389 p.

Key, CH and NC Benson. 1999. The Normalized Burn Ratio, a Landsat TM radiometric index of burn severity incorporating multi-temporal differencing. In preparation.

Key, CH and NC Benson. 1999. A general field method for rating burn severity with extended application to remote sensing. In review.

Key, CH and NC Benson. 2001. Landscape assessment. In: Fire Effects Monitoring and Inventory Protocol http://www.fire.org/firemon/lc.htm

Lea, SW and P Morgan. 1993. Resprouting response of ninebark (*Physocarpus malvaceus*) shrubs to burning and clipping. Forest Ecology and Management 56: 199-210.

Long, D.;Ryan, K.; Stratton, R.; Mathews, E.; Scott, j.; Mislivets, M.; Miller, M.; Hood, S.; 2003 Modeling the effects of Fuel Treatments for the Southern Utah Fuel Management Demonstrating Project. USDA Forest Service Proceedings RMRS _29

Medler, MJ and SR Yool. 1997. Improving Thematic Mapper based classification of wildfire induced vegetation mortality. Geocarta International 12: 49-58.

Medler, MJ, MW Patterson and SR Yool. 1997. Image processing techniques for automated terrain stratification. In Proceedings of a Symposium on Effects of Fire on Madrean Province Ecosystems, Tucson, AZ, March 11-15, 1996. Gen. Tech. Rep. RM-GTR-289: pp: 271-275.

Moreno, JM and WC Oechel. 1989. A simple method for estimating fire intensity after a burn in California chaparral. Ecologica Plantarum 10(1):57-68.

Morgan, P and LF Neuenschwander. 1988. Shrub response to high and low severity burns following clearcutting in northern Idaho. Western Journal of Applied Forestry. 3(1):5-9.

Morgan, P., G..E. Defosse, and N.F. Rodriguez. 2003. Management implications of fire and climate changes in the western Americas. Chap. 15 in T.T. Veblen, W.L. Baker, G. Montenegro, and T.W. Swetnam. Fire and climatic change in temperate ecosystems of the western Americas. Ecological Studies 160. Springer. p. 413-440.

Morrison, P.H., J.W. Karl, K.J. Harma, L. Swope, T.K. Allen, and P. Becwar. 2000. Assessment of summer 2000 wildfires: Landscape history, current conditions and ownership. http://www.pacificbio.org/pubs/wildfire2000.pdf ; http://www.pacificbio.org

Parsons, A. and A. Orlemann. 2002. Burned Area Emergency Rehabilitation (BAER) Emergency Stabilization and Rehabilitation (ESR). Burn Severity Definition/Guidelines Draft Version 1.5, 27 P.

Pollet, J.; Omi, P.; 2002 Effect of thinning and prescribed burning on crown fire severity in ponderosa pine forests. International Journal of Wildland Fire, 2002, 11 p.

Rowe, J.S. 1983. Concepts of fire effects on plant individuals and species. In: DeBano, RW and DA MacLeans, eds. The role of fire in northern circumpolar ecosystems. John Wiley and Sons, NY. pp. 135-154.

Ryan, K.C. 2002. Dynamic interactions between forest structure and fire behavior in boreal ecosystems. Silva Fennica 36(1): 13-39.

Ryan, K.C. and N.V. Noste. 1985. Evaluating prescribed fires. P. 230-238. In: J.E. Lotan, B.M. Kilgore, W.C. Fisher, and R.W. Mutch (coord). Proceedings, Symposium and Workshop on Wilderness Fire, 1983 November 15-18, Missoula, MT. USDA Forest Service, General Technical Report INT-182.

Schimmel, J. and A. Granstrom. 1996. Fire severity and vegetation response in the boreal Swedish forest. Ecology 77(5): 1436-1450.

White, J.D., K.C. Ryan, C.C. Key, and S.W. Running. 1989. Spatial correlation of forest fire severity and vegetation recovery. International Journal of Wildland Fire 6(3): 125-136.

An Accounting System for Use in Evaluating the Commercial and Environmental Effects of Public Spending on the Mitigation of Forest Fires in the Mediterranean Area[1]

Pablo Campos-Palacín,[2] José Luis Oviedo-Pro,[2] and Alejandro Caparrós-Gass[2]

Abstract

This paper proposes a financial accounting system for measuring the commercial and environmental costs of public spending on the mitigation of forest fires in wooded land with a Mediterranean climate. It describes the application of the agroforestry accounting methodology (AAM) to the Alcornocales Natural Park (ANP). The level of public spending in the fight against forest fires (under the INFOCA programme) is quite significant in the ANP. The reduction in hectares of cork oak trees destroyed by fire since the introduction of the INFOCA programme in 1993, and the simultaneous increase in public monies provided for that purpose make it appropriate to conduct an economic analysis of the contribution made by the programme to the overall income generated at the ANP. The results make it possible to reach certain conclusions concerning the multiple effects of such public spending on society as a whole.

Introduction

The net economic effect of a catastrophic fire[3] on a Mediterranean agroforestry system is more of a practical question than a matter of theory. These doubts surrounding the economic consequences of a large-scale fire in Mediterranean forests are the product of the characteristics of production under each of the distinct uses of land, particularly in the case of brushland. The degree of financial benefit or loss therefore depends on the type of vegetation and the size of the areas affected by the forest fire. Taking the Alcornocales Natural Park (ANP) as an example, when one hectare of mature cork oak trees is destroyed by fire, this causes a change in land use from cork oak to scrubland, and a landowner's group has calculated that this leads to a €1,500 ha^{-1} reduction in the average market price of the land in question, given that the average value of land covered by cork oak trees is €7,500 ha^{-1}, whereas scrubland fetches an average of €6,000 ha^{-1} (Campos 2003). On the other hand, the economic effect on private capital of a forest fire on old brushland, which does not tend to be

[1] An abbreviated version of this paper was presented at the second international symposium on fire economics, planning, and policy: a global view, 19–22 April, 2004, Córdoba, Spain.

[2] Researchers, Instituto de Economía y Geografía, Consejo Superior de Investigaciones Científicas, Pinar 25, 28006 Madrid, Spain. email: pcampos@ieg.csic.es.

[3] The term ''catastrophic'' is applied to those fires that produce a level of environmental damage considered by society to be unacceptable.

grazed, can actually increase the quantity of forage units consumed by grazing livestock.

Nevertheless, before proceeding to evaluate the economic loss or benefit caused by forest fires, it is possible to develop a theoretical accounting structure for forest fires which identifies and evaluates the total economic damage which is expected to be avoided based on the cost of efforts to control forest fires. The accounting theory employed is based on the Hicksian concept of income (Caparrós and others 2003) and total economic value (Campos 1999).

The natural environment studied for this purpose is the Alcornocales Natural Park (ANP). The park has 82,462 hectares of cork oak land, which represents 48.5 percent of the Park's total surface area (*table 1*). Other tree species cover a further 13,262 hectares within the ANP, and the total wooded surface area therefore represents 56 percent of the total surface area of the entire ANP (Campos 2002).

Table 1 – *Land uses and principal vegetation types in the ANP*

Type	Surface (ha)	Percentage (pct)
Cork oak	82,462	48.5
Gall Oak	6,291	3.7
Wild Olive	3,060	1.8
Replanted	3,911	2.3
Brushwood	38,766	22.8
Grassland	26,694	15.7
Arable	5,441	3.2
Other	3,400	2.0
Total	170,025	100.0

Source: Campos (2002).

Trees and brushwood cover 134,490 ha of the ANP, representing 79 percent of the total (*table 1*). In particular, the 38,766 ha of brushwood is the type of forest fuel which has all the necessary characteristics for spreading the first flames of any forest fire if human activity does not intervene to prevent it. It is believed that the ANP's human inhabitants have prevented the propagation of natural forest fires at least since the late 18th century and have used prescribed burning until a few decades ago as a means of productively managing the brushwood in order to produce grazing for their animals. Today, however, prescribed burning is only authorised by Government environment services in order to remove the organic debris created by cork oak forestry activities. Expenditure by private land owners in the fight against forest fires was not considered in this study. The public funds directly employed in the fight against forest fires are overseen by INFOCA programme.

The views of owners and visitors in recent contingent valuation surveys show that the ANP's environmental services are highly valued (Campos 2003, Campos et al. 2003). The Andalusia environment service's determined policy to prevent catastrophic forest fires in the ANP is only partly justified from an economic perspective. Although the autochthonous flora and fauna in the ANP have survived cyclical catastrophic natural fires in the past[4], public perception of a catastrophic

[4] Only 1 percent of forest fires in the ANP have a natural cause, which indicates that if there had recently been an increase in the frequency and effects of fires in the ANP, it might be expected that there would be greater chances of irreversible environmental effects in the present than in the past.

forest fire is now more dramatic, and the Andalusia authorities have responded to this by ploughing funds into fire extinction measures under the INFOCA programme to such an extent that the risk of a forest fire growing into a catastrophic fire has been practically reduced to zero.

If public spending on fighting forest fires were required to be economically efficient, both commercially and environmentally – it would be necessary to compare the additional gains and losses obtained by increasing or reducing public spending by a specific amount. It is thought that such a policy would be unacceptable to the groups with an interest in preserving the cork oak trees if it implied contemplating a high risk of catastrophic fire in the name of improving economic efficiency. In other words, the INFOCA programme acts as if a catastrophic fire would create an irreversible situation, in which case the relevant criteria is whether the cost of preventing the damage caused by a fire is acceptable to society. Where there is a perception of an irreversible situation, it is the precautionary principle which rules in public policy concerning forest fires.

This paper aims to present the annual economic performance of the INFOCA programme measured by means of accounting system based on the theory of national income. It was considered that the most appropriate approach would be to present the results from one single year, while simulating that the level of public spending and future prices has stabilised.

The following analysis identifies and classifies both the output and costs of public spending under the INFOCA programme in 2002 as viewed by national accounting methods. It also provides an estimate of the direct business income generated by the INFOCA programme, a minimum threshold for the amount of loss avoided in order to make the INFOCA programme economically viable and, finally, it discusses whether the INFOCA programme's strategy of focusing its efforts on suppressing fires could be redirected towards measures to intervene directly by committing increased public spending to preventative work in the National Park.

Methodology

An economic analysis of the direct effects of public spending under the INFOCA programme on the ANP's total social income requires a standardised local system of economic accounts for agro-forestry (EAAF) which makes it possible to present the data in a clear and objective manner which is comparable with the aggregate figures obtained from national accounts (Campos 1999, 2002).

The concepts of production and business costs employed in this paper are defined in the *European System of Accounts (ESA95)* (Commission 1996). Total sustainable social income (TSI) generated in a certain period in one single area is obtained from the sum of the total net value added (NVA) and the value of capital gains (CG) obtained during the accounting period in the area in question.

The lack of standardised national accounts which take into account both elements of the TSI make it necessary to employ the methodology applied in the EAAF system, which was developed in order to incorporate commercial and environmental values under the same criteria as national accounts, but extended to the environmental values and the capital balance account (Campos 1999, Campos and others 2001, Caparrós and others 2003). Applying this system to the INFOCA programme distinguishes between two sets of accounts, i.e. production and fixed capital

The INFOCA programme contributes to the ANP's economy through the production accounts by means of four activities (prevention, surveillance, extinction and health services) which imply a total direct cost for the government environmental services (GES). The total cost (TC) of any activity under the INFOCA programme is broken down into intermediate consumption (IC) of raw materials (RM) and services (SS), salaried labour (SL) and consumption of fixed capital (CFC) [5]. Total production (TP) generated is classified either as intermediate production (IP) or final production (FP). The private companies whose activities are funded by public spending obtain a net operating margin through payment for the services of capital they have invested, but no margin is contemplated where the GES undertakes the activity itself (*table 2*).

The assumption that prices and investment volume are not subject to variation, as well as the absence of catastrophic destruction, means that capital gains for the four activities under the INFOCA programme are zero (*tables 2 and 3*).

The attributable additional total cost of the remaining economic activities (RAs) carried out in the ANP, i.e. what remains after excluding the four above-mentioned activities in the INFOCA programme, is, as a result of the programme, the intermediate consumption of internal services and the aggregate annual sum of the long-standing amortizations of the clearance of brushwood yet to be amortized. [6]. It is this additional total cost, equivalent to the total production of the four INFOCA programme activities, which makes it possible to avoid the additional loss of income which would result in the ANP's remaining economic activities (RA) if the cost did not exist. The INFOCA programme may therefore be considered responsible for generating an additional total production, an additional net margin and an additional capital gain in the ANP's remaining economic activities. The sum of this additional net margin and capital gain is the additional total capital income of the RAs generated by the INFOCA programme. [7] In other words, this additional capital income represents the loss prevented by the INFOCA programme.

The additional total social income produced by the INFOCA programme over the whole of the ANP is obtained by aggregating the net added value from the INFOCA programme activities and the additional capital income arising in the RA due to the INFOCA programme. All values are known, except the additional total production (TPra) and additional capital gains (CGra) earned by all the RAs undertaken in the ANP.

The beneficiaries of the ANP's additional total social income generated through the INFOCA programme are the private land owners, the public who visit the Park and passive users who benefit from the welfare derived from the conservation of the cork oak habitat and the other environmental functions, whose consumers are impossible to identify. These passive users can be grouped under the heading 'society as a whole'.

[5] It is assumed that the consumption of capital for the own-account production of fixed capital goods is zero, except for brushwood clearing, in which respect it is considered that the government environmental service's investment in infrastructure is permanent, given that it is adequately maintained.
[6] It is assumed that all the previous amortization achieved through preventive clearance of brushwood in the years prior to 2002 is valued at replacement cost, thereby equalling the values of the previous amortization and the investment in 2002.
[7] It is assumed that the INFOCA programme does not give rise to additional private costs in the ANP's remaining activities, or, in other words, if the INFOCA programme were to be terminated, the current private costs of the RAs would not be reduced.

Table 2 – *Production accounts for the INFOCA programme in the ANP for 2002. (€ ha^{-1} of the AWB[1])*

Type	Prevention (1)	Surveillance (2)	Extinction (3)	Health services (4)	INFOCA (5=1+2+3+4)	Additional effect in remaining activities (6)	Total additional effect (7=5+6)
1 Total additional production (TP)	7.09	3.10	25.07	0.30	35.56	TPra	TPra+35.56
1.1 Intermediate production (IP)	0.00	3.10	25.07	0.30	28.47	IPra	IPra+28.47
1.2 Final production (FP)	7.09	0.00	0.00	0.00	7.09	FPra	FPra+7.09
2 Total cost (TC)	7.00	3.02	24.80	0.29	35.11	35.56	70.67
2.1 Intermediate consumption (IC)	0.87	0.24	4.71	0.06	5.88	28.47	34.35
2.1.1 Raw materials (RM)	0.06	0.00	0.77	0.01	0.84	0.00	0.84
2.1.2 Services (SS)	0.81	0.24	3.94	0.05	5.04	28.47	33.51
External services (SSe)	0.81	0.24	3.94	0.05	5.04		5.04
Internal services (SSi)						28.47	28.47
2.2 Consumption of fixed capital (CFC)	0.00	0.00	0.00	0.00	0.00	7.09	7.09
2.3 Labour (M)	6.13	2.78	20.09	0.23	29.23	0.00	29.23
3 Net operating margin (NOM = TP – TC)	0.09	0.08	0.27	0.01	0.45	TPra–35.56	TPra–35.11
4. Net added value (NAV = M + NOM)	6.22	2.86	20.36	0.24	29.68	TPa–35.56	TPra–5.88
5 Capital gains (CG)	0.00	0.00	0.00	0.00	0.00	CGra	CGra
6 Additional capital income (CI = CG + NOM)	0.09	0.08	0.27	0.01	0.45	TPra+CGra–35.56	TPra+CGra–35.11
7 Total additional social income (TSI = M + CI)	6.22	2.86	20.36	0.24	29.68	TPra+CGra–35.56	TPra+CGra–5.88

[1]AWB: area of woodland and brushwood in the Alcornocales Natural Park (134.490 ha)

Source: Own work based on data supplied by EGMASA, FAASA, CMA and officials at the Centro de Defensa Forestal at Alcalá de los Gazules (CEDEFO Alcalá)

Table 3 – *Fixed capital balance sheet for the INFOCA programme in the ANP in 2002 (€ ha^{-1} of AWB[1])*

Type	Water points	Buildings and towers	Brushw-ood clearings	Fire extinction vehicles	Communica-tion equipment	Total
Initial fixed capital (FCi)	0.32	18.70	31.25	3.49	0.77	54.43
Internal investment FCii)			7.09			7.09
External investment (FCei)						
Outflow fixed capital (FCo)						
Final fixed capital (FCf)	0.32	18.70	31.25	3.49	0.77	54.43
Appreciation (FCa)[2]	0.00	0.00	-7.09	0.00	0.00	-7.09

[1]AWB: area of woodland and brushwood in the Alcornocales Natural Park (134.490 ha)
[2]FCr = FCf + FCs – FCi – FCii – FCie.

Source: Own work based on data supplied by EGMASA, FAASA and CMA.

The effects of public spending on the INFOCA programme therefore manifest themselves, on the one hand, by generating direct income from labour and the net operating margins of the business contracted to carry out the work and, on the other, in the income obtained by the ANP's remaining production[8].

The importance of the consumption of environmental services in the Park is readily highlighted by the previously unpublished results of two contingent valuation surveys conducted among the individual private landowners and the recreational visitors who have free access to the park.

The willingness of private landowners to pay (WtP) for the environmental services they have themselves consumed is 'levied' in its totality by the market, via payment of its capital value upon sale of the estate (Campos 2003). When comparing the value of the environmental services reported by visitors to the ANP and the level of public spending, it is necessary to ascertain precisely which part of the surplus reported by the consumer could be recovered in the event of establishing charges for recreational visits and a habitat conservation fund (Caparrós and Campos 2002).

The environmental value of the ANP to its passive users, called the conservation value for 'society as a whole', is not currently known.

Economic performance of the INFOCA Programme

The information analysed by the authors concerning public spending on fire fighting and prevention in the ANP, cost them a great deal of effort making enquiries and conducting searches at various offices at the Andalusia government environmental service and among the contractors engaged in carrying out the work envisaged under the INFOCA programme in the ANP. The geographical areas covered by the

[8] Given that none of the three above-mentioned groups which benefit from public spending under the INFOCA programme interiorise the payment in the form of intermediate consumption of the intermediate production of services, their respective appropriate capital incomes are overvalued by an amount equal to the value of the intermediate production of services by public spending under the INFOCA programme.

government bodies and the contractors mentioned above regularly extend beyond the limits of the ANP. In certain cases such as the aerial fumigation company *Fumigación Aérea Andaluza S.A.* (FAASA), spending is based on the whole of Andalusia, and the costs attributed to the ANP are therefore solely an estimate obtained from a calculation based on the surface area of woodland and brushwood (AWB). It is assumed that all spending by the Provincial Operations Centre at Cadiz is allocated to the ANP, given that the Park is its principal zone of operations[9].

The INFOCA programme is implemented by public servants and also the private sector. The principal public body is the Andalusia Government's Environment Department (ED), which co-ordinates the INFOCA programme through its Provincial Operations Centres (POC). The POC with which the ANP has most contact is the centre in Cadiz. The POC is staffed by a Director and Deputy Director of the INFOCA programme in Cadiz, the fire extinction team and other specialised officers. The ED directly controls a limited company called *Gestión Medio Ambiental S.A.* (EGMASA), which handles the hiring and administration of the workforce employed under the INFOCA programme, as well as the acquisition and administration of vehicles for this workforce. The aeroplanes and helicopters are hired directly by the ED from the contractor FAASA.

Table 4 displays the average number of hectares of wooded and non-wooded areas burnt in two distinct periods, namely, the period between 1980 and 1992, when the average annual area destroyed by fire represented 0.62% of the total wooded area of the ANP, and the period under the INFOCA programme (1993-2002), during which time the average annual area destroyed by fire represented 0.4% of the total wooded area. Since its inception, the INFOCA programme has resulted in a 35% reduction in the average area destroyed by fire per year.

Table 4 – *Average wooded and non-wooded surface area burnt in the ANP in the periods from 1980 to 1992 and 1993 to 2002 (ha).*

Period	Wooded surface area	Non-wooded surface area	Total forest area
1980-1992	593.40	662.34	1,255.74
1993-2002	383.16	276.99	660.15

Source: Own work based on data supplied by the Cadiz Provincial Operations Centre

Eighty percent of the total production of the INFOCA programme's four activities is derived from the intermediate production of services, the remaining twenty percent of direct production under the INFOCA programme being supplied by the final production of internal investment. The total direct cost of these activities is divided into eighty-three percent for labour and seventeen percent for intermediate consumption (*table 2*).

Table 2 allows us to provide an estimate of 29.68 € ha^{-1} of AWB for the direct net added value of the INFOCA programme in the ANP in 2002. This demonstrates

[9] Any subjective criteria adopted in order to govern the distribution of spending under the INFOCA programme is, to a greater or lesser degree, open to criticism. It might, on the one hand, be argued that the INFOCA programme would not exist without an area covered by woodland trees, or, at least, that public spending on fighting brushwood fires would be minimal. On the other hand, it could be argued that it is the very presence of wooded and non-wooded areas of brushwood which is the real cause behind the spread of small fires into catastrophic forest fires.

that almost the entire direct income thus generated is employed in financing labour costs.

It would be helpful in evaluating the INFOCA programme if a minimum threshold could be established for the required for additional social capital income which must be generated by the whole of the remaining activities in the ANP to ensure that public spending on fire prevention and suppression reaches a specific required level of social profitability. In the hypothetical and highly unlikely case that the government environmental services were to decide that one aim of the INFOCA programme was to be that its annual investment should reach a real social profitability rate of 2.5 percent (Pearce and Ulph 1995), the question would then be what is the minimum value of additional capital income – the minimum value of avoided loss – which must be provided by the RA in order to achieve a social profitability rate of 2.5 percent in 2002? Fixed assets (FA[10]) in the INFOCA programme in the ANP amounts to 72 € ha^{-1}. In order for this annual investment to reach a real social profitability rate of 2.5 percent, the additional capital income (CIa) obtained by this investment must reach a minimum annual value of 1.8 € ha^{-1} of AWB. In other words, the minimum additional total production and capital gains obtained by the landowners, visitors and society as a whole under the INFOCA programme must reach an annual figure of 36.91 € ha^{-1} of AWB:

$$CI = (0.45 - 28.47 - 7.09) \text{ € } ha^{-1} + TPra + CGra \geq 1.8 \text{ € } ha^{-1},$$

$$Cy = TPra + CGra - 35.11 \geq 1.8 \text{ € } ha^{-1},$$

$$TPra + CGra \geq 36.91 \text{ € } ha^{-1} \text{ of AWB.}$$

The additional total social income (TSIa) generated by the INFOCA programme was not measured in this study. The identity which would make it possible to obtain the INFOCA programme's TSIa in the ANP is as follows (*table 2*):

$$TSI = TPra + CGra - 5.88.$$

It would be necessary to evaluate the additional annual gain for commercial and environmental values in the ANP represented by TPra and CGra in order to obtain a correct figure for the income gained or loss avoided through the INFOCA programme. However, doing so would imply ascertaining the level of TSI which would be attained in the absence of the INFOCA programme. At the present time, any figure given in this respect would be no more than a hypothetical estimate.

Discussion

If one accepts the postulate that loss through catastrophic fire is perceived as irreversible, the issue enjoying the greatest priority is not an evaluation of the additional income gained, but rather the level of public spending needed to prevent the loss, provided the spending levels do not reach a figure which society considers to be high. In the absence of an evaluation of the loss prevented by the INFOCA programme, provisional figures are offered for the value of the income from the environmental services consumed by the landowners and members of the public visiting the ANP which could be lost to a great extent due to repeated catastrophic fires.

[10] Fixed assets represent the mean value of the capital employed throughout 2002 in the INFOCA programme. The identity employed to obtain this value is: FA = FCi + 0.5 TCd.

With respect to private environmental services, the amount of environmental income which has been self-consumed by the private individual landowners might have reached an average value of €208 ha^{-1} $year^{-1}$ in 2002 (Campos 2003). The as yet small number of visitors to the ANP attributes a notably lower value to the public environmental services than the private landowners. The visitors' median (mean) willingness to pay (WtP) is estimated at €22.2 for the enjoyment obtained from a visit to the ANP, and the average visitor is willing to contribute an annual sum of €13.8 to a conservation fund for the ANP (Campos et al. 2003). If it is accepted that the median (mean) WTP would only be paid by half the visitors – it has been estimated that the ANP received 0.47 visits per hectare of total surface area in 2002 – the introduction of a compulsory charge for their consumption of environmental services would generate €11.82 ha^{-1} $year^{-1}$ (Campos et al. 2003). The aggregate value achieved by the capital income from both types of environmental services amounts to €219.82 ha^{-1} in the ANP, and it may therefore be stated that there is evidence that the value of the economic loss prevented by the INFOCA programme in the ANP is significant, without knowing whether or not it reaches the €36.91 ha^{-1} threshold required by a social profitability rate of 2.5 percent.

If the private landowners were to be responsible themselves for public spending under the INFOCA programme, the private sector net operating margin would decrease as part of the current level of public spending under the programme in order to maintain the current low levels of risk with respect to catastrophic fire. It seems unlikely that the landowners would be happy to accept such a situation, nor would it perhaps be desirable for society as a whole, given the sizeable presence of the public environmental services. It is perhaps the case that the only means of ensuring that the risk of a catastrophic fire in the ANP will continue to be as close as it is to zero is adequate public spending at present levels. Nevertheless, it is debatable whether spending during the INFOCA has been distributed in the most effective way, as the emphasis is on reaching the fire in the shortest possible time, as demonstrated by the limited spending under the INFOCA programme on prevention in 2002, which took up twenty percent of spending compared to the seventy percent spent on fire extinction activities (*table 2*).

Conclusion

Forest fire fighting activities in the ANP are principally characterised by public spending. Government agencies have delegated the execution of the preventive measures to the private landowners, and it would appear that the subsidies offered for implementing such treatments have not gained sufficient prominence.

This paper has presented a measure of the direct economic effect of public spending on forest fires in the ANP. The results suggest that the public bodies' success with the INFOCA programme has been considerable, if the programme is measured by the reduction in the number of hectares burnt in the last decade.

The philosophy behind the INFOCA programme continues to place the emphasis on its strategy of extinguishing fires through the provision of sufficient funding in order to achieve this aim, but without applying any criteria of economic efficiency. The strategy would seem to draw its strength from public opinion, which has shown it to be benevolent towards public spending aimed at protecting a natural or environmental resource.

Acknowledgements

The study of public spending under the INFOCA programme was financed by the research project set up by the European Union's Fifth Framework Programme, *Tools for evaluating investment in the Mediterranean mountain areas-An integrated framework for sustainable development* (MEDMONT) (QLRT-1999-31031). The contingent valuation survey of the landowners was financed by the Ministry of Science and Technology's National R&D Plan, *Economy and Silviculture of Cork Oak Woodland* (ECOSEAL) (AGL2000-0936-C02-02). Finance for the contingent valuation survey of the free-access recreational visitors to the ANP was provided by the Andalusia Government's Environment Department. A great number of people and businesses have provided information voluntarily to make this paper possible. Some, such as José Antonio González Gutiérrez (Deputy-Director of the INFOCA programme in the Province of Cadiz) and Felipe Oliveros Pruaño (Director-Conservationist at the Alcornocales Natural Park), have helped to improve this paper by providing their opinions throughout the study. The authors' acknowledgment of the people and institutions cited above in no way implies that they are in any way responsible for the data and views presented in this paper, for which sole responsibility lies with the authors.

References

Campos, P., 1999. ***Hacia la medición de la renta de bienestar del uso múltiple de un bosque*.** Investigación Agraria: Sistemas y Recursos Forestales, Vol. 8(2): 407-422.

Campos, P.; Rodríguez, Y.; and Caparrós, A., 2001. ***Towards the Dehesa total income accounting: theory and operative Monfragüe study cases*.** Investigación Agraria: Sistemas y Recursos Forestales, número fuera de serie, 1: 45-69.

Campos, P., 2002. ***Economía del uso múltiple del bosque: Montes Propios de Jerez de la Frontera (1991-1993)*.** Revista Española de Estudios Agrosociales y Pesqueros, Volumen 195: 147 – 186.

Campos, P., 2003. ***Autoconsumo de servicios ambientales privados en el Parque Natural de los Alcornocales*.** Provisional report. IEG-CSIC. Internal working paper.

Campos, P., Caparrós, A. and Oviedo, J.L., 2003. ***Uso recreativo y de conservación en el Parque Natural de los Alcornocales. Informe provisional*.** Convenio Instituto de Economía y Geografía del Consejo Superior de Investigaciones Científicas y la Consejería de Medio Ambiente de la Junta de Andalucía. Internal working paper.

Caparrós, A. and Campos, P., 2002. ***Valoración de los usos recreativo y paisajístico en los pinares de la sierra de Guadarrama*.** Revista Española de Estudios Agrosociales y Pesqueros, 195: 121-146.

Caparrós, A., Campos, P. and Montero, G., 2003. ***An Operative Framework for Total Hicksian Income Measurement: Application to a Multiple Use Forest.*** Environmental and Resource Economics, 26: 173-198.

Commission of the European Communities, 1996. ***European system of accounts (ESA 95)*.** Eurostat, Luxemburgo.

Pearce, D. and Ulph, D. (1995) ***A social discount rate for the United Kingdom***. CSERGE. Working Paper GEC 95-01, Norwich.

Fire in Mediterranean Macchia: a Case of Study in Southwest Sardinia[1]

Ignazio Camarda, Giuseppe Brundu, Vincenzo Satta [2]

Abstract

Degradation of soil and vegetation has been investigated in one burned area with Mediterranean macchia located at Is Olias, in the Rio Santa Lucia catchments in south-western Sardinia (Italy). The land uses considered are representative of situations commonly found throughout the island. The botanical investigation showed that the renewal of the natural vegetation on abandoned land is only seemingly a slow process, that the burned areas can be restored in quite a short time, especially when undisturbed by grazing which hinders the development of suckers of the evergreen sclerophylls. What is more, growth rates are far too slow to make wood production economically viable. The results of the investigation provide useful indications for steering land management strategies towards policies compatible with sustainable development, and stress the importance of understanding, through the experimental data, the degrading effects that certain choices of land use can produce.

Introduction

The Mediterranean vegetation has been widely studied along general lines (Di Castri, Goodall, Specht, 1981) and in relation to the surveying problems (White, 1985). Within the framework of Medalus, several studies have been carried out on the vegetation in relation to degradation and desertification processes linked with human activities. In the Santa Lucia area the works by Arrigoni (1968), Camarda and others (1993, 1995) and Camarda & Satta (1995) provide a general picture of the setting of the Is Olias Santa Lucia site.

In the Mediterranean basin macchia (= matorral, maquis), together with the aspects of degradation correlated therewith (garrigue, phyrgana, batha), is one of the most common kinds of vegetation. It differs in a number of aspects, depending on the climate, the botanical species making up the *macchia*, on its history and human activities, on overgrazing and catastrophic events such as fires, where natural causes and human activities are closely interdependent.

Flora and vegetation provide one of the most immediate responses to degradation and desertification processes. The decline in primary production and the changes in floristic composition represent, at times, the most appreciable sign on the landscape.

---

[1] An abbreviated version of this paper was presented at the second international symposium on fire economics, policy, and planning: a global view, 19–22 April, 2004, Córdoba, Spain.

[2] Department of Botany and Plant Ecology, University of Sassari, Via Muroni 25, 07100 Sassari, Italy. email: camarda@uniss.it, dbev.angioi@tiscali.it.

The field site of Santa Lucia

In the Santa Lucia area, a significant part of the monitoring in the experimental plots concerned the evolution of the vegetation in different environmental situations. These plots are representative of abandoned agricultural land, burned land and land reforested with eucalypts, both in Sardinia and in the Mediterranean basin. Vegetation relev6s have been carried out in the single plots and nearby areas. Here the analyses are presented as well as the general considerations that emerge there from.

Burned Mediterranean macchia

The Mediterranean *macchia* is a forest ecosystem composed chiefly of evergreen sclerophyllous phanerophytes which have developed in tufts, owing to the recurrent fires, cutting and influence of domestic animals that feed thereon. Thus it is an ecosystem of secondary origin, rejuvenated cyclically and having highly complex biodiversity, biological forms and phenology of the different species. At Is Olias, in particular, the *macchia* is thermoxerophilous and characterized by the strong presence of *Ceratonia siliqua,* whose diffusion also depends on the fact that this species, in the past, was cultivated in areas nearby.

Table 1--*Relevé on spontaneous restored vegetation after fire*

Relevé area: 80 m^2
Total cover: 100%
Tall shrub layer cover: 45%
Average height: 2 m (1. 6-3. 10 m)

Ceralonia siliqua	2
Quercus ilex	2
Arbutus unedo	*1*
Phillyrea latifolia	2
Lavatera olbia	+
Pistacia lentiscus	*1*
Rhammis alaternus	+

Dwarf shrub layer cover: 55%
Average height: 1.6 m (1.4-1.8 m)

Cistus monspeliensis	3
Cistus incanus	3
Euphorbia dendroides	+
Smilax aspera	+
Asparagus acutifolius	+
Pistacia lentiscus (pl.)	+

Herbaceous plant layer cover: 10%

Pipthatherum miliaceum	*1*
Trifolium sp. pl.	+
Medicago sp. pl.	+

The relevé of table 1 shows that, after the fire in 1991, ground cover has been completely restored by the natural vegetation in six years. The total destruction by fire of that portion of the woody plants above ground, though on the one hand exposes the soil to erosion and mineralises the organic matter in the top soil, on the other encourages the growth of a grass cover composed of a large number of species.

The Mediterranean *macchia* existing prior to the fire, namely *Pistacia lentiscus, Arbutus unedo, Ceratonia siliqua, Quercus ilex, Erica arborea, Calycotome villosa, Cistus monspeliensis* and C. *incanus,* have proven capable of re-establishing the original conditions within the space of six years. Only *Phillyrea latifiolia* has not grown back to the height it had attained before the fire (165 cm against 215 cm). All the woody species flower regularly and produce a good number of seeds. One last observation, in the overall phytomass the herbaceous component only plays a marginal role.

The natural evolutionary process of the vegetation, following the fire in 1991, can be divided into the following stages:

1 . Evolved Mediterranean *macchia*.

2. Fire and destruction of original plant cover.

3. Populations of herbaceous plants, chiefly therophytes *(Vulpia sp. pl., Bromus sp. pl., Trifolium sp. pl., Medicago sp. pl.;* flowering of *Asphodelus microcarpus;* propagation by seed of *Cistus monspeliensis, C. salvifolius, C. incanus, Euphorbia dendroides;* development of suckers of evergreen sclerophylls.

4. Garrigue of Cistus salvifolius, C. monspeliensis e C. incanus and evergreen sclerophylls with numerous annual and perennial herbaceous species (Vulpia sp. pl., Bromus sp. pl., Trifolium sp. pl., Medicago sp. pl., Asphodelus microcarpus, Carlina corymbosa, Dactylis hispanicapanica, Orchis sp.pl., Foeni lum vulgaris, Piptatherum miliaceum, Leontodon tuberosus).

5. Mosaic of *garrigue* and *macchia* with strong decrease in herbaceous species and *Cistus salvifolius.*

6. *Macchia* consisting of evergreen sclerophylls, the role of *Cistus monspeliensis* and C. *incanus* diminishing, and further reduction of the herbaceous component. *Pistacia lentiscus, Quercus ilex, Ceratonia siliqua, Arbutus unedo, Erica arborea* provide the physionomy of the vegetation, while the strictly heliophilous species take on a less important part.

The process of renewal at Is Olias has not however proceeded at the same pace everywhere and the area as a whole resembles a mosaic where, depending on the microtopography, different species dominate. In particular, among the plants that reproduce by seed, *Calicotome villosa* has been observed to be the most active species, with regard both to diffusion and duration of the formations that develop after the fire. Vegetation in the burned area (hillslope 2) has taken six years to regain its initial state, much less time than hillslope 1 on abandoned land, and in keeping with what happens in many other areas covered by Mediterranean *macchia* of the evergreen sclerophylls climax stage that have been burned.

Conclusions

After a fire, an essential part in ground cover and soil protection is played by annual

and perennial herbaceous plants, thus by *Cistus* sp.pl. and lastly by the development of sprouts of evergreen sclerophylls.

In many areas, encouraging the development of Mediterranean *macchia* is the most effective way of restoring plant cover in short times, of maintaining biodiversity and of sustaining certain economic activities (cattle fanning, mushroom growing, hunting, beekeeping, products for handicrafts, firewood) and reversing desertification processes.

Of the species completely destroyed by fire, *Euphorbia dendroides, Calycolonle villosa, Ruta chalepensis, Helichrysum microphyllum, Phagnalon saxatile* diffuse to a greater extent and more rapidly by seed and this depends essentially on the closeness and quality of the seed bank.

Quercus suber is damaged to a greater extent by the presence of eucalypts than by fire.

The burned areas can be restored in quite a short time, especially when undisturbed by grazing which hinders the development of suckers of the evergreen sclerophylls. Grazing animals are also capable of altering the florisfic composition of the vegetation selecting the more appetizable species *(Arbutus unedo, Cistus salvifolius, Phillyrea latifolia* etc.) rather than the toxic *(Euphorbia dendroides, Anagyrisfoetida),* thorny *(Calycotome villosa, Genista corsica)* or, in any case, less sought after plants (Cistus *monspeliensis, Phillyrea angustifolia, Rhammis alaternus* etc.)

References

Arrigoni, 1968. Fitoclimatologia delIa Sardegna. Webbia, 23(l): 1-100.

Aru, A., 1985. The soils of Sardinia and their state of conservation. Geoödynarnik, Band 6: 71-84.

Brandt, J. and Thornes, J.13. (Eds.), 1996. Mediterranean desertification and land use, Wiley and Sons, 554 pp.

Bryan, R.B. and Campbell, I.A., 1986. Runoff and sediment discharge in a semi-arid drainage basin. Z.Geomorphol., 58: 121-143.

Camarda, I., Lucchese, R, Pignatti, S., Wikus-Pignatti E., 1993. La flora di PantaleoGutturu Mannu-Punta Maxia nel Sulcis (Sardegna sud-occidentale). Webbia, 47(1), 79-120.

Carnarda, I., Lucchese, R, Pignatti E., Pignatti, S. 1995. La vegetazione di PantaleoGutturu Mannu-Punta Maxia-Monte Arcosu nel Sulcis (Sardegna sud-occidentale). Webba, 49(2):141-177.

Camarda, I. and Satta, V., 1995. Degradation of vegetation and desertification processes in Is Olias (southern Sardinia). In A. Aru, G. Enne and G. Pulina (Eds.), Land use and soil degradation, MEDALUS in Sardinia, Proceedings of the Conference, held in Sassari, Italy, 25 May 194. 201-209.

Cammeraat, L. H., 1993. MEDALUS Field Manual (with contributions from L.H. Cammeraat, S.C. Clark JJ. Collin, A.C. Imeson and J. Melia). University of Bristol, Bristol, 115 pp.

Di Castri, R, Goodall, D.W., Specht, R.L., 1981. Mediterranean type shrublands. Ecosystems of the World 11. Elsevier S.P.C. Amsterdam, Oxford, New York.

FAO, 1976. A framework for land evaluation. Soil Bullettin n. 32, FAO, Rome, 72 pp.

Incoll, L.D., 1997. Report to the third group meeting, Medalus Ill, project 1, April 1997.

The Increase in Forest Fires in Natural Woodland and Forestry Plantations in Chile[1]

Eduardo Peña-Fernández, [2] Luis Valenzuela-Palma[3]

Summary

The problem of forest fires affecting natural woodland and forest plantations in Chile was analysed, characterizing the occurrence and the damage caused by this phenomenon. National Forestry Corporation data base was used to undertake the study. Once the problem of forest fires had been profiled, we debated the factors which would explain the increase in occurrence and the scale of the damage recorded to date. The information compiled indicates that the occurrence of forest fires has increased at an almost exponential rate from 1973-74 to the present time, this increase being closely related to the increase in surface area planted with highly inflammable species; the community's rejection of this type of crop; and the application of intensive silviculture which produces a high available fuel load and adds fire risk factors to the forest environment. In recent years the interaction between city and woodland is an added element which produces numerous fires on the rural-urban interface. The greater surface area of damaged natural vegetation is explained by the fact that this resource does not have sufficient protection all over the country. Moreover, a high proportion of this vegetation is located in inaccessible places, for which reason there is no suitable arrival point at the fire source and the topography does not allow effective fire-fighting. Consequently many fires affect a large surface area.

Introduction

In Chile, the occurrence of forest fires has significantly increased over the last 25 years, even exceeding 7,500 fires in the 2002-2003 season, compared to less than 1,000 fires per season before 1972. This increase seems not yet even to have reached its maximum, since no decline has been observed in the number of fires, in spite of the efforts made by prevention programmes. These programmes are run by private companies, as well as the National Forestry Corporation (CONAF) which is the state authority with legal responsibility for fire forest fire prevention and fire-fighting.

Traditionally the occurrence of forest fires was concentrated in the Mediterranean climate area, which extends from the Valparaiso Region to the Bío Bío region. However, in the last few years, a significant increase has been observed in temperate areas which include the Chilean regions 9 and 10. To the greater occurrence of forest fires is added the fact that during the last few seasons, due to a greater fuel load and drier climate, the intensity of fires is greater and many have catastrophic consequences. These fires are very difficult to control, have grave consequences for the population and the safety of fire-fighters, and also have a more negative impact upon the environment. The best example of this was seen in the 1998-1999 season when more than 20,000 ha burnt in 5 days in region 8, most of

[1] An abbreviated version of this paper was presented at the second international symposium on fire economics, planning, and policy: a global view, 19–22 April, 2004, Córdoba, Spain.

[2] University of Concepción, Faculty of Forestry Sciences, Victoria 631, Concepción. Chile.
[3] National Forestry Corporatio, Region of Bío Bio, Barros 215, Concepción, Chile.

these being *Pinus radiata* and *Eucalyptus globulus*, plantations, two species which have highly inflammable foliage (oils, resins and waxes).

Without doubt, for any forest fire protection organization this increase in forest fire occurrence must be its main concern. However the problem becomes even more complicated, since in the case of Chile, at least 99 per cent of fires are caused by the activity of human beings. Either fires are used intentionally, as is agriculture or forestry, or forestland is used negligently and carelessly by the population at large. Lastly, we have the action of pyromaniacs.

In view of the above scenario, this study characterizes the problem of fires in forest plantations and natural forestland in Chile, and analyses the factors which determine the dynamics of this phenomenon. The information produced serves to understand the problem and may be used to establish strategies which would reduce the occurrence of forest fires and minimize damage to associated flora and fauna.

Characterisation of the problem of Forest Fires in Chile

Characteristics of forest fires

The accumulation of biomass and dead fuel in natural forests and plantations, added to a physical and social environment which favours the occurrence of forest fires, gives rise to fires with very particular characteristics which are summed up as follows: a) high annual occurrence, b) high intensity and propagation of the fire, producing uncontrollable fires; c) increase in provoked (actionable) fires; d) major occurrence of satellite fires; e) high frequency of fires in the same location within less than 12 years; f) urban-rural interface with high incidence of fires; g) concentration of forest fires in regions 7 to 9; and h) Major economic impact, both social and environmental.

The majority of these characteristics perfectly fit forest plantation fires, however in natural forestland the main characteristics are the increase in fires in 8th and 9th region, particularly intentional fires, causing a greater environmental impact due to the diversity of vegetation and fauna, and because these accidental fires occur in high mountain areas which are difficult to access and where fire-fighting is also more complicated. It should be underlined that fires involving natural vegetation propagate less than forest plantation fires but may cause a great deal of harm, as some of these become underground fires which transfer a great deal of heat to the mineral soil and in other cases cover a huge surface area.

Another important problem the protection programmes face is the frequency of fires in the same areas and their high level of intensity. Added to this is the fact that a large number of these occur on the wildland-urban interface (WUI) which becomes a major threat to cities in regions 7, 8 and 9 where woodland more often surrounds the city (Peña 1996). Moreover, due to the high loading and the continuity and homogeneity of the fuel, fires in recent seasons have been fairly catastrophic in their behaviour, from the point of view of intensity, propagation speed and the severity of economic, social and environmental impact.

The extreme behaviour of high propagation, intensity and the major occurrence of satellite fires make control very difficult and puts the population in the affected sectors at risk, as well as the fire-fighters involved in control. High intensity fires will most likely become more frequent in the future, due to the high loading and continuity of fuel in plantations' major surface areas. Added to this is global climate

change and the greater interaction with the human population and their activities of production (Peña 2003).

Increase in Fire Occurrence

The interaction of plantation characteristics and their physical and social environment have given rise to a situation of high forest fire risk and danger which translates into a high annual occurrence rate. In the last decade this rate exceeded 5,600 hectares burnt in each season.

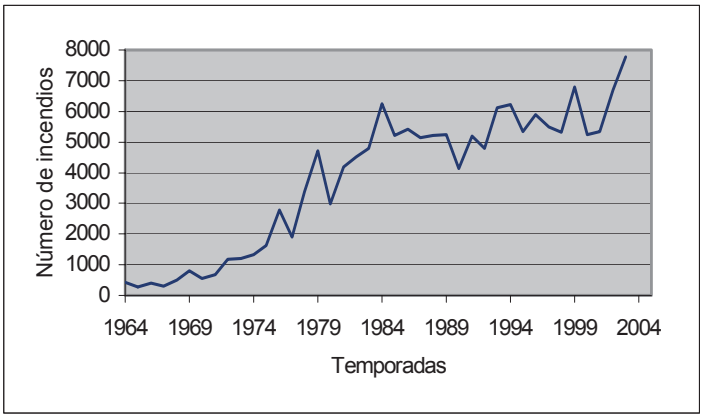


Figure 1— *Total number of fires per season for Chile (each season stretches from October to April of the following year. The value indicated for the season corresponds to the year the season ended).*

When analysing the occurrence of forest fires, it can be seen that the number of forest fires has increased exponentially from 1971-72, the first season when the figure for forest fires doubled, to reach a maximum of more than 6,000 fires in the 1983-84 season. In the following years there was a decrease in the number of fires, a trend which reverted again in 1992-93 when once again the seasonal figure exceeded 6,000 fires. Since that date virtually one of every two seasons gives figures close to or over 6,000 fires. This upward trend has been maintained, as in 2002-2003 a record figure of 7,500 fires was reached (figure 1).

It has not been possible to run an analysis of fire occurrence by vegetation type because the CONAF fire records do not undertake any sort of qualification. The reason is that in each fire different types of vegetation burns and it cannot be deduced whether this began in natural woodland or in a forestry plantation. This information may be very important, since to date there has been more damage in natural woodland, however this may be caused by a small number of fires and it may be that the majority of fires occur in plantations but affect a small surface area only.

The results, which show the increase in fire occurrence in each season, also lead us to postulate that current prevention campaigns have not had a positive result, mainly because few resources are invested in them and because they have concentrated only on changing people's attitudes but no fuel handling has been undertaken as a prevention method. Quite the reverse: a policy at national level of not eliminating waste from the harvest of natural woodland or plantations is still being

applied, with the aim of leaving the maximum amount of organic material to benefit the chemical and physical properties of the soil.

Another major aspect to consider in the analysis of forest fires is the fact that the fire rate is increasing significantly in region 8 and 9 (figure 2). Both regions have a temperate climate with a large plantation surface area, however the most important factor is that region 9 has a large surface area of natural woodland, with many park and reserve areas. Due to the above, it is considered that fires in region 9 have a more severe negative impact on flora and fauna than in cases where the fire affects only forestry plantations.

CONAF's records indicate that in recent years the greatest occurrence has been in regions 8 and 9 (figure 2) where 50% of plantations are located (INFOR 2001). The explanation for this concentration in occurrence is because these regions have a high concentration of plantations; good accessibility to planted areas; are densely populated (human population); the woodland surrounds the urban areas; and the climate is Mediterranean, creating conditions propitious to the occurrence of forest fires. Further north, where the climate is still Mediterranean, plantations are not continuous and their growth rate is lower (lower fuel loading). To the south of region 9 the temperature is lower and fuel has a higher humidity content.

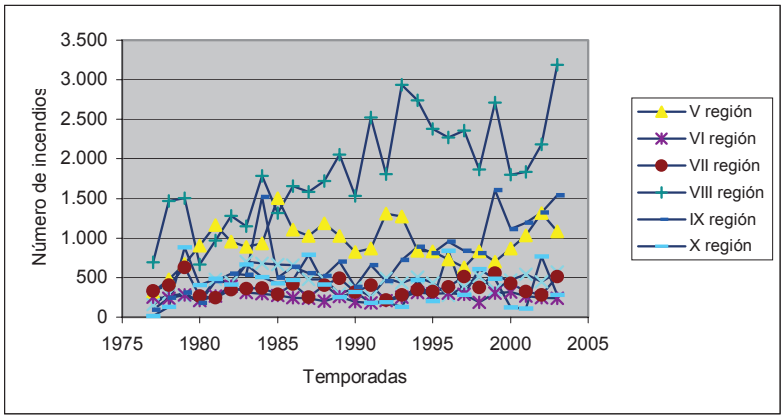


Figure 2 — *Fires by administrative region and season (regions with low forest fire occurrence are not included)*

Scale of damage from forest fires

On analysing the damage per season, it is observed that this shows a tendency to vary between 40 and 50,000 ha but shows major variations between seasons (figure 3). An extreme example of this variation can be seen in the 1998-1999 season when more than 100,000 ha burned, whereas two years later (2000-2001 season) the total burned surface area reached a second historic minimum of 10,804 ha. In this respect, experience indicates that a low percentage of fires, in general under 1 percent, produce extremely large fires which alone explain the major damage occurring in some seasons, amounting to at least 67% (CONAF 2003).

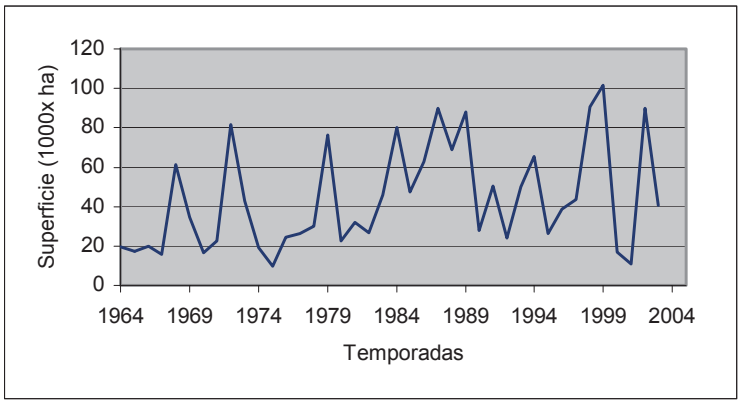


Figure 3 — *Total surface area affected by forest fires by season in Chile*

In order for some fires to damage large surface areas, they must occur in years of drought and/or days on which high temperatures are reached, there is low relative humidity, and winds over 30km per hour. The conditions described above occur from time to time in Chile. Of the 40 seasons for which forest fire occurrence records exist, 9 of these (25 per cent approximately) indicated damage of over 60,000 hectares.

On comparing fire occurrence (figure 1) with damage per season (figure 3) it can be seen that due to the high variability of damage, there is no relation between the number of fires and the surface area damaged. This can be explained by the fact that the protection programmes are increasingly more effective in detecting and fighting each individual fire source. For this reason, the average surface area affected by each fire is increasingly lower (figure 4). The damage only increases when atmospheric conditions are favourable to rapid propagation, as is the case of the presence of winds which accelerate propagation speed and increase the possibility of satellite fires at a considerable distance from the main fire front, normally 500 or more metres away. As the presence of conditions which are favourable to fire is irregular in terms of time, damage levels per season also shows major variations.

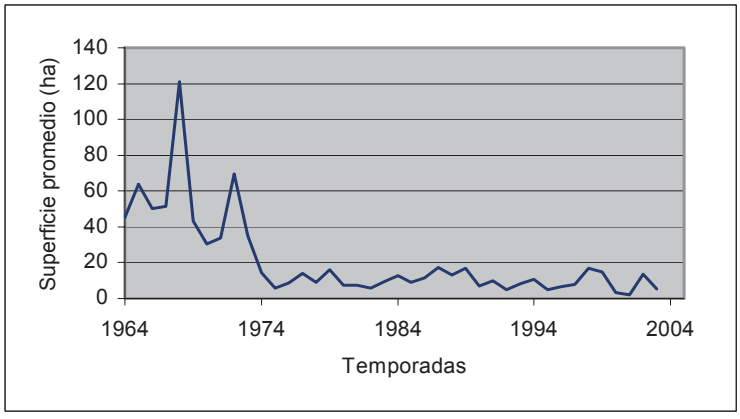


Figure 4 —*Average surface area affected by each forest fire*

In the 1973-1974 seasons the average surface damaged by each forest fire dropped to less than 15 ha from an average of over 45 ha in the past. From that date onwards the average has remained at around 10 ha (figure 4 and table 1). The results of average surface area damaged in each fire indicate that it is no longer possible to significantly improve in this regard, confirming the need to concentrate efforts on the prevention of fire occurrence. This greater effectiveness in fire-fighting coincides with the period when the forestry companies took over the cost of forest fire protection (creating their first fire brigades) and the CONAF professionalised their brigades by ruling out volunteers and hiring better skilled staff, trained for fire-fighting. Simultaneously the infrastructure available for forest fire protection programmes was improved, particularly the detection of fire sources and extinction in the shortest possible time.

Table 1— *Occurrence and damage from forest fires in Chile by five year periods from 1965-2003*

5-year period	Number of fires	Average surface area affected, by 5-year period (ha)	Average surface area affected by fire (ha)
1963 - 1968	383	26,767	70
1968 - 1973	883	39,682	45
1973 - 1978	2207	21,891	10
1978 - 1983	4239	40,679	10
1983 - 1988	5451	69,853	13
1988 - 1993	5090	47,617	9
1993 - 1998	5653	53,269	9
1998 - 2003	6346	52,348	8

Source: Soto 1995 and CONAF 2003

The analysis of the total surface area damaged, broken down between plantations and natural vegetation show that the greatest damage occurred in natural vegetation, which alone received more than 80% of the damage. Nevertheless, it should be underlined that the total damaged surface area varies considerably. In the case of plantation damage, however, this tends to remain fairly homogeneous over the course of all the seasons. Only 7 seasons out of a total of 27 record damage over 10,000 ha. Damage to natural vegetation in general exceeds 20,000 ha per season but only one third of this damage is to natural woodland. Even when the damage suffered by natural vegetation cannot be associated to a specific number of fires, it is assumed that this is caused by a small number of fires which become uncontrollable due to inaccessibility and the difficulty of fire-fighting.

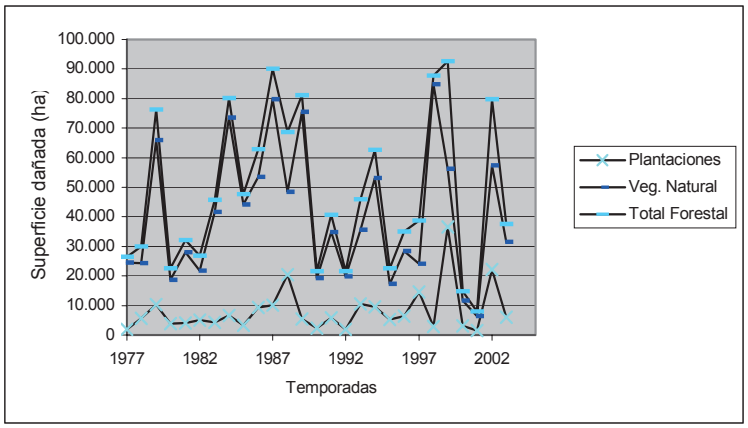


Figure 5 — *Total damaged surface area of plantations, natural vegetation and forestland*

The major difference in damage to natural vegetation and to plantations is explained by the level of investment made to protect each resource. Natural vegetation is mainly in the hands of CONAF (state-run organization) which invests less than US$ 1 per hectare, compared to the high investment to protect plantations made by private companies who invest more than US$ 7 per hectare. Moreover, the natural woodland is spread over the entire country and the plantations are concentrated in the south central area of Chile, facilitating their protection.

Causes of forest fires

The CONAF and private companies which have fire protection programmes keep records of the causes of these fires but in most cases there has been no thorough investigation done. Over the last few seasons, considering the importance of the causes of fire in prevention planning, brigades have been set up which more accurately determine the causes of each fire.

On improving the research, it has been detected that many of the fires are actionable (intentional). This is easily seen when comparing the causes of forest fires in region 8 between the decade 1990 to 2000 with the causes at national level. For region 8, 60 per cent of fires were intentional, as opposed to 26.2 per cent at national level in historical records covering all seasons (table 2). Over the last 10 years, at national level, an increase in intentional fires has also been seen, however a significant proportion of this increase is explained by the high rate of intentional fires in region 8.

The historical record at national level indicates that the main cause of forest fires is transit and transport through forestland, and second come intentional fires (table 2), a trend which has notoriously been reverted over the last few years, with intention moving into first position. This is an important message for protection organizations because they must determine what the motivation behind this intention is and with this information restructure the forest fire prevention campaigns.

Table 2.—*Distribution of occurrence of forest fires in region 8 and at national level by general causes*

Original cause	Region 8 Seasons 1990-2000 (Percentage)	National Last decade 1994-2003	National Seasons 1977-2003 (Percentage)
Forestry work	3.7	5.5	8.8
Farming work	2.5	5.1	8.0
Sport and recreation	1.3	3.4	3.0
Children's play	1.1	5.5	7.8
Transit and transport	19.3	28.3	27.4
Other activities	1.1	2.8	2.9
Intentional	60.0	37.1	26.2
Other causes	1.5	2.1	1.5
Unknown	9.5	10.1	14.4
Total	100.0	100.0	100.0

Source: Conaf 2003.

Factors explaining the increase in forest fire occurrence

Increase in planted surface area and plantation characteristics

If the forest fire occurrence curve (figure 1) is compared with the increase in surface area planted (figure 6), one can see that the increase in occurrence is closely related to the dramatic increase in surface area covered with plantations which was recorded from 1975 onwards. Before that season, between 1965 and 1974 an average of 6,000 ha was planted annually (Lara and Veblen 1993), however from that year onwards an average of over 70,000 ha were planted annually.

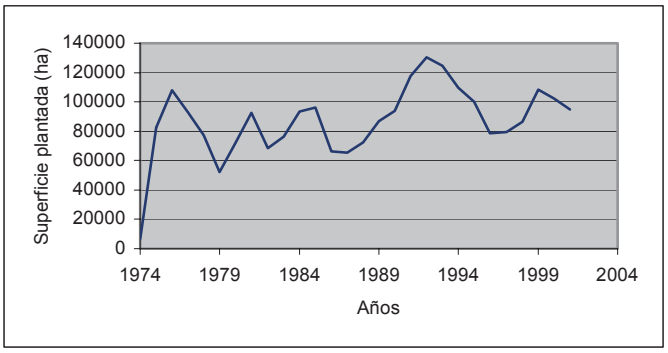


Figure 6 —*Surface planted annually in Chile seasons 1970 - 2000*

The main characteristics and conditions of Chilean forest plantations which could be directly or indirectly related to the increase in forest fire occurrence and to erratic behaviour (high intensity and spread of propagation), are listed as follows: a) single species (monocultures); b) large extension of planted surface area; c) spatial continuity of plantations; d) homogenous forest cultures (similar composition, age and density of stands); e) rapid growth, high biomass and dead fuel load; f)

inflammable foliage; g) high density of stands or abundant underbrush; h) accumulation and slow decomposition of woodland waste; and i) location of numerous plantations on the urban-rural interface.

The characteristics and conditions listed above have drastically altered the natural conditions which existed before forestry cultivation, creating major fuel loading which, in most cases, is more likely to be affected by fire, and moreover that of an erratic and unpredictable nature. In this aspect, the flammability of *Pinus radiata* and *Eucalyptus globulus* is a very important factor to consider, as in summer, the humidity content of leaves and aciculae fluctuates between 90 and 135 percent (Aliaga 1999, Fernández 2001). These species burn easily, firstly, due to their high content of inflammable elements and, secondly, because their foliage is permanently low in humidity content in comparison with normal levels of humidity in the green foliage of conifers and latifoliates which varies between 160 and 200 per cent (Chandler et al. 1983).

Forest plantations accumulate major fuel loading over a period of 8 to 12 months which, on plantations, when interacting with a constant increase in fire occurrence, creates high susceptibility to catastrophic fires. Under these conditions, any fire which occurs will be high intensity, causing what is known as a fire storm. Fire storms create their own temperature environment, relative humidity and winds, making fire behaviour unpredictable, with all the effects this has on fire-fighting planning. Under the conditions described, fires become uncontrollable for the forest fire brigades and will only be detained or controlled when the fuel runs out or when the fire leaves the woodland and affects pastureland or brush. On the other hand, to facilitate plantation work, woodland waste is accumulated or piled up in bundles. When these areas burn, the fire is more intense and behaves more erratically. Moreover, a large number of satellite or spot fires occur, which endanger the lives of the fire-fighters and hinder fire-fighting tasks.

If the conditions described above come to be, it is very clear that if the forest fire occurrence factor is not reduced significantly in Chile, in some higher risk sectors plantations could be affected by fires of catastrophic characteristics approximately every 12 to 17 years (Peña 1999). Recent studies show that the frequency of fire in one same area may be as high as 9 to 11 years (Parra 2002), however this is lower than the rotation age used currently in the country for some plantations of species of *Eucalyptus*. In view of the above and the current organization of protection, with high fire-fighting efficiency (< 10 ha/fire, table 1), forest fire protection programmes should place more emphasis on forest fire occurrence, especially those which are catastrophic in nature, and not the increase in fire-fighting resources, since in fire storm conditions these resources are never sufficient.

Intensive Silviculture

The intensive silviculture which is practised on Chilean plantations is a factor which predisposes them to forest fires. This activity is characterized by the fact that work goes on over very extensive areas, with a small number of species - in many cases only one species or genus. Also a number of different forestry treatments are undertaken during rotation. Plantations of *Pinus radiata*, *Eucalyptos globulus* and *Pseudotsuga menssiezii* (this last to a lesser extent) are intensively worked, for which

reason susceptibility to the action of fire increases, due to the availability of fuel as a result of the larger number of people and machines inside the stands.

The species indicated earlier are characterized by the fact that they have a large amount of available woodland waste material or fuel (branches, twigs, bark, leaves and decomposing material), as well as highly inflammable foliage. To this is added the continuity of the fuel (plantations) which in some cases may be over 20 km of continuous plantation. The effect of this continuity on the behaviour of fire was seen in the fires occurring in February 1999 in the vicinity of Concepcion, where fire-fighting was virtually impossible due to the high intensity and propagation of the fire and the occurrence of satellite fires. This same zone had burned in a fire of similar characteristics in 1988. Both experiences indicate that during a fire storm firewalls, forest tracks and other natural barriers are useless in stopping the advance of the fire, given that satellite or spot fires as far away as 2 km from the initial site may break out. In both cases the continuity of the fuel favoured the erratic behaviour of the fire.

In addition, the plantations are worked intensively, involving a series of forestry work tasks such as weed control, pruning and thinning which add to woodland waste, contributing a large amount of additional dry material which in turn contributes to increasing the fuel load per hectare, thus increasing the danger of fire. If an accident occurs, the release of thermal energy will be extremely intense, causing greater damage to the affected area. Apart from the contribution of additional fuel, pruning work leaves a great deal of accumulated material around the timber, which increases the probability of more damage being caused to tree cambium or tree mortality during a fire than in an untouched stand. Some thick bark species, however, show a certain resistance to fire, as is the case of *Eucalyptus globules.* When bark thickness is greater than 1 cm, these trees survive and sprout profusely from buds beneath the bark (Daroch et al. 2000, Figueroa 1997 and Morales 1998).

Types of forestry treatment may increase the danger level of fuel on plantations but they also has some beneficial effects, as is the case of pruning. This cuts off the continuity between surface fuel and aerial fuel, preventing surface fires from becoming crown fires or the occurrence of crowning. Thinning interrupts the horizontal continuity of aerial fuel, thus avoiding fire propagation across the crowns. However, by reducing the density of a stand, growing space is freed up (water, light energy and nutrients) which allow vigorous growth of undergrowth, thus increasing available surface fuel which, in many cases, may become ladder fuel, enabling the fire to reach the crown of pruned trees. In addition, the forest floor receives more solar radiation, reaching a higher temperature, facilitating drying, and increasing the temperature of the fuel which therefore causes faster ignition (Chandler et al. 1983).

The slash or woodland waste resulting from forestry work also affects the effectiveness of fire control operations, since this has a direct effect on resistance to control, as fires are of greater intensity and satellite or spot fires occur. According to those in charge of private company protection programmes, over the last few years the practice of not burning to eliminate slash has had a major effect on the increase in damage. It is also indicated that in sectors where fuel was left in bundles, as a way of minimizing the fire problem, resistance to control is greater than in sectors which were traditionally treated with prescribed burning.

In natural woodland, as a result of thinning and/or selective felling, an increase has been observed in susceptibility to forest fires. This type of vegetation is directed

mainly at fuel production, involving harvesting trees of small diameter, and leaving a large amount of slash. The resulting greater ingress of solar radiation favours ignition and propagation. This effect has been observed even in the humid tropical forests of Brazil which have low susceptibility to fire, however once ignited, since dead fuel remains and more solar radiation is received, this type of vegetation is more easily affected by fires than in natural conditions (Uhl et al. 1988).

Physical environment of plantations and natural woodland

The natural woodland has little human population, however during the summer season recreational activities significantly increase the presence of human beings in the woodland areas, increasing the risk of forest fires. Even where CONAF has no records, it is calculated that this occurrence is lower that that of the plantations but due to the difficulties of access and fire-fighting, the damage is greater.

The majority of Chilean forestry plantations are located in a physical environment which makes them highly susceptible to fire and when this occurs, fire behaviour is erratic. Their main characteristics are their location on terrain with irregular topography, in an Mediterranean climate area, surrounding cities. In recent years, added to the above is the phenomenon of global climate change which raises the atmospheric temperature and alters rainfall patterns, which in many regions may create conditions which favour the outbreak of forest fires (Peña 1993 and Woodward et al. 1991). Also, the phenomena of la Niña and el Niño occur cyclically, however there is no close relation with the occurrence of forest fires or greater damage from these (table 3). In order to establish a better explanation for this damage, background information is being compiled to determine whether or not this is related to episodes of the Puelche wind, a warm, dry wind which comes from the Andes mountain range.

In the 70s forestry plantations were begun on a massive scale in order to recover land degraded by farming and the felling and burning of natural vegetation in the coastal mountain range and the Andes in region 6 and 9. This land, or at least the most degraded areas, are located principally in the coastal mountain range, characterized by its irregular topography, a circumstance which favours the action of fire, since its gullies and canyons act as chimneys, increasing the force of the convection column and the propagation of the fire. The conditions described above increase the probability of fires which are very difficult to control and also hinder fire-fighting, since they present major resistance to control and create favourable conditions for the occurrence of fatal accidents during fire-fighting.

The major concentration of plantations, at least 58 percent of the total planted in Chile, are located in region 7 and 8 (INFOR 2001). Region 8 is the last region towards the south which has a Mediterranean climate. In part of its territory region 9 also has a Mediterranean climate, however in years of drought the whole region has this type of climate. This condition coincides with good plantation growth (over 20 m3 ha^{-1} $year^{-1}$) and the practice of intensive forestry, which creates a significant increase in the biomass and dead fuel per unit of surface area, thus creating an optimal environment for the occurrence and propagation of forest fires. Statistics for forest fires for the last decade confirm that more than 60 percent of fires which affect forestry plantations and natural vegetation occur in regions 7 and 9 (figure 2, CONAF 2003).

The expansion of plantations and the growth of cities creates a transition area which is very susceptible to the occurrence of forest fires. Over recent years, fires on the urban-rural interface have been frequent in regions 5 and 8. In the latter area they have caused major damage to housing and are a serious threat to human life, as was the case of the fires in Feb 1999 which completely destroyed numerous houses and threatened hundreds of lives. It is calculated that these occurrences will be even more serious in the future (Peña 2003). Added to the significant human presence on the interface is the increase in accessibility all over Chile, particularly to the woodland areas, linking the main cause of forest fires with vegetation. The most dramatic case is the Curanilahue commune in region 8 where 93 percent of the surface area of the commune is covered with plantations (CONAF-CONAMA-BIRF 1999) and where there is a dependency on this resource. At the same time, however, the plantations are a major threat to the population, given the probability of the occurrence of forest fires.

The phenomenon of el Niño causes drought in the south central area of Chile. This may have an effect on the occurrence of and damage caused by forest fires. When comparing the seasons of greatest damage (more than 60,000 ha burned) with the occurrence of forest fires (occurrence: 500 more fires more than the general trend) with the phenomenon of el Niño, no close relationship was found. In table 1 it was observed that out of a total of 12 seasons of greatest damage, only 5 coincide with the season with the highest occurrence of fires: 3 seasons coincide with the phenomenon of el Niño and another 4 seasons coincide with la Niña. A coincidence was considered to be when the season began in a year when either of these two climatic phenomena occurred. This lack of a significant relationship between damage and the occurrence of forest fires confirms that the greatest damage depends on certain atmospheric conditions; wind – high temperature – low relative humidity, which occurs from time to time in areas where woodland is concentrated. It should be underlined that one of the most recent events with major damage occurred in February 1999, coinciding with two consecutive years of la Niña (table 1) when, in region 8, over the course of five days, more than 20,000 ha burned, exceeding the figure of 100,000 ha damaged for the first time in that season.

Global climate change, mainly the greenhouse effect, could produce a climate even more favourable to forest fires, and many temperate regions could develop a climate similar to Mediterranean areas, since a direct result of this phenomenon would be an increase in the average temperature of at least 1.5 to 4.5 ºC , accompanied by altered rainfall patterns, with some regions becoming drier than in the past (Graham et al. 1990, Schwartz 1991 and Woodward et al. 1991), coupled with increasing susceptibility to forest fires in those areas. Vegetation will be drier and more ignition-prone, and fire behaviour and intensity will be more difficult to predict with current models of propagation. This will directly affect fire control actions, it will increase losses (economic, social and environmental) and also the risk of fatal accidents in fire-fighting.

Table 3 —*Seasons with highest occurrence of forest fires and years of occurrence of the el Niño and la Niña phenomenon in Chile.*

Season with highest occurrence	Season with greatest damage	El Niño phenomenon [1]	El niño phenomenon [2]	La niña phenomenon [1]
				1967
	1967-1968			
1968-1969		1969		
				1970
				1971
1971-1972	1971-1972	1972	1972	
				1975
1975-1976		1976	1976	
1977-1978				
1978-1979	1978-1979			
		1982	1982	
1983-1984	1983-1984			
	1985-1986	1986	1986	
	1986-1987	1987		
	1987-1988			1988
	1988-1989			
		1991		
1992-1993			1992	
1993-1994	1993-1994			
		1997	1997	
	1997-1998			1998
1998-1999	1998-1999			1999
				2000
2001-2002	2001-2002			
2002-2003				

Source: [1] Meteorology Agency of Japan
[2] Meteorology Directorate of Chile

The situation described earlier could occur in the south of Chile in region 9 and 11, where there is low forest fire frequency. This frequency only increases when there are consecutive years of drought. In this case the greenhouse effect would leave this area in a situation of greater susceptibility to forest fire. Moreover, as these regions have a high fuel load, conditions would be favourable to catastrophic fires, especially underground fires, with severe damage to the region's ecosystem. Fires caused by electric storms could also increase. This has been confirmed in recent seasons in the Andes mountain range where forest fires caused by lightning have been recorded. Formerly these did not occur.

The above analysis is based on the premise that there will, in effect, be an increase in temperature. In this respect it should be mentioned that a number of researchers indicate that, to date, the estimated temperature rise has not occurred. Others even consider that there are factors other than greenhouse gases which have a negative effect on this phenomenon, producing a drop in temperature. These have not been considered in the models used (Levi 1990 and Schlesinger 1988).

Social Environment of Plantations and natural Woodland

In Chile, statistics on the causes of forest fires show that the majority of fires are anthropic in origin (table 2). It should therefore be accepted that a very particular social environment exists which leads individuals to have a careless or negligent attitude towards forestry resources, in spite of the fact that directly or indirectly these provide the basis of the national economy. It seems that plantations involve much more complex conditions than native woodland, since they are concentrated in areas of human population. Below is a list of a number of factors which may affect this attitude, some of which are discussed in detail.

The main factors are:

a) Rapid change in production patterns from agricultural and livestock rearing to forestry, causing the displacement of the traditional peasant, leaving many people with a feeling of rejection towards forestry plantations.

b) Land ownership concentrated into major wood product companies who do not allow neighbouring communities access to their estates, or only a number of these provide this type of benefit. Thus, recreational, fishing and hunting areas are lost, as well as grazing land, the possibility of fuel removal, and the use of other forest products.

c) Harvesting and transportation of forest products causes damage to paths and local infrastructure, as well as noise pollution and pollution by solid particles in air and water sources.

d) Conflict with rural communities over water supply, due to the fact that the plantations demand more water as a result of their rapid growth. This causes a drop in the flow of springs and streams.

e) Lawsuits over land ownership and demarcations.

f) Low salaries and temporary seasonal migratory work. This creates conditions of economic instability and a certain degree of separation of the family group, due to employment far from the area of residence.

g) Environmental pressure groups which either rightly or wrongly create a negative environment for the plantations, which in turn produces a negligent attitude to forest fire protection for these areas.

The first impact of plantation-based forestry production was the displacement of traditional peasants who, in many cases, were forced to migrate to the cities (87% of Chile's population lives in urban areas), or to retrain to do a job unfamiliar to them and which offered less stability than farming or animal husbandry. Along with this, land ownership was concentrated within the major forestry companies, directly or indirectly limiting the options for use and even transit through forestry estates.

In addition, the State has no recreational areas in the vicinity of towns, or those that exist are poor quality or very small in size. This creates a major gulf between what is actually available and the demand for this type of activity, and since the public cannot use cultivated forest areas, they feel these areas offer them no benefit whatsoever, thus increasing their feelings of rejection. Over the last few years this situation has been changing on the basis of a good neighbour policy implemented by some forestry companies. This consists of maintaining good relations with

communities, granting them a number of benefits, and has resulted in a significant decrease in forest fires.

Another element to consider in this analysis of the hostile social environment for the plantations is the situation of temporary or seasonal migratory work. Most forestry work is done on a services rendered basis (contractors) with workers located in camps far from their permanent residence and family. There are a number of fundamental reasons for this from the viewpoint of output and work efficiency, however this also involves long periods away from home which deeply affects family life, since the major responsibility for the family is left to the spouse. Major problems also arise in the stability of marriages, with all the consequences this brings for the offspring and the family structure. All the above, combined with low salaries, make forestry work appear to be a low-priority opportunity for the labour force, in spite of the fact that this employment supports the family and indirectly affects the family environment. This circumstance of lack of benefit for the community has been confirmed in a number of preliminary studies undertaken in communes in region 8, the results of which indicate that the community sees little gain from forestry work, or that these benefits cannot be broken down in order to assess their contribution to the economy and local welfare (Ispizúa 1999 and Riquelme 1998).

The analysis undertaken in the previous paragraphs offers the view that probably many communities, with or without reason, feel rejection towards the forestry sector and particularly towards the plantations. The final result of this aversion towards the sector is that there is no motivation to protect the resource and a careless and negligent attitude to the use of fire still prevails, even producing intentional fires. These have increased significantly over recent seasons, particularly in region 8, where statistics for 1990-2000 show that 60 percent of forest fires in that region are intentional, compared with 37 percent for the country over all (table 3). What is happening in region 8 is alarming, as intentional fires are too prevalent for a resource which is one of the mainstays of the economy. These figures show clearly that the plantations have no social support and confirm the need to change the community's perception of woodland resources and particularly of plantations.

Final Comments

The high rate of forest fires and the trend towards the occurrence of catastrophic events from the viewpoint of fire behaviour (high intensity and speed of propagation) and scale of the damage, is determined by a series of factors inherent in the vegetation and the physical and social environment surrounding this resource. Natural vegetation has a high degree of continuity in the Andes range and due to its inaccessibility limits fire-fighting action. The plantations cover a major surface area and provide continuity of homogeneous and inflammable fuel which facilitates the action of fires. To the above is added the intensive silviculture which frequently intervenes in areas of natural vegetation, increasing and altering fuel, thus increasing the danger and susceptibility to forest fires. This interacts with the high risk due to the presence of workers and machinery in woodland areas, and the social environment which still does not fully accept forestry production, especially the forestry plantation industry. Thus, an atmosphere which is hostile towards forestry resources is created and the community takes a negative and careless attitude which produces a major number of forest fires, many of them intentional. The result of all this fire-prone environment is a high level of occurrence and damage which, to date,

in spite of all the prevention and fire-fighting efforts, has been impossible to minimize.

In order to effectively reduce the occurrence and damage of forest fires, since in Chile almost 100 percent of fires are anthropic in origin, better research into the causes of these events must be undertaken, and the motivation behind intentional fires determined. This information will reinforce the prevention programmes, which should be oriented towards modifying human behaviour, as well as preventive silviculture which would reduce the fuel load and modify the conditions of continuity and homogeneity which characterize them.

References

Aliaga, C. 1998. **Velocidad de propagación del fuego en Pino radiata, Eucalyptus globulus y Acacia melanoxylon: Un estudio de laboratorio**. Memoria de Título. Facultad de Ciencias Forestales, Universidad de Concepción.

Chandler, C.; P. Cheney; P. Thomas; L. Trabaud y D. Williams. 1983**. Fire in Forestry. Volume I, Forest fire behaviour and effects**. John Wiley & Sons. New York. 450 p.

Soto, L. 1995. **Estadísticas de ocurrencia y daño de incendios forestales temporadas 1964-1995**. Corporación Nacional Forestal, Gerencia Técnica. Departamento de Manejo del Fuego. Informe Estadístico Nº 44.

CONAF (Corporación Nacional Forestal). 2002. **Informes finales estadísticos de temporadas**. Programa de Manejo del Fuego. Corporación Nacional Forestal. Santiago

CONAF (Corporación Nacional Forestal). 2003. **Informes finales estadísticos de temporadas**. Programa de Manejo del Fuego. Corporación Nacional Forestal. Santiago de Chile.

CONAF-CONAMA-BIRF. 1999. **Catastro y evaluación de recursos vegetacionales nativos de Chile**. Comisión Nacional del Medioambiente y Corporación Nacional Forestal. Santiago de Chile.

Daroch, M.; E. Peña y M. Lineros. **Efecto del espesor de corteza viva de Eucalyptus globulus en la transferencia de calor: un estudio de laboratorio**. En Libro de Resúmenes de la IX Reunión y I Congreso Iberoamericano de Investigación y Desarrollo de Productos Forestales. 18-20 de Octubre 2000. Concepción.

Fernández, A. 2002. **Variación estacional del contenido de humedad en el follaje de Acacia melanoxylon, Eucalyptus globulus y Pinus radiata**. Memoria de Título. Facultad de Ciencias Forestales, Universidad de Concepción.

Figueroa, H. 1997. **Capacidad de rebrote de Eucalyptus globulus Labill afectado por un incendio forestal**. Memoria de Título. Facultad de Ciencias Forestales, Universidad de Concepción.

Fundación Chile. 1998. **Informe Final :Propuestas de nuevas estrategias para enfrentar los incendios forestales en Chile**. Octubre de 1998. Santiago de Chile.

Graham, R.L.; M.G. Turner y V.H. Dale. 1990. **How increasing CO_2 and climate change affects forests**. Bioscience 40(8):575-587

Haltenhoff, H. 1997. **La prevención de incendios forestales**. IX Silvotecna "Incendios Forestales". Forestal Mininco S.A. Concepción, Chile.

INFOR (Instituto Forestal). 2001. **Estadísticas forestales 2000**. Boletín Estadístico Nº 30. Santiago, Chile.

Ispizúa, M. 1999. **Impacto económico y social de las plantaciones forestales en seis comunas del secano de la VIII Región**. Memoria de Título. Facultad de Ciencias Forestales, Universidad de Concepción.

Lara, A. y T.T. Veblen. 1993. **Forest plantation in Chile: a successful model?,** pp. 119-139. En Afforestation: Policies, planning and progress. A. Mather (Ed.). Belhaven Press. London, UK.

Levi, B.G. 1990. **Climate modellers struggle to understand global warming**. Physics today 43(2):17-19

Morales, Juan. **Efecto del espesor de corteza en la transferencia de energía calórica en Pinus radiata D. Don. y Eucalyptus globulus Labill, en condiciones de laboratorio**. Memoria de Título. Facultad de Ciencias Forestales, Universidad de Concepción.

Parra, R. 2002. **Frecuencia de incendios forestales en plantaciones de Pinus radiata D. Don y Eucalyptus globulus Labill, en la Octava Región**. Memoria de Título. Facultad de Ciencias Forestales, Universidad de Concepción.

Peña E. 1993 **Efecto invernadero: Algunos impactos en Chile**. Revista Chile Forestal N° 201:11-12

Peña, E. 1996 **Incendios en la interfase urbana-rural: Tierra de nadie**. Chile Forestal. (Journal) October 1996

Peña, E. 1999. **Incendios forestales en plantaciones: ¿Un periodo de retorno del fuego de 12 a 17 años?** In Actas de las "XVI Jornadas de Evaluación del Manejo del Fuego. August,1999. Chillán.

Peña, 2003. **Incendios forestales catastróficos: ¿un fenómeno ocasional o un futuro amenazante?**. Universidad de Concepción, Facultad de Ciencias Forestales. Boletín Forestal 1(2): 3-5

Pyne, S. 1984. **Introduction to wildland fire: Fire management in The United State**. John Willey & Sons. New York. 455 p.

Riquelme, F. 1996. **Impacto socioeconómico de las plantaciones forestales sobre cuatro comunas precordilleranas de la provincia de Bío Bío: 1984-1994**. Memoria de Título. Facultad de Ciencias Forestales, Universidad de Concepción.

Schwartz, M.W. 1991. **Potential effects of global climate change on the biodiversity of plants**. The Forestry Chronicle 68(4):462-470

Schlesinger, M.E. 1988. **Negative o positive cloud optical depth feedback**? Nature 335:303-304

Uhl, C.; J.B. Kauffman; y D.L. Cummings. 1988. **Fire in the Venezuelan Amazon: Enviromental conditions necessary for forest fires in the evergreen rainforest of Venezuela**. Oikos 53: 176-184

Woodward, F. I.; G.B. Thompson y I.F. McKee. 1991. **The effects of elevated concentration of carbon dioxide on individual plants, populations, communities and ecosystems**. Annal of Botany 67: 23-38

Page left blank intentionally.

Practical Application of a Daily Prediction Model for the Occurrence of Human-Caused Forest Fires in Catalonia[1]

Cristina Vega-García,[2] Christian Ortiz Ruiz,[2] Raquel Canet Castellà,[3] Inés Sánchez Bosch,[2] Daniel Queralt Creus[2]

Abstract:
A study was conducted in 2002 with the aim of defining and analysing, both spatially and temporally, meteorological, topographic, socio-demographic and vegetation conditions which might be linked to the occurrence of forest fires caused by humans in Catalonia in Spain, by integrating them into a GIS.
Based these analyses, various daily prediction models were developed for human caused fires. All of them predicted occurrences in binary values (yes/no) in the 10 km^2 grid generally employed by various government bodies in Spain with responsibility for fire prevention and suppression. The best of these models, a statistically based logit model, was evaluated in an operative manner during the summer of 2003, once the process for generating a daily prediction map before 8:00 am had been automated.
This paper presents the modelling process, the testing of the models and the advantages and disadvantages of applying the model to the daily prediction of forest fires.

Keywords: fire occurrence prediction, Spain, logit.

Introduction

The aim of this study was to define and analyse, both spatially and temporally, meteorological, topographic, socio-demographic and vegetation conditions which might be linked to the occurrence of forest fires caused by humans in Catalonia in Spain, by integrating them into a GIS.

The analysis variables thus generated, together with the historical fire data, made it possible to construct and evaluate a daily prediction model for human caused fires, which would be operatively tested in the subsequent summer campaign. The system had to be able to predict the daily number of fires in the 10 x 10 km squares routinely employed by several government agencies such as the Forest Fire Department of the Directorate-General of Nature Conservancy (DGNC), The Environment Ministry and the Forest Fire Section of the Directorate-General of Emergencies and Civil Protection (DGECP) of the Catalonian Regional Government.

---

[1] An abbreviated version of this paper was presented at the second international symposium on fire economics, planning, and policy: a global view, 19–22 April, 2004, Córdoba, Spain.

[2] Dept. d'Enginyeria Agroforestal, ETS d'Enginyeria Agraria, Universitat de Lleida, Av. Alcalde Rovira Roure, 191 25198 Lleida, Spain email: cvega@eagrof.udl.es.
[3] Secció d'Incendis Forestals. Direcció General d'Emergències i Seguretat Civil. Departament d'Interior. Generalitat de Catalunya. Ctra. de la Universitat Autònoma s/n, 08290 Cerdanyola del Vallès, Barcelona, Spain.

The stated goals for the trials of the model included evaluating the technical difficulty of setting the model up, the necessary sources of data, the personnel requirements and the qualifications required for these people, and an assessment of its practical worth in the day-to-day work of the Catalonian Government's Fire Brigades.

Methods

The area chosen for the study was Catalonia, which already possessed fuel model maps (by Vélez Muñoz, 2000) before the project commenced, i.e. in the provinces of Barcelona and Gerona, as well as part of the provinces of Tarragona and Lérida (*fig. 1*).



Figure 1 – Local areas in Catalonia with fuel models available for the project.

The layers available for analysis in GIS format were obtained from the Catalonia Cartographic Institute and the Environment Department of the Catalonian Government, and included road networks, railways, power lines, urban centres, housing developments, and protected zones at 1:50,000 scale, and a digital terrain data model at 45 m resolution, all digitalised in 1994. All these cartographic sources were drawn upon to generate new gridded and raster layers for the corresponding 10 km x 10 km prediction squares (348). These newly-created layers made it possible to draw up the geographical analysis variables listed in *table 1*.

Table 1—*Geographic analysis variables.*

Name	Description	Units
Elevation	Average elevation for the square taken from a 50 metre Digital Terrain Model	Metres
Class-O1,O2,O3,O4,O5	Orientation in the square Flat North East South West	Percent of surface area occupied by each class. During the analysis stage, Class 1 (flat) was considered to be the same as south (Class 4)
Class-P1,P2,P3,P4	Surface occupied by one of the following categories of slope 0-5% 5-15% 15-30% >30%	Percent of surface occupied by each category
Roads1	Average distance per square to motorways and principal roads.	Metres
Roads2	Average distance per square to asphalt roads (not taking into account motorways and principal roads)	Metres
Roads3	Average distance per square to unsurfaced roads, these considered to be earth roads and paths	Metres
Rail	Average distance per square to railway lines	Metres
Powli	Average distance per square to power lines	Metres
Housdev	Average distance per square to housing developments	Metres
Urbcent	Average distance per square to urban centres	Metres
P-SNV	Surface occupied by a Protected area of Special Natural Value-	Percent of occupied surface
Mod2,mod3,mod4,mod5,mod6, mod7,mod8,mod9,mod10	Surface occupied by each fuel model	Percent of surface occupied by each model

Eighty-four of the automatic stations operated by the Catalonia Meteorological Service and the Catalonia Agrometeorological Network were used to gather the daily meteorological variables over a five-year period from 1996 to 2000, not too long after the raster layers were digitalised. The daily variables taken into account included the usual meteorological parameters, such as relative humidity, precipitation, temperature, wind, but also some danger ratings such as the DGNC[4]'s probability of ignition index, the Canadian Fire Weather Index (Van Wagner 1987), the Keetch-Byram Drought Index (Keetch and Byram, 1988) and the intensity of potential solar radiation as developed by Volk (1997) in each 10 x 10 km cell. The calculation and spatial interpolation of all these variables was only carried out during

[4] Según apuntes del Curso Básico de Defensa contra Incendios Forestales organizado por el Colegio de Ingenieros de Montes de España.

each year's summer campaign during the five-year period, which, in Spain, runs from 15th May to 15th September. The variables are set out in *table 2*.

Table 2— *Meteorological analysis variables.*

Name	Description	Units
Intensity	Intensity of potential solar radiation - Volk	mm
P24	Precipitation in 24 hr, daily	10^{-1}mm
Taverage	Average daily temperature	Degrees centigrade
RHaverage	Average daily relative humidity	Percent, 0-100%
WSaverage	Average wind speed each day	m/s
WDaverage	Average wind direction	Degrees
Tmax	Maximum daily temperature	Degrees centigrade
RHmin	Minimum relative humidity each day	Percent, 0-100%
WSmax	Maximum daily wind speed	m/s
PWS	Peak Wind Speed	m/s
SD	Standard deviation of wind	Degrees
RadG	Real solar radiation at the station	mj/m^2
FWI	Fire Weather Index	Open-ended, 0 to +100
KBDI	Keetch-Byram Drought Index	Scale 0-800
FDFM	Fine dead fuel moisture,	Percent, 0-100%
	The DGNC's probability of ignition	

The forest fire database for 1996 to 2000 needed rasterizing and relating to the 10 x 10 km square, which defined the prediction units. From an overall available total of 3,310 forest fires including verified location and causes, 1,600 were caused by humans in the summer campaigns between 1996 and 2000. However, the removal of incomplete observations following the cross-referencing of all the geographic and meteorological databases associated with the prediction cells produced a database with 36,190 daily observations in 348 squares over a five-year period, with 43 fields (variables) associated with each observation, of which 35,896 did not include forest fires and only 294 were witness to fires.

An analysis of the small number of occurrences in the squares indicated that it would not be possible to develop models, as originally intended, to predict the number of occurrences in each prediction cell and day due to a lack of data. There were only 10 cases of 2 fires/day square and 2 cases of 4 fires fires/day square in a database containing 36,190 items of data. This even led to the rejection of appropriate statistical models for rare events such as the Poisson distribution, and made it necessary to consider binary response models, such as the logit model, which others had previously used in forest fire prediction (Martell et al. 1987, Chou et al. 1993, Loftsgaarden and Andrews 1992, Vega-García et al. 1995). The evaluation of logit models in fire prediction (yes / no in a particular cell and day) in our own Mediterranean area was one of the specific goals of this project.

The logit models were developed in accordance with the recommendations of Hosmer and Lemeshow (1989) and Cox and Snell (1989), after generating a database which was smaller and more balanced in respect of the dependent variable by means of the random removal of 294 observations with no forest fire, which were brought together with the 294 observations which did include fires, in a similar way to the study by Vega-García et al. (1995). One of the advantages of the logit model is that it is possible to create equilibrium between the proportions of the dependent variable

(forest fire yes / no) within the observations employed to create models. It then becomes possible to create models which are equally effective in predicting occurrences and non-occurrences, and which can subsequently be applied to the real world (where the non-occurrences are much more common) by means of a simple transformation of the independent variable (Maddala 1988, Prentice 1986). The 598 observations were, at the same time, randomly combined and 117 (20 percent) were separated out in order to validate the models.

Different logarithmic regression models were calculated using automatic procedures (stepwise, backward elimination, forward selection) and the SAS v8.2 program (SAS Institute Inc. 1999), although steps were also taken to evaluate models employing subsets of non-correlated variables in order to avoid causing multicolinearity problems in the models. The analyses placed particular emphasis on evaluating the contribution of the various danger indices to the prediction, as a means of comparing the performance of the indices. An attempt was also made to find models which were relatively simple, both with respect to the number of variables and the ease of calculation of variables, i.e. models which were easy to set up for practical use.

Rather than selecting the best model on the basis of one sole criterion, an analysis was conducted of all the possible criteria of goodness of fit, predictive capacity, coefficients and residuals.

The model selected for testing in real situations during the summer of 2003 was validated with the 117 data which had not been used in building the model, and which had previously been segregated from the reduced database. However, the data in the full database of 36,190 was also evaluated in proportionately real-life conditions.

In order to implement the model in operative conditions, the daily calculations were automated by AML, the programming language created by ArcInfo (ESRI 2002). This was responsible for performing the necessary tasks of interpolation and map algebra, as well as generating a JPG file available on an Intranet before 8:00 am each morning between 1st August and 15th September 2003. Qualified personnel were asked to evaluate the daily occurrence probability map and to give their subjective opinion each day throughout this period, stating whether or not they felt the predictions were correct. At the end of the period in question, all the statistical data on forest fires occurring during that time were assembled and used to conduct a statistical test of the predictive ability of the model by means of a classification table similar to that used in validating the model.

Results

The statistical analyses of the 43 variables naturally produced high correlations between the risk indices and the variables with which they were calculated, but this was also the case between various geographic variables.

The average and maximum values for the meteorological variables were highly correlated, as was to be expected (>85 percent). This was also true for relative humidity and temperature, albeit negatively (around –60 percent). The RadG variable was positively correlated to the FDFM index (45 percent), to Intensity (30 percent) and to Tmax (35 percent), and negatively correlated with P24 (-40 percent), RHmin (-44 percent) and RHaverage (-41 percent).

The Canadian FWI index presented only a slight linear relation with the other variables, a positive figure of around 20 percent with FDFM, KBDI, Tmax, and a negative correlation with RHmin, also at around 20 percent. It should be borne in mind that the calculation requirements for this variable, added to the relative lack of continuity in the meteorological data from automatic weather stations produced a large number of zeros in the database.

The KBDI index showed positive correlations with Taverage and Tmax (59 percent y 57 percent) and negative correlations with RHaverage and RHmin (-30 percent and -29 percent). The correlations with other indices were low, at 20 and 23 percent respectively for the FWI and FDFM. These data were consistent with its original development as a risk index based on the state of the duff on the ground, rather than the fine dead fuels in the DGNC's index (FDFM). The KBDI is defined as a number which represents the net effect of evapotranspiration and precipitation in producing cumulative moisture deficiency in the deep duff or upper soil layers.

The DGNC's FDFM showed a high negative association with RHmin (-91 percent) and RHaverage (-81 percent), and a positive correlation with temperature (Tmax, 60 percent, Taverage, 37 percent), which appear to indicate that this index responds better, or more swiftly, to the most extreme daily conditions, as would be expected from the response of fine dead fuel. If one takes the degree of exposure of the fuels and cloud cover into account, positive correlations are the found with the intensity of potential solar radiation (24 percent) and RadG (45 percent).

Turning to the geographical variables, the slope categories clearly showed the effects of elevation, the lower categories being negatively correlated to elevation (-46 percent) and the upper categories positively correlated (68 percent).

Housing developments, power lines, railways and roads, which are usually concentrated in specific areas of terrain such as valley floors, also showed positive correlations amongst themselves. The percentage of protected areas of Special Natural Value showed positive correlations with elevation (39 percent), steep slopes (77 percent) and proximity to centres of population (47 percent), which reflects the true situation in this area. The correlations for fuel models suggested a relative degree of independence with respect to the other variables and amongst themselves. The only correlations worthy of note are those between model 2 for grazing and elevation (62 percent), steep slopes (54 percent) and Protected Areas of Special Natural Value (35 percent), and those for model 8 for forests with steep slopes (58 percent), Protected Areas of Special Natural Value (56 percent) and elevation (56 percent). Both models were correlated amongst themselves at 53 percent. The majority of the fuel models showed slightly negative correlations with gentle slopes and slightly positive correlations with the steep slopes, which reflects the fact that the vegetation in the study area has been relegated to the worst sites by other, more productive uses of the land.

The use of automated and manual procedures to build models led to several which offered a good predictive capacity.

The best logit model selected by automatic procedures included the following variables: Elevation, percentage of surface area with slope between 0 and 5%, percentage of surface facing east, radiation intensity, RadG, FWI and KBDI. Although the overall percentage which it predicted correctly was 74.7 percent, the model was not considered satisfactory for several reasons. The negative value for the FWI variable did not coincide with expectations based on its physical meaning, given

that the value should actually increase in step with the fire risk. Furthermore, the selected variables would require relatively complex daily calculations and continuity from the meteorological data, which cannot be guaranteed.

The building of models related to the risk indices showed the DGNC's probability of ignition index, FDFM, to enjoy a predictive capacity which was apparently superior to that of the KBDI and FWI. Models which depended exclusively on these indices (together with a constant) correctly predicted 61.1 percent of the observations for the FDFM, 59.7 percent for the KBDI and only 50.5 percent for the FWI. Use of the FDFM index with Elevation provided a correct prediction rate of 67.7 percent of the observations. Adding proximity to power lines (powli) and wind speed (Wsaverage) pushed the performance of the model up to 68.6 percent.

The weakly related subsets which had been selected manually led to the creation of two interesting models. One model consisted solely of the Tmax and average elevation of the square, and was capable of correctly predicting 70.5 percent of the observations. When brushwood fuel models (models 4, 5 and 6) were incorporated into the model, the value rose to 73 percent, although this would mean incorporating 3 variables which might be difficult to update in real situations.

In view of the (meaningful) statistical data, the robust nature of this particular model and the limited amount of data input, as well as the foreseeable updating of forest maps which can be converted to fuel maps, this model was considered to be the best. The formulation, statistics and classification table are presented in *table 3*. Tests using data which had not been used in building the model also resulted in a correct prediction rate of 73.5 percent of the validation observations.

Table 3—*Formulation and classification table for the best prediction model for human caused forest fires.*

$P(Y=1) = \text{Exp}(Z_i) / (1 + \text{Exp}(Z_i))$, where
$P(Y=1)$ is the likelihood of the occurrence of at least one forest fire in one cell and day
$Z_i = 0.1294 * \text{TMAX} + 0.0577 * \text{MOD4} + 0.0136 * \text{MOD5} + 0.0162 * \text{MOD6} - 0.0032 * \text{ELEVINT} - 2.9845$

Association of Predicted Probabilities and Observed Responses

Percent Concordant	79.3	Somers' D	0.588
Percent Discordant	20.5	Gamma	0.589
Percent Tied	0.2	Tau-a	0.294
Pairs	55448	c	0.794

Classification Table

	Correct		Incorrect		Percentages				
Prob Level	Event	Non-Event	Event	Non-Event	Correct	Sensitivity	Specificity	False POS	False NEG
0.450	192	143	96	40	71.1	82.8	59.8	33.3	21.9
0.500	184	160	79	48	73.0	79.3	66.9	30.0	23.1
0.550	164	175	64	68	72.0	70.7	73.2	28.1	28.0

Analysis of Maximum Likelihood Estimates

Parameter	DF	Estimate	Standard Error	Wald Chi-Square	Pr > ChiSq
Intercept	1	-2.9845	0.7454	16.033	<.0001
ELEVINT	1	-0.00320	0.000618	26.781	<.0001
TMAX	1	0.1294	0.0255	25.721	<.0001
MOD4	1	0.0577	0.0151	14.638	0.0001
MOD5	1	0.0136	0.0160	7.233	0.0395
MOD6	1	0.0162	0.0129	15.837	0.0208

Application of this model to real validation data from 1996, 1997, 1998, 1999 and 2000, i.e., to all the available data, produced an overall rate of precision of 70.3 percent, 72.3 percent, 62.2 percent, 67.6 percent and 77.5 percent respectively, although the percentage of correct predictions of forest fires in these years was 80.8 percent, 81.0 percent, 72.3 percent, 83.3 percent and 33.3 percent of the observations. It should be borne in mind that the data available in 2000 was extremely limited and

fragmented due to problems with the automatic weather station network, consisting of no more than 1,164 observations, of which 3 were forest fires.

Once this particular model had been selected, it was fully tested on a day-to-day basis at the headquarters of the Catalonian Regional Government's Directorate-General of Emergencies and Civil Protection (DGECP), where the necessary programs were developed to carry out the daily automatic computation of the probability maps for the occurrence of forest fires and the task of disseminating them on the Directorate-General's Intranet.

Given that the chosen model employed a small number of variables, it was only necessary, from a technical point of view, to use the digital maps for: a) a 10 x 10 km square, b) elevations and c) fuel[5] which were already available (*fig. 2, fig. 3* and *fig. 4*). The main difficulty consisted of the need to acquire a daily map of predicted maximum temperatures (Tmax) for the study area, to be combined with these other maps by means of the logit model and to generate a map of probability values between 0 and 1 which would could be transformed into map showing those areas where a forest fire was unlikely that day ($p<0.5$), and those areas where there probably would be a fire ($p> 0.5$). The reliability of the prediction for the following day would obviously depend at all times on the precision with which it was possible to predict the Tmax variable.

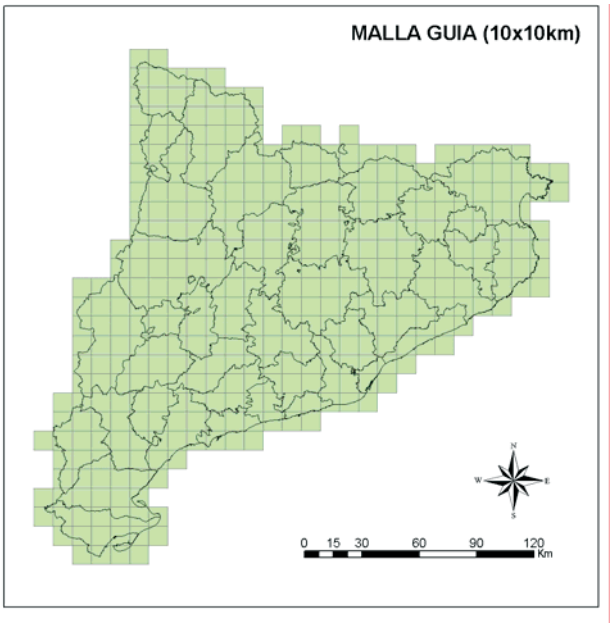


Figure 2— Regular 10 x 10km grid used to calculate the probability of forest fire ignition through human causes, including the local municipal areas within Catalonia.

[5] Cabe destacar que en el momento de la redacción del presente documento (tres años después de la construcción del modelo) ya estaban disponibles los mapas de combustibles para toda Cataluña, como se refleja en la *Fig. 4*.

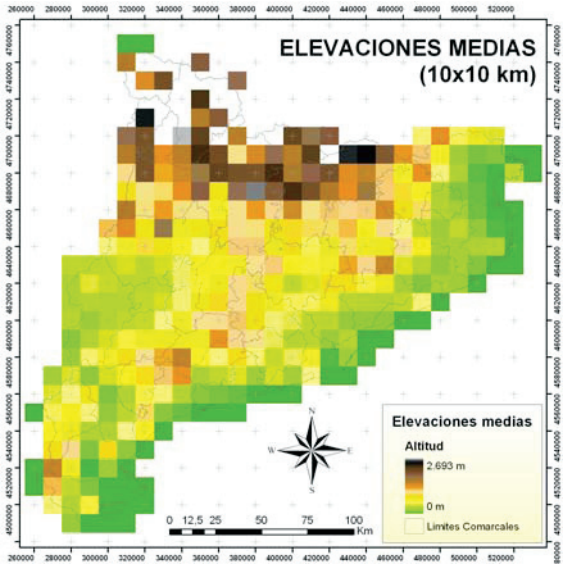


Figure 3—Map showing the average elevation in each cell of the 10x10 km grid, used for calculating the probability of ignition.

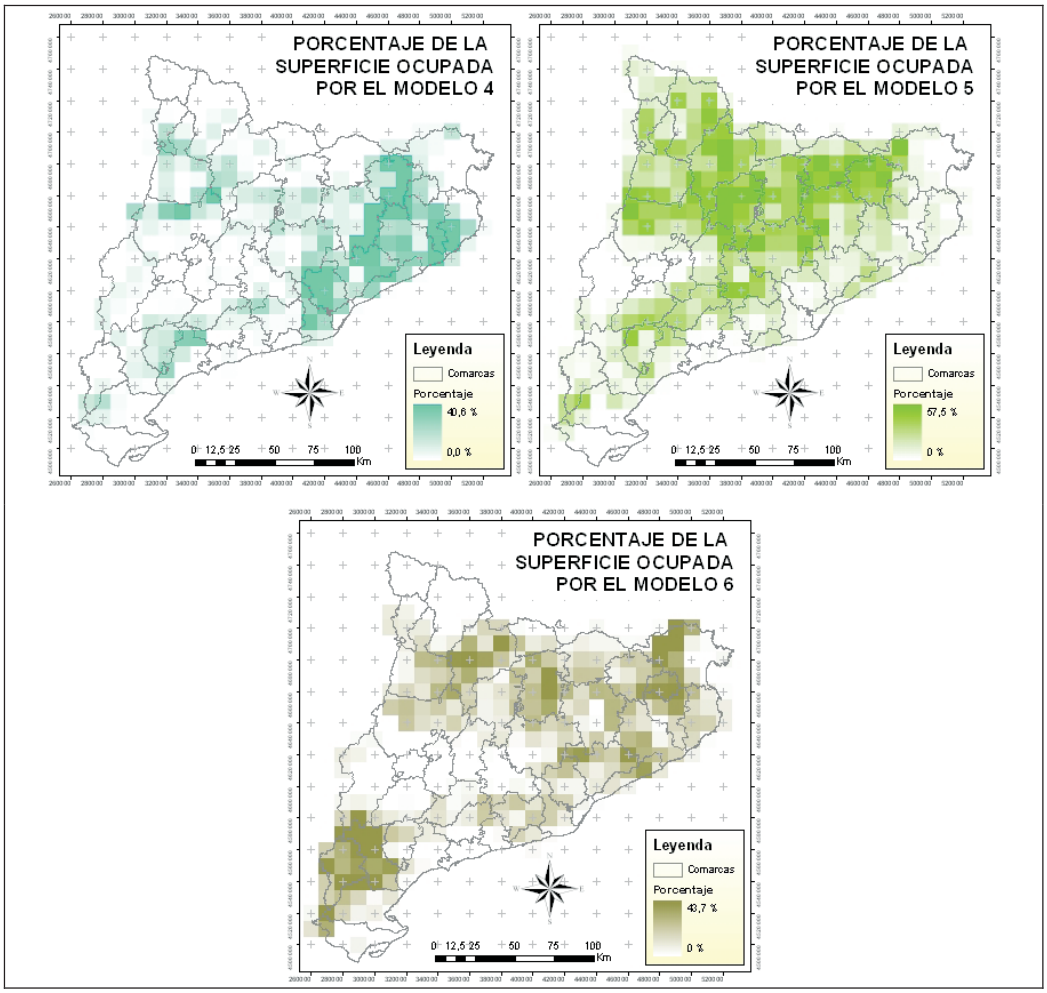


Figure 4—Maps used to calculate the probability of ignition showing the percentage of surface area taken up by fuel models 4, 5 and 6.

The predicted Tmax data were generated using the MASS model (*Mesoscale Atmospheric Simulation System*) developed at the University of Barcelona and Tmax was assumed to be the temperature predicted for 12:00 am UTC. The calculation produced a matrix of evenly-spaced grid points, 15 km apart, and was interpolated on a daily basis to the corresponding predicted Tmax value, using the ArcInfo (ESRI 2002) Spline command, to create a continuous surface in the space for the predicted temperature values (*fig. 5a* and *fig. 5b*).

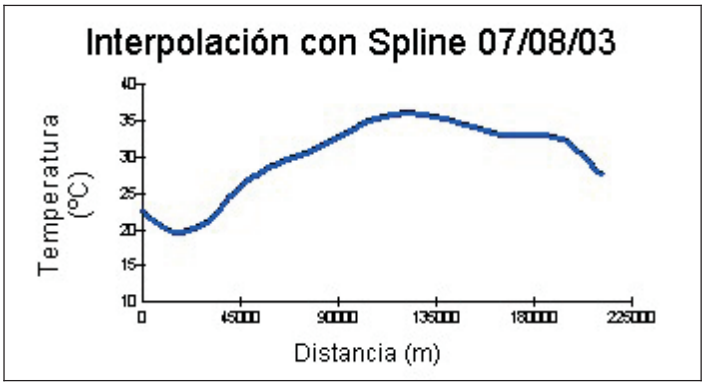


Figure 5a—Graph representing the temperature tendency created by the Spline along the observed line in *fig. 5b*.

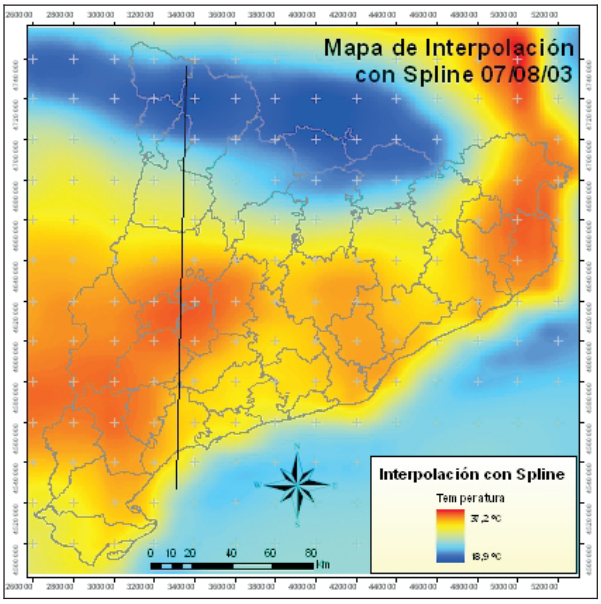


Figure 5b—Map resulting from the Spline interpolation using ArcInfo (ESRI 2002).

The automatic calculation of the probability of ignition map in ArcInfo (ESRI 2002) and publication of the map on the Directorate-General's Intranet was arranged in the space of a few days (*fig. 6*). However, the co-operation which was sought in order to test whether the model was of any practical value for the specialists responsible for planning fire suppression activities was subject to considerable delay.

The delay was principally caused by bureaucracy, as the three members of staff chosen to evaluate the model did not belong to the same department at the DGECP which had automated the calculation of the model.

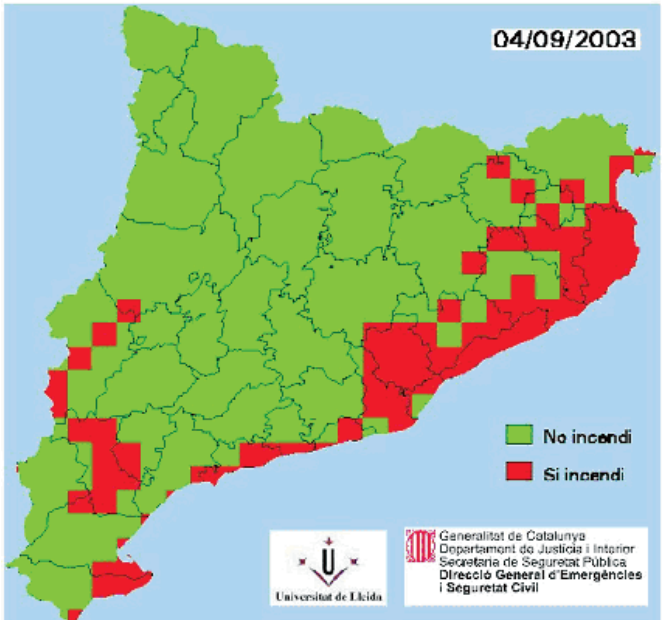


Figure 6—Specimen map published daily on the DGECP's Intranet.

The evaluation was intended to consist of a daily survey, early in the morning, of the results produced by the model and a comparison with the specialists' own perception of risk for that particular day based not on the results, but on their practical experience. It is clear from the reports submitted by the specialists, that the type of evaluation required of them had not been explained with sufficient clarity, as they all comment that there did indeed appear to be a close correlation between the predictions generated by the model and the number of vegetation-based fires attended by the Catalonia Government Fire Brigade. On the other hand, they make no reference to any correlation between the model and their own personal predictions concerning the risk of ignition.

The behaviour of the model was tested three years after the period when the original dataset had been obtained in order to build the model, and the results are presented in *tables 4* and *5*. Attention should first be drawn to the fact that the total number of ignitions in each of the two tables is not exactly the same (212 in the table presenting the predicted temperatures, and 200 in the table for real maximum temperatures). This is the result of the failure of certain meteorological stations which made it impossible to gather Tmax values and, therefore, the probability of ignition for some of the fires. However, the prediction file for maximum temperatures was obtained without problems throughout the whole test period.

As would be expected, the model was more effective if used with real temperatures, at a correct prediction rate of 77.5 percent for ignition occurrences, than with the temperature predictions, where the correct prediction rate, although perfectly acceptable, dropped to 70,7 percent. It is foreseen that this difference in effectiveness would be reduced by analysing alternative sources for maximum temperature predictions and other methods of interpolating these sources.

Table 4— *A comparison of the number of ignitions predicted by the model, calculated using the maximum temperature predictions from the MASS model and the real ignitions occurring in the same period of time.*

Ignition predictions	Yes	No	Total
Yes	150	5,958	6,108
No	62	8,446	8,508
Total	212	14,404	14,616

Table 5— *A comparison of the number of ignitions predicted by the model, calculated using the real temperatures and the real ignitions occurring in the same period of time.*

Ignition predictions	Yes	No	Total
Yes	155	6,414	6,569
No	45	6,842	6,887
Total	200	13,256	13,456

The most negative result was the high number of false alarms provided by the model, i.e. the predicted ignitions which did not actually occur. In this particular case, the percentage was practically the same, independently of the temperature values employed. It is nevertheless hoped to be able to reduce this percentage significantly through small adjustments over successive summer campaigns.

Discussion and implications for managing forest fires

This paper has highlighted the clear difficulties referred to in so many studies of fire occurrences concerning the lack of source data, whether it be geographic or meteorological, given that an original 1,600 forest fires were reduced to 294 observations appropriate for building the models. This lack of data was noticeable not only when building the model, but also when evaluating its performance during the summer of 2003, when the lack of meteorological data made it necessary to eliminate 5.6 percent of ignitions from the analysis.

When the model was being built, variables related to topography, the presence of protected areas, fuels, power lines, housing developments, maximum daily temperature, solar radiation and risk indices were associated in differing degrees to the occurrence of fires in the study area.

Applying logarithmic regression techniques to the prediction of forest fires in Catalonian municipalities using fuel model maps makes it possible to correctly predict, every day, the occurrence of at least one fire in 10 x 10 km squares with a likelihood of at least 70 percent.

The results also suggest that false alarms might be an obstacle to use of the model in the real world if users are not adequately instructed in the correct interpretation of the predictions.

Furthermore, the classification of probability in a map with only two classes (fire yes / fire no) reduces the information available on the risk in that area. As a result, it would be advisable to publish a map with a higher number of probability classes, preferably ten.

The usefulness of this statistical model in a Mediterranean environment was confirmed when it was installed at the DGECP during the summer of 2003, although there is room for improvement through analysis of other interpolation methods for the meteorological variables and alternative sources for the variables.

Bibliography

Chow, Y.H., R.A. Minnich and R.A. Chase. 1993. **Mapping Probability of Fire Occurrence in San Jacinto Mountains, California, USA**. Environmental Management 17(1): 129–140.

Cox, D.R. and E.J. Snell. 1989. **Analysis of binary data**. Second edition. Chapman & Hall, New York, New York, USA.

ESRI. **ArcInfo** [Computer program]. 2002. Redlands, CA: Environmental Systems Research Institute, Inc. Available from: 380 New York Street, Redlands, CA 92373-8100, USA.

Hosmer, D.W., Jr. and S. Lemeshow. 1989. **Applied logistic regression**. John Wiley & Sons, New York, New York, USA.

Keetch, J.J. and Byram, G.M. 1988. **A drought index for forest fire control**. Res. Paper SE-38. Asheville, North Carolina. Southeastern Forest Experiment Station, Forest Service, U.S. Department of Agriculture; 36 p.

Loftsgaarden, D.O. and P.L. Andrews. 1992. **Constructing and testing logistic regression models for binary data: Aplications to the National Fire Danger Rating System**. USDA Forest Service, Intermountain Research Station, General Technical Report INT-286. 36 p.

Maddala, G.S. 1988. **Introduction to econometrics**. Macmillan Publishing Co., New York, USA.

Martell, D.L., S. Otukol and B.J.Stocks. 1987. **A logistic model for predicting daily people-caused forest fire occurrence in Ontario**. Canadian Journal of Forest Research, 17: 394–401.

Martell, D.L., E. Bevilacqua and B.J. Stocks. 1989. **Modeling seasonal variation in daily people-caused forest fire occurrence**. Canadian Journal of Forest Research 19: 1555-1563.

Prentice, R.L. 1986. **A case-cohort design for epidemiologic cohort studies and disease prevention trials**. Biometrika 73: 1–11.

SAS Institute Inc. 1999. **SAS** Online Doc. Version Eight. SAS Institute Inc., Cary, NC, USA.

Van Wagner, C.E. 1987. **Development and structure of the Canadian Forest Fire Weather Index System**. Government of Canada, Canadian Forestry Service, Ottawa, Ontario, Canada. Forestry Technical Report n. 35.

Vega-García, C., P.M. Woodard, S.J. Titus, W.L. Adamowicz and B.S. Lee. 1995. **A logit model for predicting the daily ocurrence of human caused forest fires**. International Journal of Wildland Fire 5(2): 101–111.

Vélez Muñoz, R. 2000. **El concepto de combustibilidad**. pp. 7-1 to 7-16 in: Vélez Muñoz, R. (Coord.). 2000. La defensa contra incendios forestales. Fundamentos y Experiencias. McGraw-Hill, Madrid.

Volk, G. **RADIATION** [Computer program]. 1997. Universitaet fuer Bodenkultur, Centre for Geo-Informatics, Daenenstrasse 6, A1190 Wien, AUSTRIA. Available at: http://bzgserver.boku.ac.at/volk/

Page left blank intentionally.

Technical and Economic Assessment of the Use of Aerial Resources in Fighting Forest Fires[1]

J.C. Mérida,[2] J.J. Gallar, E. García,[3] E. Primo[3]

Abstract

There has been a notable increase in recent years in the use of airplanes and helicopters in the extinction of Spanish forest fires. As well as being extremely useful in combating fires, airborne units are costly to acquire, hire and operate. Since 1992, the Directorate-General for Nature Conservancy (DGNC) has maintained a database holding data on the details of every intervention by its airborne units. This paper demonstrates some of the uses to which this database can be put in order to determine the performance, improvements in certain aspects of logistics and infrastructure and operating efficiency of the aerial resources employed in Spain.

Introduction

The use of aircraft for fire extinction in Spanish forests commenced in 1969 with the use of Boeing Stearman biplanes in the Sierra de Guadarrama, where payloads consisted of 600 liters of water mixed with bentonite. That very same year, a Canadair CL-215 was hired to cover Galicia in August. This was the first amphibian plane of its kind to be seen in Europe and was subsequently acquired by France.

From that time on, there was a steady increase the use of aerial firefighting measures. Trials of the Twin Otter plane (2,500 liters) in Pontevedra in the summer of 1970 led to a decision to acquire two Canadair CL-215 planes, which arrived in Spain in spring 1971. A further seven CL-215s were acquired throughout the seventies (although one of these was lost in an accident in 1976), at the same time as the use of agricultural crop spraying planes such as the Piper Pawnee, Piper Brave, Trush Commander, etc. was also being expanded.

The eighties were to see a large increase in aerial fire suppression resources. The government's fleet of amphibian CL-215s grew to a total of 14 planes. In 1984, helicopters were used for the first time to transport firefighting personnel, and 1988 witnessed the first use of helicopters as water bombers, employing for the purpose a Bell 212 with a 1,300 litre Conair-type belly tank. A contract was signed in 1989 to replace the whole fleet of amphibious CL-215s, which were powered by piston engines, with CL-215Ts turboprops.

---

[1] An abbreviated version of this paper was presented at the second international symposium on fire economics, planning and policy: a global view, 19–22 April 2004, Cordoba, Spain.

[2] Head of Services, Forest Fire Department, Ministry of the Environment, DGCN, Gran vía San Francisco 4, 28005 Madrid, adcif@mma.es.

[3] Technical staff , Forest Fire Department, Ministry of the Environment, DGCN, Gran vía San Francisco 4, 28005 Madrid, adcif@mma.es.

In the nineties, aerial fire extinction units were increasingly being acquired by regional governments (*Comunidades Autónomas*) when they became responsible for firefighting activities between 1983 and 1985, which led to the national government making efforts to differentiate it by developing a focus on large capacity airplanes capable of being deployed over the whole of the country. There was frequent use of eastern European aircraft such as the Mi-8, Mi-2, Sokol PZL and KAMOV helicopters. In 1992, the Special Forest Fire Reinforcement Brigades (*BRIF*) were created, with transport capacity provided by Russian Army Mi-8 helicopters. Towards the end of the nineties there were 20 amphibian planes in service (15 CL-215T and 5 CL-215). At the same time, planes such as the CANSO PBY, Thrush Commander and Grumman were gradually discarded.

In 2003, 206 airplanes (Table 1) were employed during the summer campaign, 48 of which were owned by the national government, operating out of 157 bases. The entire fleet offers a tanker capacity of 396,000 liters (236,000 liters of which is provided by the *Comunidades Autónomas* and 160,000 liters by the DGNC), a seating capacity of 845 (704 corresponding to the *Comunidades Autónomas* and 141 to the DGNC). The fleet cost approximately 65.5 million euros to hire and operate (39.7 million euros for the *Comunidades Autónomas* and 25.8 million euros for the DGNC).

The tendency in Spain is currently to place more emphasis on improving the capabilities of the aircraft rather than on increasing the actual number of aircraft available or more hired capacity. The amount of money involved means that the use of airborne firefighting equipment cannot escape serious economic analysis of the performance and efficiency of this particular technique.

Table 1--*Aircraft Use in Spain in 2003.*

Region	Airplanes					Helicopters				Leadplanes
	CL-215 CL-215T	C-130	ACT 3100 l.	ACT 2100 l.	HB 4500 l.	HT 2500 l.	HT 1500 l.	H 1200 l.	H 500 l.	
Andalusia	0	0	5	0	2	0	0	16	0	2
Aragon	0	0	0	0	0	0	0	0	4	0
Asturias	0	0	0	0	0	0	1	0	3	0
Balearics	0	0	2	1	0	0	0	1	2	1
Canaries	0	0	0	0	0	0	0	2	0	0
Cantabria	0	0	0	0	0	0	0	1	0	0
Castilla La Mancha	0	0	0	8	0	0	0	6	0	0
Castilla León	0	0	3	0	0	0	0	20	0	0
Catalonia	0	0	3	0	0	0	0	11	5	1
Extremadura	0	0	0	0	0	0	0	2	4	0
Galicia	0	0	1	7	0	0	12	0	0	2
La Rioja	0	0	0	2	0	0	0	0	0	0
Madrid	0	0	0	0	0	0	0	6	0	1
Murcia	0	0	0	0	0	0	0	1	1	1
Navarre	0	0	0	0	0	0	0	2	0	0
Basque Country	0	0	0	0	0	0	0	0	0	0
C. Valenciana	0	0	3	4	0	0	0	7	0	1
DGNC	14	1	10	3	4	3	10	0	0	4
TOTAL	**14**	**1**	**27**	**25**	**6**	**3**	**23**	**75**	**19**	**13**

The DGNC's aerial resources database

The Directorate-General for Nature Conservancy, under the aegis of the Ministry of the Environment, has gathered data on a standard form since 1992, recording the operations undertaken by the aircraft under its control. The form is used whenever an aircraft has taken off, whether to extinguish a fire, on a false alarm, on a reconnaissance mission or any other reason. The form is set out on a spread sheet and is therefore easy to record and manipulate on computers. A program called RMAIF was written for this specific purpose and employs Visual Basic as the programming language and ACCESS as the database program used to process the data on the forms and obtain specific manipulated data. If one includes the full input of data for 2003, the database has a total of 19,860 entries.

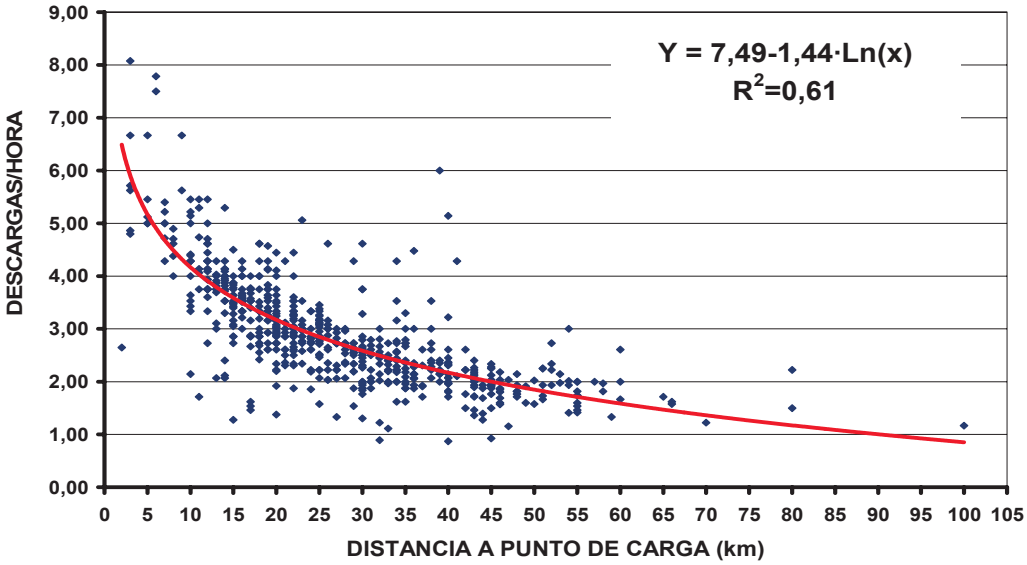
This program has made it possible in recent years to develop performance graphs for each of the distinct types of aircraft, to improve the logistics of aerial operations, simulate alternative patterns of distribution and use, undertake an economic evaluation of the cost per litre of water dropped on fires, choose higher performance models and analyze the working practices of the air bases and contractors. All of these data have been employed to shape the way the aerial firefighting equipment controlled by the Spanish Ministry of the Environment is distributed and operated.

Some of the many uses of the database are discussed below:

Performance indicators for specific aircraft types

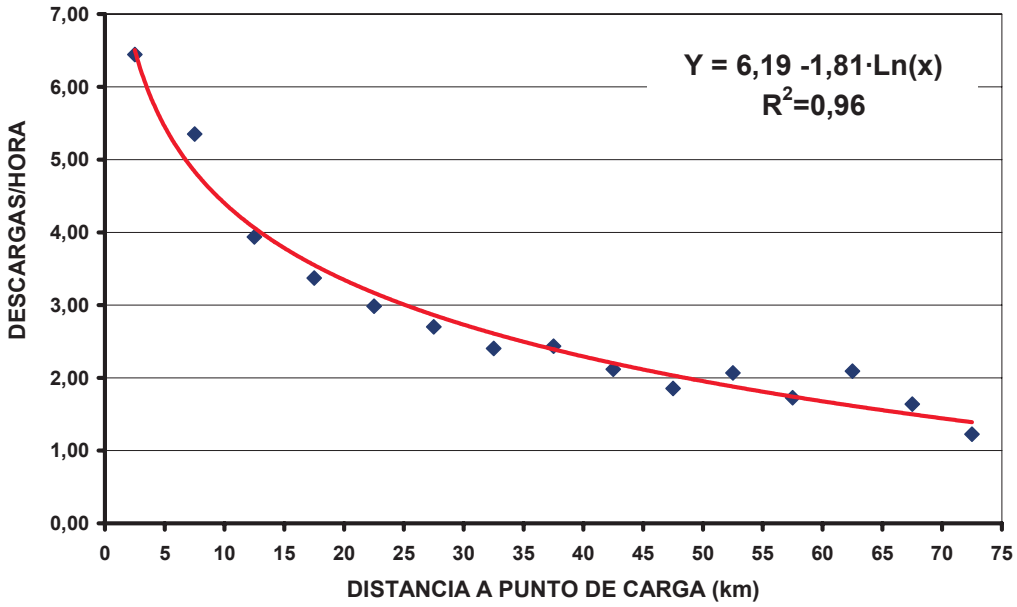
The available information in the database has made it possible to produce graphs illustrating the performance of different aircraft types based on the distance between the fire and the point where the water is loaded.

The most satisfactory results have been achieved with semi-logarithmic plotting, where $y = k - a \ln x$. This has achieved correlation coefficients of over a $r^2 = 0{,}60$, where y = the number of discharges per hour, k and a are constants depending on the type of aircraft and x = the distance between the fire and the point where the water is loaded (Graph 1).



Graph 1—*"Performance of Airtractor 802".*

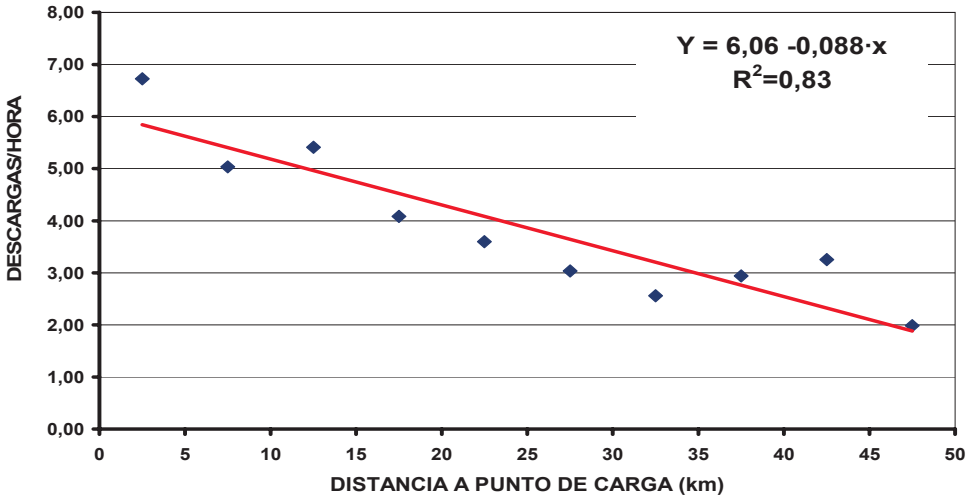
With input data based on 5 km class intervals and an average performance within each interval, the same curve produces correlations of over 90 percent (Graph 2).



Graph 2—*"Performance of Airtractor 802"*

The semi-logarithmic curves are asymptotic to the x-axis, which means that an increase in distance leads to a decline in the performance of the aircraft, tending to zero over very long distances. Given that the graphs are difficult for field workers to manage in view of the logarithms, they have been simplified by converting them into straight lines which solely cover the intervals between nought and 50 km in respect of the planes and 0-25 km for the helicopter bombers (Graph 3).

It is not considered appropriate to employ aircraft over greater distances due to the heavy cost with respect to the volumes of liquid they are capable of discharging. The fire fighting teams are therefore provided with simplified calculations of the following type: $y = a - b\,x$, which is easy to memorize and use, and which offer information on the foreseeable performance of the aircraft in question in extinguishing the fire.



Graph 3— *"Performance of Canadair Cl215"*

Calculations such as discharges per hour = 6 minus 0.88 discharges per hour for every additional 10 km between the loading point and the fire for a CL-215 airplane ($y = 6 - 0.88\,x$), are common currency amongst Extinction Team Leaders.

Improvements in logistics and infrastructure for aerial operations

An analysis of the database makes it possible to obtain information on the characteristics of the work carried out by each individual aircraft and its effectiveness, which facilitates the detection of problems and highlights areas which are capable of improvement.

Two examples are given below.

1) A comparison between the operations and output of two Sokol PZL helicopters with a firefighting team and 1,500 liters bambi bucket (Table 2).

Following the usual analysis in 2002 of all the data on aircraft performance obtained in the summer from every air base in the country, there was a noticeable difference in performance between two Sokol PZL helicopters, one of which was stationed at Becerreá, in the province of Lugo, and the other stationed at Tineo, in the province of Asturias. The two helicopters had a very similar number of flight hours on extinction duties and both were operated by the same company. The air bases were less that 60 km. apart and were located in the same mountain range, which meant that the terrain where they were working was very similar. As a result, there should not have been any significant differences between the performances of the two helicopters.

Table 2—*Comparison between the operations and output of two Sokol PZL helicopter with a firefighting team and 1,500 liters bambi bucket.*

PARAMETER	Becerreá			Tineo		
	2000	2001	2002	2000	2001	2002
Number of firefighting sorties	101	44	78	77	52	25
Number of fires attended	95	39	77	63	49	19
Flying hours on fire duty	214:37	86:35	125:27	217:28	92:38	55:10
People transported	970	461	710	815	510	246
Bucket discharges	1,331	567	904	931	439	436
People per hour	4.52	5.32	5.66	3.75	5.51	4.46
Discharges per hour	6.20	6.55	7.21	4.28	4.74	7.90

An analysis of the data revealed that the only significant difference which might explain the discrepancy was the “distance between the loading point and the fire”, which was much greater in the case of Tineo. Fire extinction managers in Asturias were subsequently contacted and a water point construction programme was then carried out in 2001 and 2002, which enabled the performance of the Sokol PZL at Tineo to rise from 4.28 discharges per hour in 2000 to 4.74 and 7.90 discharges per hour in the next two years respectively.

2) Improvement of the helicopter fuel supply logistics .

Forest fire fighting professionals are almost unanimous in their opinion that helicopters are “the machine which runs out of fuel just when it’s most needed”. It is indeed true that heavy helicopters bring high water-carrying capacity but also high fuel consumption and a shorter range than airplanes. On frequent occasions, helicopters are sent on firefighting duties a very long way from their normal air base. It is necessary to ensure that plans take into account the fuel needed to supply the helicopters at locations close to the fire, as the aircraft will otherwise need to make long trips with no payload, which reduces the actual time spent at the site of the fire. One approach is to send a mobile fuel tank with the helicopter to be placed near the site of the fire.

The table (Table 3) below presents the operations data obtained from the first KAMOV helicopter fitted in 1994 with a 4,500 litre bambi bucket to be used in Spain. It was not accompanied by a mobile fuel tank. A simulation was set up to determine what would have happened if such a fuel tank had been available, had been

placed 10 km away from the fire and had been used from the 3rd refueling onwards in long-lasting forest fires over 75 km away from the main air base.

Table 3—*Operations data from the first KAMOV helicopter fitted with a 4,500 liters bambi bucket in 1994 used in Spain.*

		ACTUAL DATA			SIMULATION
		Situation A	Situation B	Situation C	Situation D
PARAMETER	No. of fires	26	19	7	26
	Flying time (min)	6,300	4,195	2,105	6,300
	Refueling time (min)	2,405	1,935	470	690
	Refueling time as %	38.20	46.10	22.30	11.00
	No. of discharges	440	245	195	827
	Discharges per hour	4.19	3.50	5.56	7.88
	Cost of contractor (million pesetas)	49.50			53.00
	Cost per litre (peseta/l)	28.10			16.00

Situation A: All flights to fires are taken into account

Situation B: Only includes those flights with refueling from the main base

Situation C: Only includes those flights with refueling at another base

Situation D**:** Simulation taking into account all flights and including refueling with a mobile fuel tank at 10 km. from the site of the fire, a distance to the main base to refuel of over ≥ 75 km. and from the 3rd refueling onwards.

The percentage of flying time spent refueling is reduced by 38.20 to 11%. The aircraft's performance increases from 4.19 to 7.88 discharges per flying hour.

The following example (Table 4) sets out the data obtained from the operations carried out by two different helicopters, a KAMOV K32A and a SOKOL PZL, hired by the DGNC during the Buendía forest fire in the province of Cuenca in 2003. In this particular forest fire, the pump on the mobile fuel tank happened to be non-operational and was impossible to replace. As a result, the helicopters were obliged to refuel at bases which were quite a long way from the fire itself (Buenache and Villares). A comparison was made between the real firefighting activity of the helicopters and data simulating the existence of fuel tanks during the second and third days of the fire. The difference generated by the absence of a fuel tank close to the fire was equivalent to 32 discharges from an amphibious CL-215T (168,000 liters).

Table 4—*Comparison of two DGNC helicopters performance in the Buendía forest fire*

	KAMOV		SOKOL	
	Actual data	Simulated data	Actual data	Simulated data
Days firefighting	1	1	4	4
Flying hours	7:15	7:15	22:42	22:42
Time firefighting	4:15	6:07	12:42	16:30
Time refueling	3:00	1:08	10:00	6:12
Refueling time as %	41.38	15.63	44.05	27.31
Distance to Buenache	75	75	-	-
Distance to Villares	-	-	81	81
Distance to fuel tank	-	5	-	5
Discharges	75	108	96	125
Water volume	300,00	432,000	120,000	156,250
Perf.. Discharges/hour	0	15.00	4.23	5.51
Perf. Liters/hour	10.34	60,000	5,286	6,883
Cost in euros/litre	41,380	0.054	0.447	0.343
	0.078			

Cost per litre of water deposited on the forest fire (BCL)

The DGNC employs the basic cost of each litre of water (BCL) deposited on the fire as an indicator which combines both aircraft performance and financial cost. In order to enable comparisons between different aircraft, the cost calculation solely takes into account the flying time actually spent extinguishing fires, and excludes false alarms and returns to base before entering into action because the fire is already under control, etc. The unitary value of flying hours is determined as a quotient between the cost of contracting the aircraft and the number of hours for which it has been contracted. The volume of water is calculated as the result of the average discharge volume (assuming that these are discharges solely of water) divided by the number of discharges. The indicator thus obtained is independent of the number of flying hours for each aircraft and the use of retardants.

In addition to the indicator, the data also provides a measure of the real cost per litre discharged which includes manpower costs, infrastructure costs for the air base, the cost of retardants deployed on the fire, real flying time, etc. However, the variable nature of this data means that the figure for real cost cannot be used as an indicator enabling comparisons between different types of aircraft and bases.

The results in 2003 (Table 5)for aircraft either owned or hired by the DGNC were as follows:

Table 5—*Cost per liter of water dropped in 2003 for aircrafts owned or rented by DGNC.*

	BCL (€/litre). 2003				
Aircraft	Minimum		**Average**	Maximum	
	€/l.	Base		€/l.	Base
Amphibious CL-215T planes	0.132	Pollensa	**0.224**	0.398	Torrejón (pre-season)
Amphibious CL-215 planes	0.335	Talavera	**0.353**	0.559	Matacán (pre-season)
Hercules C-130 plane	-	-	**2.168**	-	-
AT-802 planes	0.172	Son Bonet	**0.244**	0.275	Manises
Dromader PZL planes	0.112	Rosinos	**0.134**	0.141	Tafalla
KAMOV K-32A helicopters	0.094	Caravaca	**0.114**	0.201	Los Rodeos

Although this indicator is not the only tool relied on to determine the use of a particular aircraft model in the fleet, it has provided the basis for many decisions to dispense with the services of aircraft with a lower efficiency figure.

As a result, the CANSO PBY planes were no longer hired after 1995 due to a BCL of 85.8 pesetas/litre compared to a BCL of 22.3 pesetas/litre for the CL-215T, and a BCL of 26.7 pesetas/litre for the Dromader PZL planes in 1994.

Furthermore, in 1995, use was made for the first time in Spain of the Mi-17 helicopter for water bombing. In view of its BCL of 42.5 pesetas/litre, against a $CBL_{average}$ of 15.62 pesetas/litre for the KAMOV helicopters, the Mi-17 was not hired again.

Page left blank intentionally.

A Fast Method for Calculating Emergency Response Times Using Travel Resistance Surfaces[1]

David C. Hatfield,[2] Marc R. Wiitala,[3] Andrew E. Wilson,[4] Eric J. Levy[5]

Abstract

An algorithm is described that quickly calculates minimum travel times between locations for initial response forest fire suppression units. The algorithm was developed for integration into wildfire planning simulation models to quickly identify fire suppression units with the fastest response to a fire during a simulation. While generally quite fast, network-based path minimization algorithms are not suitable for the wildfire problem since fires are often located away from existing network features, such as roads and trails. On the other hand, traditional raster-based least-cost path algorithms can take minutes, if not hours, to calculate each resource's travel time, too slow to be effective within a simulation model. The algorithm presented in this paper enhances the raster-based technology, providing a multi-resolution approach. Our test results show the new algorithm dramatically increases the speed of calculations with only limited loss of accuracy

Introduction

One vexing problem confronting the design of realistic simulation models for initial attack wildfire planning is accurately estimating ground suppression resource travel times between locations. From the standpoint of initial attack simulation model building, there is more than just a need for accurate estimates of travel times; there is also a need within the simulation model to quickly make these calculations thereby maintaining reasonable simulation run times.

In this paper, we describe a computationally efficient shortest-path algorithm for computing travel times within an initial attack wildfire simulation model. This algorithm, COSTPATHSQ (Q for quick), was developed to meet the needs of the Wildfire Initial Response Assessment System (WIRAS), a comprehensive wildfire initial attack planning tool (Wiitala and Wilson, this proceedings).

---

[1] An abbreviated version of this paper was presented at the second international symposium on fire economics, planning, and policy: a global view, 19–22 April 2004, Córdoba, Spain.

[2] GIS Developer, Digital Visions Enterprise Unit, Forest Service, U.S. Department of Agriculture, 333 SW 1st Ave, Portland, OR, 97204.

[3]Operations Research Analyst, Forestry Sciences Laboratory, Forest Service, U.S. Department of Agriculture, 620 SW Main Street, Suite 400, Portland, OR 97205.

[4]Resource Information Specialist, Forestry Sciences Laboratory, Pacific Southwest Research Station, U.S. Department of Agriculture, 620 SW Main Street, Suite 400, Portland, OR 97205.

[5]GIS Analyst, Digital Visions Enterprise Unit, Forest Service, U.S. Department of Agriculture, 1230 NE Third St., Suite A-262, Bend, OR 97701.

WIRAS simulates the effectiveness of a ground and air resource suppression organization in fighting forest wildfires. During a simulation, WIRAS needs to evaluate the opportunities for dispatching up to 100 suppression resources to numerous fire locations. This need for evaluation can happen many times during a single simulation leading to tens of thousands of travel time estimates. To be effective, the WIRAS simulation model requires computations to occur within a fraction of a second while providing a limited loss of accuracy on estimates of travel time. To accomplish this objective, we first explored the possibility of computing travel times over a network using the Dijkstra shortest-path algorithm (Dijkstra 1959). While numerous enhancements have been made over the years to the Dijkstra algorithm (Zahn 1997), for our particular problem, tests using the Dijkstra algorithm as implemented within ArcInfo (ESRI 2001) proved much too slow. Therefore, we decided to develop COSTPATHSQ, a new variation on the implementation of the Dijkstra algorithm that could exploit the particular nature of our travel time problem and meet the computational requirements for the WIRAS simulation model.

Methods

COSTPATHSQ uses the Dijkstra algorithm to estimate the least-cost path, where cost refers to travel time in this instance. In our model, travel is performed on a raster cost surface or grid rather than a vector network because wildfires do not necessarily fall on network features, such as roads and trails. A network could be constructed across the whole landscape, but the file size would be excessive and we believe the processing time would be prohibitively slow. A raster cost surface can be viewed as a regular triangular network with a network node at the center of every cell in the raster and network links radiating from each node to each of the eight adjacent nodes, horizontally, vertically, and diagonally. The main enhancement to the Dijkstra algorithm described here is the construction and employment of a multi-resolution cost surface, or cost pyramid. The cost pyramid allows COSTPATHSQ to initially and quickly move across a coarse resolution surface. The algorithm employs finer resolution surfaces to more accurately locate the end points (*fig. 1*). Depending on computational tolerance and accuracy needs, the user of COSTPATHSQ determines the number successive levels of resolution desired.

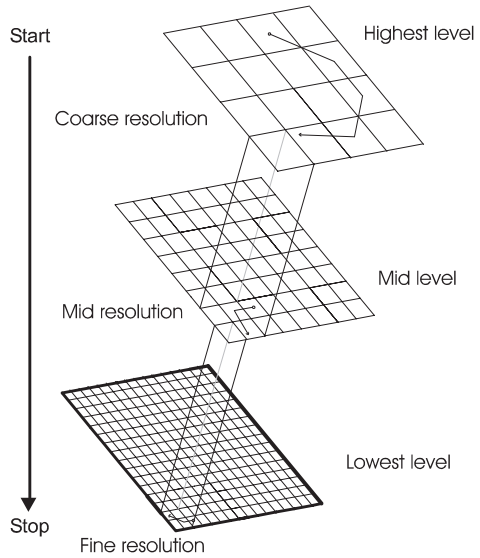


Figure 1—How least-cost paths are constructed using a cost pyramid.

Cost Pyramid

The COSTPATHSQ algorithm determines for a cost surface the least-cost path between points using the Dijkstra algorithm in a manner similar to its implementation in ArcInfo (ESRI 2001). As mentioned above, COSTPATHSQ enhances the Dijkstra algorithm by employing the use of a multi-resolution cost surface, or cost pyramid. The cost pyramid is constructed by successively aggregating blocks of four cells in an upward progression through the surfaces *(fig. 1)*. The first or bottom level of the pyramid is constructed of the original cells in the cost surface. These cells are grouped into fours to form new cells on the second level of the pyramid. Within each second-level cell, the first-level cell that is deemed to be the best pathway is selected as the center or hub of the second-level cell. The cost to travel between adjacent second-level cells is calculated between the cells' hubs using the Dijkstra algorithm to travel on the first level of the pyramid. These eight travel costs are stored in each of the cells in the second level of the pyramid. Subsequently the second-level cells are grouped into fours to form cells on the third level of the pyramid (the highest level in *fig. 1*). Within each third-level cell, the second-level cell that is deemed to be the best pathway is selected as the hub, and the cost between third-level cells is calculated using the Dijkstra algorithm to travel on the second level of the pyramid. This process is repeated until only two rows and/or columns of cells remain. The result is increasingly generalized cost surfaces that retain much of the accuracy of the source data. This system of cost surfaces allows COSTPATHSQ to estimate the least-cost path between points in a fraction of a second with a limited loss of accuracy.

Pathways

The determination of which cells make better pathways is done prior to constructing the pyramid and is based upon the underlying transportation network. It is accomplished by selecting the one cell from the entire raster that bears the lowest cost and traveling the least-cost path to this origin cell from every other cell in the cost surface. If more than one cell bears the lowest cost, then one of these cells is selected at random to be the origin cell. The result of this preprocessing is a pathway grid. The value of each cell in the pathway grid is the number of times that that cell is crossed when traveling from each cell in the grid to the origin cell. Cells that receive higher values are deemed to be better pathways. Thus when four first-level cells are grouped to form a second-level cell, the first-level cell with the highest value in the pathway grid is selected as the hub of the second-level cell. This maximum value is assigned to the second-level cell and is used during the determination of hubs on the third-level of the pyramid, and so on.

Least-Cost Path

Once the cost pyramid has been constructed, it can be used to quickly estimate the least-cost path between two points. The user selects which level of the cost pyramid to use for the analysis. Traveling on higher levels is faster but less accurate. Operating on a selected level, the least-cost path between the source and target points is determined using the Dijkstra algorithm. However, the path stops one cell short of the source and target points *(fig. 1)*. This is necessary because the target points may not fall on the hub of the cell, and traveling to the hub of the cell may result in backtracking and thus an overestimation of cost. Instead, a least-cost path analysis

between these end points and the hubs of the next to last cells in the path are performed on the next lower level of the pyramid, again stopping one cell short of the destination. This process is repeated down to the lowest level of the pyramid. Finally, the cost, and optionally the actual path, is output to a file.

Test Procedures

The Umatilla National Forest in Eastern Oregon and Washington in the northwestern United States was selected as the site to test the speed and accuracy of the COSTPATHSQ algorithm. At this site, a cost surface of travel times was constructed where the value of each cell in the grid was set equal to the fraction of a minute it would take for fire suppression resources to travel one meter within the cell. The cost surface was constructed based on on-road and off-road travel speeds (Wilson and Wiitala 2003). The size of each cell was 30 meters on a side. In the whole grid there were over 8,000 rows and columns of cells.

We conducted our primary test on a subset of the grid containing 2,169 rows and 2,235 columns, about 4,400 square kilometers in area. To determine how well the COSTPATHSQ algorithm would perform on smaller and larger datasets, we also performed tests on 655 by 677 and 7,177 by 7,375 grids—about 390 and 46,600 square kilometer areas, respectively.

Ten source points (representing suppression resources) and 32 target points (representing wildfires) were selected at random within each of the three Umatilla datasets. In each test, this required determining 320 travel times between the sets of points.

Travel times were also calculated using the standard Dijkstra algorithm from the Grid module of ArcInfo 8.1 to produce a baseline with which to compare the results from COSTPATHSQ. Tests were conducted on a computer with a 1.0 GHz processor, 512 MB of RAM, and a Windows 2000 operating system.

Results

We report the full results of the test for the mid-sized dataset only *(table 1)*, and briefly comment on performance in the smaller and larger datasets. As our benchmark for performance comparisons, the Dijkstra algorithm, which produces optimal results, took 2,500 seconds to find the minimum travel time paths for the 320 combinations of source and target points. By contrast, running the COSTPATHSQ algorithm at level 9 of the pyramid, the coarsest level of resolution, took only 16 seconds (.05 second per path) and was 160 times faster than Dijkstra. However, at this level of resolution there was a 15 percent average overestimate of travel times relative to the Dijkstra algorithm. Running COSTPATHSQ at successively lower levels of the pyramid (finer grid resolutions) improves accuracy, but only at the expense of slower calculation times. At pyramid level 5, accuracy improved by almost five times with only a doubling of the run time *(table 1)*. Below level 5, gains in accuracy came at the expense of increasingly greater run times. In this instance COSTPATHSQ did not yield results on levels 1 and 2 of the pyramid because the computer used to run the tests did not have enough memory.

Table 1--*A comparison of COSTPATHSQ and Dijkstra test results.*

	Dijkstra	Pyramid build	COSTPATHSQ								
			Pyramid level								
			9	8	7	6	5	4	3	2	1
Run time (sec)	2,500	2,200	16	18	19	21	32	84	490	-	-
Relative speed[1]	1.0		160	140	130	120	78	30	5.1	-	-
Accuracy[2]	.00		15	11	8.6	4.8	3.1	1.5	.67	-	-

[1]*Magnitude faster than the basic Dijkstra algorithm.*
[2]*Percent by which travel time is overestimated.*

Before leaving these results, we wish to point out there is an up front computational cost to using the COSTPATHSQ algorithm. In this test, it took 2,200 seconds to build the cost pyramid, nearly as long as running the Dijkstra algorithm *(table 1)*. However, after building the pyramid, COSTPATHSQ achieves tremendous performance gains over the standard Dijkstra algorithm. Our tests with the smaller and larger datasets provided some interesting observations. The relative performance advantage of COSTPATHSQ increases with the size of the dataset. For example, if it is acceptable to overestimate the least cost by five percent, our tests with the smaller dataset showed COSTPATHSQ to be only about 12 times as fast as Dijkstra. In the mid-sized dataset COSTPATHSQ was 120 times as fast. Moreover, our tests with the large dataset showed COSTPATHSQ to be about 1,500 times faster than Dijkstra. Our experimentations also showed the performance of COSTPATHSQ relative to Dijkstra to increase with greater numbers of source and target points.

Conclusions

COSTPATHSQ has successfully opened the door to making more realistic and computationally fast travel time calculations thereby improving initial attack forest fire simulation models. This algorithm under most circumstances is much quicker than the standard Dijkstra algorithm in calculating suppression resource response travel times in the forest wildfire environment. Using a multi-resolution approach, our test results show COSTPATHSQ to yield fast results with a limited loss of accuracy. We also found the benefit of using COSTPATHSQ to be greater when dealing with larger datasets. Furthermore, it enables the user to select the resolution of the analysis, so they can strike an acceptable balance between speed and accuracy.

Acknowledgements

The multi-resolution approach to least-cost path analysis was inspired by Alan Ager, Pacific Northwest Research Station, USDA Forest Service, La Grande, Oregon.

References

Dijkstra, E.W. 1959. **A Note on Two Problems on Connection with Graphs**. Numeriche Mathematik, 1:269:271.

Environmental Systems Research Institute. 2001. **Cell-based Modeling with GRID–Weighted Distance Functions**.

Wilson, Andrew E., and Marc R. Wiitala. 2003. **Estimating Travel Times to Forest-Fires Using Resistance Surfaces**. Twenty-Third Annual ESRI International User Conference Proceedings, 7-11 July 2003, San Diego, California: Environmental Systems Research Institute, Inc., Redlands, California; unpaginated CD-ROM.

Zahn, F. Benjamin. 1997. **Three Fastest Shortest Path Algorithms on Real Road Networks: Data Structures and Procedures**. Journal of Geographic Information and Decision Analysis 1(1):69–82.

Preliminary Development of a Probability-Based Fire Severity Modeling System for California Forests[1]

John W. Benoit,[2] Haiganoush K. Preisler[3]

Abstract

In this currently ongoing study, we examine historical fire data, weather, and fuel conditions in the national forests in California. We build logistic regression models to determine the probabilities of fire ignitions and of ignitions becoming large fires. We use the same methodology that was developed in a previous study using data for the state of Oregon. Our objective is to further develop this process as a risk assessment tool for fire managers and planners.

Introduction

Fire managers in California rely on a variety of factors to help determine fire severity and make decisions about resource allocation and fire-fighting tactics. California's diverse environmental regions necessitate the use of a range of variables which describe weather conditions, fuel moisture, and fire behavior. An indicator of fire potential considered suitable at one location may be deemed ineffective at another. Each local fire expert might therefore choose a set of indicators to rely on. This can cause difficulty when one wants to compare fire severity across different regions.

In the United States, the National Fire Danger Rating System (NFDRS) is a process that produces a set of indices for any particular area of the United States, given current weather and fuel conditions. These indices give an idea of the fire potential and fire behavior in a given area. Fire experts use NFDRS indices to determine times for prescribed burning, assess the need for fire suppression resources, and make tactical firefighting decisions. Though these indices are heavily relied upon, their actual relationship to fire occurrence has not been thoroughly examined.

In a previous study, we gathered fire history, observed weather station data, and NFDRS index values, along with other geographic layers, for the state of Oregon (Preisler and others 2004). Logistic regression equations were then constructed to estimate, for any given day and location in Oregon, 1) the probability of a fire ignition, and 2) the probability of an ignition becoming a large fire (greater than 100 acres, or approximately 45 hectares). The probability of having a large fire could be computed from these two probabilities.

---

1 An abbreviated version of this paper was presented at the second international symposium of fire economics, policy, and planning: a global vision, 19–22 April, 2004, Córdoba, Spain.

2 Computer specialist, USDA Forest Service, Riverside, California.

3 Statistician, USDA Forest Service, Albany, California.

In the current study, we want to apply and adapt this methodology for use in California. There are a few differences between these two studies – mainly to do with the collected observed data. For example, we have access to more current and higher resolution GIS layers for California than we did for the Oregon study. Also, California is more geographically and climatologically diverse than Oregon. However, these factors should not affect our methodology, as the models we build take such differences into account through explanatory variables; they are robust for any given location.

Data

The Wildland Fire Assessment System (WFAS) provides a collection of observed data and forecast products related to fire severity within the United States. WFAS has made raw (tabular) observed data from stations in the Weather Information Management System (WIMS) catalog available online since January 2000[4]. We obtained this station data for 2000 through 2002 for every day for all stations reporting on each day. Included in each station's daily record were temperature, relative humidity, wind speed, precipitation, energy release component (NFDRS index), spread component (NFDRS index), Keetch-Byram drought index, and ten-, hundred-, and thousand-hour fuel moisture values. It was of benefit that this data included NFDRS information along with weather and fuels conditions, since generating NFDRS indices from historical data is a troublesome process. Prior to 2000, historic NFDRS indices were not archived, nor were some of the necessary input variables into NFDRS easily accessible. For example, observed fuel moisture – a key input into NFDRS – was sparsely recorded at many WIMS stations.[5]

We acquired observed data for all fires that occurred on national forests in California from 2000 through 2002. The fire data originated from the National Interagency Fire Management Integrated Database (NIFMID).[6] It included the date of the fire, the location, the suspected cause, and the fire size. Since this set of fire data contained not only fires originating in, but also fires *that threatened* the forests (e.g. fires started on lands adjacent to the forests), the California national forest boundaries were used as a mask to ensure that we had a list of fires whose ignitions truly occurred within the forest. Also, only fires that consumed more than 0.1 acres and classified as wildfires were included. There were 4746 fires that met this criterion during the study period (Figure 1).

Elevation data for the national forests was obtained at kilometer resolution. Because the intended application of the procedure we are developing is over fairly large regions, the one-kilometer spacing of values was adequate.

Finally, a fuel model data layer for California was taken from the California Department of Forestry and Fire Protection's Fire and Resource Assessment Program (FRAP).[7] This was a map of vegetation grouped according to similar burning

[4] See http://www.fs.fed.us/land/wfas/wfas29.html. Before 2000, only maps (graphics) of spatially interpolated values are available from this site.
[5] In our Oregon study, we used NFDRS indices for 1989 through 1996 generated by a process different than that used to produce indices at the WIMS stations in WFAS. While developing our procedure for California, we did not want to combine these two different data sets until we can verify that their general characteristics are similar.
[6] See http://famweb.nwcg.gov/kcfast/html/ocmenu.htm.
[7] See http://frap.cdf.ca.gov/.

characteristics. The fuel model data was resampled to have a cell size of one kilometer.

All data layers were georegistered (spatially aligned) to one another. We converted all coordinates to the Lambert Azimuthal geographic projection, which places locations in a Cartesian plane. This becomes convenient in our methodology, when we want to compute the expected number of ignitions or large fires for a given day.

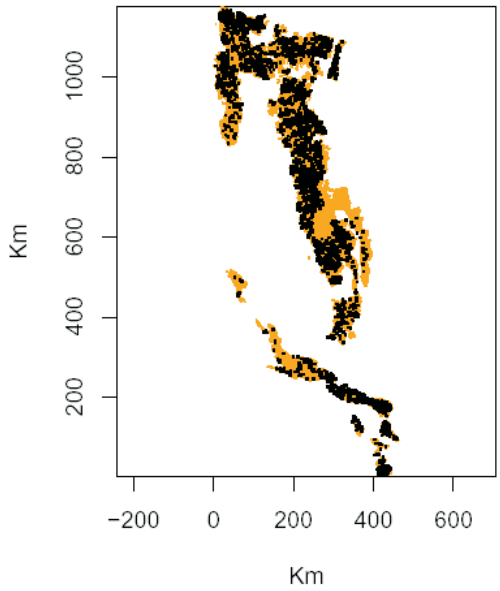


Figure 1—California federal fires from 2000 to 2003. The shaded area represents national forest land within the state of California. The black dots are the locations of fire ignitions.

Methodology

The observed study data was spatially arranged on a Cartesian grid with a one kilometer unit size and temporally by day. Our basic unit for sampling was a single square kilometer for a particular day. This unit was referred to as a *voxel*. In our California national forests data for 2000 through 2002, there were 117,438,750 voxels, with 5,317 of these having at least one fire ignition. Since the proportion of voxels with fires to those voxels without fires is extremely low, a two-stage sampling technique was implemented (Brillinger 2003). This involved defining a set that included all voxels that had fires and a small sample of the voxels with no fire[8]. Parameter estimation can then be performed using this smaller set of voxels rather than on the entire population of the study data.

For each day, observed weather, fuel moisture, and NFDRS values at specific stations are interpolated from the WFAS station location values to the individual voxels. Inverse distance weighted interpolation can be used to arrive at the one-kilometer cell values for any particular day. Alternatively, other interpolation

[8] The size of the sample of voxels with no fire is determined by choosing a small proportion (e.g. ~0.15%). The entire collection no-fire voxels are then randomly sampled at this rate.

methods, such as loess or thin-plate splines can be used, and most likely will give more accurate values. The interpolated grids of values are stored for later use.

We now consider an indicator variable such that:

$N_{x,y,t} = 1$ if there was at least one ignition in the voxel at location (x, y) and day t, and

$N_{x,y,t} = 0$ if there were no ignitions in the voxel

Next we can define the probability p_1 that a fire ignition occurs in voxel (x,y,t) with the logistic model:

$$p_{1,x,y,t} = \text{Prob}(N_{x,y,t} = 1 \mid U_{x,y,t}) = \frac{e^{\theta_{x,y,t}}}{1 + e^{\theta_{x,y,t}}} \quad (1)$$

where $U_{x,y,t}$ represents the historic values of explanatory variables at voxel (x,y,t) and $\theta_{x,y,t}$ is the set of parameters we wish to estimate. The *logit* of $p_{1,x,y,t}$ is defined as:

$$logit(p_{1,x,y,t}) = \log\left(\frac{p_{1,x,y,t}}{1 - p_{1,x,y,t}}\right) \quad (2)$$

From (1) and (2), we have

$$logit(p_{1,x,y,t}) = \theta_{x,y,t} = \beta_{0,x,y,t} + \beta_{1,x,y,t}x_{1,x,y,t} + \ldots + \beta_{n,x,y,t}x_{n,x,y,t} \quad (3)$$

where n is the number of independent variables in the model. The value of $logit(p_{1,x,y,t})$ can range anywhere in $(-\infty,\infty)$. Assuming independence among the voxels, we can use regression techniques to obtain estimates of the coefficients in (3).[9] Using generalized additive model (GAM) would allow for nonlinear relationships among the explanatory variables:

$$\begin{aligned} logit(p_{1,x,y,t}) = {} & g_1(x,y) + g_2(t) + g_3(Elev_{x,y,t}) + g_4(FM_{x,y,t}) + g_4(BI_{x,y,t}) \\ & + g_5(ERC_{x,y,t}) + g_6(KB_{x,y,t}) + g_7(TH_{x,y,t}) + g_8(WS_{x,y,t}) \\ & + g_9(RH_{x,y,t}) + g_{10}(Temp_{x,y,t}) \end{aligned} \quad (4)$$

Here, $Elev_{x,y,t}$ is elevation, $FM_{x,y,t}$ is the fuel model, $BI_{x,y,t}$ is the burning index, $ERC_{x,y,t}$ is the energy release component, $KB_{x,yt,}$ is the Keetch Byram drought index, $TH_{x,y,t}$ is the thousand hour fuel moisture, $WS_{x,y,t}$ is the wind speed, $RH_{x,y,t}$ is the relative humidity, and $Temp_{x,y,t}$ is the temperature at voxel (x,y,t). The functions $g(\bullet)$ are nonparametric smoothers estimated simultaneously with the GAM. $g_1(x,y)$ represents location effect and $g_2(t)$ is the temporal effect in the model.

The conditional probability $p_{2,x,y,t}$ that a large fire occurs (over 100 acres) given that there was an ignition can be modeled using very much the same technique as that for finding $p_{1,x,y,t}$. The same or a similar set of coefficients may be used. In the case of $p_{2,x,y,t}$, however, coefficients are estimated using only the set of the voxels in which fires *did* occur.

[9] Naturally, we cannot easily assume that the data is temporally and spatially independent. For example, after a fire has burned an area (a set of voxels), another fire in the same location is not likely to occur for some time. We hope that some of these relationships are accounted for by the explanatory variables with each voxel – a recently burned area may exhibit a change in its fuel moisture, which would affect the chance of another fire occurring in the same location soon afterwards.

Finally, given $p_{1,x,y,t}$ and $p_{2,x,y,t}$, we can easily compute the unconditional probability that a large fire will occur, since

$$p_{3,x,y,t} = P(\mathbf{A} \cap \mathbf{B}) = P(\mathbf{A}) \cdot P(\mathbf{B} \mid \mathbf{A}) = p_{1,x,y,t} \cdot p_{2,x,y,t} \quad (5)$$

where

A = event of a fire ignition, and

B = event that an ignition becomes a large fire.

A convenient feature of using voxels as our basic unit for computing probabilities is that we can quickly get the expected number of fire events for a particular day. For example, the expected number of fires within the study area or subset of the study area for a specific day is the sum of the values of $p_{1,x,y,t}$ at every kilometer in the desired area for that day. The expected number of ignitions becoming large fires and the expected number of large fires per day can be found in the same way, using $p_{2,x,y,t}$ and $p_{3,x,y,t}$, respectively. Additionally, confidence intervals can be derived for the three probabilities (see Preisler and others 2004).

Further Work

Our study of California is currently in progress. Presented here are the findings as of now, along with the procedure we intend to use (much of which has been performed on our study of Oregon). There are some options that we plan to investigate. We would like to get a larger study period than just the years 2000-2002. The main hindrance has been obtaining historic values of NFDRS indices, which we wish to relate to fire occurrence. We are presently investigating possible methods of generating historic NFDRS values.

Our procedure allows for the testing of different spatial interpolation methods on the observed daily station data. Inverse distance weighted interpolation is one of the simplest schemes to employ (and commonly used in WFAS products), but more accuracy can be found in using locally-weighted methods, such as loess and spline techniques.

The work outlined here has been concerned with observed data. However, the intention is to use the developed logistic regression equations in forecasted data to produce maps of future severity probability (Figure 2). The testing of different weather model outputs will be of interest. We therefore want to eventually integrate different weather models, such as RSM (Roads 2000 & 2002) or MM5, to our procedure.

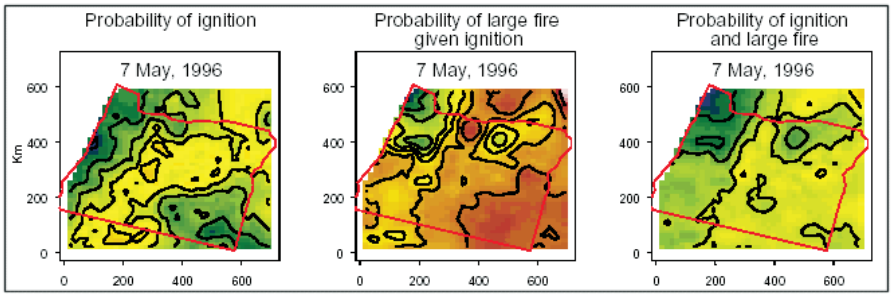


Figure 2—Maps of probabilities of fire ignition, of a large fire given an ignition, and of an ignition and large fire for Oregon. Colors range from blue/dark green (low

probability) to reddish brown (high probability). We will produce similar maps for California.

The intent of this work is to eventually produce a fire severity forecast product that is based on technology and tools being currently used by the fire community. We would hope this product is scaleable, from a national scope down to the forest district level. Finally, it should be easy to use and understand. This probability-based approach shows promise in achieving these tasks.

References

Bradshaw, Larry S.; Deeming, John E.; Burgan, Robert E.; Cohen, Jack D., compilers. 1984. **The 1978 National Fire-Danger Rating System: technical documentation.** Gen. Tech. Rep. INT-169. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 44 pp.

Brillinger, D.R.; Preisler, H.K.; Benoit, J. W. 2003. **Risk assessment: a forest fire example.** In: Goldstein, Darlene R., editor. Institute of Mathematical Statistics Lecture Notes – Monograph Series 40: 177-196.

Preisler, H.K.; Brillinger, David R.; Burgan, Robert E.; Benoit, J.W. 2004. [In press]. **Probability based models for estimation of wildfire.** International Journal of Wildland Fire.

Roads, J.O; Chen, S.-C.; Kanamitsu, M. 2002. **US regional climate simulations and seasonal forecasts.** Journal of Geophysical Research-Atmospheres.

Roads, J.O.; Fujioka, F.; Burgan, R. 2000. **Development of a seasonal fire weather forecast for the contiguous United States.** Preprints. Third symposium on fire and forest meteorology, Long Beach, CA. Amer. Meteor. Soc.; 99-102.

S-PLUS 2000 guide to statistics, vol 1. Data Analysis Products Division, MathSoft, Seattle, WA; 638 p.

An Integrated System for Static and Dynamic Risk Evaluation at a National Level[1]

Paolo Fiorucci,[2] Francesco Gaetani, [2] Riccardo Minciardi[2 3]

Abstract

An integrated approach for forest fire risk assessment over a wide geographical area is presented in this paper. Such an assessment is finalized to support decisions regarding long-term planning and pre-operational phases. Risk assessment is carried out both in dynamical and in static situations. The information used for risk assessment is relevant to hazard, and to vulnerability and cost of the exposed elements. Hazard assessment is carried out, in the dynamic case, by use of a cascade of two models, the former tracking the moisture content of the available dead fine fuel, and the second providing an estimate of the potential spread and of the linear intensity of a fire possibly ignited in the cell. The two models are driven by meteorological information (real-time and forecast) and by territorial information stored in a GIS database. Instead, in the static case, hazard assessment is based on a deep analysis of the fires historically occurred in each cell.

Introduction

Since ancient times a great number of wildfires have burnt Mediterranean forests. In fact, during the centuries, the necessity to sustain the growing population has altered the original equilibrium of natural habitat. A large amount of the forested areas was destroyed aiming at creating new spaces for settlements, pasturage and agriculture. Later on, the industrial age and the consequent large urban settlements dramatically transformed the territory. In this connection, woodlands were the places where Mediterranean populations found the materials and the energy (wood, timber and lignite) needed by the industry. Nowadays, in the middle of the petrol age, forests have lost their importance, but also as a consequence of the urban sprawl, the population living near or inside a vegetated/forested area has grown. On the counterpart, the rural population has decreased and, by now, a growing population without any rural or agricultural knowledge lives and visits woodlands, perceiving them only as leisure-holiday areas.

In this connection, the presence comes out of two different land uses, separated by a borderline, which divides the natural environments from the anthropic settlements. Therefore, it should not be surprising to recognize that the maximum

[1] An abbreviated version of this paper was presented at the second international symposium on fire economics, policy, and planning: a global view, 19–22 April, 2004, Córdoba, Spain.

[2] Centro di Ricerca Interuniversitario in Monitoraggio Ambientale, University of Genova. Via Cadorna, 7-17100 Savona, Italy.

[3] Dipartimento di Informatica, Sistemistica e Telematica, University of Genova. Via Opera Pia, 13-16145 Genova, Italy.

frequency of forest fire ignitions arises along such borderline, namely in the so-called Wildland Urban Interfaces (WUI). In fact, where the peripheral urban zones enter in contact with productive agricultural surfaces or abandoned areas, a situation of serious hazard arises, for instance related to the agricultural practices that generally require the ignition of fires in proximity of zones rich of biomass and near inhabited areas. Actually, in some regions the frequency of fire occurrences, and the effects that they have on natural habitat and human activities make wildfires represent the most remarkable natural risk also for the complexity of the organization needed to manage such a risk and to effectively fight an active forest fire.

Some preliminary notations can be made about terminology; in fact, in the literature, the terms *risk* and *hazard* are considered as nearly equivalent. Instead, in this paper, the term hazard will be used to designate the physical distribution of the conditions favoring a potential ignition, irrespective of the presence over the territory of an *exposed element*. The latter term will be used to designate the set of entities, which can suffer from an external stress (in this case, a fire) and suffer damage. Exposed elements are, of course, related to human lives, settlements, industrial activities, infrastructure, and also wildlife areas. To analyze the impact of an external stress over an exposed element, the *vulnerability* of the element has to be taken into account. Then, the *risk* suffered by an exposed element can be evaluated on the basis of the existing hazard, of the vulnerability of the element, and of some measure of the value of the element itself.

At least in Mediterranean areas, the ignition of a fire in a vegetated area is, almost in the totality of the cases, imputable to human activities (either as a voluntary action or as an involuntary consequence of the human activities), and, therefore, not properly recognizable as a natural event. However, the propagation of an ignited fire is heavily influenced by the characteristics (topographical, vegetational, etc.) of the interested territory, as well as by the meteorological conditions and the conditions of the fuel (especially as regard its moisture content). Actually, it is clear that it is improper to think of forecasting the ignitions, whereas, it seems to be sensible to assess and forecast the danger that a (somehow) lighted fire may find favorable conditions for its propagation and, therefore, the consequence of such a fire on the territorial system (exposed elements).

The purpose of this paper is to provide a first development of an integrated system for support in decisions regarding long term planning and pre-operational phases aiming at reducing the impact of wildfires over the territory. To this end, hazard assessment is first considered, both as regards the static and the dynamic cases. Then, a possible way to evaluate the risk relevant to a single territorial unit is introduced, and, on this basis, two optimization problems are defined in order to formalize the above mentioned decisional processes.

The hazard assessment

As happens in connection with other kinds of natural risks, forest fire hazard assessment can take place starting within three different conceptual frameworks. In the first one, which can be denoted as *static hazard* assessment, the evaluation and the distribution of the hazard over the territory is carried out on the basis of topographic information and land use (including vegetational cover), climate, possibly considered for the different seasons, and average fuel (i.e., vegetation) conditions, again referred to the various seasons. Static hazard assessment has also to

be based on the analysis of the data available from historical series corresponding to forest fires occurred in the considered region.

The purpose of such an assessment could be that of preserve the forest from the fire and to plan the sizing and the location of the different kinds of resources (men, trucks, engines, aircrafts, infrastructures, etc.) necessary to manage forest fire risk over a wide territory. Another objective of such an analysis could be that of obtaining indications about land use and urban planning, over a small-medium regional area. Actually, the design and the allocation in protected or natural areas of infrastructures dedicated to forest fires emergency constitutes a serious issue, owing to the necessity of limiting the impact over wildlife, as well as the construction and maintenance costs. The management of extinguishing ground operations require a wide range of facilities and a perfect coordination among the subjects involved in the emergency phase. In addition, it is necessary to ensure a continuous action of the emergency resources and thus it is fundamental to design an overall system able of proving continuous water supply when and where it is necessary.

Within the second framework, which will be denoted as *dynamic hazard* assessment, it is assumed that real-time information is available, and that the hazard assessment is carried out with reference of a certain time horizon (say 2-3 days) for which reliable meteorological forecasts are available. Along with forecast information, the real-time information used for dynamic hazard assessment may come from different sources: present weather conditions, ground-measured data relevant to vegetational conditions, data coming from satellite or airborne sensors (again, mainly referring to vegetational conditions). With a slight abuse of terminology, in the following the term "real-time information" will be intended to include also the meteorological forecasts for the short time horizon over which forest fire hazard is assessed.

The main advantage of a dynamic hazard assessment is that of identifying, within the considered territory, the areas affected by the highest hazard, and the time intervals within the considered time horizon in which this hazard takes place. The purpose of dynamic hazard assessment is that of getting reliable information useful to take a number and a variety of pre-operational actions that can reduce the impact of potentially lighted fire over the considered territory, within the considered time horizon. Such actions may include, for instance, re-locating the available resources over the territory, recalling day-off resources to service, alerting local authorities or emergency managers, issuing prohibitions of some dangerous agricultural practices (such as stubble burning), and patrolling the areas affected by the highest hazard.

Finally, the third framework is that corresponding to a situation in which some active fires have been detected, and there is the problem of selecting the best actions to fight such fires, taking into account the information corresponding to the distribution of hazard over the considered territory. In this case, a hazard assessment relevant to each detected fire has to be carried out. On this basis, an operational decision procedure can be applied in order to support the decision makers in taking decisions about the actions to undertake in order to contrast effectively or to extinguish the detected fires.

Summing up, for any of the above-mentioned three frameworks, an information-processing phase, aiming at performing some hazard assessment has to be considered, followed by a decision-oriented phase, whose objective is the selection of the best actions to undertake, on the basis of the available information. What

distinguishes the three frameworks, which can be denoted as information processing/decision levels, is the time horizon characterizing their operations and the available information. Clearly, information generated at any of the levels is passed to the subsequent one.

For the sake of completeness, a fourth level can be added to the above outlined conceptual scheme, referring to information processing and decision making after having extinguished a fire. Actually, the actions relevant to such a level are of a considerable importance in the management of forest fire risk, but on the whole, their discussion is beyond the scope of the present paper.

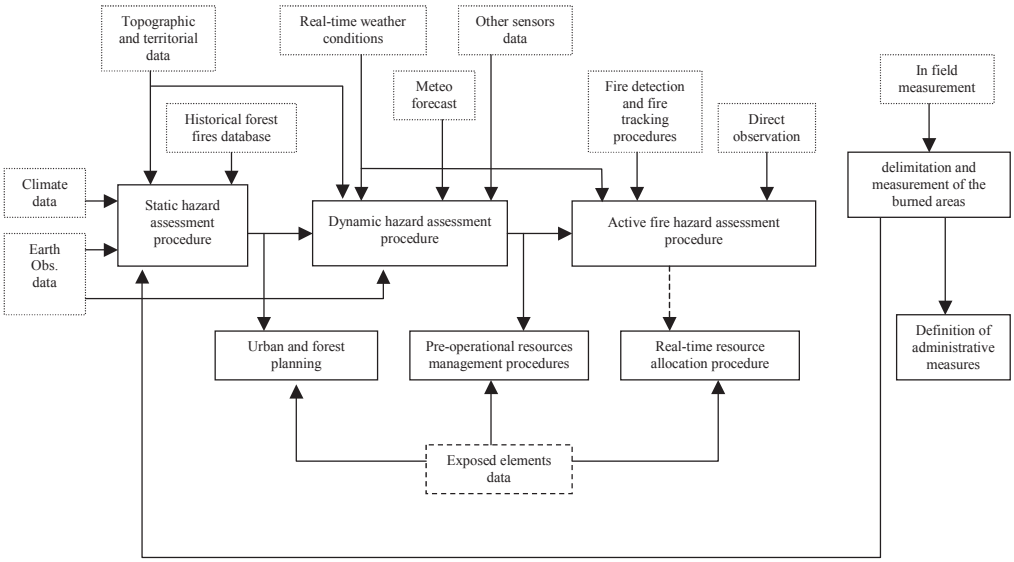


Figure 1—Conceptual scheme of wildfire hazard assessment. Each block in solid lines represents a procedure (or a module of the system), whereas dotted blocks represent input or output information, and lines represent information flow (including, of course, information relevant to actions to be undertaken).

In this paper only the first two frameworks are considered, whereas the real time hazard assessment and the post-event phase are not considered. Namely, static and dynamic hazard assessment procedures relevant to planning and to pre-operational phases are discussed; moreover, problems and policies relevant to the mitigation of the expected or forecasted risk, for a certain area, and for a determined set of exposed elements.

The dynamic hazard assessment

It is convenient, for ease of presentation, to present this module before the static hazard assessment module. The structure of the considered module can be represented as in Figure 2. The structure depicted in this figure shows that the overall module may be decomposed into two models, namely the fuel moisture model and the potential fire spread model. The function of the fuel moisture model is that of representing the dynamic behaviour of the distribution, over the territory, of the variable expressing the water content of the fuel that is mostly interested by the ignition process. The second model is used to quantitatively describe the behaviour of a lighted fire, leaving out of consideration any possible extinguishing action. Such a

model is not used to obtain a forecast of the propagation process of a given fire, but only to evaluate the potential riskiness after a possible ignition.

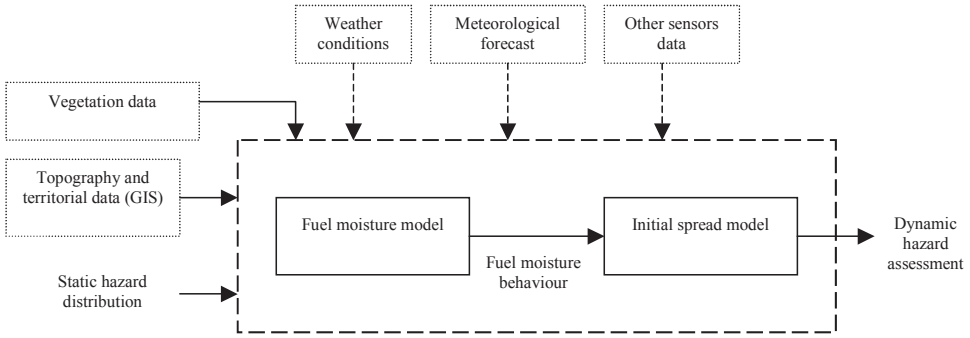


Figure 2— A schematic representation of the structure of the dynamic forest fire hazard assessment module.

The information that can be used by the two sub-models represented in Figure 2 is partly static and partly dynamic. Namely, static information is relevant to topographic and territorial data (orography, land use, road network, etc.), which can be obtained by a Geographical Information System (GIS), and to the vegetational cover of the considered areas. The latter kind of information may be considered as static, even as regards biomass density. In fact, the seasonal biomass dynamics is much slower than the dynamics of the two sub-models depicted in Figure 2, so that one can reasonably think of considering the average vegetational load for each season of interest.

On the other hand, dynamic information may be of several different kinds. First of all, there may be a network of ground sensors (rain gauges, anemometers, solar radiation sensors, etc.) capable of providing real-time measurements of variables whose relevance is apparent for the evaluation of forest fire hazard. Other sensors may be used to acquire information related to fuel moisture. Finally, a source of dynamic information is also provided by the outputs of a meteorological model, assuming that the forecasts over a horizon of suitable length [say, 48-72 hours] can be considered sufficiently reliable

The above functions are discrete in time and space. Actually, it is reasonable to choose the time discretization interval and the space discretization grid as those corresponding to the outcomes of the meteorological model. The variables that are determined to assess the forest fire hazard on each cell of the space grid are the rate of spread and the linear intensity that a fire could assume (in case of a successful ignition). The rate of spread is obtained through the application of a model, which is not used to evaluate the dynamics of a given fire but to evaluate the physical characteristics that a fire could attain, in each cell, on the basis of the variables locally the possibility of a successful ignition and fire propagation.

At this moment, a first implementation of the system has been realized, which is based only on the information provided by the outputs of a meteorological Limited Area Model (LAM), and on a GIS database. As regards the LAM, the information used consists of: the cumulate rainfall [m] in each time interval of three hours, the air temperature [K], the dew point temperature [K], the wind speed [m s-1], and the wind direction [rad]. Besides, a Digital Elevation Model (DEM) has been utilized to define

the average value of the aspect angle [deg], the slope [%], and the elevation [m] of each grid cell.

The vegetation information available to the system is organized in a vectorial map of the whole area. The morphological data are stored in a GIS database and are: the fuel loads [kg m^{-2}], the average height of the plants [m], and the crown height [m]. Moreover, the physiological characteristics of the fuels, that is the average seasonal tissue moisture content [%] of live fuel are included in the GIS database, as well as the average seasonal Higher Heating Value (HHV) [kJ kg^{-1}], both for dead and live fuels.

The fuel moisture model

The basic structure of the proposed fuel moisture model closely resembles the one corresponding to Byram's equation (Byram, 1963). However, the justification of the structure is somehow different and, more important, the dependence of the model parameters on meteorological variables is represented in an effective and operational way. Namely, such a dependence will be structured on the basis of some simple semi-physical considerations, making use of a set of calibration parameters that can be determined in order to fit the model performances with experimental observations. A first remark that has to be done in connection with the proposed fuel moisture model is that only the dynamics of the dead fine fuel is modeled. Instead, the live fuel moisture is considered practically time-invariant, and provided by values corresponding to the specific vegetational cover and to the considered season.

The dynamics of the dead fine fuel moisture is represented by using, for each cell k over the considered region, a specific model, which does not interact with the models of the other cells, as no fire propagation is represented.

Then, let $u_k^o(t)$ represent the dead fine fuel moisture at cell k, at time instant t. It is assumed that the evolution of the above quantity is governed by the differential equation

$$\frac{du_k^o(t)}{dt} = K_1\ \mathrm{step}(t) - K_2\ u_k^o(t) \qquad (1)$$

where step(t) is the unit step function[4]. In fact, the solution of (1) has an asymptotic behaviour determined only by the ratio (K1/K2), namely

$$u_k^o(t) = \frac{K_2\ u_k^o(0) - K_1}{K_2}\ e^{-K_2 t}\ \mathrm{step}(t) + \frac{K_1}{K_2}\ \mathrm{step}(t) \qquad (2)$$

Of course, the asymptotic value (K1/K2) is independent from the initial state $u_k(0)$, and the transient behaviour is decaying (increasing) if $u_k\ (0) > (K1/K2)$ ($u_k\ (0) < (K1/K2)$. Observe that the "time constant" characterizing the speed at which the transient term in the r.h.s. of (2) vanishes, is given by 1/K2.

Actually, note that the solution (2) of eq. (1) is correct only in the assumption of time-invariance of coefficients K1 and K2, which however, as it will be discussed

[4] Function step[x] is defined as equal to 1 if x≥0 and equal to 0 otherwise.

below, must be considered time-varying, as their values depend on a set of meteorological variables, Thus, the use of solution (2) is correct only whenever the dynamics of model (1) (which is characterized by the time constant ($1/K_2$)) is considerably slower than meteorological dynamics (determining the variation of K_1 and K_2). However, discretization of (2) is in any case allowed, even when K_1 and K_2 are significantly time-varying. For this reason, hereafter the dependence of such coefficients on time (and on cell k) will be explicitly reminded by the notation.

It is assumed that coefficients $K_{1,k}(t)$ and $K_{2,k}(t)$ are functions of the meteorological variables $p_k(t)$, $w_k(t)$, $\rho_k(t)$, $\tau_k(t)$, that is the cumulated rain $p_k(t)$ [m], the wind intensity $w_k(t)$ [ms^{-1}, rad], the relative humidity $\rho_k(t)$ [%], and the air temperature τ_k [K], respectively. In the proposed model, instead of trying to model such a dependence through thermodynamic considerations, a semi-physical structure is assumed by expressing the asymptotic value ($K_{1,k}(t)/K_{2,k}(t)$) as a function of the meteorological variables in the following way

$$\frac{K_{1,k}(t)}{K_{2,k}(t)} = e^{\frac{\rho_k(t)+\alpha_1}{\alpha_2+\alpha_3\tau_k(t)}} \text{ if } \; p_k(t) \le p^* \qquad (3)$$

$$\frac{K_{1,k}(t)}{K_{2,k}(t)} = \beta_1 \quad \text{if} \quad p_k(t) > p^* \qquad (4)$$

where α_i (i=1,..,3), β_1 are constants having suitable dimensions and p^*[m] is a threshold value for the cumulated rain. Note that (3) holds in absence of significant rainfall (in the last time interval), whereas (4) holds whenever such a rainfall cannot be neglected. Of course, the constant values must be selected so that

$$\beta_1 > e^{\frac{\rho_k(t)+\alpha_1}{\alpha_2+\alpha_3\tau_k(t)}} \qquad (5)$$

for any possible value of $\rho_k(t)$, and $\tau_k(t)$. Note that the dependence of the r.h.s. of (4) on $\rho_k(t)$ can be justified by observing that, the higher the value of $\rho_k(t)$, the higher the asymptotic value of $u_k^o(t)$. Besides, the fact that the r.h.s. of (4) is independent of $p_k(t)$ can be justified by the assumption that the asymptotic values of the fuel moisture is independent of the rainfall intensity (whenever such an intensity exceeds a certain threshold). Finally, the fuel moisture is uncorrelated with temperature and humidity in case of rain, as the rain brings the fuel moisture condition at the fiber saturation point, which is greater than 35% (Cheney, 1981). The assumed values of parameters β_1 and α_i (i = 1,..,3), are reported in Tab 1.

As regards the dependency of $K_{2,k}(t)$ from meteorological variables, recalling that $1/K_{2,k}(t)$ is the time constant that (in time-invariant meteorological conditions) characterizes the transient behaviour represented in (2), the following structure can be proposed

$$K_{2,k}(t) = \alpha_4 e^{\text{sign}\left[u_k^0(t) - e^{\frac{\rho_k(t)+\alpha_1}{\alpha_2+\alpha_3\tau_k(t)}}\right][\alpha_5\tau_k(t)+\alpha_6 w_k(t)]} \text{step}\left[p^* - p_k(t)\right] + \max\left\{p_k(t) - p^*, 0\right\}\beta_2 \quad (6)$$

where further constants having suitable dimensions have been introduced. For the sake of simplicity, only the case of $\tau_k > 0$ is considered. The structure of the r.h.s. of (6) may be justified as follows. First of all, note that ($1/K_{2,k}(t)$) represents the time

constant of the transient term in (2). Then, observe that the first term in the r.h.s. of (6) applies in absence of significant rainfall and thus $K_{2,k}(t)$ represents the speed of the drying (resp., moistening) process when $u_k^0(t) > e^{\frac{\rho_k(t)+\alpha_1}{\alpha_2+\alpha_3\tau_k(t)}}$ (resp., $u_k^0(t) < e^{\frac{\rho_k(t)+\alpha_1}{\alpha_2+\alpha_3\tau_k(t)}}$). Clearly, the dependence proposed in (6) makes so that, in absence of a significant rainfall, high values of temperature and wind intensity favor drying and hamper moistening. Instead, the second term in the r.h.s. of (6) applies in presence of significant rainfall, and assumes a linear dependence of the moistening speed on the rainfall intensity. Of course, from (3), (4) it turns out that

$$K_{1,k}(t) = K_{2,k}(t)\left\{\text{step}\left[p^* - p_k(t)\right]e^{\frac{\rho_k(t)+\alpha_1}{\alpha_2+\alpha_3\tau_k(t)}} + \left(1 - \text{step}\left[p^* - p_k(t)\right]\right)\beta_1\right\} \quad (7)$$

At this point, after model (1) has been discussed, also as regards the dependence of the coefficients appearing in (1) on the meteorological variables, it is worth providing explicitly the discretized version of the model, which is actually implemented in the developed system, namely

$$u_k^0(t+1) = u_k^0(t)\left[1 - T\,K_{2,k}(t)\right] + T\,K_{1,k}(t) \quad (8)$$

where T is the length of the discretization interval (3 hours), and the time variable t is (now) an integer number.

Table 1—*List of parameter values for the fuel moisture model*

Fuel moisture parameter						
Model parameter	α_1	α_2	α_3	α_4	α_5	α_6
Value	24.210	34.940	0.100	0.2317	7.5×10^{-3}	17.5×10^{-6}
Model parameter	β_1	β_2	p^*			
Value	40.000	0.100	0.001			

Obviously, the behavior of the fuel moisture model is deeply affected by the value of parameters α_i (i = 1,..,6), and β_i (i = 1, 2), and p^*. Actually, a preliminary calibration of such parameters, for a case study relevant to the whole Italian territory and to the summer season, has led to the values reported in Table 1. Essentially, such a calibration has been conducted on the basis empirical evidence over a wide set of test cases (relevant to actually detected fires).

The potential spread model

The purpose of this model is that of providing a measure of the hazard, for each cell in the considered area. The dynamic information that such a model uses is that relevant to forecast meteorological variables, and that provided by the fuel moisture model. In the same time, the propagation model makes use of topographical information, and of information related to vegetation (kind and density per m^2), again referred to the considered cells. The information concerning density and kind, for each cell, of dead and live fuel, is considered as *static*, as only seasonal variations are

considered, simply by taking different values of the relevant parameters for the various seasons.

The development of the potential spread model will follow the same basic lines first proposed by Drouet (1974), as regards the definition of a forest fire propagation model, but introducing some important novelties as regards the procedures to evaluate the forest fire hazard.

It is convenient to recall again that, in the present paper, we are not properly interested in a fire propagation model; instead, we are interest in determining a quantitative evolution of the hazardousness over the whole considered region. Such a hazardousness is related to the behavior of a potential fire after an accidental or deliberate ignition. The first information on which the potential spread model is built is represented by the *nominal rate of spread* $v_{0,k}$, which is a quantity referring to standard conditions as regards the temperature and the average live fuel moisture, in absence of wind, within a perfectly flat terrain, and with perfectly dry dead fuel. Obviously, $v_{0,k}$ depends on cell index k, as it depends on the kind of fuel (i.e. particle size, bulk density, moisture, and chemical composition of the fuel) and on the vegetation density (biomass per square meter) of live and dead fuel. Besides, such a value has to be specified in connection to the various seasonal conditions, as they determine the average moisture of live fuel. Clearly, the determination of $v_{0,k}$ needs a great amount of experimental tests and a deep knowledge on the vegetation covering over the territory. On this basis, the *potential rate of spread,* which takes into account the influence of the meteorological variables, can be defined and determined as follows

$$v_k(t) = v_{0,k}\, Z_k(t) \frac{W_k(t)}{N_k(t)}\, S_k\, D_k(t) \qquad (9)$$

where

$Z_k(t)$ is a (multiplicative) correction [dimensionless] due to air temperature, at time t and in cell k, with respect to the standard temperature (0°C) assumed as the reference one;

$W_k(t)$ is a (multiplicative) correction [dimensionless] due to wind speed on flat terrain, at time t and in cell k;

$N_k(t)$ is a normalization term [dimensionless] which takes into account the influence of topography on coefficient $W_k(t)$;

S_k is a (multiplicative) correction [dimensionless] due to the slope of the cell k;

$D_k(t)$ is a (multiplicative) correction [dimensionless] due to the dead fine fuel moisture, at time t and in cell k.

The way such terms depend on real-time information can been modelled as follows. Term $Z_k(t)$ in (13) can be assumed to be given by (Drouet, 1974)

$$Z_k(t) = e^{\gamma_1 \tau_k(t)\,(1+\frac{(1-\chi_k(t))}{\gamma_2})} \qquad (10)$$

where γ_1, γ_2, are parameters having suitable dimensions, and $\chi_k(t)$ is the total cloud cover (dimensionless) of cell k at time t, ($\chi_k(t) \in [0, 1]$), which can be directly measured, or forecast by meteorological models.

As regards term $W_k(t)$, the following expression can be used (Drouet, 1974)

$$W_k(t) = \left\{1 + \delta_1\left[\delta_2 + \tanh\left(\frac{w_k(t)}{\delta_3} - \delta_4\right)\right]\right\}\left[1 - \frac{w_k(t)}{\delta_5}\right] \quad (11)$$

where parameters δ_i (i=1,..5) have suitable dimensions and are fixed as in Tab. 2.

Wind speed has the most remarkable influence on fire behaviour when the angle $\theta_k(t)$ between wind direction and cell aspect is null. Obviously, in case of flat terrain or week slope steepness, the influence of wind speed on the rate of spread is independent of the cell aspect. On the other hand, in case of significant slope steepness the angle between the wind direction and the cell aspect heavily influences the (potential) fire behaviour, in that, when $\theta_k(t)$ is about π, wind speed influence over the rate of spread has to be negligible. Then, in order to represent the influence of topography over the effect on wind speed (represented via the correcting factor $W_k(t)$), term $N_k(t)$ has been introduced in eq. (9), given by

$$N_k(t) = 1 + \frac{2\ \text{arctg}\ s_k}{\pi}\left(W_k(t) - 1\right)^{\frac{2\ \text{arctg}\ s_k}{\pi}} e^{-\frac{(\theta_k(t)-\pi)^2}{2\varepsilon^2}} \quad (12)$$

where:

ε is a parameter having suitable dimensions, whose value, reported in Tab. 2, is purposely chosen in order to allow a dependence on $\theta_k(t)$ like the one that will be described in the following;

s_k is the slope steepness [dimensionless].

It is important to observe that slope steepness has a twofold effect on fire propagation. In fact, besides to conditioning the wind effect on propagation, as above discussed, slope steepness has also a direct effect, as the flames of a fire burning upslope are positioned closer to the fuels ahead of the fire. This dries and preheats the fuels at a greater rate than if they were on flat terrain. Thus, it is necessary to introduce term S_k in equation (9), representing the slope contribution to the rate of spread, and structured as follows

$$S_k = 1 + \lambda_1\left(\frac{2\ \text{arctg}\ s_k}{\pi}\right) \quad (13)$$

where λ_1 is a dimensionless parameter. In Tab. 2 the value selected for such parameter is reported.

As already pointed out, only dead fine fuel moisture dynamics is taken into account, whereas moisture of live fuel is determined only (as a static parameter) on the basis of seasonal average values for the kind of vegetation characteristic of the considered cell. That is to say, whereas dead fine fuel moisture is represented via a variable $u_k^0(t)$, live fuel moisture is represented by a constant u_k^1.

Then, the influence of the dead fine fuel moisture can be taken into account by the introduction in (9) of the dimensionless term $D_k(t)$ defined as

$$D_k(t) = e^{-\left(\frac{u_k^0(t)}{\phi}\right)^2} \quad (14)$$

where ϕ is a dimensionless parameter (whose value has been fixed as reported in Tab. 2).

Table 2—*List of parameter values for the potential fire spread model*

Potential spread parameter					
Model parameter	ε	γ_1	γ_2	ϕ	λ_1
Value	0.500	0.001	1.400	24.040	1.000
Model parameter	δ_1	δ_2	δ_3	δ_4	δ_5
Value	1.500	0.848	16×10^3	1.250	25×10^4

Having so clarified the way to compute the potential rate of spread $v_k(t)$, which provides a quantification of the quickness characterizing the (potential) spreading of a fire, it is necessary to quantify also the intensity of the phenomenon, which is the ultimate measure of the hazard. To this end, Byram's equation (1959) can be used to determine the (potential) hazard $H_k(t)$, that is the fire linear intensity [kWm^{-1}], namely

$$H_k(t) = v_k(t) \sum_{i=0}^{1} LHV_k^i \; d_k^i \qquad (15)$$

where

d_k^0, (d_k^1) [kg m^{-2}] is the density of dead fuel (live fuel), for the considered season in cell k;

$LHV_k^0(t)$, (LHV_k^1) is the Lower Heating Value [kJ kg^{-1}] of the dead fine fuel, (live fuel) in k at time t, given by:

$$LHV_k^0(t) = HHV_k^0 \left[1 - \frac{u_k^0(t)}{100}\right] - Q \frac{u_k^0(t)}{100} \qquad (16)$$

$$LHV_k^1 = HHV_k^1 \left[1 - \frac{u_k^1}{100}\right] - Q \frac{u_k^1}{100} \qquad (17)$$

where

HHV_k^0, (HHV_k^1) is the Higher Heating Value [kJ kg^{-1}] of the dead fine fuel, (live fuel) based on the prevailing species composition in cell k, whereas Q is the latent heating value [kJ kg^{-1}].

The static hazard assessment

As it has been pointed out in the introduction, in the Mediterranean regions the ignition of a wildfire is in almost the totally of cases imputable to human intervention either as a voluntary action or as an involuntary consequence of some activity. Thus, although a high potential hazard could affect significant portions of the territory, not all the areas characterized by high hazard actually burn.

Then, it is essential, in order to evaluate the static hazard over a considered territory, to have access and make use of the information related to a large amount of fires occurred over a wide area (for instance, the entire Italian national territory) and for a period of time long enough to be statistically representative of the average climate conditions for the considered regions (e. g., 10 years).

For instance, referring to the Italian territory, according to *Forest Service's Daily Journal of Detected Fires* (Corpo Forestale dello Stato, 2002), a set of data relevant to Y years have been collected. For each fire, the following information is available:

the geographical coordinates of the ignition;

the burnt area (woodlands and non forested areas);

the number and the typology of means that took part in the intervention;

the duration of the intervention;

the meteorological local conditions relevant to the intervention time interval.

the topography and the vegetation of the case study area.

Then, for each occurred fire, a hazard index is defined as follows:

$$\tilde{h} = \left(\kappa_1 A_1 + \kappa_2 A_2\right) \frac{\sum_{m=1}^{M} \lambda_m x_m \tau_m}{\tau_{tot}} \qquad (18)$$

where:

$\tilde{h}$ [m^2] is the hazard index;

κ_1, κ_2 [dimensionless] are weighting coefficients;

A_1, A_2 [m^2] is the reported burnt area of woodlands and non-forested lands respectively;

λ_m, m=1,..,M, [dimensionless] is a coefficient relevant to each different typology of means belonging to class m (trucks, engines, aircrafts, helicopters) whose value represents a measure of the effectiveness of that class of means as regards the extinguishing action;

x_m, m=1,..,M, [dimensionless] is the number of means belonging to class m, which took part in the extinguishing actions;

τ_m, m=1,..,M, [s] is the duration of the intervention, as regards means belonging to class m.

τ_{tot} [s] is the total duration of the intervention.

The meaning of $\tilde{h}$ is apparent, as it is an index useful to measure the hazard of the detected fires, which takes into account the kind of wildfire, and also the number and the typologies of actions that can take place in the extinguishes action.

Then, a set of hazard class σ =1,..,Σ can be defined, by introducing suitable threshold values for index $\tilde{h}$. On this basis, for each cell k =1,..,K, the static hazard H_k can be defined as a function of the number of occurrences of wildfires of the various classes, in cell k, within the considered time horizon Y.

$$H_k = \sum_{y=1}^{Y} \sum_{\sigma=1}^{\Sigma} \psi_\sigma \, N_{ky}^{\sigma} \qquad (19)$$

where:

H_k [dimensionless] is the static hazard relevant to cell k;

ψ_σ [dimensionless] is a weighting coefficient relevant to wildfires of class σ;

N_{ky}^{σ} [dimensionless] represents the number of wildfires of class σ occurred in cell k during the year y.

The risk assessment

The forest fire risk assessment and the subsequent mitigation are strictly related with the typology of the considered exposed elements. Such elements are defined both by their physical characteristics, and by their functionality inside a more complex territorial system.

In the proposed methodology, it is assumed that the territorial system is described and modeled by using a limited number or class of exposed elements, which, at different spatial and time scale, must be preserved and protected by the community from a potential forest fire, in order to avoid their loss, damage, or temporary unavailability. Thus, data relevant to land-use, infrastructures, and urban zones, can be identified and stored in a GIS database, and a number n of classes of objects can be defined, in order to represent the various classes of exposed elements in each cell k.

The remarkable number of exposed elements identifiable on the territory and the heterogeneity of their physical characteristics or their use, impose a radical simplification of the system aiming at classifying within homogeneous classes the greater number of elements without a great loss of information. To this end, seven general classes of areal and linear exposed elements have been defined, as reported in the Table 3. Besides, considering urban settlements, one can observe that in these zones the fuel load is generally negligible and thus the cell integrally occupied by such exposed elements are characterized by null hazard. For this reason, in order to obtain a meaningful evaluation of the risk affecting such settlements, a buffer zone has to be defined, whose depth is a function of the typology or class of the settlement. The presence of a fire in such a buffer zone can determine a potential loss of functionality of the settlement or, in the worst case, can yield a real physical threaten.

Table 3—*The seven main typology of exposed elements considered by the system.*

n	Typology	Class description	Buffer zone depth [m]
1	Areal	Urban settlements	500
2	Areal	Production settlements	500
3	Areal	Cultivated areas	200
4	Areal/Linear	Highway network and service areas	300
5	Linear	Traffic network	300
6	Areal/Linear	Railway network and accessory areas	300
7	Areal/Linear	Electrical network and accessory areas	300

In urban settlements residential and commercial activities are concentrated; the presence of a wildfire in these areas or in their proximity represents an extremely dangerous event. The industrial settlements are characterized by a prevailing presence of industrial or manufacturing installations or by the presence of commercial centers of great dimensions. They are generally located in the peripheral zones of the inhabited centers, sometimes in direct contact with the forested areas or with shrublands or cultivations. The cultivated areas and the neighboring ones are the zones where it is more frequent the ignition of a fire that often can degenerate in a severe forest fire. The traffic and railway networks constitute an important linear element of discontinuity. These networks are often interested by the phenomenon of forest fires that, among the various natural catastrophes, is the one that most frequently affects their normal functioning. Besides, the production of electricity is often interrupted by wildfires; the inefficiency is serious if the fires are wide, prolonged and interests main electric lines. The high-tension lines interruptions could provide severe consequences on the regular power supply or in the functionality of the network (overloads). Besides, the interruption of the lines of high tension is necessary to guarantee the safety of the operators in the extinguishing phases, particularly when airplanes are used.

The "*value*" or *cost* of cell k, C_k, can be defined as follows

$$C_k = \sum_{n=1}^{7} \xi_{nk}\ c_n \qquad (20)$$

where

C_k [€] estimated cost of cell k;

$\xi_{nk} \in \{0,1\}$ is a coefficient that expresses the absence/presence of objects of class n within cell k;

c_n [€] cost of exposed element n (expressed in euro), assumed as a measure of the value of the existing objects, i. e., the economic expense that is necessary to rebuild or restore the considered element.

In addition, a vulnerability function has to be introduced, with the purpose of modeling the relationship among hazard and the physical/functional characteristic of cell k (i. e., implicitly, of the exposed elements that are present in cell k). The analysis of the fire propagation dynamics is crucial as regards the vulnerability evaluation. First, it is apparent that wildfire vulnerability cannot be defined merely as a relationship between the stress solicitation and the effects on the exposed element. Actually, forest fire dynamics is comparable to extinguishing dynamics and, therefore the physical vulnerability of the elements must be considered mainly as a function of the available extinguishing resources. Thus, vulnerability is assumed to be a function of the intervention efficiency, defined in terms of available resources (weighted by their distance to the considered cell) that can cope with a fire in case of an emergency or, in pre-operational phase, can patrol the cell in order to avoid an ignition. In addition, the vulnerability of a cell k is usually dependent on the physical (geographical) characteristics of the cell and on the functional relationships between the existent facilities or structures that, in case of an external stress of given *magnitudo*, can intervene on that cell.

The resources can be partitioned in two sets; the first one includes the mobile resources that are relocated in a certain area for a long period of time (season). These

resources are generally scarce but their dynamics, slower then the dynamic of an active fire and the high costs required for their displacement suggest a limited movement/repositioning (at least seasonal) in the area affected by the highest value of risk. On the other hand, the other set of resources is relevant to the (fixed) infrastructures that should be utilized in case of emergency; this set includes the water supply points, and the Forest Service firefighters' stations, where the mobile resources are located for medium/long interval of time.

Specifically, it is assumed that the vulnerability can be defined as the product of two independent terms. The first one, $\tilde{V}_k$, that is the *nominal* vulnerability of cell k, is assumed as a (given) parameter whose value is a function of the physical characteristics of cell k, and the existent infrastructures able to serve cell k, namely

$$\tilde{V}_k = 1 + \left(\chi_1 \, d_k + \chi_2 \, s_k + \chi_3 \, o_k + \chi_4 e_k\right) \qquad (21)$$

where

$\tilde{V}_k \in (0, 1)$ [dimensionless] is the *nominal* vulnerability of cell k ;

d_k [m^{-1}] accessibility of cell k for landforce intervention, expressed in terms of meters of road network per m^2 of cell;

s_k [m] distance between the cell k and the nearest available water supply point;

o_k [m] index of the *roughness* of the cell, expressed as follows

$$o_k = b_k \, \Delta z_k \qquad k=1,..,K \qquad (22)$$

where b_k represents the number of main river branches (valley) in cell k, and Δz_k represents the average slope [%] of cell k;

$e_k \in [0, 1]$ is = 1 if in cell k there are signaled at least one obstacle for the air navigation (electric networks, cableways, etc.);

χ_i i=1,..,4 are suitable parameters.

Finally, the value of V_k, that is the *actual* vulnerability of cell k, is given by the product between the nominal vulnerability of cell k, $\tilde{V}_k$, and a term introduced in order to weight the promptness of the available resources m_h located in cell h and ready to intervene on cell k

$$V_k = \tilde{V}_k \, \frac{1}{1 + \vartheta \, e^{-z_k}} \qquad (23)$$

where

$V_k \in (0, 1)$ [dimensionless] is the vulnerability of cell k ;

$z_k = \min_h \left\{ m_h \, d_{kh} \right\}$ [m] is a term which takes into account the number of the nearest resources m_h placed in cell h and distant d_{kh} from cell k;

θ is a suitable parameter.

Once the vulnerability, the cost, and the hazard (both static and dynamic) have been defined and evaluated, a suitable way of defining the risk associated to a given cell is that of simply taking the product of such quantities.

$$R_k = H_k\ C_k\ V_k \qquad (24)$$

Forest fire risk mitigation via mathematical programming approach

The planning phase

From the above section, it appears that territorial planning must be finalized not at the total elimination of the risk, but at its mitigation. The mitigation of the risk on a territorial system can be reached according to two different approaches:

a) reduction of the hazard H_k, with direct intervention on the physical characteristics of the available fuel in cell k, i.e., with actions of forest planning toward to the decrease of the available caloric power on the considered cell, or maintaining sufficient moisture fuel values by using opportune techniques able to irrigate the considered area;

b) reduction of the vulnerability V_k, by means of structural or functional interventions on the exposed elements, i.e., by the construction of new infrastructures of water supply, Fire Brigade barracks, etc.

Both approaches generally require a considerable economic expense. In this paper, only the second typology of intervention is considered. Thus, the problem is formalized as that of optimally assigning the total available (monetary) resources among the whole set of cells, aiming at creating new infrastructures or reallocating the existing ones, in order to minimize the (potential) damage suffered by the territorial system. The problem is formalized with the objective of minimizing the maximum risk over the set of considered cells. In addition, construction costs for each new resource must be taken into account, as well as the necessity of penalizing the nominal assignment of extinguishing resources located at a certain cell j to a cell k too distant from that cell.

Then, the problem can be formalized as:

min y

s.t.

$$y \geq I_k\ V_k\ C_k \qquad k = 1,..,K \qquad (25)$$

(20)÷(24)

$$\sum_{j=1}^{J} c_j\ m_j \leq \tilde{C} \qquad (26)$$

where

y is the cost function;

c_j is the cost of construction of a new infrastructure in location j;

m_j is the number of available resources in cell j;

$\widetilde{C}$ is the total amount of (economical) resources available for the planning phase in the whole target area.

The pre-operational phase

In a pre-operational phase, the problem to be faced is the optimal partition of the total available mobile resources (i.e., aircrafts, initial-attack teams, etc.) among the set of cells (say, Z cells) having $R_k > 0$. Such a problem must be formalized taking into account the objective of minimizing the weighted sum of the differences between the (hypothetical) request resources and the actual assigned resources for each cell of interest. In addition, transportation costs from a location j to another h must be taken into account, as well as the objective of penalizing the assignment of resources located at a certain location j to a cell k too distant from that location.

The problem is modelled assuming that the resources are continuous, for instance represented by the amount of power available to extinguish forest fires, i.e., m^3/s of water disposable on the fire front considering the time needed for the refueling, the scooping and the mission between the fire and the water supply zone. Besides, the current amount of available power in all locations j, $\widetilde{U}_j$, should be provided for the problem formalization.

On the other hand, the service demand D_k [kW] is represented by the sum over the whole time horizon of the (forecasted) linear intensity $H_k(t)$ [kW m^{-1}] times the side length of cell k, Δ_k [m]

$$D_k = \sum_{t=0}^{T-1} H_k(t)\,\Delta_k \qquad (27)$$

The decision variables of the problem are

q_{jh} [kW] resources located at location j that should be moved to location h, j=1,..,K; h=1,..,K; j≠h;

u_{jk} [kW] resources located in j, assigned to satisfy predicted demand of cell k, j=1,..,K; k=1,...,K;

the problem can be stated as

$$\min \sum_{k=1}^{K} \left\{ \sum_{n=1}^{N} \xi_{nk}\, c_n\, V_k\, \max\left(D_k - \sum_{j=1}^{J} u_{jk}, 0 \right) \right\} + \alpha \sum_{j=1}^{J} \sum_{\substack{h=1 \\ j\neq h}}^{J} d_{jh}\, q_{jh} + \beta \sum_{j=1}^{J} \sum_{k=1}^{K} d_{jk}\, u_{jk} \qquad (28)$$

where

α, β are suitable weighting parameters

s.t.

$$\sum_{k=1}^{K} u_{jk} = \widetilde{U}_j + \sum_{\substack{j=1 \\ j\neq h}}^{J} q_{jh} - \sum_{\substack{j=1 \\ j\neq h}}^{J} q_{hj} \qquad (29)$$

which represents the resource conservation constraint.

Of course, once the optimum solution of such a problem is found, it is necessary to convert this solution in the terms of the actual resources, which are indeed discrete.

Conclusions and further research directions

An approach has been presented in this paper for the structural and operational design of a decision support system aiming at forest fire risk management. Both static hazard and dynamic hazard have been considered and risk assessment is based on the estimate of such hazards as well as on the evaluation of the vulnerability and of the cost associated to each cell. On the basis of the risk distribution estimate over the considered territory, two problems have been formalized. The first one is related to the planning of monetary resource assignment in order to reduce the overall vulnerability on the territory. The second one is finalized to optimally reallocating the available extinguishing resources over the territory, in a pre-operational phase, i.e., whenever an incoming situation of high fire risk is forecasted.

Present research activity is oriented towards more proper definition of the vulnerability and risk of a cell, as well as a more suitable definition of the static hazard of the single cell. Experimental implementations of the two decisional procedures presented in the previous section are presently carried out.

Acknowledgement

The activities reported in the paper are presently carried out with reference to the case study relevant to the Italian Civil Protection and have been funded by the Gruppo Nazionale per la Difesa dalle catastrofi Idrogeologiche GNDCI, U.O. n. 3.28, Special project n. 4 Structural and operational design of a decision support system based on a national geographical information system and aiming at forest fire risk management.

References

Byram GM (1959) Combustion of forest fuels. In Forest Fire: Control and Use. Editor Davis KP, McGraw-Hill, NY, pp. 113-126.

Byram GM (1963) An analysis of the drying process in forest fuel material. Unpublished report USDA Forest Service, Fire Science Laboratory, Rocky Mountain Research Station, Missoula USA.

Cheney NP (1981) Fire behaviour. In 'Fire and the Australian biota'. Australian Academy of Science, Canberra, AUS. pp. 151-175.

Corpo Forestale dello Stato (2002) *Foglio Notizie Antincendio Boschivo*, Rome, Italy.

Drouet JC (1974) Theorie de la propagation des feux de forets. Master Thesis Universitè d'Aix- Marseille, France.

Actions of the International Association for Mediterranean Forests to Prevent Forest Fires[1]

International Association for Mediterranean Forests[2]

Abstract

The objective of the International Association for Mediterranean Forests is to facilitate exchanges of knowledge and experience between people concerned about Mediterranean forest areas.

In pursuit of this goal, in 2001 the IAMF organised a seminar[3] in Valencia (Spain) concerning the risks incurred by Mediterranean forests, as part of the Interreg IIC project "The Problem of the Mediterranean Forest". Following on from this, it has set up a number of projects [4] entitled "Structuring of networks and co-operation actions for the Mediterranean forest", and invited southern European Union partners to take part in them. The aim of these projects is to promote sustainable management of forests and to ensure they are taken into greater account in land-use planning policies.

They will take the form of exchanges between personnel from different organisations who will carry out experimental management operations in pilot territories.

Most of these actions[5] are concerned with fire risk prevention through planning and organisation of forest areas.

The success of these operations will depend not only on the local projects themselves, but equally on the energy and dedication that will be devoted to the exchanges.

In order for the lessons learned to be beneficial to as many people as possible, they will be summarised and analysed by the IAMF, and then disseminated widely throughout its network. It will be possible to capitalise on them in the project currently under preparation "Mediterranean forests faced with worldwide concerns and local demands" which will lead to the First Mediterranean conference on forest and natural land areas.

Introduction

The International Association for Mediterranean Forests is the only non-governmental organisation concerned with every aspect of Mediterranean forests and natural land areas. It is therefore naturally interested in the risks incurred by Mediterranean forests,

---

[1] An abbreviated version of this paper was presented at the second international symposium on fire economics, policy, and planning: a global view, 19–22 April, 2004, Córdoba, Spain.

[2] Association Internationale Forêts Méditerranéennes (International Association for Mediterranean Forests), 14, rue Louis Astouin 13002 Marseille. Phone. : +33 4 91 90 76 70. Fax : +33 4 91 90 71 62. email: info@aifm.org – Web: www.aifm.org - President : Mohamed Larbi CHAKROUN.

[3] This resulted in the "Valencia Conclusions."

[4] As part of the Interreg IIIB community project. The "Recoforme" project in the Medoc zone has the following partners: the **National Vesuvius Park** (It.) — which is the project leader, the Umbria Region (It.), the Generalitat Valenciana (Sp.), the Murcia Region (Sp.), The Algarve Regional Directorate of Agriculture (Pt.), the Alpilles Massif management office (Fr.) and the **IAMF** as technical advisor.
The "Foremed" project in the Sudoe zone comprises the **Association of forest landowners in Soria** (Sp.) —which is the project leader–the Murcia Region (Sp.) , the AFLOPS association (Pt.), FORESTIS (Pt.) and the Regional forest landownership centre for Languedoc-Roussillon (Fr.).

[5] For example: experiments in development techniques making use of "biological engineering," land-use planning that will include preventive forestry techniques, forest area management models, operations to reduce combustible material as part of forest fire protection systems, and training of forest fire brigades.

and in particular forest fires. Below we present the actions the IAMF has taken and is taking to help prevent forest fires, first of all through the projects that it has led or is leading, such as "The Problem of the Mediterranean Forest", "Structuring of networks and co-operation actions for the Mediterranean forest" (RECOFORME) and "Mediterranean forests faced with worldwide concerns and local demands" (FOMEMOND), and also via the projects is has initiated such as "Organisation of networks and co-operation actions for Mediterranean forests" (FOREMED) led by the Association of forest landowners in Sória.

The Interreg IIC-Medoc "The Problem of the Mediterranean Forest" - Conclusions from Valencia[6]

The seminar "Risks Threatening Mediterranean Woodlands and Natural Land Areas and the Role of Woodlands in Risk Prevention" resulted in the drafting of a number of conclusions which have been named "The Conclusions from Valencia".

Within the framework of the Interreg IIC programme entitled "The Problem of the Mediterranean Forest", in which are involved the Provence-Alpes-Côte d'Azur (France) and the Campania (Italy) Regions, a group of experts on risks met with representatives of the International Association for Mediterranean Forests in Valencia (Spain) on 8-9 June 2001, at the invitation of the Environment Council of the Valencia Region. The meeting undertook a consideration of the situation regarding forests around the Mediterranean Rim and adopted the following conclusions:

1. Mediterranean woodlands are made up of natural land environments that are subject to a Mediterranean bioclimate. Such woodlands range from extremely deteriorated areas afflicted by erosion to the most magnificent stands. These woodlands are subject to various risks, some natural, some human, which threaten their function in protection or production as well as in their social and cultural role. Yet these functions or roles are all indispensable if human activity in the region is to reach its full development.

2. Certain risks, like wildfire, have increased over the last few decades, bringing in their wake other problems such as erosion, the increase of pests and diseases, a decline in water reserves and the development of urbanisation. Risks, interacting with natural phenomena like drought, increase the vulnerability of woodlands and lead to people being endangered. Hence the need to take preventive measures to avoid the accumulative effect of the various risks.

3. Socio-economic factors influence the evolution of risk e.g. the abandonment of agricultural land on the northern side of the Mediterranean Rim; human pressure on woodlands on the southern side; the gulf that is generally widening between urban and rural populations.

4. The risks that threaten Mediterranean woodlands are not well understood in countries that are not themselves Mediterranean. This fact has negative consequences on policy decisions made by international organisations or leads to their lack of interest in Mediterranean matters. In particular, it has been noted that, in certain situations, European Union sheep and goat livestock grants have generated increased risk of wildfire on account of inadequate prior consultation and cooperation between the forestry and livestock advisory services. Similarly, the FAO has significantly reduced

[6] Workshop " Risks threatening Mediterranean forests and natural land areas and the role of forests in risk prevention" held on 8th-9th June 2001 in Valencia (Spain), led by Ricardo Velez Muñoz, Head of the Wildfire Protection Service of the Spanish General Service for the Protection of Nature (Madrid, Spain).

the activity it used to foster through the Silva Mediterranea commission. This situation contrasts starkly with the need to counteract the desertion of rural areas by their inhabitants which is the ultimate risk threatening extensive mountain regions around the Mediterranean.

5. It was felt to be essential to bring society at large to an understanding of the vital role played by Mediterranean woodlands in the quality of the Mediterranean environment. It seems clearly indispensable that a policy specifically for Mediterranean woodlands must be designed and put into effect. To this end, we need to develop a broad vision of woodland management, centred on silviculture and coordinated with land use development policy, having as its aims: 1/ that forests should be wanted and considered useful by the whole population as fitting in with its actual needs; 2/ the establishment of a reasoned management policy, based on scientific and technical knowledge and know-how, that will take into account the interrelation between risks of wildfire and those from pests, disease, erosion, flooding and loss of biodiversity; 3/ the bringing together of all concerned with Mediterranean woodlands so that everyone can submit his or her ideas about policies and collaborate to get them put into effect. Such people include, notably, public and private owners of woodlands, professional foresters, researchers, fire prevention and firefighting authorities, local elected bodies, the media, NGOs and managers of protected areas and reserves.

6. It was felt that the prevention and control of risks that threaten woodlands can only be achieved with the full involvement of owners who, on the northern Mediterranean, are mostly private; and, on the southern side of the Rim, of users. To this end it is necessary to promote effective organisation of voluntary associations which facilitate sustainable development of woodlands. This point was recently accepted in various international gatherings, including ministerial conferences at Helsinki and Lisbon.

7. It is essential that the damage resulting from the various risks that prevail around the Mediterranean be monitored. By this means, their extent and evolution can be assessed as a means of foreseeing short- and middle-term problems via an overall map plotting risk factors. In particular, we should base efforts here on the decentralised databank of forest fires that was set up in the 90's by the FAO's Silva Mediterranea commission. By the same token, we consider that it is necessary to create and distribute maps charting the wildfire threat during the peak risk periods throughout the whole of the Mediterranean zone. Furthermore, it is essential to extend to the eastern Mediterranean and North African areas the programme for monitoring the state of forest health that presently covers a large part of Europe. For all these aspects, we feel that it is essential to contact the European Commission in order to highlight the desirability of updating and reinforcing the regulations governing protection from and prevention of wildfire and pollution.

8. We need to establish a Mediterranean-wide strategy for mutual help in times of acute crisis due to wildfire or predators (for example, locusts). This strategy should be based on bilateral and multilateral agreements between states, facilitating the loan of equipment and offers of help from areas able to make such things available to other areas under the greatest threat.

9. There is a need for study of risk due to other factors capable of affecting woodland environments, such as the expansion of invasive species, be they plant or animal.

10. As a final recommendation, we consider it necessary to tackle the risks to Mediterranean woodlands in a preventive manner, in conformity with present and future models derived from dynamic socio-economic and forestry factors. We thus

propose continuing the work undertaken at the seminar in the light of the current project "The Problem of the Mediterranean Forest", notably within the framework of the Interreg IIIB programme; and that the International Association for Mediterranean Forests continues its activities for the promotion of exchanging information. With all these points in mind, the participants recommended that the First Mediterranean Conference on Forests and Natural Land Areas be organised and held in the near future.

Brief presentation of the Interreg IIIB Medoc project RECOFORME "Structuring of networks and co-operation actions for the Mediterranean forest"

Through the project entitled "Structuring of networks and co-operation actions for the Mediterranean forest" led by the Vesuvius National Park (Italy), we propose to tackle all the issues affecting Mediterranean natural land areas and forests, in order to promote sustainable management of forests and the environment, and ensure they are taken into greater account in land-use planning policies.

To do this it is necessary to make the most of the work carried out in the Interreg IIC project "Problem of the Mediterranean Forest". The project consists of a co-operation programme made up of exchanges between pilot territories: shared implementation and monitoring of sustainable development and planning programmes in the territories. The partners have chosen pilot territories, and in each territory after carrying out an analysis of the situation and the options for action, a project has been launched, comprising programming, execution, monitoring, and assessment phases. In these territories, every aspect of the Mediterranean forests and natural areas will be taken into account (land-use planning, sustainable development, forestry, protection against fires, pastoral agriculture, public access and use, etc.).

Each of these projects is led by a local organisation, and will bring together representatives from the partner regions, for both execution and supervision. This will be achieved through 1/ the participation of foreign technical experts, working side by side with the local team, from one or more partner regions (who in return will include one or more technical experts in their teams), for one or more periods of varying length throughout the programme; 2/ the creation of an inter-regional steering committee which will bring together representatives from the relevant partner regions, and will meet at least once a year.

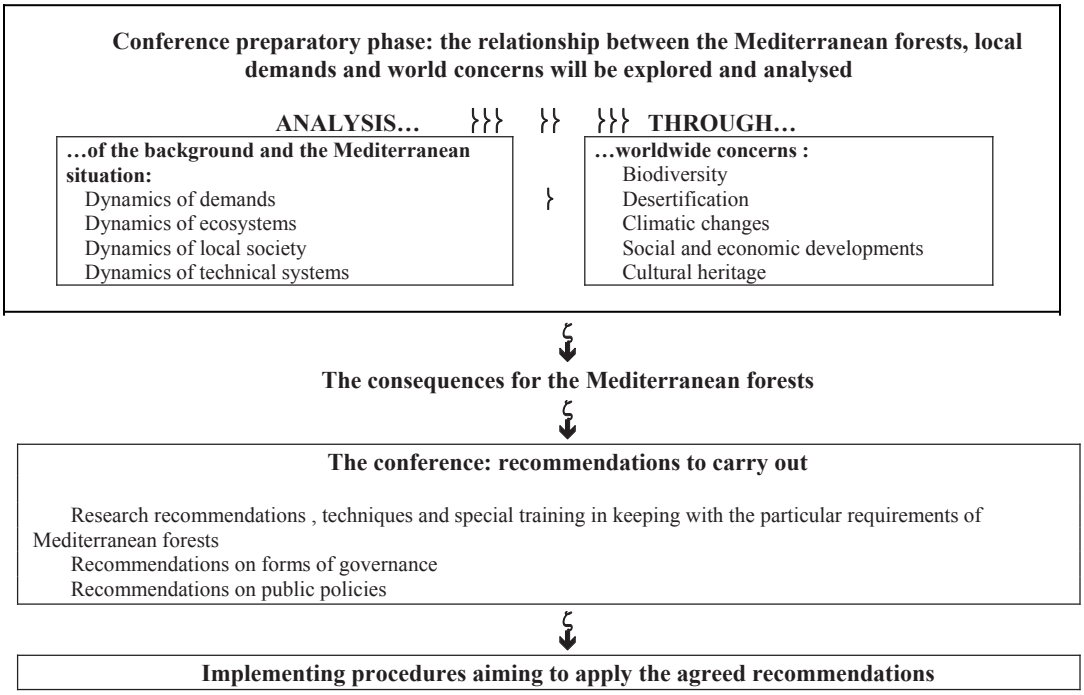
Each partner region proposes one or more sites that have a predominant characteristic and specific problems to be solved, and where common reflection will be beneficial, not only for the region in question but also for the technicians originating from the partner regions. These exchanges will make it possible to compare each person's know-how in each specific situation: some teams have already solved technical or organisational problems that others have yet to solve. The success of these operations depends on how the co-operation agreements have been prepared, and how they will be set up, managed and supervised. The strictly technical aspects of the projects will be handled virtually exclusively by the partner regions (accommodation in the pilot territories). However, taken as a whole such a project also requires practical management (collection and dissemination of information, organisation of exchanges and travel, capitalisation of outputs, assessment, etc.) by a single operator. The International Association for Mediterranean Forests will play this role, co-ordinating and organising these exchanges between the different structures proposed by the partner regions, and will compile an overview of these exchanges. The relevant

territories are: Campania (Italy): Vesuvio National Park; Valencia (Spain): Comarca Alto Palancia; Umbria (Italy): Catchment basin of Lake Trasimeno; Murcia (Spain): Regional Park of Sierra Espuña; Algarve (Portugal): Serra do Caldeirão; Provence-Alpes-Côte d'Azur (France): Alpilles Massif. Operations on the Campania, Valencia, Murcia and Provence-Alpes-Côte d'Azur sites will essentially be centred on fire risk prevention.

The Interreg IIIC project FOMEMOND : "Mediterranean Forests in relation to World Concerns and Local Demands"

The project **"Mediterranean forests in relation to world concerns and local demands"** aims to ameliorate the transition to the local practise level, of the world concerns over biodiversity, the fight against desertification, global climatic change, long term forest management, and cultural heritage. These evolutions will be analysed by "type" defined as "major world concerns" viewed from the perspective of international conventions and agreements, in seminars dedicated to each theme, in relationship with the authorities responsible for overseeing the various conventions. The synthesis of these studies will take place during a conference set up with the express aim of producing concrete recommendations from them. This conference will proceed with participants from various levels, from political decision makers to land managers. The conference will not be an end in itself but will give rise to various other activities which might in turn perform the recommendations in some of the areas which will come to light. Thus, the project is composed of three phases (cf. figure n°1).

Figure 1— Steps of the FOMEMOND project



Page left blank intentionally.

The Economics of Interface Wildfires[1]

John Handmer,[2] Beth Proudley[2]

Abstract

The new Australian Bushfire CRC (Cooperative Research Centre) is a major long-term effort intended to improve the safety of Australian communities by harnessing research for improving wildfire related policy and practice. One of the CRC's projects concerns the development of "Reliable Assessment Methods for the Total Costs of Bushfires and the Benefits of Mitigation". The initial part of this project is the subject of this presentation.

Economic analysis for flood hazard management has a long history and is highly developed for urban areas. Drawing on this extensive material, as well as existing approaches to the economics of fire and the criminological literature on the economics of arson, we are working towards the development of a model for the comprehensive assessment of the economics of interface wildfires. Special attention is paid to the "exceptional" events that contribute most fire losses – and for which suppression is problematic. In addition, the extra costs imposed by arson will be incorporated into the approach. We will be identifying the primary drivers of costs and benefits, and the main opportunities for significant cost savings in the current and likely future Australian fire management environment. Future elements of the project will examine the economic implications of different approaches to fire and fire management, and link the preferred economic model and its outputs with models of fire behaviour and suppression.

[1] An abbreviated version of this paper was presented at the second international symposium on fire economics, policy, and planning: a global view, 19–22 April 2004, Córdoba, Spain.

[2] Bushfire Cooperative Research Centre, Centre for Risk and Community Safety, Department of Mathematical and Geospatial Sciences, RMIT University, Melbourne, Australia.

Introduction

An appreciation of the full costs (and benefits) of interface wildfires is needed as a key input to evidence based decision-making on fire mitigation and management. For government agencies, the method needs to be based on the principles of economics rather than financial losses to individuals or areas. Existing fire economics models are generally designed for specific purposes, in particular forestry protection, and do not consider the substantial additional costs of criminal action – reducing their utility for interface fires where a significant proportion of fires may be deliberately lit.

Assessment may be made of disasters that have actually occurred or those risks which have the potential to threaten a community. Another important aim of loss assessments is to enable comparisons of actual or potential fire impacts between places, communities and with other hazards. Understanding of the causal factors that underlie losses provides the ability to synthesise losses for given risks and assists in evaluation of alternative mitigation strategies. The ability to undertake these applications of loss assessment has been hampered by the absence of a standard agreed approach. Many loss assessments fail to consider the principles of economics, further limiting their utility and credibility in the eyes of finance agencies.

This paper reports on the initial stages of a major project "Reliable Assessment Methods for the Total Costs of Bushfires and the Benefits of Mitigation", to develop an approach for interface-bushfire loss-assessment in Australia. The project is part of the recently established Bushfire Cooperative Research Centre.

The Bushfire CRC

The Cooperative Research Centre (or CRC) program is intended to increase Australian research in the areas covered by CRCs by linking researchers and practitioners from across the nation. (Cooperative Research Centres Association: http://www.crca.asn.au/ Cooperative Research Centres: https://www.crc.gov.au/)

After a lengthy and exhaustive process of discussion between the research and practitioner groups involved, the Bushfire CRC formally commenced operations late 2003 (www.bushfirecrc.com). It is one of the larger CRCs worth approximately AUD100 million over seven years involving 34 organisations with initially 30 research projects based at 20 research institutions.There are four major research themes organised into research Programs plus a Program dedicated to training and education all dedicated to providing the evidence base for better wildfire management for safer communities. These programs may evolve over time. They are:

- Increase understanding of bushfire behaviour and ability to manage (Program A);
- Develop tools for effective, safe, ecologically sound planning and use of fire in landscape (Program B);
- Increase community self-sufficiency in managing the bushfire risk (Program C);
- Develop knowledge to reduce building loss, occupant injury, fire-fighter risks and to maintain the supply of volunteers (Program D);
- Developing more fire researchers and research capacity, and ensuring transfer of knowledge to users (Program E).

This paper reports on initial thinking in one of the projects in Program C.

Economics is an important consideration in most government funded activity, including bushfire management, as a test of whether the expenditure is worthwhile.

Pressure to satisfy such tests is increasing in Australia. In loss assessments economics is frequently confused with any analysis based on money. However, an economic analysis is based on a particular set of principles which are distinct from those used by accounting for example. Non-economic approaches are generally termed financial assessments in the loss assessment literature. In defining economic losses we follow normal Australian and UK practice and include intangible losses, such as social or environmental items. Economic assessment is about (following the principles of cost-benefit analysis:

- All members of a defined society or economy, not individual firms;
- Changes to economic activity in the defined economy, not components within it;
- Market (or depreciated) rather than replacement values;
- Counting all impacts on the economy, both positive and negative.
- Economics is not about distributional effects; nor is it about commercial profit and loss.

Economic Justification

In summary, an economic analysis is concerned with the impact of an event on the economy of the area selected for analysis. Defining this economy in space and time is a key step. If it is defined as the nation, then national economic efficiency becomes the aim, rather than fire damage reduction or fire-fighting cost control per se.

Economic loss assessment is interested in the net change to the economy of a defined area. It counts the losses to the economy in this area as well as the benefits from the event being assessed. Benefits may be insurance, disaster relief funds, and increased local economic activity. To obtain "net economic loss", any benefits to the economy need to be subtracted from the assessed losses. This is one measure of the regional impact of disaster, and is the approach adopted by the U.S. General Accounting Office (GAO). For example, the GAO examined studies of the economic cost of the Sept 11 attacks in New York. The GAO endorsed a report that estimated the loss to New York City at about US$ 83 billion, offset by US$ 67 billion of benefits, for a net loss of about US$ 16 billion (United States General Accounting Office 2002). (This study included amounts for the loss of life.) However, net economic loss may not always be appropriate or politically viable as an indicator of what should be spent on mitigation.

In contrast, a financial analysis is usually undertaken to assess the loss from the perspective of a commercial enterprise (or groups of enterprises). Note that assessments made on the basis of insurance data or assumptions may be quite different for tangible losses than those prepared using economic principles. One reason for this is that household insurance policies value lost items as new ones, rather than at their market (or depreciated) value.

Work on the economics of other hazards

Most effort has gone into the assessment of flood losses and flood mitigation strategies. See for example, BTE (2001) and BTRE (2002), and Handmer et al (2002). The idea of systematic loss assessment was formalised and mandated by the 1936 US Flood Control Act. Partly because of this Act, as well as the existence worldwide of large flood management bureaucracies along with the convenient characteristics of flooding in terms of its reasonably well defined spatial extent and

randomness through time, flooding is the best documented natural hazard (more properly called risk under contemporary Australian terminology, see Emergency Management Australia http://www.ema.gov.au). Major research groups have dedicated themselves to developing approaches for economic flood loss assessment in both the United States (e.g. the Corps of Engineers and more recently the FIA (Federal Insurance Administration) and the UK (e.g. Flood Hazard Research Centre and the Department for Environment, Food and Rural Affairs - Defra). Many other groups are active elsewhere, but few use economics as their basis.

It seems reasonable that we should draw on this long experience and on the principles underpinning flood loss assessments for national governments. The fundamental principle is that the assessments should be based on economics – and the US Flood Control Act of 1936 sets out the essentials of cost-benefit analysis. As set out above, this approach can alter the question asked from loss and/or cost minimisation to 'what is it worth doing?' And what is it worth doing in terms of the economy? Most work on natural hazard loss assessment has been for urban areas, rendering it broadly comparable to the interface bushfire zone. Some other potentially useful aspects of flood loss assessment are set out below.

Loss assessment for other hazards is undertaken, but for many hazards it is difficult to identify the extent and occurrence probability of the hazard, and the mitigation options may be limited or otherwise problematic. As a result loss assessment to support selection of mitigation strategies is more difficult.

An important principle of flood loss assessment and of cost-benefit analysis is that all costs (and benefits) should be included. Elsewhere in the paper we identify areas receiving little attention in assessments. Traditionally, flood loss assessment classifies loss into two major categories of loss, direct and indirect, which can be further subdivided into tangibles and non-market impacts or intangibles according to whether or not the loss can be valued in conventional economic terms. It is useful to distinguish the two types of tangible loss from intangible losses (note that we follow the traditional UK/Australian classification here):

- *Direct Damages* result from the physical impact of the hazard, for example damages to buildings. They are the most obvious and often largest losses. The minimum of economic principles are needed to evaluate these losses. The principles involved, such as estimating the economic value of assets lost, are common to all evaluations;
- *Indirect Losses* arise as a consequence of the physical impacts of a disaster event, for example disruption of transport when roads are flooded, or loss of manufacturing production from affected businesses. A distinct category of indirect loss is the potential impact of the disaster on financial markets - this would be linked with the cost of rebuilding and of insurance payouts. Such financial impacts are only likely to be severe in the case of an exceptionally large disaster. Indirect losses are more complex to evaluate, particularly because of the need to avoid double counting losses which have already been assessed as direct losses;
- *"Intangibles"* or non-market loss is a catch-all term which simply identifies direct and indirect impacts for which there is no commonly agreed method of evaluation, such as deaths, ill-health, heritage and environmental losses. Methods for estimating these impacts in economic terms are either difficult to apply, experimental, or not generally accepted; but this does not mean that they are

unimportant. Intangibles are often found to be more important than tangible losses, and efforts therefore should be made to assess and include them.

Some risk management measures can be more readily assessed in economic terms than other measures, for example, the direct losses avoided by structural works. Smaller scale alterations to buildings, making them more fire or flood resistant, may be simple to assess - but compliance with the measure has to be estimated. A similar problem arises with other mitigation measures that rely on public response, such as warning systems, or on negotiation, such as land use regulations. Again economic assessments are fairly straightforward. But there is great uncertainty over response and compliance - and the economic outcome will generally hinge upon them.

A variety of approaches to flood loss assessment (including non-economic approaches) have been developed (see also Handmer et al 2002). They can be loosely classified in three groups:

- The averaging approach, based largely on pre-existing average data on losses, e.g. an average loss per flooded property - the least expensive and quickest method Victorian Rapid Appraisal Method (RAM) (Read & Sturgess and Associates 2000);
- The synthetic approach, a detailed assessment based on pre-existing databases covering a range of average building types and contents. Loss tables are often developed theoretically or synthetically - as opposed to being based on experience (manuals from the UK's Flood Hazard Research Centre at Middlesex University, Risk Frontiers);
- The survey or historical approach is based on detailed surveys of a recent event to establish the actual loss. It is difficult to use without a recent flood.

In spite of the amount of work – and volume of publications – loss assessment guides rarely deal with economics or with intangible loss. When they do, they require a very high level of specialist expertise to use, making them expensive to apply in practice. Some inherent problems with most approaches to loss assessment are set out in Handmer (2002).

Arson

It is estimated by the NSW Rural Fire Service that approximately 50 percent of bushfires are deliberately lit (Mayhew 2003) and with bushfires between 1997 and 2002 averaging a cost of $60 million per annum it is roughly assumed that $30 million may be attributable to arson (Mayhew 2003). Many more result from negligence, which in some circumstances may result in police action and often require extensive investigation. These sources of ignition can result in major increases in the costs of fires. The nature of arson makes its costs difficult to quantify, and there is little, if any, empirical data on bushfire arsonists in Australia (Kocsis 2002). Not all reports of alleged arson are recorded by police, and police figures are not representative of the true extent of arson. Bushfire arson is an unusual crime in that it is not committed for monetary gain, which is often the case for its urban counterpart. Instead it seems to be a more psychologically based crime.

Bushfire arson has a huge potential for causing widespread damage, but it is difficult to assess exactly how many bushfires are truly a result of arson. Many arsonists strike during high fire risk periods. With a catch cry of ‘cold fires leave hot

trails' arson investigation teams like NSW's Strike Force Tronto are utilising forensics, satellite inventory and aerial photography in their efforts to track down bushfire arsonists (McDonnell 2003a). Paradoxically, the increasing investigative technology available and the investigation teams that employ it contribute to the increasing overall costs of bushfire arson.

The more obvious costs resulting from bushfire arson are usually concerned with direct damage i.e. property damage/loss. However this is only part of the picture. It is difficult to apply dollar values to indirect losses (i.e. lost productivity, business disruption) and intangibles (Mayhew 2003) such as water catchment degradation and ecological damage (Institution of Engineers Australia: Victorian Division 1988).

In a 2003 report into the costs of crime in Australia published by the Australian Institute of Criminology, the total costs of dealing with bushfire and urban arson are estimated at $1.35 billion; a figure which includes 'property loss, and estimates for indirect costs and intangible losses', fire and ambulance services and volunteer hours. (Mayhew 2003) This figure does not include the financial costs of the legal ramifications of urban/bushfire arson i.e. court administration, incarceration, police costs and specialised arson investigation etc. which are subsumed under other costs of dealing with crime. In comparison to the cost of arson, the annual cost of bushfires (regardless of their initial ignition cause) is approximately $77 million (Bureau of Transport & Regional Economics 2001).

An additional cost associated with bushfires started by arsonists is that they may result in more difficult psychological recovery processes compared with bushfires that have occurred naturally. There are many anecdotal accounts of arsonists who are connected to (or who have been rejected from) fire fighting organisations. This is another facet of arson that has largely unquantified costs. Outcomes of firefighter arson include 'injuries and loss of life to fire fighters, apparatus accidents, the cost of fire suppression, damaged equipment, and negative publicity and possible liability' (Aurnhammer 2002) as well as other direct, indirect and intangible losses associated with bushfires. A selection of firefighter arson related headline from both the U.S. and Australia demonstrate that the problem is not merely a local one:

- CFA Arsonist Jailed (AAP) - Australia
- Firefighter torched school (Lenaghan 2002) – Australia
- Fayette fire chief's arson trial begins (Ove 2004) – US
- Hillcrest volunteer firefighter accused of arson (Lieberman 2004) - US

'At least 17 volunteer firefighters have been charged across Australia with lighting bushfires in the last five years' (McDonnell 2003b) leading up to 2003, yet Australia does not have a national approach to arson or any arson rehabilitation programs. Until the Bushfire CRC the cause of bushfire arson – the arsonists – has received almost no research or resources. Under the CRC there is a research program into the subject.

Opportunities for savings

Opportunities for savings should come from a rigorous appreciation of the costs of fires and the costs and benefits of the full range of approaches to fire management and community safety. Substantial benefits would flow from even a small increase in our ability to screen arsonists and prevent their activities. Preventative planning

through recognition of bushfire prone properties by local Government (Koperberg 2003) would also have a significant payoff through reducing risk as well as possibly reducing the need for service provision.

Assumptions, limitations and uncertainties

Many areas of bushfire assessment and management are the subject of widely different views and estimates – probably more than for other 'natural' hazards. The precise nature of the links between many approaches to mitigation and mega-fires is not well established – and it is these fires that generally cause most losses. Importantly, allowance should be made for errors in estimates, forecasts etc. This allowance may be large and a significant part of any economic assessment.

There is nothing unique to wildfire about these uncertainties and potential errors. Every part of the disaster loss assessment process contains inherent uncertainties, especially where assessment rests on assumptions about the loss of assets and behaviour of the fire in question. In some cases uncertainties may be large and irreducible through conventional data collection and analysis (see Handmer 2002). One area where wildfire may be different in degree from for example, floods and cyclones, is the potential cost of emergency response, and the potential costs associated with some hazard reduction measures such as fuel reduction burning.

Towards comprehensive loss assessment

A comprehensive approach to wildfire loss assessment needs to be based on the principles of economics and on other principles central to effective contemporary loss assessment - as widely accepted and practiced in flood loss assessment. The implications of an economic approach are set out above. A central issue in the approach is the spatial extent of the area of assessment, and the difficult problems posed by very large fires. It also needs to be comparable as far as possible with existing approaches and any differences should be set out clearly. Examples of some models already in use are outlined in *Table 1*.

Table 1—*Some existing approaches.*

Model	Description	Pro	Con
Least Cost Plus Loss Pyne, S. J., Andrews, P. L. and Leven, R. D. (1996) 'Fire Economics'. Introduction to Wildland Fire, (2nd Edn), John Wiley & Sons, pp. 425-439.	Fire suppression is only justified by the damage prevented. If more is spent on suppression than the final resource losses amount to, then the fire is often just best left to burn.	Most popular model of fire management Recognises the importance of reducing costs as well as losses	'Until some calculus existed by which to measure fire damages, the theory could not determine the point at which cumulative costs and losses reached a minimum.'
Adequate Protection Pyne, S. J., Andrews, P. L. and Leven, R. D.	'The level of investment in fire protection should equal that which a prudent person would be willing to invest for fire insurance.'	Recognises that some losses do occur. Is difficult to apply to 'lands	Is difficult to apply to 'lands without a readily calculated

(1996) 'Fire Economics'. Introduction to Wildland Fire, (2nd Edn), John Wiley & Sons, pp. 425-439.		without a readily calculated market value'.	market value'.
Minimum Damage Pyne, S. J., Andrews, P. L. and Leven, R. D. (1996) 'Fire Economics'. Introduction to Wildland Fire, (2nd Edn), John Wiley & Sons, pp. 425-439.	Aggressive fire suppression: 'losses should not exceed 0.1% of the total acres under protection, and no more than 15% of all fires should reach sizes greater than 10 acres.'	Very simple to administrate.	Aggressive suppression is not always the most desirable approach.
Intervention/Non Intervention Bennetton, J., Cashin, P., Jones, D. and Soligo, J. (1998) 'An economic evaluation of bushfire prevention and suppression', Journal of Agricultural and Resource Economics, 42 (2), pp. 149-175.	An evaluation of the Victorian Department of Natural Resources and Environment Fire Management Program (FMP). 'The net benefits of the FMP are determined by subtracting both the cost of the FMP and value of the actual damage caused by bushfires from the value of the potential damage caused by bushfires…'	Proves the worth, in dollar terms, of the Victorian Department of Natural Resources and Environment Fire Management Program.	Is specific to one particular fire management plan. Non-intervention is not an option if the fire threatens the urban interface

In addition to the principles of economics, the approach should satisfy a number of other criteria drawn from reviews of existing approaches to assessment and the expressed needs of many Australian emergency managers:

- It should support a risk based approach to bushfire management;
- as far as possible it should be designed for practical implementation, rather than for the exclusive use of specialists (see for example;(Handmer, Read & Percovich 2002);
- it should emphasise comparability between different places, fires and approaches to mitigation and fire management. This is so that choices can be made about the allocation of resources and likely returns on investment on a consistent basis;
- it should be equally useful for assessing losses after an event as well as for planning scenarios in the absence of an actual fire;
- it should cover all types of loss not simply those for which measurement is relatively straightforward.

Expanding on the last point, types of loss receiving little attention include:

- intangible costs generally, especially physical and psychological injuries, heritage and environmental damage;
- indirect losses are often poorly assessed;
- Arson – the added costs of the criminal justice system and the potential intangible costs of arson;
- The costs of waste, over-servicing etc;
- The impact of evolving approaches to fire management;
- The incorporation of uncertainties and error.

Comprehensive approaches need to consider the tension between the need to control and extinguish fires, and fire for ecological and fire management reasons.

The approach being developed is based on a modified conventional cost-benefit analysis with the addition of methods to incorporate the areas often ignored as set out above. It will sit within a step-by-step guide to assessment from the initial decision to undertake an assessment, through to presentation of the results and improvement of the datasets and method. The modifications referred to above concern the emphasis on comparability rather than the hugely variable accuracy of each individual assessment. It also refers to the possible incorporation of approaches that do not simply focus on the losses avoided by fire management – as is conventional in disaster loss assessments - and that examine instead the cost effectiveness of different fire management measures where the data is available. One approach would be to document what a particular mitigation strategy can achieve in specified circumstances where these have been established. Expenditure beyond what can be achieved may be an economically inefficient allocation of resources – and can be thought of as over-servicing. Where this is the case it may indicate an area where immediate cost savings are possible at least in theory. The policy significance is that the funds saved can be directed to areas well short of their potential. U.S. reports suggest that one reason for over-servicing, or rather waste, is the commercial nature of some wildfire fighting – where the first priority may be profit rather than suppression (O'Toole 2002) (Mangan 2001).

To help refine and reality test the approach, case studies will be undertaken as it is being developed. At this stage we expect to examine the overall costs of a major interface bushfire, and a major rural fire. In addition, more specific studies will examine the costs of arson, costs and benefits of mitigation and response, and the potential problems of errors and uncertainties in data and predictions. Where appropriate, the benefits induced by the fires or management approaches would be identified.

Economic assessments generally require making assumptions about society and fires many years into the future. An obvious social trend which should be part of any such analysis is the rapid expansion of the urban-rural-bush interface in Australia and the associated steady increase in bushfire risk. Another well documented fire-risk related issue is the strong warming trend in the Australian climate (Karoly, Risbey & Reynolds 2003). Combined with the long period of below average rainfall, this has also increased the fire risk, and it has increased the risk of exceptionally large fires with the costs and trauma they bring. There are many other trends which are probably of relevance. Among other things, these concern issues of community, volunteerism, and changing expectations among people and commerce about who should bear the risk. Ensuring that important trends are identified and as far as possible incorporated into the analysis is part of the project.

Acknowledgments

We thank the Bushfire Cooperative Research Centre and RMIT University for their support.

References

AAP **CFA Arsonist Jailed**, Herald Sun, viewed February 12, 2004. <http://www.heraldsun.news.com.au/footy/common/story_page/0,8033,6049451%255E1702,00.html>.

Aurnhammer, T.W. 2002. **Addressing the Fire Fighter Arson Problem**, New Mexico Municipal Fire Chiefs Association, viewed February 11 2004, <http://nmfirechiefs.com/articles/ffarson.htm>.

Bureau of Transport & Regional Economics. 2001. **Economic Costs of Natural Disasters in Australia**, 103, Bureau of Transport Economics, Canberra, Australia.

---- 2002, **Benefits of flood mitigation in Australia**, 106, Canberra.

Handmer, J. 2002**. 'The chimera of precision'**, International Journal of Mass Emergencies and Disasters, vol. 20, no. 3, pp. 325-46.

Handmer, J.; Read, C.; Percovich, O. 2002. **Disaster loss assessment guidelines**, Queensland Department of Emergency Services and Emergency Management Australia, Canberra.

Institution of Engineers Australia: Victorian Division 1988, **Bushfires and Technology**, Institution of Engineers Australia, Victorian Division, Melbourne.

Karoly, D.; Risbey, J.; Reynolds, A. 2003. **Global warming contributes to Australia's worst drought**, WWF Australia.

Kocsis, RN 2002, **Arson: Exploring Motives and Possible Solutions**, Australian Institute of Criminology, Canberra.

Koperberg, P. 2003. **'The Politics of Fire Management'**, paper presented to The 3rd International Conference on Wildland Fire and International Wildland Fire Summit, Sydney, Australia,.

Lenaghan, N. 2002. **Firefighter torched school**, The Age, viewed February 12, 2004, <http://www.theage.com.au/articles/2002/04/04/1017206240622.html>.

Lieberman, S. 2004. **Hillcrest volunteer firefighter accused of arson**, The Journal News, viewed February 11 2004, <http://www.thejournalnews.com/newsroom/011704/a0117arsonarrest.html>.

Mangan, R.J. 2001. **'Issues in Reducing Costs on Large Wildland Fires'**, Fire Management Today, vol. 61, no. 3, pp. 6–10.

Mayhew, P. 2003.. **Counting the Costs of Crime in Australia: Technical Report**, 4, Australian Institute of Criminology, Canberra.

McDonnell, S. 2003a. **Interview with Assistant Commissioner John Laycock**, ABC Online, viewed February 11 2004, <http://www.abc.net.au/4corners/content/2003/20030224_fire_starters/>.

---- 2003b. **The Firestarters: Warrimoo**, ABC Online, viewed February 11, 2004, <http://www.abc.net.au/4corners/content/2003/transcripts/s791531.htm>.

O'Toole, R. 2002. **Reforming the Fire Service: An Analysis of Federal Fire Budgets and Incentives**, Thoreau Institute, Bandon, Oregon.

Ove, T. 2004., **Fayette fire chief's arson trial begins**, Pittsburgh Post-Gazette, viewed February 11, 2004, <http://www.post-gazette.com/pg/04013/260837.stm>.

Read & Sturgess and Associates 2000, 'Victorian **Rapid Appraisal Method'**.

United States General Accounting Office. 2002. **Review of Sept 11 loss assessments**, United States General Accounting Office, Washington DC.

Bibliography

Blong, R. (2002) **'Estimating residential flood damage'**, In Smith, D.I. and Handmer, J. (Eds.), Residential flood insurance: the implications for floodplain management policy, Water Research Foundation, Canberra, pp. 175-200.

Emergency Management Australia (2000) **Emergency Risk Management - Applications Guide**, Emergency Management Australia, Canberra.

Handmer, J. and Smith, D.I. (1994) **Cost-effectiveness of Flood Warnings**, Centre for Resource and Environmental Studies, Australia National University, Canberra.

Parker, D.J.; Green, C.H.; M., T.P. (1987) **Urban Flood Protection Benefits: a project appraisal guide**, Gower Technical Press, Farnborough.

Penning-Rowsell, E.C.; Green, C.H.; Thompson, P.M.; Coker, A.M.; Tunstall, S.M.; Richards, C.; Parker, D.J. (1992) **The Economics of Coastal Management: a manual of assessment techniques**, Bellhaven Press, London.

Percovich, O. and Handmer, J. (2002) **Disaster Loss Assessment Case Study**, Queensland Department of Emergency Services and Emergency Management Australia, Canberra.

Zamecka, A. and Buchanan, G. (1999**) Disaster Risk Management**, Department of Emergency Services, Brisbane.

Page left blank intentionally.

Effects of Liability and Regulation on Prescribed Fire Risk in the United States[1]

Jonathan Yoder[2]

Abstract

In past the fifteen years, many state laws regarding prescribed fire use in the United States have been adopted and revised, and many new statutes now explicitly recognize the benefits of prescribed fire for wildfire risk mitigation. From an economic perspective, the characteristics of liability law and regulation will affect the incentives for prescribed fire use and precaution. This article examines the effect of liability law and common regulations on the incidence and risk of escaped prescribed fire. The analysis is based on annual, state-level data from 1970 to 2002 from the National Interagency Fire Management Information Database in conjunction with a categorization of statutory law. Regression results show that the incidence and severity of escaped prescribed fires tends to be lower in states with more stringent statutory liability law and regulatory restrictions. These effects are strong for private landowners burning on private land, but weak or nonexistent for public employees on federal land. The regressions control for various factors that affect baseline risk and incentives for precaution, such as land values, population demographics, the overall incidence of wildfires, and other factors. It is important to recognize that even though more lenient or less restrictive laws may lead to higher incidence and severity of escape, leniency in the context of well designed law and regulation may be useful or even optimal from a societal perspective to facilitate important vegetation management objectives.

Introduction

Prescribed fire is the subject of increasing legislative attention and regulation in many states. For example, in the last 15 years many southeastern states have enacted legislation that explicitly recognizes careful application of prescribed fire as a public good, and simultaneously clarifies liability rules and codifies more stringent specific regulations over its use (Haines and Cleaves 1999). In contrast, the state of Washington now prohibits burning to clear grass-seed fields except under special circumstances (Washington Administrative Code 173-430-045), and in California, the Connelly-Areias-Chandler Rice Straw Burning Reduction Act of 1991 prohibits burning rice straw in California except to control disease.

Liability law and regulations are designed to affect behavior. In the context of prescribed fire as a land management tool, law and regulation can affect the frequency of prescribed fire use and the care with which it is used by affecting the private expected net benefits of burning as well as the incentives for investing in precaution (Brown 1973; Yoder and others 2003). This article examines the effect of liability law and common regulations on the incidence and risk of escaped prescribed

[1] An abbreviated version of this paper was presented at the second international symposium on fire economics, planning, and policy: a global view, 19–22 April, 2004, Córdoba, Spain.

[2] Department of Agricultural and Resource Economics, Washington State University, yoder@wsu.edu.

fire. The analysis is based on data from 1970 to 2002 from the National Interagency Fire Management Information Database (NIFMID), in conjunction with a categorization of state statutory law. The analysis is broad in that it focuses on a broad definition of prescribed fire and uses data in aggregate form for all land cover types.

Regression results show that the incidence of escaped prescribed fires originating from private land and landowners or their agents tends to be lower in states with more stringent statutory liability law and regulatory restrictions. Public employees using prescribed fire on federal land face federal law that does not vary across states, and are not as responsive to variation in state law. The regressions analyses control for various factors that affect baseline risk and incentives for precaution, such as land values, population demographics, the overall incidence of wildfires, and other factors.

Effects of Liability on Prescribed Fire Use and Precaution

Consider a simple representation of the expected number and overall severity of escaped prescribed fires in a state: $E[\text{damage}] = D_{ij} \cdot n_{ij}(x) \cdot p_{ij}(y)$, where D_{ij} is average potential costs of an escaped prescribed fire in state i and year j (including, for example, damage and suppression costs), n_{ij} is the number of prescribed fires started for vegetation management purposes in state i and year j, and p_{ij} is the fraction of those fires that escape. Given this definition of expected damage, the expected number of prescribed fire escapes is $n_{ij}(x) \cdot p_{ij}(y)$. The values n_{ij} and p_{ij} are indirect in that precautionary inputs are implicit in them, and the arguments x and y include exogenous factors that affect the values of n_{ij} and p_{ij} both directly and through their effects on the behavior of land managers who use prescribed fire. For example, one would expect that number of prescribed fires applied in a given state or year (n_{ij}) would decline if the benefits from prescribed fire were low for some reason, or the risks of escape were especially high for a given level of precaution. On the other hand, if the marginal costs of prescribed fire precaution were low, then more fires would be started and more precaution would be used, leading to an increase in n_{ij} and a decrease in p_{ij}. Due to the available data, this analysis will examine the total acreage of wildfires that started as prescribed fires as a proxy for total damage, and will therefore refer to damage in these terms below.[3]

Yoder and others (2003) develops a theoretical framework for understanding the effects of different liability rules on the use of prescribed fire. Although the discussion in that article focuses on relative efficiency of different legal rules, the model provides implications about the frequency of prescribed fire use and the degree of precaution taken. Implications following from the model about the effects of law to examined empirically in the present article can be interpreted in terms of their effect on n and p as discussed above.

First consider a comparison between a negligence rule, where a prescribed burn manager is liable for damage from an escape only if found negligent, and strict liability, where the burn manager who starts a fire may be held liable for damage

[3] Total acreage of wildfires started as prescribed fires is far from a perfect proxy for a measure of damage from escapes, but the two variables are likely to be strongly correlated.

regardless of how careful he or she was. Expected costs to the burner of an escaped prescribed fire will be higher for individuals applying prescribed fires under strict liability. Therefore, prescribed fires will be used less often under strict liability than under negligence rules, more precaution will be used under strict liability than under negligence, and prescribed fire timing will tend toward less risky environmental conditions under strict liability. The implication is that, all else constant, fewer escaped prescribed fires will tend to occur under strict liability, and the total damage of wildfires due to escaped prescribed fires will tend to be lower under strict liability than under a negligence rule.

Regulatory permit systems that restrict the number and timing of prescribed fires in order to limit risks will tend to lead to fewer escaped prescribed fires and fewer acres of wildfires originating as prescribed fires. Also, stricter criminal penalties for negligence associated with an escaped prescribed fire will tend to increase expected costs to prescribed fire users. They therefore will increase their precaution in terms of timing and effort. Stricter criminal penalties will lead to less prescribed fire use, fewer escapes, and smaller total acreage of wildfires started as prescribed fires.

Prescribed fire will tend to be used less, and precaution will be higher, when potential damage from escape is large. Therefore, fewer escapes will tend to occur when potential damage is higher. Also, per acre costs of prescribed fire use tend to be higher when the prescription area is small, and the ratio to benefits versus risk of escape will tend to be small. Therefore, to the extent that landholding size limits the geographic extent of prescriptions, prescribed fire will be used less often where landholding sizes are small.

Finally, federal employees carrying out their duties on federal land face liability under the federal Tort Claims Act; they do not directly face state liability and criminal laws. Therefore, strictly speaking, variations in state law should not lead to significant variations in the incidence and severity of escaped prescribed fires started by federal employees and originating on federal land. This result may not hold to the extent that federal employees perceive pressure to follow local laws.

Each of the hypotheses discussed above are testable in principle. The emphasis of the analysis is on the effect of law on the incidence and severity of escaped prescribed fires, but a number of control variables are included in the econometric estimation that also pertain to the non-legal hypotheses outlined above.

Current state law and prescribed fire use

Prescribed fire laws vary across states and across years. A dataset was developed to represent the basic characteristics of state statutory code for each state and year from 1970 to 2002. A summary of 2002 law is presented in table 1.[4]

[4] For a more complete summary of state laws, see Yoder and others (2003).

Table 1*: State statues for selected prescribed fire laws, 2002*

Liability or property rule	State[1]
Burner strictly liability	CT, ND, NH, OK
Permits or bans supported by statute	AL, AZ, CA, CO, CT, FL, GA, ID, IA, ME, MA, MN, MS, NE, NV, NH, NJ, NY, OR, RI, SD, UT, WV, VT, WA
Criminal penalties for unattended fire or negligent escape	AL, AK, CA, MI, NJ, NM, NV, NC, OK, OR, SC, SD, TN, UT, WI, WY
Prescribed Burn Manager Laws	AL, FL, GA, LA, SC, TX[2]

[1]Citations for supporting statutes are available from the author.
[2]TX has a Certified Burner law, no one had been certified as of 2002, arguably due to a difficult-to-satisfy insurance requirement.

Most states with statutory law relating to prescribed fire explicitly specify a negligence rule. In the absence of statutory law, state-level common law forms the basis for court decisions about prescribed fire liability, and common law tends to be predicated on negligence rules (American Law Reports 1994). Four states, however, impose strict liability on prescribed burners --- Connecticut, North Dakota, New Hampshire, and Oklahoma. If a fire escapes, the burner is liable for damage regardless of his or her effort to contain the fire. There are a great many subtle differences in statutory liability law for prescribed fire across states, but we focus only on the two fundamental forms, strict liability and negligence rules. For more detailed descriptions and analysis (see Yoder and others 2003).

Permits and fire bans can be interpreted as a regulatory attempt at reducing the number of high risk prescribed fires. From an economic perspective, the potential of facing criminal penalties for negligence will tend to increase the perceived costs of negligence, and so will have the effect of reducing accidental escape by increasing incentives for investing in precautionary effort. The potential effect of Prescribed Burn Manager (PBM) laws is more complex. These laws tend to reduce the stringency of liability that prescribed burn managers face, but only if they satisfy a relatively strict set of guidelines. In two cases, Florida and Georgia, PBMs are now liable only if found grossly negligent as long as an explicit set of regulatory conditions are met. From an economic perspective, reductions in liability will tend to lead to reduced incentive for care, and therefore more escaped prescribed fires. However, the stricter regulatory conditions counteract this effect. The final effect on the number and severity of prescribed fires therefore depends on the interaction between these two components of PBM laws.

Data and Estimation

The effect of basic liability, criminal laws and regulation on the incidence of prescribed fire is examined using data from the National Interagency Fire Management Integrated Database (NIFMID). The data for this analysis have been acquired in two related but separate and incomplete forms. First, a pre-aggregated dataset was acquired through the National Interagency Fire Center in Boise, Idaho.[5] Second, fire-specific data were downloaded from KCFAST (NIFMID 2003).[6]

[5] I thank Penny Sternberg at the National Interagency Fire Center for making these data available to me.
[6]By fire-specific, I mean that each observation represents one wildfire, some of which were started as prescribed fires.

The first (pre-aggregated) dataset is based on the complete version of the second dataset, but only part of the complete fire-level data are available through KCFAST. Ideally, a "complete" dataset would include data for every state from 1970 through 2002, and it would be broken down in terms of (1) the landowner at the origin of the fire, and (2) the category of person who started the fire (e.g. landowner, contractor, public employee, or other), if the fire originated as a prescribed fire. However, neither form of the available data provide all of this information in useable form. The pre-aggregated dataset provides a breakdown of fire information in terms of general landownership categories for each of state and year up to 1997, but it does not provide information about ownership at the fire origin, or the category of people who initiated intentional management ignitions. On the other hand, the fire-specific dataset includes approximately 360,000 observations on individual fires from 1970 through 2002, but it does not include data for Connecticut, Hawaii, Iowa, Massachusetts, Maryland, New Jersey, or Rhode Island. These are not states with substantial wildfire activity, but this set includes one of the four states that have strict liability laws --- one of the legal parameters of interest for this analysis. Due to the relative incompleteness of both datasets, each is used for different aspects of the analysis.

The central focus of this paper is prescribed fire use risk. The NIFMID data have a number of categories for fires ignited intentionally for management purposes. A broad category, *debris fires*, is chosen for this analysis to represent the set of legitimately and intentionally set fires, because prescribed fire law tends to cover this range of fire use. This broad category includes subcategories such as field burning, land clearing, slash burning, and similar categories (USDA Forest Service 1998). For this broad based analysis, observations on escaped prescribed fires are included regardless of the land cover class at their origin. In particular, the data are not limited to forest land.

The analysis is comprised of three sets of regressions, each of which model the distribution of a state/year-level summary statistic of escaped debris fires as a dependent variable, regressed on a set of independent explanatory variables. The three dependent variables are (1) the number of escaped debris fires, (2) total acreage of escaped debris fires, and (3) the ratio of the number of escaped debris fires started on private land by private individuals divided by the number of escaped debris fires started on federal land by public employees. Explanatory variables include control variables, and variables to capture differences in the legal and regulatory environment. Brief data descriptions are presented in table 2, and summary statistics for all variables used in estimation are presented in table 3.

Because state law will affect private and federal incentives differently, three regressions are estimated for two of the three dependent variables: one is based on data for all land ownerships and all types of people using the pre-aggregated data; one is based only on observations for fires started on private land by private landowners and their agents;[7] and one only uses observations on fires started by public employees on federal land. Because of the comparative advantages of the two related datasets described above, the pre-aggregated dataset is used for regressions

[7]Because state law affects landowners and contractors differently it would be interesting to discern differences between these two groups as well, but there are not enough observations in one or the other of these categories to generate reasonably credible estimates.

that includes data for all people and land ownerships, but comparable state/year summary statistics from the KCFAST database are used for the other regressions.

Table 2: Descriptions of data used in estimation [for data not from NIFMID, sources are listed in brackets]

# esc. debris fires	Number of debris fires that escaped, by state, year.
priv/fed escapes	Ratio: number of escaped debris fires started by private landowners on private land ÷ number of escaped debris fires started on federal land by public employees.
Total escaped debris fire acres	Sum of all wildfire acreage that started as debris fires.
fire ac., oth. causes	Sum of wildfire acreage for a state and year for wildfires that were not started as debris fires.
# other wildfires	Number of wildfires for a state/year that did not start as debris fires.
land value ($2000)	Average value of agricultural land ($US2000).[National Agricultural Statistics Service.]
avg. farm size	Average farm size [U.S. Census of Agriculture.]
federal land ac.	Total acreage of federal land [1000s acres]
state land ac.	Total acreage of the state [1000s of acres].
population	Human population. [U.S. Census Bureau.]
# farms	Number of farms [U.S. Census of Agriculture.]
criminal penalties	Binary variable; equals 1 if state statutes specify criminal penalties for negligent escape; zero otherwise.
strict negligence	Binary variable; equals 1 if state statutes specify strict liability; zero otherwise.
permit required	Binary variable; equals 1 if state statutes support a permit for the application of prescribed fire; zero otherwise.
PBM law	Binary variable; equals 1 if state statutes support a law that conditionally limits liability for prescribed burn managers; zero otherwise.
PBM gross neg.	Binary variable; equals 1 if state statute specifies conditional gross negligence requirement for liability; zero otherwise.

Table 3*: Summary statistics for variables used in estimation*

Variable	N	Mean	Std Dev	Minimum	Maximum
# esc. debris fires	1274	14.627	18.227	0.00	117.00
priv/fed escapes	1274	0.097	0.116	0.00	1.00
fire ac., oth. causes	1089	931.689	5361.360	0.10	103254.00
# other wildfires	1274	300.799	515.300	1.00	3890.00
land value ($2000)	1242	762.868	436.768	103.35	2559.23
avg. farm size	1273	0.855	1.203	0.10	6.65
federal land ac.	1273	17443.7	39071.5	130.20	244626
state land ac.	1273	53732.8	56776.6	5740.20	365039
population	1273	4941514	5292405	302583	34600463
# farms	1273	23912.2	23248.9	420.00	142800
criminal penalties	1273	0.494	0.500	0.00	1.00
strict liability	1273	0.071	0.258	0.00	1.00
permit required	1273	0.605	0.489	0.00	1.00
PBM law	1273	0.042	0.200	0.00	1.00
PBM gross neg.	1273	0.005	0.069	0.00	1.00

The state/year summary statistics used in all regressions (regardless of data source) are based on the number of wildfires occurring in that state/year; the more wildfires, the larger the number of observations are used to calculate the summary statistic. This characteristic of aggregation leads to inherent heteroscedasticity if the number of wildfires varies across states and years (and it does). To increase asymptotic efficiency, weighted least squares was therefore used for estimation. Each variable in the regression was multiplied by $\sqrt{n_{ij}}$, where n_{ij} is the number of wildfires in state i and year j. These weights are designed such that the disturbances associated with weighted least squares are homoscedastic.

Finally, based on examination of residuals from preliminary regressions, each of the continuous variables in the analysis is transformed to natural log form (also to relieve heteroskedasticity problems). Because of the log transformation, parameter estimates associated with the continuous variables are elasticity estimates. Dummy variables are used in the regressions to represent legal characteristics of a state. For these dummy variables, the percent difference in the dependent variable between one legal regime and another (i.e. legal dummy variable=1 versus legal dummy variable=0) is 100*(exp[c]-1), where *exp* is the exponential function and c is the parameter estimate associated with the dummy variable (Halvorsen and Palmquist, 1980). The results are presented (in table 4) as (exp[c]-1), so the percent difference is 100 times the value presented in the table.

Results

Regression results are presented in table 4. The table contains three regressions on the number of escaped debris fires, three regressions on the total acreage of wildfires started as debris fires, and one regression on the ratio of escaped private fires over

escaped public (federal) fires. For each regression, the first nine rows of independent variables (excluding the intercept) are variables that attempt to capture non-legal characteristics of states for a given year. Not all of these variables are used in each regression because of the different definitions of the dependent variables. The discussion below begins with a focus on regression groups 1 and 2, after which is a discussion of the group 3 regression.

In group 1 regressions (dep. Var: number of debris fires), *# other wildfires* is included to capture the general propensity for wildfires in a given state/year, and therefore the risk associated with performing prescribed fires. For group 2 regressions (dep. Var.: total escaped debris fire acreage), *other escaped fire acres* is included as a control for general severity of wildfires for a given year and state. As might be expected, there is a statistically strong relationship between these two variables and their respective dependent variables (in all cases, $p<0.0001$). The elasticity estimates for these two variables range between 0.59 and 0.81; all less than one. This means that the incidence and severity (as measured by total acreage) of escaped prescribed fires increases less than one percent for every one percent increase in overall wildfire incidence and severity. This is consistent with a hypothesis that people performing prescribed fires tend to invest in additional precaution when wildfire risk is high, postpone prescribed burning until it is less risky to do, or forego prescribed fire altogether.

Table 4*: Regression results*

Dependent variable →	**GROUP 1: # escaped debris fires**			**GROUP 2: Total escaped debris fire acreage**			**GROUP 3: priv÷fed escapes**
Independent variables ↓	All[1]	Private	Federal	All[1]	Private	Federal	All
Intercept	4.952**	-3.329**	0.777	4.848**	-4.546	-6.504	-5.246**
# other wildfires	0.811**	0.708**					
fire ac., oth. cause			0.712**	0.734**	0.928**	0.588**	
land value	-0.404**	0.225**	-0.004	-0.394**	-0.295	1.240**	0.236**
population density	-0.162**	-0.102*	-0.280 **	-0.316**	-0.022	-0.796**	-0.113*
avg. farm size	-0.932**	-0.004	-0.282 **	-1.176**	-0.990 **	-0.214	-0.241**
federal land ac.	-0.044 *	-0.120*	0.148**	-0.107**	0.264	1.017**	-0.624**
state land ac.	-0.121	0.409**	-0.372 **	-0.139	-0.804	-1.637 *	0.867**
total farm acreage	0.505**	-0.114	0.263**	0.779**	1.083**	0.942 *	-0.223**
criminal penalties	-0.254**	-0.159**	-0.119 **	-0.292**	-0.514 **	-0.455**	-0.160**
strict liability	-0.241**	-0.200*	0.483**	-0.235 *	-0.725 *	1.532	-0.213
permit required	0.043	-0.107*	0.255**	-0.054	-0.375 **	0.250	-0.224**
PBM law	0.946	0.368*	0.275	1.354 **	0.501	0.747	-0.088
PBM gross neg.	---[2]	0.049	-0.204	---[2]	1.094	-0.835	-0.130
R-sq.	0.770	0.723	0.710	0.770	0.381	0.364	0.527
N[3]	1327	760	442	1327	760	442	1060

[1]NIFC pre-aggregated data used. For all other regressions, fire-level NIFMID data from the KCFAST database were aggregated as needed to the state/year level. A single asterisk denotes significance at the 10 pct level and a double asterisk denotes significance at the 5 pct level.

[2]No states had adopted gross negligence for PBMs until after 1997, so the effect is not estimable using the pre-aggregated data.

[3]N is the number of observations used in the regression. If states did not have any recorded wildfires that year for that category, the observation was dropped. The pre-aggregated data includes all states and therefore the regressions listed under "All" have more observations.

The variables *land value* and *population* are proxy variables that attempt to capture the potential costs associated with escaped fire. High land values and large population densities are likely to be positively correlated with higher values-at-risk, because land values reflect the current and future value of resources on the land, and high population densities are associated with a high density of homes, businesses, and other valuable capital.[8] For regressions in groups 1 and 2, the parameters associated with these variables are expected to be negative for each regression, and they are negative for 10 of 12 estimates, significantly so for 7 of these. The distribution of population, land value, and land use matters, however, and so additional control variables *state land acreage, federal land acreage, and total farm acreage* were included as proxies for both the total land area of a state as well as broad land use categories. These variables likely pick up a number of factors affecting incentives and fire behavior, so it is not clear what signs to expect on their associated parameters.

The effects of the legal variables *criminal penalties*, *strict liability*, and *permit required* are all expected to be negative for private land, but are *a priori* indeterminate for public employees on federal land. The *criminal penalties* variable is negative and significant for every regression, suggesting that statute-based criminal penalties may be a strong deterrent to negligence not only on private land and for private landowners and their agents, but also perhaps for federal employees. Consider the effect of criminal penalty statutes on the number of escaped prescribed fires for all sources (the first regression in group 1). The results suggest that a statute specifying criminal penalties for negligent escape are associated with 25.4 percent lower number of escaped prescribed fires (all else constant). *Permits required* (which also accounts for statutory support for burn bans) also tends to reduce the incidence and severity of escaped prescribed fires, with negative and significant signs for private land in regression groups 1 and 2. Counter-intuitively, however, the number of escaped prescribed fires from public employees on federal land appears to significantly increase when permits and burn bans are written into state law.

Strict liability laws also appear to reduce the incidence of escaped prescribed fires for private land and landowners. When all landowners and types of prescribed burn managers are considered (the dataset with all states is used), strict liability law is associated with 24.1 percent fewer escaped fires and 23.5 percent fewer acres of escaped prescribed fires. Both of these estimates are significantly different from zero at the 5 or 10 percent level (group 1 and group 2 regressions labeled "All"). For private landowners only, the results also show a statistically significant negative relationship, again, supporting the hypothesis that strict liability provides incentives to reduce the risk and severity of escape. In contrast, both parameters for the effect of strict liability for public employees on federal land are positive, and one of them is statistically significant. Although a significantly positive effect of state-level strict liability is unexpected, these results are all consistent with the theory developed above in that public employees on private land are not influenced by state law in the same way that private landowners are.

The expected signs of parameters associated with the PBM laws are unclear even for private land, because of the offsetting effects of relaxed liability and more

[8] Interestingly, if prescribed fire were mainly used to reduce wildfire risk, then higher land values may increase the use of prescribed fire as a (risky) wildfire risk mitigation tool. (see Yoder in press).

stringent conditions. However, for regression groups 1 and 2, the number and size of escaped prescribed fires tend to be higher for states under these laws although the evidence is mixed and relatively weak.

The dependent viable for the group 3 regression is the ratio of the number escaped prescribed fire started by private individuals on private land over the number of escaped prescribed fires started by public employees on federal land. To the extent that state law affects private incentives and actions of private individuals more than those of federal employees, the signs of the legal parameters should all be negative. Indeed, the parameter estimates are all negative, and significantly so for both *criminal penalties* and *permit required*. Again, these results are consistent with the idea that that state law has a stronger effect on the incentives and actions of private individuals than on federal employees.

Conclusion

Attitudes and some laws relating to prescribed fire have changed substantially over the last couple of decades. The empirical analysis in this paper finds evidence to suggest that different liability and regulatory rules affect the number and size of escaped prescribed fires. All else constant, states with strict liability rules tend to have fewer escaped prescribed fires than states with a negligence rule. Further, permit systems and criminal penalties for negligence reduce the incidence and extent of escape as well.

This article provides a broad perspective on the incentive effects of prescribed fire law and regulation. There are a number of weaknesses associated with the data relied on in this article as well. Little information is available about the extent of damage associated with prescribed fire in the aggregate, or even the fraction of prescribed fires that do become out of control. Nowhere in this analysis is the number of prescribed fires actually relied upon. Because the data are collected in a decentralized manner, many different individuals provide the data by filling out forms, and the definitions of the data requested are often not defined very clearly. Furthermore, the requested data are often omitted for any given fire. To the extent that these data omissions or survey misinterpretation are not systematically related to the scale or incidence of escaped prescribed fire, these omissions will result only in a higher variance in parameter estimates. To the extent that data omissions or misinterpretations are correlated with those variables, bias might be introduced into the estimation process. To the extent allowed by the data, related future work will focus more closely on specific categories of land cover types, forest land in particular, as well as more specific categories of prescribed fires as wildfire sources and other factors.

It is crucial to recognize that these results, which suggest that higher incidence and severity of escaped prescribed fires occur under less stringent laws, is in no way an indication that more stringent laws are better. As recognized by a number of state statutes in the southern states, prescribed fires can provide public goods in the form of wildfire risk mitigation and other vegetation management goals. It is entirely plausible that the additional costs of increased prescribed fire use are more than compensated by the benefits of increased prescribed fire use. Unfortunately, the datasets used in this analysis do not allow an analysis of these net benefits. A great deal of research and data are needed to better understand the tradeoffs associated with prescribed fire use.

Acknowledgements

This research was supported in part by the USDA Forest Service, Southern Research Station under Agreement No. SRS 03-CA-11330133-053, and by the Washington State Agricultural Research Center.

References

American Law Reports. 1994. **Liability for Spread of Fire, Intentionally Set for Legitimate Purpose**. American Law Reports 5th 25:391–567.

Brown, John. 1973. **Toward an Economic Theory of Liability**. Journal of Legal Studies 2:323–349.

Haines, Terry K.; and Cleaves, David A. 1999. **The Legal Environment for Forestry Prescribed Burning in the South: Regulatory Programs and Voluntary Guidelines**. Southern J. Applied Forestry 23:170–174.

Halvorsen, Robert; Palmquist, Raymond 1980. **The Interpretation of Dummy Variables in Semilogarithmic Equations**. American Economic Review 70(3):474–475.

NIFMID. 2003. **National Interagency Fire Management Integrated Database**. http://famweb.nwcg.gov/kcfast/mnmenu.htm.

USDA Forest Service. 1998. National Interagency Fire Management Integrated Database (NIFMID) Technical Guide [draft]. **Fire and Aviation Management**. Washington DC.

Yoder, Jonathan. In press. **Playing with Fire: Endogenous Risk in Resource Management**. American Journal of Agricultural Economics.

Yoder, Jonathan; Tilley, Marcia; Engle, David; Fuhlendorf, Samuel. 2003. **Economics and Prescribed Fire Law in the United States**. Review of Agricultural Economics 25(1):218–233.

Page left blank intentionally.

Tradeoffs Between Fire and Habitat Management in a Forest Reserve[1]

S. Hummel,[2] D. Calkin,[3] R.J. Barbour[2]

Abstract

Silvicultural treatments to manage fire behavior affect both forest values that can be priced (market) and those that cannot (non-market). When the purpose of the treatments is to benefit a non-market value, evaluating their net effect is complicated by difficulties in assessing their total cost. Production possibility (PP) curves illustrate the relative cost, or tradeoffs, of managing for a non-market value in terms of market or other non-market values.

We combined simulation and optimization models to schedule treatments that reduce fire threat (FT) and maintain late successional forest habitat (LSF structure) for the northern spotted owl over thirty years in a 6070 ha forest reserve. We evaluated the tradeoffs between reducing FT and maintaining LSF structure by constructing a set of PP curves. Results suggest that at low and moderate levels of LSF structure in the reserve, treating non-LSF units is as effective in reducing fire threat as is treating LSF units. In this range, the treatments impose a low cost on owl habitat. In contrast, at high levels of LSF habitat structure, treating some LSF units could reduce fire threat in the reserve. In this range, treatments come at a cost to owl habitat.

Treatment effects in the reserve, whether ecological or financial, need to be evaluated at scales relevant to fire and owls. Hence, we evaluated net present value (NPV) for the collection of treatment units in the reserve over thirty years rather than for each unit in each decade. Results indicate that the lowest cost to the non-market values of LSF structure and FT reduction was achieved by a mixture of treatments -- some that earned money and some that lost money in an individual unit but that collectively broke even (NPV≥0). In contrast, if breaking even was required within each decade the cost was similar to requiring that treatments earn $0.5 million NPV over thirty years. This implies that constraining the time period within which the financial effect of the treatments was evaluated imposed a cost on the non-market values in the reserve.

Introduction

Background

A network of forest reserves exists in the Pacific Northwestern United States (PNW). The main objective for the reserves is to provide habitat for species associated with structurally complex, late successional forest (LSF). One such species is the northern spotted owl (*Strix occidentalis caurina*). The Northwest Forest Plan (Plan), which

---

[1] An abbreviated version of this paper was presented at the second international symposium on fire economics, planning, and policy: a global view, 19–22 April 2004, Córdoba, Spain.

[2] Research Forester, Human and Natural Resource Interactions Program, and Manager of the Focused Science Delivery Program, respectively, Pacific Northwest Research Station, USDA Forest Service, P.O. Box 3890, Portland, OR 97208 USA. email:shummel@fs.fed.us and jbarbour01@fs.fed.us.

[3] Economist with the Economic Aspects of Forest Management on Public Lands Program, Rocky Mountain Research Station, USDA Forest Service, P.O. Box 8089, Missoula, MT 59807 USA, email: decalkin@fs.fed.

established the reserves, permits silvicultural treatments within them to avoid potentially negative impacts on habitat (LSF structure) associated with extensive natural disturbances like wildfire (USDA/USDI 1994). The Plan distinguishes between treatments permitted in reserves lying to the west or to the east of the Cascade Range (Cascades) due to regional differences in climate, vegetation, and management history (USDA/USDI 1994). The eastern region (eastside) is characterized by mixed-severity fire regimes with shorter average fire return intervals than the western region (Agee 1993). Consequently, more silvicultural flexibility is permitted in eastside reserves.

Issue

Silvicultural treatments within reserves are contentious, in part because of limited information on the effectiveness of treatments in reducing the likelihood of large-scale disturbances, their financial cost, and their effects on the primary reserve objective of maintaining LSF structure.

Objectives

Our objectives were threefold: 1) quantify the relationship between two non-market values: LSF structure and fire threat (FT) in an eastside reserve; 2) schedule silvicultural treatments over thirty years to maintain LSF structure while maximizing FT reduction in the reserve; and 3) evaluate the effects of different financial constraint levels on FT reduction and on treatment options to maintain LSF structure in the reserve.

Methods

Characterize Current Vegetation Structure

We selected an eastside reserve in Washington State for this analysis (*fig. 1*). On the eastern slopes of the Cascades, annual precipitation decreases on a west-east gradient. In the 6070 hectare (ha) reserve this gradient is modified somewhat by Mount Adams (3700 meters (m)), located immediately to the north. Changes in precipitation and elevation within the reserve influence the spatial patterns of variables like vegetation and fire, and their interaction.

We began our analysis by characterizing current vegetation structure in the reserve using 1995 aerial photos (1:12,000 scale). Patches of vegetation (159 total) sharing similar structure and composition were photo-interpreted using methods from Hessburg and others (1999) and entered into an ArcView® GIS database. A summary matrix was constructed from two patch attributes, structure class and potential vegetation, to stratify all patches into 15 stand types (details in Hummel and others 2001). In combination, these two attributes provide information on the current forest structure in any given patch and the conditions influencing its potential rate of change. Each stand type was assigned a root disease severity rating using methods from Goheen (1997).



Figure 1--Location of the study reserve (black star) in the northwestern United States. California (CA) is provided for reference.

We next summarized available vegetation data for each stand type and discarded data collected before 1999. Using a randomized design with probability proportional to size, we selected patches for field sampling in 2000 and 2001. The range of stand types was sampled. All data were collected using the USDA Forest Service Region 6 stand exam protocol. The number of exams done within each patch depended on the patch size. Exam data were used to create "tree lists" for that patch following standard procedures for the Forest Vegetation Simulator (FVS) (Dixon 2003). Using the set of existing FVS tree lists within each stand type, any unsampled patches were randomly assigned a FVS tree list within the same stand type.

We divided some photo-interpreted patches, based on species composition or special features, to refine our GIS coverage. A unit is the smallest area to which a treatment can be applied, and is the basis for our analysis of current and projected vegetation structure. Units in the reserve averaged 18 ha and ranged in size from 0.8 ha to 464 ha. All units were assigned the FVS tree list associated with their original patch (details in Hummel and others 2002).

Develop Structural Definitions for Fire Threat (FT) and Late Successional Forest (LSF) Habitat

We developed structure-based definitions for LSF and for a spatially explicit FT index. We focus on structure, or the arrangement and variety of living and dead forest vegetation, because it can be measured and it is physically and biologically relevant to fire and to owl habitat. In addition, it provides a common denominator for the non-market values of LSF and FT.

For LSF structure, we relied on published data and knowledge of local conditions (Thomas and others 1990, Buchanan and others 1995, Mendez-Treneman 2002). The LSF structure definition is based on the basal area of trees in specific

diameter classes (*table 1)*. We assumed that providing structural conditions consistent with published studies of eastside owl habitat would enable the reserve to support reproductively successful owl pairs.

Table 1--*Structural definition of late successional forest (LSF)*

Basal area (BA) at least 55.2 m^2/ha
BA of trees greater than 61.0 cm dbh $\geq$ 8.3 m^2/ha
BA of trees greater than 35.6 cm dbh $\geq$ 33.1 m^2/ha
BA of trees less than 35.6 cm dbh $\geq$ 8.3 m^2/ha

For FT we used three variables: flame length, crown fire initiation, and crown fire spread (Scott and Reinhardt 2001). The FVS tree list was evaluated with the Fire and Fuels Extension (FFE) (Reinhardt and Crookston 2003) to estimate these three variables for each unit. A unit's FT index was a weighted combination of the within-unit variables and those in adjacent-units (details in Hummel and others 2002, Calkin and others in review). A FT index level (low, moderate, or high) was developed for each unit. We included information on neighboring units in our FT index so that treating one unit could influence FT in adjacent units and vice versa. A landscape FT was computed from the proportion of the reserve in each of the low, moderate, and high FT categories for every decade. We chose a 30-year analysis period by considering fire return intervals for mixed-conifer forests in the region (Agee 1993).

Simulate Vegetation Response to Silvicultural Treatments

We used the East Cascades FVS variant (Johnson 1990), the Western Root Disease Model (Frankel 1998), and FFE-FVS (Reinhardt and Crookston 2003) to evaluate LSF structure and to assign a FT level in each unit. FVS keywords (Van Dyck 2000) were used to bring all tree lists to a common date, modify the default large tree diameter growth equation based on calibration statistics from local samples, change default values for down wood and fuel moisture based on field samples and site visits (e.g. Hummel and Agee 2003), classify the unit according to our LSF definition, set wind speed values based on local weather station data, and simulate tree regeneration (details in Calkin and others in review).

Variable-intensity silvicultural treatments were applied in FVS to all units and forest development simulated over three, 10-year cycles. The treatments differ in the type of thinning, species removed, maximum diameter limit, residual basal area target, and residual fuel loads (*table 2*). Passive management in the reserve was simulated by applying the "no prescription" (noRx) treatment to all units. Active treatments that cut trees were applied according to a rule set. The rules were chosen by consulting applicable laws, Plan standards and guidelines, and managers of the reserve (details in Calkin and others in review). For example, no active treatment was applied in any unit which met structural criteria as spotted owl nesting habitat.

Vegetation structure in each unit in each cycle associated with each treatment was evaluated according to the definitions established for FT and LSF using FVS commands. We used results from the noRx simulation to identify baseline values for the reserve. Thus, the maximum projected area of LSF structure with passive management (6982 ha) became the maximum area of LSF structure to be maintained over thirty years.

Table 2--*Silvicultural treatments*

Treatment (Rx)	Rx Objective	Silvicultural treatment applied in FVS	Citation for Rx targets
No Rx	Minimize human disturbance	No activity scheduled	
Reduce Rx	Reduce crown fire potential in historically low fire-severity forest ecosystems	40% canopy cover Thin from below to 50.8 cm dbh Preferentially remove ABGR Pile and burn Plant PSME, PIPO, LAOC	Agee 1996 Agee 2000 Graham et al. 1999
Restore Rx	Reduce density of shade-tolerant true fir trees (Abies) that have established since the 1920s	Thin from below to 38.1 cm dbh Keep at least 23 m2/ha basal area Retain PSME, PIPO, LAOC, PIEN Pile and burn	Hummel et al. 2002
Protect Rx	Protect large trees (>53.3 cm dbh) and retain sufficient basal area to meet LSF definition	If more than 55.2 m2/ha in unit then thin trees 0-35.6cm dbh to 8.3 m2/ha Pile and burn	Johnson and O'Neil 2001 Mendez-Treneman 2002
Diameter Rx	Reduce density of shade-tolerant understory true fir trees (Abies)	Thin from below to 25.4 cm dbh Keep at least 23 m2/ha basal area Retain PSME, PIPO, LAOC, PIEN Pile and burn	
Accel Rx	Accelerate the development of LSF structure	Thin to 247 trees/ha Keep PSME, PIPO, LAOC Plant 247 PSME/ha	

ABGR = grand fir (*Abies grandis*)
PSME = Douglas-fir (Pseudotsuga menziesii)
PICO = lodgepole pine (*Pinus contorta*)
LAOC = western larch (*Larix occidentalis*)
PIPO = ponderosa pine (*Pinus ponderosa*)

All FVS simulation results were saved and linked to the GIS database. The list of trees cut by FVS following any active treatment was saved in a format compatible with the Financial Evaluation of Ecosystem Management Activities (FEEMA) model (Fight and Chmelik 1998).

Develop Production Curves by Varying Silvicultural Treatments and Area Treated

Production possibility (PP) curves illustrate the relative cost, or tradeoffs, of managing for a non-market value in terms of market or non-market values (Montgomery 2003). We developed a simulated annealing (SA) algorithm (Kirkpatrick 1983) to construct a set of PP curves for the reserve. The SA algorithm

was written to maximize the reduction of landscape FT subject to constraints on the total area of LSF structure maintained over thirty years and the amount of area that could be treated in any cycle. Each point on the PP curves represents the results of different combinations of silvicultural treatments in terms of FT reduction and LSF structure, while each curve represents the relative tradeoffs between FT reduction and LSF structure subject to a given area constraint. The LSF constraint was varied from allowing any unit that qualified as LSF to be treated (unconstrained) to allowing no unit that qualified as LSF to be treated (strict). Intermediate constraints included 6678, 6780, and 6880 ha of LSF structure maintained over the 30-year analysis period. The effectiveness of treatments was assessed by identifying if existing FT levels were reduced for treated units and their overall effect on landscape FT (details in Calkin and others in review).

Identify Marginal Cost of Silvicultural Treatments

We entered price assumptions, harvest costs, fuel treatment, and wood products into FEEMA to calculate net revenues per unit per treatment per decade. Harvest costs, including hauling, road maintenance, contractual requirements, reforestation, slashing, and piling and burning were obtained from reserve managers. The amount of defect by log size class was estimated by using previous timber sale records for the area and recommendations from personnel responsible for scaling and cruising. Wood product prices representing a stable high market (fourth quarter 1999) and a stable low market (fourth quarter 2001) in the PNW were averaged to reflect a stable market. Product prices and all harvest and operational costs were assumed to be constant over time. Future costs and revenues were discounted by 4 percent.

We identified a range within which silvicultural treatments could achieve relatively high FT reduction at relatively low cost to LSF structure by using the PP curves. We then examined how FT reduction levels within this range would be affected by different financial requirements for the treatments. To develop a three-dimensional production function in terms of net present value (NPV), LSF structure, and FT, we held LSF structure and treated area constant. The objective function was to reduce landscape FT while the area of LSF structure (6880 ha), the maximum treated area (≤10% of the reserve), and NPV were set as constraints. The NPV constraint levels were USD $0, $0.5 million, $1 million, and $1.5 million in addition to an unconstrained baseline. The three cases in excess of $0 are also referred to as +NPV.

Results

Tradeoffs Between LSF and FT Reduction (FTR)

Figure 2 illustrates the tradeoffs between LSF structure and reduction of the landscape FT index (FTR) for different treatments and area treated. Point (a) illustrates the strict area constraint and maximum amount of LSF structure projected over thirty years. Curve (b), drawn freehand for illustration, is the case when only the diameter limit treatment (DiameterRx) was applied. The outermost curve (e), also drawn freehand, is the unconstrained case. The other curves represent mixtures of silvicultural treatments and area treated.

The relatively flat portion of the curves implies that, for low and moderate levels of LSF structure in the reserve, treating non-LSF units is as effective in reducing fire

threat as is treating LSF units. In this range, the treatments impose a low opportunity cost in terms of owl habitat. In contrast, the sloping portion of the curves indicates that, at high levels of LSF habitat structure, treating some LSF units could reduce fire threat in the reserve. In this range, treatments come at a cost to owl habitat.

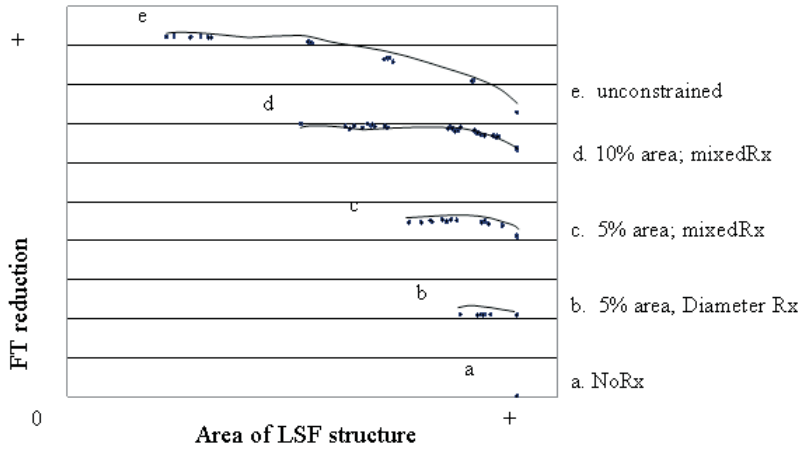


Figure 2--Tradeoffs between late successional forest (LSF) structure and fire threat (FT) reduction) for different silvicultural treatments (Rx) and constraints on area treated (5% or 10% of the reserve). For illustration, curves b, c, d, and e were drawn freehand rather than fitted.

Treatment Options

Results for passive management indicate that landscape FT levels increased over thirty years. Several units changed from low or moderate FT to a high FT level in the first two decades and remained high in the third. In contrast, the area projected to be in LSF structure remained fairly constant over the same analysis period. This baseline analysis suggests an increasing likelihood of large-scale disturbance to LSF structure in the reserve over time.

Results for active management indicate that a mix of silvicultural treatments, rather than a single treatment, was better at achieving landscape objectives for maintaining LSF structure and FT reduction. Application of the diameter limit treatment did not result in a reduction of FT for many units.

Marginal Costs of Silvicultural Treatments on LSF and FTR

Over our 30-year analysis period, a constraint to break even (NPV≥0) did not bind the simulated annealing algorithm. This means that with or without a financial requirement to break even, treatments accomplished about the same level of FT reduction and LSF structure. However, although the treatment results were similar, the net revenues were not. For similar levels of FT reduction and LSF structure, net revenues for various mixtures of treatments ranged from -$1,000,000 to $3,000 over thirty years. Financially unconstrained solutions always resulted in large negative NPV solutions.

Requirements for the collection of treatments to earn money (+NPV) negatively affected FT reduction over the 30-year period. Extreme constraints carried high marginal costs. This is because silvicultural treatments that consistently lost money were not applied despite reducing fire threat at low cost to LSF structure. Some treatments had negative net present values on all units in all decades. A requirement to make money, therefore, imposed a cost on non-market values in the reserve.

Finally, if breaking even was required within each decade, the cost was similar to requiring that treatments earn $0.5 million NPV over all three decades. This implies that constraining the time period within which the financial effect of the treatments is evaluated came at a cost to the non-market values in the reserve. Results are sensitive to the non-market values considered and to the time period over which they were evaluated.

Discussion

The ecological and financial implications of silvicultural treatments need to be evaluated at geographic and temporal scales relevant to their objectives. In this analysis, with objectives related to wildfire and owl habitat, we considered results for the collection of treatment units in the reserve over thirty years rather than unit by unit. Our results suggest that variable-intensity silvicultural treatments can be applied that reduce FT at low opportunity cost to existing or projected LSF structure within the reserve.

The USDA Forest Service is not required by law to make money. Prudence dictates, however, that public forest management objectives be achieved at the lowest cost. When the objectives include non-market values, the total costs will include impacts not measurable in dollars. One way to evaluate these impacts is by identifying production relations between non-market values and then estimating the relative cost of managing one in terms of the other. For example, given a NPV$\geq$0 strict area constraint, our results indicate that the marginal cost of an 8 percent improvement in FT reduction is a 1.5 percent reduction in LSF structure.

Although PP methods can increase understanding of potential tradeoffs between non-market values, two or three dimensions are likely insufficient to capture biologically and socially important variables. In this analysis, for example, uncertainty over the relation of forest structure to owl persistence will affect perceptions of the risk to owls from different silvicultural treatments. This, in turn, will introduce other constraints that are outside the scope of our analysis. Economic efficiency is not the only factor considered by managers of public lands, but economic methods can be used to provide information on tradeoffs associated with different management options.

Citations

Agee, J.K. 1993. **Fire ecology of Pacific Northwest forests**. Washington, DC: Island Press. 493 p.

Agee, J.K. 1996. **The influence of forest structure on fire behavior**. In: Proceedings, 17th Annual Forest Vegetation Management Conference. Redding CA: Pp. 52–68.

Agee, J.K., Bahro, B., Finney, M.A., Omi, P.N., Sapsis, D.B., Skinner, C.N., van Wagtendonk, J.W. and Weatherspoon, C.P. 2000. **The use of shaded fuel breaks in landscape fire management**. Forest Ecology and Management. 127: 55–66.

Buchanan, J.B.; Irwin, L.L.; McCutchen, E.L. 1995. **Within-stand nest site selection by spotted owls in the eastern Washington Cascades**. Journal of Wildlife Management. 59(2): 301–310.

Dixon, Gary E. comp. 2003. **Essential FVS: A User's Guide to the Forest Vegetation Simulator**. Fort Collins, CO: U. S. Department of Agriculture, Forest Service, Forest Management Service Center. 193 p.

Fight, R.D.; Chmelik, J.T. 1998. **Analysts guide to FEEMA for financial analysis of ecosystem management activities**. Gen. Tech. Rep. FPL-GTR-111. Madison WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory 5 p.

Frankel, S.J. (tech. coord.). 1998. **Users guide to the western root disease model, version 3.0**. Gen. Tech. Rep. PSW-GTR-165. Albany, CA. Pacific Southwest Research Station, Forest Service, US Department of Agriculture; 164. p.

Goheen, E.M. 1997. **A multistand assessment approach for evaluating insects and diseases, establishing treatment priorities, and predicting vegetative development**. In Teck, R.; Moeur, M.; and Adams, J. (comps). Proceedings: Forest Vegetation Simulator conference 1997 February 3-7; Fort Collins CO. USDA Forest Service Intermountain Research Station Gen. Tech. Rep. INT-GTR-373. Ogden, UT. Pp 107–110.

Graham, R.T., Harvey, A.E., Jain, T.B. ,and Tonn, J.R. 1999. **The effects of thinning and similar stand treatments on fire behavior in western forests**. General Technical Report PNW-GTR-463. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research. 27 p.

Hessburg, P.F.; Smith, B.G.; Kreiter, S.G. [and others]. 1999. **Historical and current forest and range landscapes in the interior Columbia basin and portions of the Klamath and Great Basins. Part I: Linking vegetation patterns and landscape vulnerability to potential insect and pathogen disturbances.** Gen. Tech. Rep. PNW-GTR-458. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 357 p. Quigley, Thomas, M. tech. ed.; Interior Columbia Basin Ecosystem Management Project: scientific assessment).

Hummel, S. and Agee, J.K. 2003. **Western spruce budworm defoliation effects on forest structure and potential fire behavior**. Northwest Sci. 77 (2): 159–169.

Hummel, S.S., R.J. Barbour, P.F. Hessburg, and J.F. Lehmkuhl. 2001. **Ecological and financial assessment of late successional reserve management**. Res. Note PNW-RN-531. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 25 p.

Hummel, S.S., D.E. Calkin, and R.J. Barbour. 2002. **Landscape analysis with FVS and optimization techniques: Efficient management planning for the Gotchen late successional reserve**. In Crookston, N.L. and R.N. Havis Second Forest Vegetation Simulator Conference; 2002 February 12-14; Fort Collins, CO. Proc. RMRS-P-25. Ogden, UT: U.S.D.A., Forest Service, Rocky Mountain Research Station. Pp 78–82.

Johnson, R.J. 1990. **East Cascades Prognosis Variant of the Forest Vegetation Simulator**. Ft. Collins, CO. USDA Forest Service. 13 p.

Johnson, D.H. and O'Neil, T.A. (managing directors) 2001. **Wildlife-Habitat Relationships in Oregon and Washington**. Oregon State University Press, Corvallis. 736 p.

Kirkpatrick, S., C.D. Gelatt, and M. Vecchi. 1983. **Optimization by simulated annealing**. Science 220: 671–680.

Mendez-Treneman, R. 2002. **Development and maintenance of northern spotted owl habitat in the Gotchen Late Successional Reserve of the Gifford Pinchot National Forest, Washington**. In Parker, S. and S.S. Hummel, Beyond 2001: a silvicultural odyssey to sustaining terrestrial and aquatic ecosystems? Proceedings of the 2001 national silviculture workshop, May 6-10, Hood River, OR. Gen. Tech. Rep. PNW-GTR-546. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. Pp. 10–19.

Montgomery, C. 2003. **The production possibilities approach to understanding and modeling compatibility**. Chapter 2 in R.A. Monserud, R.W. Haynes, and A.C. Johnson (eds.) Compatible Forest Management. Kluwer Academic Publishers. The Netherlands. Pp 35–52.

Reinhardt, E.D. and N.L. Crookston (tech. eds.). 2003. **The fire and fuels extension to the Forest Vegetation Simulator**. Gen. Tech. Rep. RMRS-GTR-116. Ogden, UT: US Department of Agriculture Forest Service. Rocky Mountain Research Station. 209p.

Scott, J.H. and E.D. Reinhardt. 2001. **Assessing crown fire potential by linking models of surface and crown fire behavior**. Research Paper RMRS-RP-29. Fort Collins, CO: U.S.D.A., Forest Service, Rocky Mountain Research Station. 59 p.

Thomas, J.W.; Forsman, E.D.; Lint, J.B. [and others]. 1990. **A conservation strategy for the northern spotted owl**. U.S. Department of Agriculture, Forest Service; U.S. Department of the Interior, Bureau of Land Management; Fish and Wildlife Service; National Park Service. Washington, DC: U.S. Government Printing Office.

U.S. Department of Agriculture, Forest Service; U.S. Department of the Interior, Bureau of Land Management. 1994. **Record of decision for amendments to Forest Service and Bureau of Land Management planning documents within the range of the northern spotted owl**. [Place of publication unknown]. 74 p. [plus Attachment A: standards and guidelines].

Van Dyck, M.G. 2001. **Keyword reference guide for the Forest Vegetation Simulator**. USDA Forest Service. Forest Management Service Center. June 2001. 93 p.

Managing Efforts to Prevent Forest Fires in South America [1]

Guillermo Julio-Alvear[2]

Background

South America is divided into 13 countries and has a total population of around 340 million people inhabiting an area covering 17.4 million square kilometres. It has a wide variety of climates, landforms and vegetation, as well as notable differences in this respect within some of the countries themselves. There are similarly wide-ranging economic and social differences with respect to per capita income, access to basic services, infrastructure, education, scientific and technological development and public institutions and civil society.

Table 1—*Basic data for South American countries*

COUNTRY	Land area (km^2)	Population ('000)	Pop. Density (pop/km^2)	Rural pop. (%)	GDP per capita (US$) in 1997
Argentina	2,736,690	36,577	13.4	10.9	8,075
Bolivia	1,084,380	8,142	7.6	36.0	912
Brazil	8,465,510	167,988	19.8	19.3	4,514
Colombia	1,038,710	41,564	40.0	25.5	2,039
Chile	748,810	15,019	20.1	15.5	4,478
Ecuador	276,840	12,411	44.8	38.3	1,531
French Guiana	88,150	174	2.0	22.4	n/a
Guyana	121,498	855	4.4	62.3	766
Paraguay	397,300	5,358	13.5	44.8	1,946
Peru	1,280,000	25,230	19.7	27.6	2,580
Suriname	156,000	415	2.7	48.4	415
Uruguay	174,810	3,313	19.0	8.9	6,076
Venezuela	882,060	23,706	26.9	13.0	3,499
TOTAL	17,450,478	340,752	19.5	20.2	4,329

Source: *FAO (2003), "State of the World's Forests"*

Over fifty percent of the surface area of South America is covered by forest, and it is therefore possible to consider it a forest region. Based on work at the University of Wisconsin's Cartography Laboratory, Mery *(1987)* has established a classification distinguishing six categories of autochthonous vegetation in the region's forests.

[1] An abbreviated version of this paper was presented at the second international symposium on fire economics, policy, and planning: a global view, April 19–22, 2004, Córdoba, Spain.

[2] Ingeniero Forestal, Profesor Titular del Departamento de Manejo de Recursos Forestales, Facultad de Ciencias Forestales de la Universidad de Chile; Casilla 9206, Correo Central de Santiago de Chile; Teléfono: 56-2-541 7971; email: gjulio@uchile.cl.

These categories are set out below, together with a generalised indication of their distribution.

1) Tropical forests, this being the predominant type of forest in South America.
2) Pygmy forest, brushland and grasslands on low-lying land, found in varying degrees in most countries in the region, particularly common in Brazil, Paraguay, Ecuador, Bolivia, Chile and Argentina.
3) Tropical savannas, principally found in Brazil, Colombia and Venezuela
4) Mixed Deciduous-Coniferous Forests at medium elevations, principally in Brazil, Argentina and Chile
5) Medium altitude grasslands, which are most common in Brazil, Paraguay, Argentina and Uruguay.
6) Vegetation in arid zones, specifically located in Ecuador, Peru, Chile and Argentina.

Table 2--presents the South American forests and wild areas enjoying protection in 2003 based on reports published by FAO (2003) and PNUMA (2000).

Table 2—*Protected forests and wild areas in South America*

COUNTRY	Total forest (‘000 ha)	Total forest (Pct. of country)	Natural forests (‘000 ha)	Planted forests (‘000 ha)	Wild protected areas (‘000 ha)	Wild protected areas (Pct. of country)
Argentina	34,648	12.7	33,722	926	9,126	3.3
Bolivia	53,068	48.9	53,022	46	17,818	16.4
Brazil	543,905	64.3	538,923	4,982	52,672	6.2
Colombia	49,601	47.8	49,460	141	9,365	9.0
Chile	15,536	20.7	13,396	2,140	14,137	18.9
Ecuador	10,557	38.1	10,390	167	15,552	56.2
French Guiana	7,926	89.9	7,925	1	n/a	n/a
Guyana	16,879	78.5	16,867	12	n/a	n/a
Paraguay	23,372	58.8	23,345	27	1,401	3.5
Peru	65,215	50.9	64,575	640	6,676	5.3
Suriname	14,113	90.5	14,100	13	n/a	n/a
Uruguay	1,292	7.4	630	662	47	0.3
Venezuela	49,506	56.1	48,643	863	56,040	63.5
TOTAL	885,107	50.7	874,472	10,635	209,282	10.7

Sources: UNEP (2000) “GEO – Latin America and the Caribbean”.
FAO (2003) “State of the World’s Forests”.

The GEO report on the future of the environment *(UNEP, 2000)* stated that the most common obstacles were lack of financing, technology, qualified personnel, and, in some cases, the presence of cumbersome and complex legal frameworks, frequently ill-adapted to the realities of the tasks they face. It also drew attention to the three principal environmental issues affecting this region, where state intervention and use of forestry resources is crucial:

- Widespread poverty in rural areas and a progressive population flow into urban areas, principally to mega-cities, where poor air quality is a threat to health and water shortages are an everyday occurrence.
- The depletion and destruction of forests and the threat to biodiversity.
- The impact of climate change, with disasters such as forest fires and floods, causing immeasurable loss to the communities and natural resources.

Although South America could be classified as a forest region due to its high proportion of forest cover, there are only two countries where forestry and timber production play an important role in overall development. In general, forest management has only minimal presence in national economic and social strategies.

The Current State of Protection in South America

Forest fires represent a serious problem in South America, given the way in which they destroy natural renewable resources and their economic, social and environmental impact. This has been confirmed on several occasions at meetings on forest programmes in Latin America organized by the FAO, at which it has been repeatedly emphasized that forest fires and burning constitute significant causes of deforestation and the destruction of forests. However, there have not been any real tangible changes in national policies or in the attitude of the local populations in response to these problems, and therefore their impact has not been reduced.

Forest fires in South America vary tremendously from country to country due to natural variations in climate, vegetation, landforms, land use, education and the behavior of the human population. This results in notable differences in the frequency and extension of fires. If the data is analyzed by country, there are also significant differences within the countries themselves with respect to the size and nature of the problem, and between one season and another.

Furthermore, the management of forest fire prevention and suppression activities also varies greatly in terms of effectiveness and the precise manner in which they are carried out. The distinct economic capacity of each individual country leads to differences in the implementation of forest fire programmes, in awareness of the problems and in the application of efficient technology and organizational frameworks. The national approach to the value and priority of forestry resources and the need to protect them through policy initiatives also has an affect. In addition, traditional land use, which frequently constitutes an insurmountable form of atavism, gives rise to situations which are sometimes incomprehensible, gravely inhibiting the ability of the poorest of countries to take steps which are commonplace elsewhere.

The inherent variability of forest fires and the conditions which make it possible to control them leads to the conclusion that each country should find its own fire

suppression model which adjusts to the principal factors leading to the start and extension of forest fires and to the capacities and limitations in each specific country affecting the establishment of effective prevention and fire fighting systems. The implication is that it is not advisable simply to copy a fire suppression system and to install it in another. Nevertheless, forest fire suppression covers a wide range of specific activities designed to prevent, fight and also use fire, with results which are sometimes worthy of emulation.

The Incidence of Forest Fires

In general, there are serious defects in South American statistics on forest fires. There are exceptional cases of national statistics which are complete and reliable. There are some cases where there are incomplete national records from several sources which do not always agree. On the other hand, practically half the countries concerned do not hold, or do not publish any data on the subject.

An effort has been made to gather statistical data drawing on official reports, various publications and also informal sources in order to gather estimated data on the incidence of forest fires, and the results are presented in Table 3. Argentina, Bolivia and Brazil are conspicuous for the huge surface areas damaged by forest fires, representing around 88% of the total surface area damaged in the six countries studied.

Table 3—***Estimated data on forest fires in South America***

Country	Dates	**Average number of fires** (per year)	Surface area burnt (average ha/year)
Argentina	1990-1999	11,513	1,028,739
Bolivia	1991-2000	N/a	917,400
Brazil	1990-2000	160,000	1,500,000
Colombia	1995-1998	3,246	59,215
Chile	1981-2002	5,251	53,395
Ecuador	N/a	N/a	N/a
French Guiana	N/a	N/a	N/a
Guyana	N/a	N/a	N/a
Paraguay	N/a	N/a	N/a
Peru	N/a	N/a	N/a
Suriname	N/a	N/a	N/a
Uruguay	1990-94	2,353	3,311
Venezuela	1987-99	1,394	8,230

Source: *G. Julio (2003), "Planificación y Prevención de Incendios Forestales en Ecosistemas Nativos-Una Perspectiva de Latinoamérica".*

The six countries concerned suffered an average of 126.96 fires for every 10,000 ha of land per year. If this extrapolated to the other seven countries for which information was unavailable, it can be assumed that there are a total of around 230,000 forest fires a year in South America as a whole. In addition, if it is assumed that these remaining seven countries lose 35 ha of forest per fire, it can be concluded that around 4.8 million ha per year are lost in South America through forest fires. If the direct loss per hectare is valued at US $300, the damage caused by forest fires can be calculated at 1.44 billion dollars per year, without even considering the social and environmental cost arising from the destruction of renewable natural resources and other elements of value on the outskirts of the cities and the villages.

The causes of forest fires

The available information on the origin of forest fires is even more threadbare than the data presented above on the incidence and extension of fires. Table 4 solely provides data on four countries. Unfortunately, the classification criteria are distinct and in certain cases important risk factors such as burning are classified under other headings (negligence, agricultural activities).

Table 4—*Percentage distribution of current estimated causes of forest fires in four South American countries.*

CAUSE	Argentina	Brazil	Chile	Venezuela
Rural activities	-	3	4	30
Burning	-	32	10	9
Recreation and bonfires	-	5	4	-
Cigarettes, etc.	-	10	-	-
Children's toys	-	-	8	-
Railways	-	1	2	-
Movement of people and vehicles	-	-	32	-
Lightening and natural phenomena	10	1	0,3	-
Incendiary	28	41	37	33
Miscellaneous and other acts of negligence	37	7	3	6
Unknown	25	-	-	22

Sources: *G.Julio (2003), "Planificación y Prevención de Incendios Forestales en Ecosistemas Nativos-Una Perspectiva de Latinoamérica".*

R.Vélez (2000), "Los Incendios Forestales en Iberoamérica".

SIF/FUFEF/IPEF (1998), "Anais 1° Seminario Sul-Americano sobre Controle de Incendios Florestais".

Although there are no statistics available to support the claim, the most significant cause of forest fires and the destruction of forests is the use of fire in clearing land for agriculture and livestock. Burning is traditionally carried out without the appropriate control or techniques to secure a positive outcome. Not only does it give rise to situations where the fire spreads out of control, destroying vegetation and valuable property, it also causes the continual degradation of renewable natural resources and the environment, leading to a loss of soil fertility, an increase in erosion, a deterioration of water resources, air and water pollution and, in general, damage to biodiversity and the quality of the human population's living space.

Burning is a complex issue because the rational use of fire involves factors which are beyond the capacity of the farmers. In general, the greatest damage takes place in socially and economically deprived rural areas, with small estate owners, smallholders, communal or indigenous peoples excluded from development and technology, who have the compelling need to survive and who find fire to be their only means of continuing with their traditional use of the land.

The situation is also serious on the large ranches specialising in extensive livestock production, where burning is used to improve grazing due to its ease of use and low cost and because it does not really matter if the fire spreads over large areas, even less so if it causes environmental damage.

In general, the incidence of burning as a percentage of forest fires held steady in the majority of countries. A good example of this problem is Brazil (Table 5), where the percentage of fires caused by burning did not see any reduction over a ten year period.

Table 5—***Changes in patterns of causation in Brazil (percentage of fires over two periods)***

Cause of forest fire	1983 - 87	1994
Forestry activities	6.7	2.7
Burning	33.6	32.2
Cigarettes etc.	8.0	10.2
Recreation	10.9	5.4
Railways	0.9	1.1
Lightening	2.1	1.1
Incendiary	29.8	41.4
Miscellaneous	8.0	5.9

Source: G.Julio (2003), "Planificación y Prevención de Incendios Forestales en Ecosistemas Nativos-Una Perspectiva de Latinoamérica".

One exception to this rule is Chile (Table 6), where burning as a cause of forest fires has dropped over a twenty-five year period from 41.3 % between 1976 and 1980

down to 10-12 % between 1991 and 2000. The factors influencing this change were fire prevention campaigns, intensified legal controls, greater environmental awareness amongst the public and also the decision of the forestry companies to reduce their use of fire in favour of alternative measures.

Table 6—*Changes in patterns of causation in Chile (% of total fires per five year period).*

CAUSE	1976-1980	1981-1985	1986-1990	1991-1995	1996-2000
Burning	41.3	24.0	16.8	10.1	12.4
Forestry work	3.8	3.5	2.9	1.5	2.5
Agricultural work	1.4	2.2	2.1	0.9	1.3
Sport and recreation	4.8	3.5	3.2	2.6	3.1
Children's toys	12.0	8.8	11.1	8.0	6.9
Railways	4.6	3.6	1.9	2.2	1.2
Vehicle transit	2.0	2.0	2.1	1.9	2.1
Human transit	14.2	27.7	31.6	32.5	27.5
Other negligence	1.0	2.5	1.5	1.2	1.3
Incendiary	13.4	20.9	24.9	37.1	39.2
Natural Phenomena	0.1	0.1	0.1	0.3	0.2
Accidents	1.4	1.2	1.8	1.7	1.3
TOTAL FIRES	12,977	24,923	23,774	24,044	22,923

Source: *G.Julio (2003), "Planificación y Prevención de Incendios Forestales en Ecosistemas Nativos-Una Perspectiva de Latinoamérica".*

CONAF: (1976-2001)Anuarios del Sistema Nacional de Estadísticas en Manejo del Fuego

It has also been noted both in Brazil and Chile that there has been a significant increase in the number of intentionally started forest fires. There are several reasons for this particular cause of fires, which is probably to be found over the whole of South America, but they are all basically the product of the increased levels of risk created by the growth of undesirable attitudes amongst the population. Pyromania is experiencing huge growth as a mental illness on the outskirts of large urban areas, the product, it would seem, of development or civilization, and accompanied by a similar growth in suicides and drug addiction and alcoholism.

In addition, Chile, suffers the effects of the introduction of large-scale forest plantations and enormous timber-producing industrial complexes. The benefits of these developments, usually to be found in poverty-stricken rural areas, do not really reach the local inhabitants, and this leads to a state of permanent protest in which the destruction of forests by fire has become one of the weapons used against these huge business empires. This has become one more element in the fight by the indigenous peoples to claim their rights in the lands they believe stolen from them many years ago.

Organization in the control of forest fires

It has already been mentioned that South America is host to a wide variety of climates, land forms and renewable resource, as well as natural environments and ecosystems in general. There are also highly heterogeneous levels of economic,

social and cultural development. This creates differences in the nature of the problems which give rise to fires and their spread into forest fires, as well as varying capacity, criteria and methods applied in the suppression of fires.

Although there is usually an awareness of the damage caused by forest fires, it is noticeable that there is an insufficiently clear notion of how the problem is to be tackled, which is related to a certain extent to the lack of political will to promote effective forest protection. The following comments can be made in this respect:

a) Responsibility for forest protection generally falls upon government agencies. However, although forests are a prime natural resource, the sector appears to be ill-defined or low in the priorities of the state apparatus. In general, forestry activities are considered to be an extension of agriculture, which places a heavy limitation on the depth of analysis and evaluation required to formulate proposals for the sector's development.

b) This means that the alarm and damage caused by forest fires leaves governments turning to a wide range of institutions with only a partial capacity to address the problem, such as firefighters, the military and police, etc. These organizations do not normally have the degree of specialization or adequate equipment to fight fires in rural areas, and their efforts are often inefficient. The experiences of the developed countries indicate that the most effective method of combating forest fires is the use of professional bodies which specialize in this specific task.

c) In any event, fire management is much more than firefighting, given that it covers a wide range of activities which must be undertaken simultaneously and in a co-coordinated fashion. Aspects such as prevention, fire detection and even the manner, in which the firefighting forces themselves are organized, must all be placed within the same overall framework in order to plan and develop successful fire management programmes. In the current situation, when the above-mentioned activities are put under the control of several different bodies, there is a noted tendency for each body to approach their responsibilities with differing criteria and degrees of preparation, and they frequently compete amongst themselves rather than reinforce their efforts through co-operation and synergies.

d) The lack of reliable data makes it difficult to analyze the difficulties and obstructs appropriate planning of prevention and firefighting activities. It is not possible to develop appropriate policy initiatives or the necessary strategies without sufficient knowledge of the nature and degree of the damage being done or of the available resources to put the control measures into effect.

e) Some countries frequently draw on foreign organizations to evaluate the problem of forest fires, and to obtain proposals for action. The consultants generally take their work seriously and duly provide their recommendations. However, the situation nearly always returns to the point of departure once the experts have taken the plane home, and the reasons might be found in the following comments:

    i. The government which receives the international input is often institutionally incapable of carrying the consultant's work forward. Perhaps, the most serious flaw however, is the failure to assign adequate resources to the expert report to permit the joint participation of local officials in the analysis of the existing problems

and in the generation of proposals to ensure that the project begun by the outside experts may be taken further in the future.

ii. In addition, the consultants offer their own personal views, based on experience which does not always include a sufficient understanding of the nature and conditions of the country concerned. Furthermore, when the experts come from a more developed country in the other hemisphere, the tendency is for them to propose solutions which are much better suited to their home countries than the country seeking advice, where the solutions are almost impossible to put into action. The consultants are not really in the country long enough (normally only a couple of months) to build up an accurate picture of the situation and circumstances which should form the basis of their recommendations.

FINAL COMMENTS

The information provided above indicates that South American countries are being seriously affected by the number and extent of forest fires and also that the majority of governments have not yet established effective means of protecting their renewable natural resources.

It is thought that there are no significant technical barriers in any of the South American countries to the design and implementation of a proprietary system for the control of forest fires based on the specific conditions and resources available in each individual country. However, this can only be achieved if the relevant bodies take their responsibility for the protection of forests seriously. Once the specialists with links to the problem, particularly those involved in forestry activities, are transformed from passive spectators to active agents of change, much of the groundwork will have been laid to achieve the level of organization required to control forest fires.

It should not be forgotten that although foreign experience can be extremely helpful in this task, a significant proportion of each individual country's circumstances are unique and different from those of their neighbours. This suggests that the initiative, creativity and determination to confront the problem should principally be drawn from those who are directly affected by the problem.

It is essential that steps are taken to set up effective training programmes for all officials involved in this issue, at all levels of the organizations concerned. It is not only the organizations' workforces which need to be adequately trained in order to carry out their duties in the prevention, suppression and use of fire, but also the senior managers, who need to have a global understanding of the problem and to be aware of the capabilities of the available fire protection resources, as well as the general and specific criteria and strategies which are applicable to fire prevention. It must be stressed that the principal barrier in these countries is not the lack of funds (although money is, in general, in short supply), but rather in the manner in which they are allocated and used.

Some of these countries have managed to incorporate obligatory modules on forest fire prevention into courses for forestry specialists at technical colleges and universities. These are the very same countries which enjoy the highest levels of prevention and firefighting capability. This policy should be generally applied,

because experience has shown that the professionals produced by these schools are the most able to pass knowledge on to the workforce, while at the same time they also lay the foundations for policy creation and planning in this respect within the general context of the management of sustainable forest resources, given their greater capacity to set out the arguments and persuade the authorities of the need to establish organisational frameworks which are technically sound and capable of implementation.

BIBLIOGRAPHY

BAPTISTA, P. (1998) Los Incendios Forestales en la República Oriental de Uruguay. Anais 1° Seminario Sul Americano sobre Controle de Incendios Florestais. SIF/FUPEF/IPEF, Belo Horizonte, Brazil. pp. 332–345.

CORNACCHIA, G., Pereira de Sá, S. (1998) Sistema Nacional de Prevencao e Combate aos Incendios Florestais-Prevfogo-Metas e Resultados 1995-97. Anais 1° Seminario Sul Americano sobre Controle de Incendios Florestais. SIF/FUPEF/IPEF, Belo Horizonte, Brazil. pp. 21–31.

FAO (2003). Situación de los Bosques en el Mundo. Departamento de Montes, FAO, Roma. 151 p.

HEREDIA, R. (1999) Plan Nacional de Manejo del Fuego: República Argentina. FAO Meeting on Public Policies Affecting Forest Fires. FAO Forestry Paper 138. Rome. pp. 307–311.

IFFN (2003) Fire Situation in Argentina. Country Notes, IFFN No. 28. pp 37–40.

IFFN (2003) Fire Situation in Bolivia. Country Notes, IFFN No. 28. pp 41–44.

IFFN (2003) Fire Situation in Brazil. Country Notes, IFFN No. 28. pp 45–50.

IFFN (2003) Fire Situation in Colombia. Country Notes, IFFN No. 28. pp 67–72.

JULIO, G. (1996) Control de Incendios Forestales en Chile: Participación del Gobierno y Empresas Privadas. Anais IV Reuniao Tecnica Conjunta FUPEF/SIF/IPEF em Controle de Incendios Florestais. Curitiba, Brazil. pp. 29–39.

JULIO, G. (2001) Estado Actual y Perspecticas de la Protección contra Incendios Forestales en América Latina. Actas 1° Simposium Nacioal sobre Técnicas de los Medios Aéreos en Incendios Forestales. Universidad de Córdoba/ENRESA/Junta de Andalucía. Córdoba. pp. 137–148.

JULIO, G. (2003) Planificación y Prevención de Incendios Forestales en Ecosistemas Nativos-Una Perspectiva Latinoamericana. VI Maestría en Conservación del Medio Natural. Universidad Internacional de Anadalucía, La Rábida, Spain. 14 p.

MENDES RAMOS, P. (1999) Public Policies Affecting Forest Fires in Brazil. FAO Meeting on Public Policies Affecting Forest Fires. FAO Forestry Paper 138. Rome. pp. 313–317.

MERY, G. (1987) "Latin America Forest Sector Development: A Short-Term Review and Prospects". In: Deforestation or Development in the Third World? - Volume I. Division of Social Economics of Forestry, Finnish Forest Research Institute, Pub.Nr 272, Helsinki. pp. 143–219.

MUTCH,R., LEE,B., PERKINS,J. (1999) Public Policies Affecting Forest Fires in the Americas an the Caribbean. FAO Meeting on Public Policies Affecting Forest Fires. FAO Forestry Paper 138. Rome. pp. 65–107.

PNUMA. (2000) GEO – América Latina y El Caribe. Perspectivas del Medio Ambiente. Oficina Regional del PNUMA, Mexico City, 144 p.

TESOLIN, O. (1999) Políticas Públicas que afectan los Incendios Forestales en Argentina. FAO Meeting on Public Policies Affecting Forest Fires. FAO Forestry Paper 138. Roma. pp. 303–305.

VELEZ, R. (2000) La Defensa contra Incendios Forestales – Fundamentos y Experiencias. McGraw Hill-Interamericana de España, Madrid. 1302 p. (14)

YEGRES, L.E. (1998) Control de Incendios Forestales en Venezuela. Anais 1° Seminario Sul Americano sobre Controle de Incendios Florestais. SIF/FUPEF/IPEF, Belo Horizonte, Brazil. pp. 13–19.

Page left blank intentionally.

Remfiresat, Real Time Emergency Management for Forest Fire Services via Satellite[1]

Jesús Gonzalo,[2] Susana Martínez,[3] Gonzalo Martín[3]

Abstract

The main aim of Remfiresat is to demonstrate the synergetic use of available space technologies for the management of forest fires. A consortium led by INSA, in collaboration with 'Junta de Castilla y León', and financed by the European Space Agency developed and evaluated the system during the summer campaign of 2003 in Castilla y León. The demonstration process was executed in three phases: the first focused on the design and using a few representative resources, the second developing the whole system and the third under real fire conditions (June to September 2003).

Satellite Earth Observation, Navigation and Communication services were combined in a single management tool that allowed operators to make use of all available datasets from any location, from central offices to in-field command centres. Current assets were fully integrated with the satellite-based system.

The Dynamic-Distributed-GIS tool manages national, regional, provincial and local information, following the established decision-making chain. The test site was the province of Salamanca (Provincial Centre + Mobile unit), monitored from Valladolid (Regional Centre) and reporting to the National DGCN (Valladolid and Madrid).

Private and Public communication networks were complemented by satellite communication lines to provide redundancy or access to remote areas. Mobile resources were referenced by a GPS system and communicated via ORBCOMM (or existing INMARSAT terminals).

An Earth Observation processing centre, located at LATUV (Valladolid) acquired and prepared the satellite images from general purpose satellites (NOAA, FENYUNG, TERRA, METEOSAT) and dedicated ones (BIRD). Five different products were generated on at least a daily basis (depending on acquisition frequency): fire risk index, hot spot map, fire-line maps, burned area cartography and weather forecasts.

In some specific situations a deep study of the evolution and consequences of a big fire was required. So, high-resolution images, as LANDSAT images, were acquired to obtain the burned area map, and a fire area simulator (FARSITE) was used to analyse the fore behaviour, starting pint and possible evolutions.

German satellite BIRD also supported the image provision, thanks to its dedicated thermal sensors, specialized in the identification of hot spots. Results showed that even as small as 5-m fire-line outbreaks can be detected.

Images and more information can be obtained directly contacting the authors.

---

[1] An abbreviated version of this paper was presented at the second international symposium on fire economics, planning, and policy: a global view, 19–22 April, 2004, Córdoba, Spain.

[2] Project Manager, INSA Ingeniería y Servicios Aeroespaciales. Department of Studies and Missions, Pº Pintor Rosales, 34, Madrid, CP 28008.

[3] System Engineer, INSA Ingeniería y Servicios Aeroespaciales. Department of Studies and Missions, Pº Pintor Rosales, 34, Madrid, CP 28008.

System Concept

The objective of Remfiresat is to demonstrate the use of satellite technologies to manage an emergency situation as the uncontrolled fire is. The system has been designed following a user requirement driven approach and the system suitability has been proved and validated through a comprehensive set of demonstrations to check the benefits of the application under real crisis scenarios.

Remfiresat combines the main satellite technologies to provide a new orientation in the management of natural disasters: Earth Observation, Navigation systems and satellite communications. These space based systems work in a synergetic manner with the ground user facilities to reach a more efficient utilization of available technology.

Remfiresat General Description

Architecture of the Remfiresat System

Fire Fighting services in the European countries are organized in different centralized or de-centralized structures to optimize the management of resources. Remfiresat system is embedded at decision maker premises to receive all information from external and internal sources.

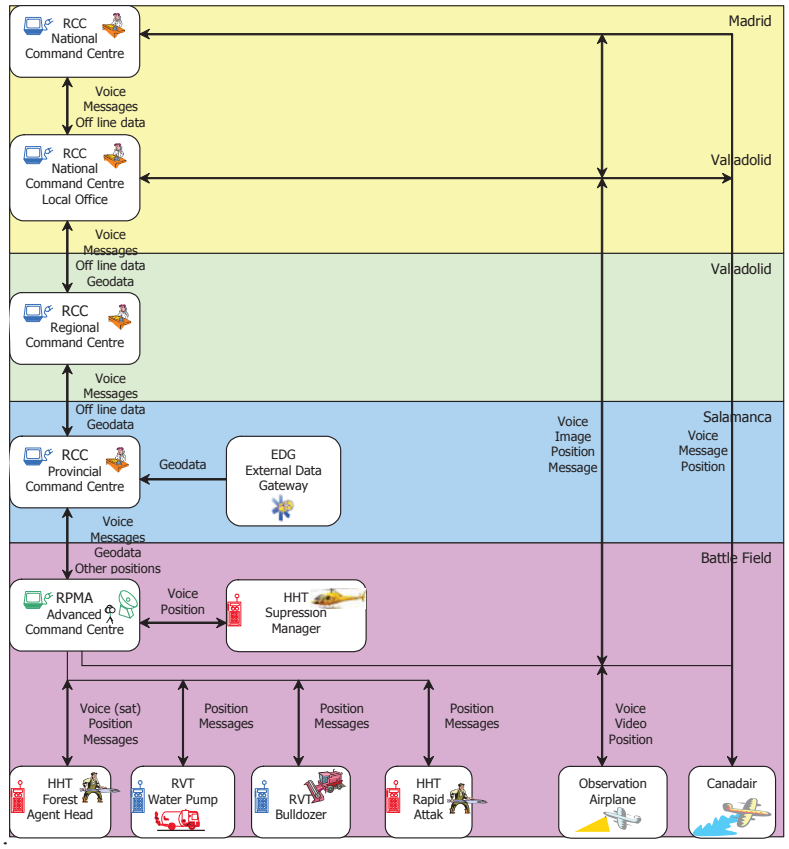


Figure 1—Remfiresat system architecture embedded at user hierarchical organization. HHT is a hand-held terminal and RVT is a vehicle terminal.

The Castilla-Leon Forest Fire service in Spain has been selected to run the experiment as reference user. The region encloses several provinces, regional managers report to national authority and provincial ones to regional. Within provinces, if a fire has enough entity an advanced command centre is deployed in the battle field for accurate management activities.

Remfiresat system is present at all scales in the fire fighting decision chain, providing communication lines for transferring information among managers, but also from sources to managers. This communication is established following the hierarchical user structure. The transferred information includes apart from traditional voice and fax capabilities, digital data, imagery and positioning of mobile resources.

The different user bodies are equipped with data gathering terminals and appropriate communication devices to form the system network. Besides, mobile resources are equipped with positioning capability and forest agents in the battle field are fitted out with communication assets.

The External Data Gateway (EDG), included in the Remfiresat network, is in charge of satellite data processing.

Remfiresat Command Centres

The Command Centres are the brains of the Remfiresat system. These are a group of nodes interconnected through a telecommunication network where operator can access system services, manage resources, watch Earth observation products and communicate each other.

The generic Remfiresat Command Centre (RCC) is located at user decision level. The RCC is a standard desktop computer with specific hardware and software to connect to other system terminals. This centre is able to receive process and transfer the requested information, either external or generated by the system. The main data packages, manage by the RCC are: voice and message communications, positioning of mobiles, geo and meteorological data and voice, fax and internet with other authorities.

The Advanced Command Centre (RPMA) is normally deployed in a forest area relatively close to the fire front; this centre is a replica of the provincial centre and becomes the neurological centre at the battle field. It requires specific equipment to provide high bandwidth link between the provincial module and the advanced one to exchange large pieces of information, for instance satellite data. The link is provided by a portable VSAT station which is deployed at the RPMA unit and a second antenna permanently installed at the provincial centre.

The RPMA has been installed either in a tent peg or a UMMT (Mobile unit for Meteorological Data). Computers and subsystems are installed in user existing facilities so that size and power consumption are adapted to these premises.



Figure 2—Remfiresat Advanced Command Centre installed in a tent peg and a mobile vehicle.

Remfiresat Hand-held and Vehicle Terminals

Remfiresat terminals are individual units to be operated directly during the fire-fighting activity. There are different models of terminals, which are utilised depending on the user requirements in a real situation:

- Remfiresat Hand-held terminals (HHT): They are units providing voice and automatic positioning among HHT and either the provincial or the advanced command centre. There are two kind of hand-held terminals regarding different messaging capabilities:
    - HHT1: is a satellite mobile phone which provide voice capabilities through Globalstar system
    - HHT2: is an ORBCOMM message communicator. It includes automatic GPS positioning reported to its corresponding command centre and a user interface with an input keyboard and LCD display.
- Remfiresat Vehicle Terminals (RVT): they are units installed in fire fighter vehicles, water pump trucks, bulldozers, airplanes and RPMA vehicle to provide GPS positioning and messaging capabilities to provincial and advance command centres. Orbcomm is the used system for terrestrial units and Inmarsat is the one for aerial units.



Figure 3—HHT1: Globalstar mobile phone. HHT2: Communicator ORBCOMM + ALCOM terminal. RVT: Psyon Orbcomm terminal

There is other alternative, a Personal Digital Assistant (PDA) with an expansion kit including GPS and GPRS capabilities. The PDA has implemented a reduced version of the Remfiresat system that allows introduction and sharing information, viewing layers, etc.

Earth Observation Processing Centre

Remfiresat system intends to integrate different space technologies in a compact-friendly system to generate value-added products that improve efficiency to the protocols currently in use. The EDG is in charge of the acquisition, processing, storing and dispatching of the Earth observation data and related products, making use of as much as possible remote sensing satellites and suppliers.

The most important dataset managed by the EDG is the remote sensing data, both near real time and historical. The source of this information provides from diverse satellites which different passing hours. The appropriate agreements are signed with data providers to ensure the timely arrival of the data from the different sources.

The EDG produces interesting products for fire fighting. It takes the satellite raw data and the ancillary data to further generate the following products:

Fire line: It consists of a vector representation of the fire front. The product is generated when a fire is produced during a pass of the MODIS-TERRA satellite and within their coverage area. BIRD demonstration satellite has been also used during demonstrations. The fire line is ready one hour and ten minutes after the beginning of the raw data transmission. Attending to external data, the calendar of high resolution satellites passes is studied and the passes coinciding with a fire development of certain relevance are located, so the image is acquired to estimate fire line and burned area map.

Hot spot map: It is composed of a GIS layer containing suspicious points hotter than initially expected. NOAA, FENGYUN and MODIS are used to cover the whole Castilla-Leon and areas of Portugal.

Risk index: It is a referenced map in UTM-H30 with a grid of 10x10 km containing an estimate of the fire risk, indicating the probability of occurrence of fire spreading. The fire risk index is daily elaborated at passing of the NOAA, FENGYUN and MODIS satellites. As time difference between FENGYUN and TERRA satellites is very short the most appropriate image is selected in each case.

Burned area map: It consists of a geo-referenced image in raster format with the burned area highlighted. The product is generated by using NOAA and FENGYUN satellites providing 1x1 km resolution, but also TERRA with 250x250 m resolution. The detected burn surface has to be large enough to be seen in both scales. NOAA and FENGYUN satellites can cartography minimum burned area around 70 hectares, while TERRA around 5 hectares approximately. Commercial satellites can be also used, as for instance Landsat, providing quite better resolution.

Weather forecast: The weather forecast products (ground temperature, humidity, accumulated rainfall, wind velocity and wind direction) are elaborated by using the MM5 Weather Forecast Model.

Fire propagation forecast: It consists of the propagation of the fire line by using the FARSITE fire propagator. The mentioned simulation tool incorporates existing models of surface fire, crown fire, point-surface fire acceleration, spotting, and fuel moisture. The models are integrated using a vector propagation technique for fire perimeter expansion that control for both space and time resolution of fire growth over the landscape. The model produces vector fire perimeters (polygons) at specified time intervals. The vertices of these polygons contain information on the fire's spread rate and intensity, which are interpolated to produce raster maps of fire behaviour.

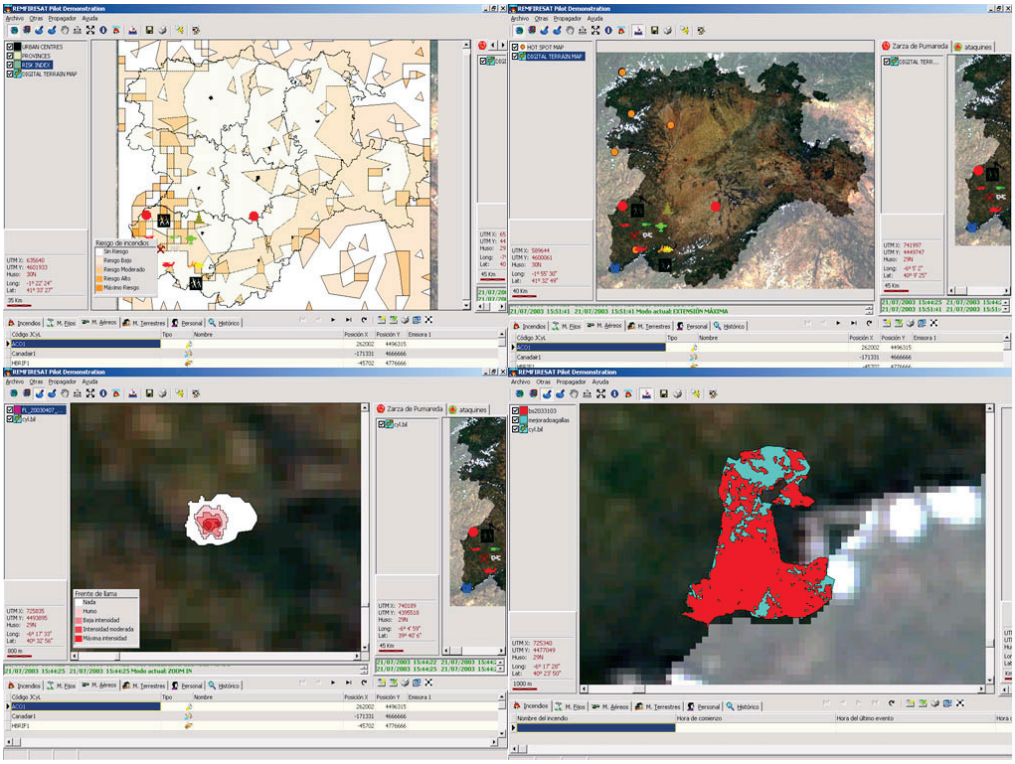


Figure 4—Earth Observation elaborated products in the Remfiresat tool. From left to right: Risk index map, hot spot map, fire front line and burned area map

Table 1—*Earth Observation elaborated products and features regarding forest fire fighting phase.*

Forest Fire Fighting Phase	Remfiresat Product	Features
Prevention phase	Risk index	10 km resolution
Detection phase	Hot spot map	1000-250 m resolution (real time) Pixel size accuracy
Suppression phase	Fire front representation Fire propagation forecast (optional)	1000-250 m resolution (real time) 30 m resolution (off-line) Pixel size accuracy
Damage assessment phase	Burned area assessment	1000-250 m resolution (real time) 30 m resolution (off-line)
All phases	Weather forecast	Pixel size accuracy

It is worthy of mention the German BIRD satellite (Bi-spectral Infra Red Detection micro satellite) which is a technological demonstrator. The main objective of this satellite is to show forest-fire services capacities and possibilities of a future fire-activities dedicated satellite constellation. Its thermal sensors have better resolution than currently existing general purpose satellite sensors, such as AVHRR or MODIS, making it able to locate small fires. BIRD detected fire lines as small as 5-m during a set of prescribed fires performed in the region of Galicia on May 2003. BIRD satellite images were also used during demonstration activities within Remfiresat.

Dynamic and distributed geographical information system

The DDGIS is the application running at the Command Centres allowing users to manage local and external resources temporally allocated to them, alarms, fires, geographic data and other events of interest for the fire fighting activities in the different phases of the crisis.

The dynamic and distributed GIS (DDGIS) tool uses a data model (distributed database) that automatically actualized with the information received or requested.

The DDGIS tool provides a friendly and easy-to-learn user interface, allowing the operator to see the evolution of the different means. Each element (fires. alarms, bulldozers, canadairs, brigades, etc) is represented on the maps, in their current position, with a representative symbol. Layers with topographic information can also be loaded. Users decide in any moment the visualized information.



Figure 5—DDGIS main view. Different elements are present in the main window. The chief components are a general map and a group of maps that represents zoomed areas of the general one. These maps are complemented with a system log (under both maps) and a properties window, placed under the group of maps. These four elements are where operators can analyse results of software functions accessed by the main menu and the toolbar buttons, both placed at the top of the window.

The software has two operational modes: A Real-time mode, involving fire fighting, resource assignment, communications between nodes and reception of external data, and an off-line mode, where history processing shall be made in order to generate reports and statistics.

System demonstration and operational use

The system has been widely demonstrated in order to verify its performances and to fulfil user expectations. Several proofs have been carried out: concept proof, full commissioning, two real fire demonstrations and finally full season operation during 2003 fire campaign.

The concept proof validated the proposed technical solutions provided by a limited and representative set of Remfiresat modules. The full commissioning was carried out after the full system integration. Two prescribed fires were executed along with this last demonstration in order to obtain satellite images to produce the first forest fire fighting products and to test the system in a real situation.

After demonstrated the successful system operation, the system was running during the 2003 summer campaign. It was intended that operators used the whole system functionalities and capabilities during a long period of time, for them to see

the advantages of space technologies and in forest fire fighting, and to generate a feedback used by Remfiresat system engineers to prepare the migration to a full operational system.

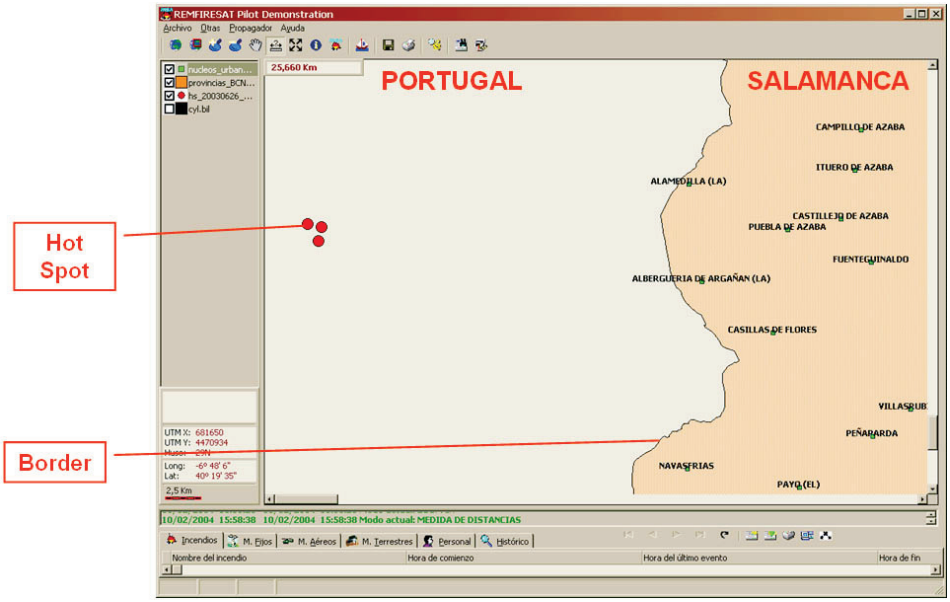


Figure 6—The hot spot map obtained from MODIS-TERRA satellite revealed the existence of a forest fire 25 km far from the Spanish border. The Forest Fire service was warmed by the provided map and then prepared attack resources in case an intervention was needed.

Conclusions

The appropriate synergy among communication, navigation and remote sensing satellite services leads to a system that fulfils the requirements of the authorities and operators involved in the forest fire-fighting activities in a cost effective manner.

The system is composed of a network of Command Centres, one of them offering the capability of installation close to the fire area, from which all the suppression activities are commanded and monitored. The Command Centres share the information in a hierarchical manner, minimising the data flows and ensuring data integrity.

Additionally, the system provides data terminals and communicators to be carried by the field personnel and the fire suppression vehicles. These terminals open new easy and robust communication channels, providing extra features like messaging capabilities or positioning to allow managers to better organise the work.

Finally, remote sensing data from existing satellites are served by the system automatically in such a way that the fire suppression manager has accurate information on the extent and position of the fire, together with other data supplied by the fire propagation software. Other products, like fire risk index and fire damage, are also available before and after the fire.

Remfiresat is a high value tool for the fire fighters at all levels in the decision making chain.

References

Gonzalo, Jesús; Martín, Gonzalo; López, Álvaro; Romo, Alfredo. 2003. **Remfiresat, Real Time Emergency Management for Forest Fire Services via Satellite. Final Report.** RMST-INSA-28000-TN-02. (In printer)

Vélez, Ricardo. 2000. La **defensa contra incendios forestales, fundamentos y experiencias.** McGraw Hill Interamericana.

MODIS cloud mask team. 1997. **ATBD-MOD06: Discriminating clear-sky from cloud with MODIS algorithm theoretical basis document (mod 35).**

MODIS science team. 1997. **ATBD-MOD14: Algorithm Technical Background Document.**

Martínez, Susana; Casanova, José Luis. 2002. **Trade-offs on Earth Observation Data Sources.** RMST-INSA-13100-TN-01

Martínez, Susana; Casanova, José Luis. 2002. **System/Subsystem Design: Earth Observation Data.** RMST-INSA-15100-TN-01.

Alonso, Ainhoa. 2003 .**RCC Management Application User Manual.** RMST-INSA-23300-TN-01.

Towards Developing a Global Wildland Fire Strategy[1]

Johann G. Goldammer[2]

Abstract

Considering the transboundary and global issues related to wildland fire there is a need to develop informal partnerships and formal, internationally binding agreements to address wildland fire problems. These must be in compliance with international laws and conventions. The mechanisms developed by the United Nations are essential and must be involved, and their efficiency must be improved. These include the UN agencies and conventions with their specific mandates (e.g, FAO, WHO, WMO, UNEP, UNDP etc., UN Conventions on Biodiversity (UNCBD) and Combat of Desertification (UNCCD), the Ramsar Convention on Wetlands, and the UN Framework Convention on Climate Change (UNFCCC).

Given the large number of sectoral responsibilities within the UN system the need has been recognized to pragmatically facilitate a common policy dialogue by setting up a Working Group on Wildland Fire within the Inter-Agency Task Force for Disaster Reduction of the United Nations International Strategy for Disaster Reduction (UN-ISDR) in 2001. The establishment of the Global Wildland Fire Network was one of the priority fields addressed by the UN-ISDR Working Group on Wildland Fire, aimed at enhancing existing capabilities in fire monitoring, early warning and impact assessment, and facilitation of international cooperation in fire management. The Global Wildland Fire Network was endorsed by the International Wildland Fire Summit, held in Sydney, Australia, 8 October 2003.

Introduction

"The increasing incidence, extent and severity of uncontrolled burning globally, together with its many adverse consequences, has brought fire into the international environmental policy arena, with growing calls for international action leading to greater control of burning, especially in tropical countries and in the boreal zone. Despite this concern, there is a paucity of accurate and timely information on the number of fires, area burned and phytomass consumed annually at national, regional and global scales, and on the social, economic and environmental costs. Given that fire is also an important natural process in many ecosystems, and that people have traditionally used fire for millennia as a land-management tool, the challenge is to develop informed policy that recognizes both the beneficial and traditional roles of fire, while reducing the incidence and extent of uncontrolled burning and its adverse impacts."

---

[1] An abbreviated version of this paper was presented at the second international symposium on fire economics planning, and policy: a global view, 19–22 April, 2004, Córdoba, Spain.

[2] Coordinator, Wildland Fire Advisory Group, UN International Strategy for Disaster Reduction (UN-ISDR), Global Fire Monitoring Center (GFMC) and Fire Ecology Research Group, Max Planck Institute for Chemistry, c/o Freiburg University, P.O. Box, 79085 Freiburg, Germany; Tel: +49 761 808011, Fax: + 49 761 808012, email:johann.goldammer@fire.uni-freigurg.de.

This statement has been taken from the closing paper of the 3rd International Wildland Fire Conference (3-6 October 2003) that aimed at summarizing the findings of the conference and providing directions for the International Wildland Fire Summit (Sydney, Australia, 8 October 2003) and the follow-up process. The Summit was held in accordance with the outcomes of the World Summit for Sustainable Development (WSSD) (Johannesburg 2002) which provided the ground and mandate for an action programme to reduce the negative effects of wildland fires on environment and humanity. Consequently the summit was held under the theme *Fire Management and Sustainable Development: Strengthening International Cooperation to Reduce the Negative Impacts of Fire on Humanity and the Global Environment.*

The Summit theme had been selected to underscore the need to address the increasing vulnerability of ecosystems and human populations to uncontrolled wildland fires as well as the inappropriate or excessive application of fire in modifying vegetation cover. Consequently a high priority has been given to define solutions and to enhance international cooperation in the arena of wildland fire management. These solutions must be based on pragmatic and realizable approaches and instruments that result in a consensus of common strategies, frameworks for implementation and financing mechanisms.

The Summit provided a number of strategic recommendations aimed at harmonization and standardization of approaches, e.g., templates for international agreements for cooperation in wildland fire management, or standard operating procedures aimed at facilitating multilateral cooperation in wildland fire crises. Most crucial, however, is the development of mechanisms that will result in concrete action at international level. Such mechanisms will include both informal and formal agreements at bilateral and international levels. Informal agreements are carried out predominantly bilaterally, often through involvement of civil society including non-government organizations. However, there is an increasing role of informal international projects such as the IUCN-WWF Project FireFight South East Asia, The Nature Conservancy (TNC) or the newly established IUCN-WWF-TNC Global Fire Partnership.

Considering the transboundary and global issues related to wildland fire there is a need to develop informal partnerships and formal, internationally binding agreements to address wildland fire problems. These must be in compliance with international laws and conventions. The mechanisms developed by the United Nations are essential and must be involved, and their efficiency must be improved. These include the UN agencies and conventions with their specific mandates (e.g., FAO, WHO, WMO, UNEP, UNDP etc., UN Conventions on Biodiversity (UNCBD) and Combat of Desertification (UNCCD), the Ramsar Convention on Wetlands, and the UN Framework Convention on Climate Change (UNFCCC).

Given the large number of sectoral responsibilities within the UN system the need has been recognized to pragmatically facilitate a common policy dialogue by setting up a Working Group on Wildland Fire within the Inter-Agency Task Force for Disaster Reduction of the United Nations International Strategy for Disaster Reduction (UN-ISDR) in 2001. The establishment of the Global Wildland Fire Network was one of the priority fields addressed by the UN-ISDR Working Group on Wildland Fire, aimed at enhancing existing capabilities in fire monitoring, early warning and impact assessment, and facilitation of international cooperation in fire management. The Global Wildland Fire Network was endorsed by the International Wildland Fire Summit.

With the upcoming termination of the lifetime of the Working Group on Wildland Fire, the Inter-Agency Task Force for Disaster Reduction in November 2003 endorsed the Global Wildland Fire Network as a follow-up programme under the ISDR, and established the Wildland Fire Advisory Group. In continuation of the Working Group the Advisory Group will serve as a liaison between the international wildland fire community, the Global Wildland Fire Network and the ISDR. The ultimate goal of the work of the advisory group is to provide advice and guidance to the international community, through the United Nations system, to reach an international consensus on modalities and promote common protocols and action to reduce the negative impacts of fire on humanity and the global environment.

History, proposed *Modus Operandi* and Status for building Regional Wildland Fire Networks

History

In accordance with the Framework for the Implementation of the International Strategy for Disaster Reduction (ISDR) a proposal was submitted in 2000 to create a "Working Group on Wildland Fire" within the UN-ISDR Inter-Agency Task Force for Disaster Reduction (IATF). This proposal was in line with several declarations made in international conferences during the 1990s and intended to bring together both the technical members of the fire community and the authorities concerned with policy and national practices in wildland fire management to realise their common interests of fire risk management and disaster reduction at global scale. The IATF at its second meeting on 11 October 2000 agreed to establish the Working Group on Wildland Fire as the 4th Working Group ("WG-4") at UN inter-agency level.

Through the Working Group it was envisaged to establish an interagency and inter-sectoral forum of UN and other international agencies and programmes, including civil society and NGOs. One of the priority fields of activity to be addressed by WG-4 was the establishment of the "Global Network of Regional Wildland Fire Networks". The 3rd Global Wildland Fire Conference and the International Wildland Fire Summit (Sydney, 3-6 and 8 October 2003) were used as a platform to convene representatives from regional networks. The strategy agreed by the Summit ("Strategy for Future Development of International Cooperation in Wildland Fire Management") includes the following agreement (see Annex I of the English version of this paper):

"The Regional Wildland Fire Networks will be consolidated, developed and promoted through active networking in information sharing, capacity building, preparation of bilateral and multilateral agreements, etc. This process will be facilitated through regional Wildland Fire Conferences and Summits in cooperation with the International Liaison Committee and the UN-ISDR Working Group on Wildland Fire".

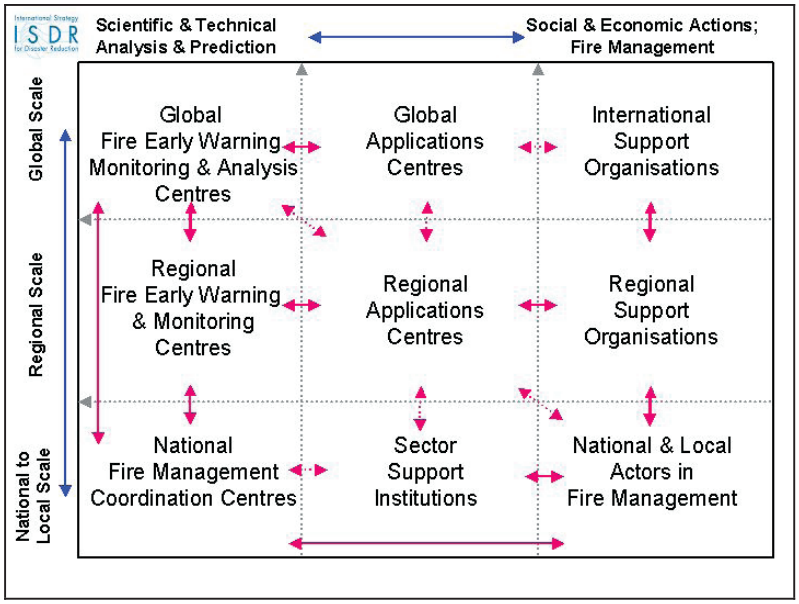


Figure 1—The role of the Global Wildland Fire Network in collection and dissemination of local to global wildland fire information for development of informed policy and decision support

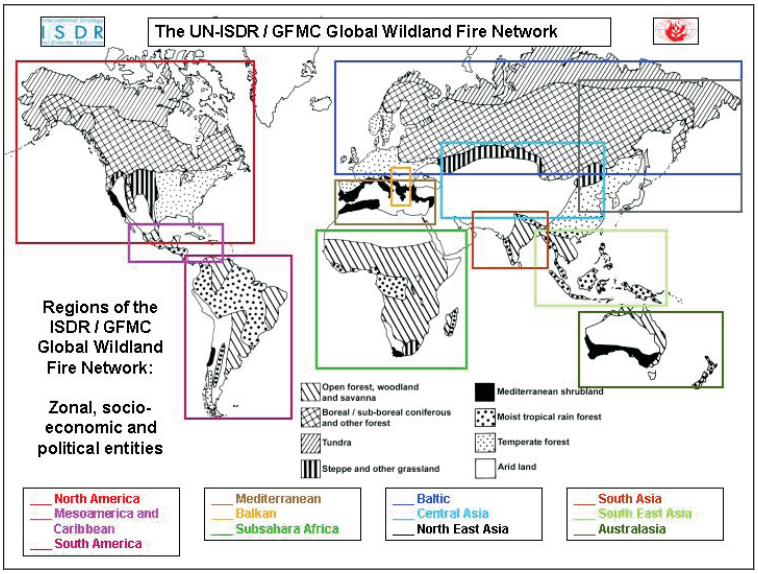


Figure 2—Delineation of regions within the Global Wildland Fire Network

During the Sydney conference and summit a side meeting was held on 5 October 2003 with the regional fire management groups mandated under the auspices of the UN (ISDR Working Group on Wildland Fire, UN ECE/FAO/ILO Team of Specialists on Forest Fire, Fire Management Working Group, FAO North American Forestry Commission (NAFC) and the Forest Fire Group of FAO *Silva Mediterranea*). This was the first joint meeting of the four UN groups, attended also by ILC / AFAC (Australian Fire Authorities Council) members. A key output of the

joint meeting was the recommendation to maintain a body under the auspices of the UN to enable the international community to maintain a unifying platform for UN- and non-UN groups and agreements.

The Global Fire Monitoring Center (GFMC) reported the results of the Summit and the joint meeting of the UN-mandated wildland fire groups to the 8th Meeting of the UN-ISDR Inter-Agency Task Force for Disaster Reduction (5-6 November 2003) and recommend that the ISDR would provide further support to the Global Wildland Fire Network and create an advisory group at UN level. The report recommended:

"The Working Group suggests the IATF to support the further establishment and strengthening of the Global Wildland Fire Network as a key instrument to foster the international dialogue und efficient cooperation in the arena wildland fire. Given the inter-sectoral nature of wildland fire and the number of UN agencies and programmes involved, as well as other international organizations and civil society, it is suggested to maintain an advisory body for the UN within the IATF."

The recommendation to maintain an advisory body for the UN must be understood i.a.w. the constitution of the IATF and the expected lifetime of a Working Group of ca. two to three years. Following these rules of the IATF the Working Group 4 on Wildland Fire would finish its work by end of 2003 and transit to an active outreach programme, the Global Wildland Fire Network (GWFN). To support the work of the GWFN the IATF accepted the proposal to create a *Wildland Fire Advisory Group* (WFAG) under the auspices of the ISDR. The WFAG will represent an advisory body to the UN system aimed at providing technical, scientific and policy-supporting advice to the UN family through the International Strategy for Disaster Reduction (UN-ISDR) and the IATF, and acting as a liaison between the United Nations system, the Global Wildland Fire Network and its supporting partners. It is envisaged to call for participation and support from UN agencies and programmes, other international organizations, non-government organizations, notably the IUCN-TNC-WWF Global Fire Partnership, government agencies, inter-governmental institutions and agreements, civil society, academia, the International Liaison Committee (ILC) of the series of International Conferences on Wildland Fire and the Global Fire Monitoring Center (GFMC) (to act as convener and secretariat).

Proposed Modus Operandi

On behalf of the ISDR the Global Fire Monitoring Center (GFMC) is facilitating the establishment of the Global Wildland Fire Network by supporting the establishment of Regional Wildland Fire Networks and enhancing inter-regional communication and cooperation. The GFMC will liaise with existing operational and proposed international networks, notably with the FAO Forestry Department, the UN-mandated regional teams (ISDR Wildland Fire Advisory Group, ECE/FAO/ILO Team of Specialists on Forest Fire, Fire Management Working Group of the FAO North American Forestry Commission (NAFC), Forest Fire Group of FAO *Silva Mediterranea*), the Global Observation of Forest Cover - Global Observation of Landcover Dynamics (GOFC-GOLD) Fire Implementation Team (a subset of the Global Terrestrial Observing System - GTOS), and the Advisory Group on Environmental Emergencies (AGEE) and the Joint Environment Unit of the United Nations Office for the Coordination of Humanitarian Affairs (OCHA) and the United Nations Environment Programme (UNEP).

Status of the Regional Wildland Fire Networks

Regional Networks are formed in two ways. First, independent regional initiatives that were in place before 2001-2002 and after have been contacted and encouraged to become connected to the Global Wildland Fire Network. Second, a number of activities are being initiated in those regions where no such regional efforts are in place. The following information is taken from the website of the Global Wildland Fire Network: http://www.fire.uni-freiburg.de/GlobalNetworks/globalNet.html

Regional Subsahara Africa Wildland Fire Network

The Regional Subsahara Wildland Fire Network ("Afrifirenet") was the first regional network that has been launched formally in 2002. The network includes the "Africa Wildland Fire Training Center" which is offering capcity building in wildland fire management for Subsahara Africa. Regional website:
http://www.fire.uni-freiburg.de/GlobalNetworks/Africa/Afrifirenet.html

Regional South East Asia Wildland Fire Network

Within the ASEAN region (Association of South East Asian Nations) the signing of the legally binding ASEAN Agreement on Transboundary Haze Pollution (10 June 2002; meanwhile ratified and entered into force on 25 November 2003) constitutes a multinational agreement for cooperation in fire management. At the ASEAN Senior Officials for Environment (ASOEN) Haze Technical Task Force meeting (10 June 2002) and the subsequent ASEAN Ministerial Meeting on Haze (11 June 2002) it was recommended that the ASEAN nations work together with the GFMC to establish a South East Asian Wildland Fire Network. Regional websites are:
ASEAN Haze Action Online Website: http://www.haze-online.or.id
GFMC Regional Website:
http://www.fire.uni-freiburg.de/GlobalNetworks/SouthEastAsia/ASEAN-FireNet.html

Regional North East Asia Wildland Fire Network

This network is currently being prepared and will include the participation of the Republic of Korea (South Korea), Democratic People's Republic of Korea (North Korea) (not yet confirmed), Japan and the Far East of the Russian Federation. During the International Wildland Fire Summit the representatives of the Republic of Korea have indicated a strong interest to support the formation of a regional node in South Korea. In November 2003 the Korean Forest Research Institute, Forest Fire Division, made its resources available to build the regional network. A kick-off meeting has been held in Seoul on 6 March 2004. Preliminary regional website:
http://www.fire.uni-freiburg.de/GlobalNetworks/Northeast-Asia/Northeastasia.html

Regional Central Asia Wildland Fire Network

Central Asia and its neighbour countries have recently suffered major forest and other wildland fire problems. The need has been recognized to initiate regional cooperation in wildland fire management, including wildland fire science. The "ECE/FAO International Conference on Management of Forest Fire Emergencies and International Cooperation in the Eastern Mediterranean, Balkans and adjoining Regions of the Near East and Central Asia" (Turkey, April 2004) provided an

opportunity to clarify detailed objectives and modus operandi of the networking arrangement. A preliminary website in which the conference results will be presented (not finalized at the time of writing this manuscript) has been established at:
http://www.fire.uni-freiburg.de/GlobalNetworks/CentralAsia/CentralAsia.html

Regional Australasia Wildland Fire Network

In 1993 the Australian Fire Authorities Council (AFAC) was established to improve the collaboration and co-ordination of efforts between those Australian agencies with a responsibility for the protection of life and property from fire and other emergencies. The membership of agencies from the greater region saw AFAC's name change to the Australasian Fire Authorities Council in 1996. AFAC aims to promote and coordinate activities in fire prevention, management and research through five Strategy Groups. This regional arrangement offers the most suitable conditions for taking the lead in building the Regional Australasia Wildland Fire Network. For more details see the websites of AFAC and the GFMC:

www.ausfire.com

http://www.fire.uni-freiburg.de/GlobalNetworks/Australasia/Australasia.html

Regional Mediterranean Wildland Fire Network

Following the discussions with FAO *Silva Mediterranea* in 2002 the formation of a Regional Mediterranean Wildland Fire Network is practically established under the auspices of this FAO group. A Workshop "Multilateral Assistance Against Forest Fires in the Mediterranean Basin" was held in Zaragoza, Spain, 10-11 June 2003. The objectives of the workshop included to study procedures to coordinate the existing mutual agreements and common legal and logistical tools to make effective, when needed, the multilateral assistance against forest fires within the Mediterranean Basin by sharing resources. A discussion was included about the possible role of the regional network and the GFMC to facilitate this process. The workshop was a preliminary activity to prepare a future Mediterranean conference on Multilateral Assistance against forest fires. For details see:
http://www.fire.uni-freiburg.de/GlobalNetworks/Mediterrania/Mediterrania.html

Regional Balkan Wildland Fire Network

After initial discussion at the International Scientific Conference "Fire and Emergency Safety During the XXI Century - The Course of Europe" in Bulgaria in 2002 and a regional meeting of the International Commission for the Prevention and Extinction of Fires (CTIF) the network formation is underway. In March-April 2004 the "ECE/FAO International Conference on Management of Forest Fire Emergencies and International Cooperation in the Eastern Mediterranean, Balkans and adjoining Regions of the Near East and Central Asia", held in Turkey (see Regional Central Asia Wildland Fire Network) provided an opportunity to clarify detailed objectives and modus operandi of the network. Regional website:
http://www.fire.uni-freiburg.de/GlobalNetworks/Balkan/Balkan.html

Regional Baltic Wildland Fire Network

At the Baltic Exercise for Fire Information and Resources Exchange - BALTEX FIRE 2000 (Finland, June 2000) the UN ECE/ECE/ILO Team of Specialists on Forest Fires, through the Global Fire Monitoring Center (GFMC), initiated a communication and coordination process among the countries bordering the Baltic Basin. The initiative is the starting point for the Regional Baltic Wildland Fire Network structures. On 10 May 2004 a Regional Baltic Wildland Fire Meeting will be convened in Finland (host: Ministry for Interior, Finland). Regional website:
http://www.fire.uni-freiburg.de/GlobalNetworks/BalticRegion/BalticRegion.html

Regional Mesoamerica Wildland Fire Network

An important regional initiative has been launched by the First Central Mesoamerican Meeting on Forest Fire Protection (Primera Reunión Mesoamericana de Cooperación en Materia de Protección contra Incendios Forestales) held in Guatemala City, 8-9 July 2002, with participation of Belice, Costa Rica, El Salvador, Guatemala, Honduras, México, Nicaragua and Panamá. The countries agreed formally to launch a programme of cooperation which includes sharing of information and resources in fire management as well as in capacity building. All materials on the cooperative processes in the Mesoamerica Region are available at:
http://www.fire.uni-freiburg.de/GlobalNetworks/MesoAmerica/MesoAmerica.html

Regional South America Wildland Fire Network

Several regional activities will be involved in building a Regional South America Wildland Fire Network. The formation of the network will be discussed and founded at the upcoming 3rd South American Symposium on Forest Fire Control (3º Simpósio Sul-Americano sobre Controle de Incêndios Florestais), 14-17 June 2004, Curitiba, Brazil. This foundation meeting will be co-sponsored by the Global Wildland Fire Network (through GFMC), FAO, UNEP, GOFC-GOLD, The Nature Conservancy (TNC) and the U.S. Forest Service. The recommendations of the Foundation Meeting of the network will be presented to the participants of the Western Hemispheric Wildland Fire Conference, scheduled for 23 October 2004 in Costa Rica. This conference will be a one-day side event of the joint meeting of the members of the FAO Forestry Commissions of North America and Latin America / Caribbean. Information on the meeting and preliminary regional website see:
http://www.fire.uni-freiburg.de/course/meeting/meet2003_14.htm
http://www.fire.uni-freiburg.de/GlobalNetworks/SouthAmerica/SouthAmerica.html

Regional North America Wildland Fire Network

Discussions about the formation and possible *modus operandi* of a Regional North America Wildland Fire Network are currently underway. The Fire Management Working Group (FMWG) of the North American Forestry Commission (NAFC) represents a regional network which will liaise North America's contribution to the Global Wildland Fire Network. Websites:
http://www.fs.fed.us/global/nafc/fire/aboutus.htm
http://www.fire.uni-freiburg.de/GlobalNetworks/NorthAmerica/NorthAmerica.html

Regional South Asia Wildland Fire Network

This network is currently under construction and most likely will include India, Bangladesh, Nepal, Bhutan and Pakistan. The Dehradun Forest Research Institute, India, has indicated interest to serve as a coordinating unit. Nepal has indicated interest to support the network.

The International Wildland Fire Summit: Pragmatic Short-to-Medium-Term Solutions

The International Wildland Fire Summit was an important step towards building international consensus and initiate pragmatic action in international cooperation in wildland fire management. There is no need to repeat what has been summarized in the Communiqué of the Summit (see Annex I of the English version of this paper). However, out of the list of the Summit Outputs and the specific actions to be taken by Summit participants two of the five agreements are worth to be mentioned here explicitly because they are straight forward, pragmatic and ready for implementation, (a) an international agreement template that can be used by agencies wishing to form a cooperative or mutual aid arrangement with one or more other countries for cooperation in wildland fire management, and (b) an agreement that an Incident Command System (ICS) should become the international standard for wildland incident management in international or interagency agreements and exchanges. The agreed "Strategy for Future Development of International Cooperation in Wildland Fire Management", however, is important for the future roadmap (cf. section 4 and Annex II of the English version of this paper).

Inter-Regional and Global Dialogue at UN Level: Medium-Term Perspectives and Long-Term Challenges

At the time of writing this paper in early 2004 there are the following perspectives and challenges to commence or consolidate the regional to international dialogue on wildland fire issues:

Short- to Medium-Term Perspectives

It is now crucial that the Global Wildland Fire Network will be activated and the recommendations of the Summit be implemented straight forward by enhancing the international dialogue and building informal and formal partnerships. The following events will take place within the near future:

- A series of consultations in the frame of Regional Wildland Fire Networks has been initiated for in Northeast Asia (March 2004), the Baltic Region (May 2004), South America (June 2004) and Mesoamerica (second half of 2004). These consultations will be used to define critical issues in the regions and come up with priority issues to be addressed by regional cooperative efforts.
- Activation of the UN-ISDR Wildland Fire Advisory Group
- A Western Hemispheric wildland fire conference is scheduled for October 2004 (Costa Rica). In this meeting the heads of forestry

agencies will be invited by the Regional Forestry Commissions of Latin America / Caribbean and North America to express their views on needs and opportunities in wildland fire management cooperation in the Americas.

- A number of international wildland fire management training courses and workshops will be conducted in the regions (e.g., workshops conducted in Africa jointly by GFMC, the Regional Subsahara Wildland Fire Network, FAO, UN-OCHA, UNEP, UNU). These inter-agency workshops will have a pilot role for other regions.
- A ministerial meeting held at FAO Rome in March 2005 will focus on wildland fire issues. This meeting will play an important role in bringing forward the recommendations from regional-level consultations in 2003-2004 to the international actors.

Long-Term Perspectives

The above-listed short- to medium-term activities will provide political fora to define priority fields of action and political consensus. Most important, however, are technical and procedural agreements to initiate programmes that would address, among other, the following key issues:

- Common methodologies to assess wildland fire impacts (standards for wildland fire inventories / statistics; common algorithms for application of remote sensing tools)
- Regular national wildland fire impact assessments as part for global wildland fire inventories
- Standards for economic damage assessments
- Role of sustainable vegetation fire management in the carbon-trading market
- Wildland fire mitigation strategies and methodologies for urban interface areas in industrialized countries; including education
- Enabling legislation and institutional strengthening for sustainable fire management in the developing world
- Capabilities of local communities in fire preparedness, prevention, suppression and in rehabilitation of burned over areas.
- Advanced high-level training in cooperative wildland fire management at international level through the United Nations University, Institute for Environment and Human Security.

With the bottom-up networking arrangement of the Global Wildland Fire Network, the recommendations of the International Wildland Fire Summit, including the Summit's predecessor conferences, and the recommendations of the 2005 Ministerial Meeting at FAO Rome it will be possible to

- Conduct the Global Forest Fire Assessment 2005 jointly with FAO, GFMC and GOFC-GOLD

- Recruit additional agencies and international organizations and programs to fund the Global Wildland Fire Network
- Prepare an input paper to the UN General Assembly that seeks the support of countries to strengthen international cooperation in response to wildland fire disasters and post fire mitigation

To achieve these goals it is essential that formal and informal arrangements will work hand in hand. However, the mandates of the United Nations agencies, programmes and conventions require a lead of the UN system. The ISDR is available as an international, inter-agency and inter-sectoral platform and will be supported by the UN-ISDR Wildland Fire Advisory Group.

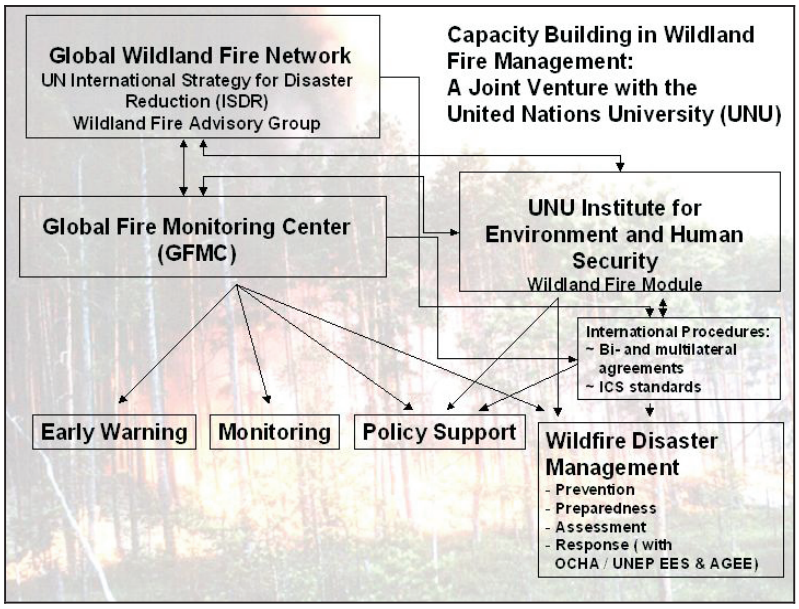


Figure 3—Model of cooperative arrangements between the Global Wildland Fire Network und the United Nations University for high-level capacity building in wildland fire management.

Conclusions and Outlook

During the period 2000 to 2005 a number of bilateral and international cooperative agreements in the arena of sustainable wildland fire management have been initiated. There is a strong consensus at international level to further promote informal and formal cooperation programmes. A large number of bilateral and multilateral projects have been supported by the FAO (through Technical Copperation Projects [TCPs]), the International Tropical Timber Organization (ITTO), the U.S.A. (through agencies including the U.S. Forest Service, the Bureau of Land Management, the U.S. Agency for International Development, the Office for Foreign Disaster Assistance), Canada, Australia, Germany (through the German Agency for Technical Cooperation [GTZ]), and other countries. The large number of bilateral agreements between countries sharing a common border or common disaster management system (e.g., the ICS) indicate the willingness of nations to offer and share resources.

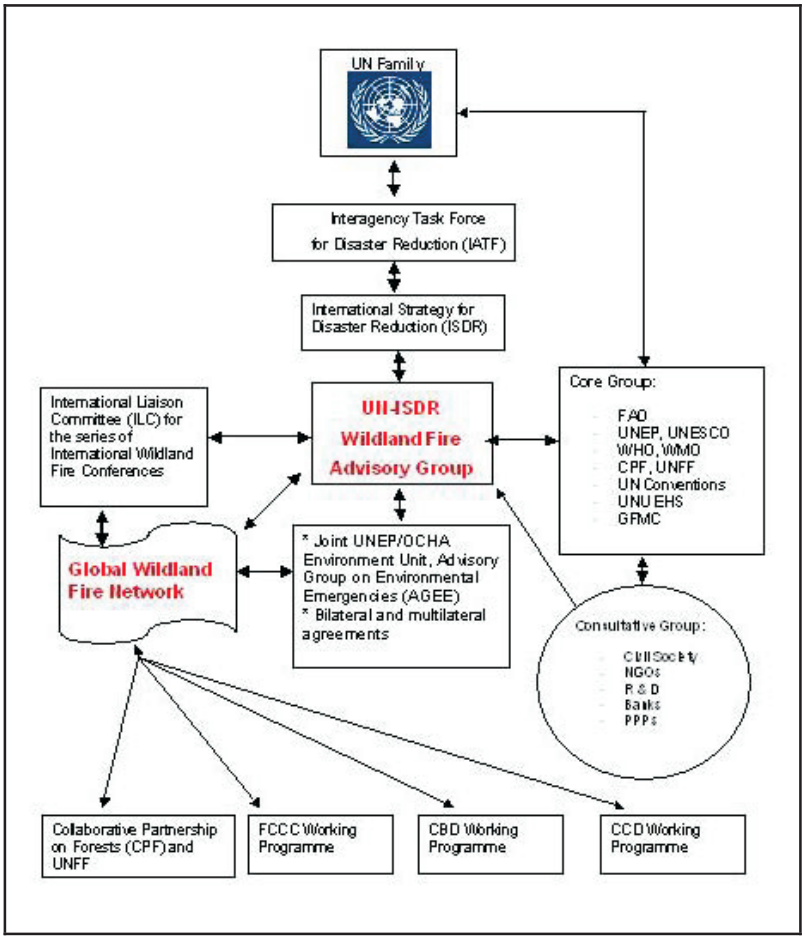


Figure 4—Draft scheme of cooperative relationships between the Wildland Fire Advisory Group, the Global Wildland Fire Network und the International Liaison Committee of the series of International Wildland Fire conferences

The United Nations have recognized the significance of wildland fires in global change processes and have offered an inter-agency approach towards harmonizing the international efforts in reducing the negative consequences of wildfires, land-use fires and other excessive burning. The reasons for increasing vegetation degradation by fire and the increase of vulnerability of vegetation systems and humans to wildland fire, as well as the underlying causes of excessive burning are complex. Solutions towards sustainable fire management must address a broad range of factors contributing to this development. Demographics, poverty, social and political instability, and the consequences of economic globalisation are part of this development and difficult to be addressed by single or sectoral measures.

Annexes

Annexes I and II cited in this Spanish version of the paper are included in the original (English) version of this paper.

References

Global Fire Monitoring Center (GFMC):
http://www.fire.uni-freiburg.de/

UN-ISDR Wildland Fire Advisory Group
http://www.unisdr.org/eng/task%20force/tf-working-groups4-eng.htm

Global Wildland Fire Network
http://www.fire.uni-freiburg.de/GlobalNetworks/globalNet.html

International Wildland Fire Summit
http://www.fire.uni-freiburg.de/summit-2003/introduction.htm

Global Observation of Forest Cover / Global Observation of Landcover

Dynamics (GOFC/GOLD) - Fire Mapping and Monitoring
http://gofc-fire.umd.edu/

Convention on Biological Diversity
http://www.fire.uni-freiburg.de/programmes/un/cbd.htm

FAO Fire and FAO Global Forest Fire Assessment 1990-2000
www.fao.org/forestry/site/11481/en
http://www.fire.uni-freiburg.de/programmes/un/fao/Wp55_eng.pdf

Joint UNEP/OCHA Environment Unit /

WSSD Partnership for Environmental Emergencies
http://www.reliefweb.int/ochaunep/
http://www.reliefweb.int/ochaunep/tools/wssd.htm

WHO Health Guidelines on Vegetation Fire Events
http://www.who.int/peh/air/vegetation_fires.htm

International Tropical Timber Organization (ITTO) Wildland Fire Websites
http://www.itto.or.jp/live/index.jsp
http://www.fire.uni-freiburg.de/programmes/itto/itto_start.htm

International Forest Fire News (IFFN)

http://www.fire.uni-freiburg.de/iffn/iffn.htm

Page left blank intentionally.

Estimating the Impact of Proximity of Houses on Wildfire Suppression Costs in Oregon and Washington[1]

Geoffrey H. Donovan,[2] Peter Noordijk,[2] Volker Radeloff[3]

Abstract

The relationship between development in the wildland urban interface (WUI) and suppression costs has received increasing attention from policy makers in recent years; however, few empirical studies have addressed the issue. Data from 58 wildfires that burned in Oregon and Washington during the 2002 fire season and 2000 census data are used to examine the relationship between proximity of houses and suppression costs. Results fail to show a relationship between either total housing or housing density and suppression cost. Several possible explanations of this negative result are offered.

Introduction

The rising cost of wildfire suppression on public land in the United States has been attributed to two main factors. First, increases in fuel loads and changes in stand structure have resulted in more intense wildfires that are more difficult and costly to suppress (Arno and Brown 1991). Second, development in the wildland urban interface (WUI) has increased the values at risk from wildfire, prompting increased suppression spending to protect these structures (USDA 2003). Although there is broad agreement that increases in both fuel loads and development in the WUI have contributed to rising suppression costs (USDA Forest Service 1995; USDA 2003), little empirical work has been done to quantify the effect of either. In this paper we examine the importance of the second of these two factors—development in the WUI—by empirically estimating the effect of proximity to housing on wildfire suppression costs. Our hypothesis is that if there are more houses in proximity to wildfire, then that wildfire will be more expensive to suppress, because fire managers will uses more resources to protect the threatened houses.

Few studies in the fire economics literature that have looked empirically at the factors that drive wildfire suppression costs, however, some studies have examined the cost of different components of a wildfire organization. González-Cabán (1983) developed a model to estimate suppression costs based on the number and type of resources used to fight a fire. González Cabán and others (1984) used a cost-aggregation approach to estimate the cost of hand crews, engines, helitak crews,

[1] An abbreviated version of this paper was presented at the second international symposium on fire economics, planning. and policy: a global view, 19–22 April 2004, Córdoba, Spain.

[2] Research forester and social science technician, respectively, USDA Forest Service, PNW Research Station, 620 SW Main, Suite 400, Portland, OR, 97205. (503) 808-2043, gdonovan@fs.fed.us.

[3] Assistant Professor, Department of Forest Ecology and Management, University of Wisconsin, Madison, WI, radeloff@wisc.edu.

smokejumpers, and bulldozers. The authors found considerable variation in resource cost estimates both between fires and between different regions of the country.

Although there has been little empirical work on the factors that affect wildfire suppression costs, several authors have studied the determinants of prescribed fire costs. Early work by Rich (1984) studied prescribed burning costs in 1982 on the Powell District of the Clearwater National Forest in Idaho. He investigated both managerial factors and physical site characteristics including aspect, slope, elevation, slash, fuels, and other topographical features. Rich concluded that managerial factors influence costs more than physical factors. A follow-up study (Rich 1989) looking at similar information from the Powell district from 1982-1985 supported his conclusion that management variables have greater influence on prescribed burning costs than physical variables. Jackson and others (Jackson, Flowers et al. 1982) examined total project costs and per acre costs for prescribed burns used to improve wildlife habitat. They found both physical and managerial factors to be significant, and that economies of scale existed with increasing fire size.

Cleaves and Brodie (1990) analyzed the economics of prescribed burning, focusing on benefits, costs, and risks of prescribed fire. They determined that fuels, topography, weather, management objective, and unit size and shape were important influences on the cost of prescribed burning projects. Additionally, they emphasized the impact that risk can have on burning costs, including the risk of escape, risk of smoke interference in surrounding areas, and managers' perception of risk. In conclusion, they point to the need for reliable cost records for future economic analyses of prescribed fire.

Cleaves and others (2000) analyzed trends and influences on prescribed burning costs in the National Forest system during the period 1985-1994. Using survey methodology they asked managers to rank the importance of several factors on the cost of prescribed burning: unit size and shape, compliance with environmental laws and regulations, labor costs and availability, insurance availability, liability, residential development, crew safety, weather, multiple objectives satisfaction, and safeguards to minimize escaped fires. Nationally, managers ranked unit size and the cost and availability of labor as the most important factors influencing costs. Safeguards to minimize escaped fires ranked third, and compliance with environmental laws and regulations was fourth. In the Pacific Northwest, unit size, costs and availability of labor, and compliance with environmental laws and regulations ranked highly. However, unit shape and the need to satisfy multiple objectives were also among the most important factors in this region. The availability of liability insurance and agency policies about risk-taking received low ranks in all regions.

Rideout and Omi (1995) used a National Park Service database to estimate prescribed fire cost models. Their data included information on project size, fuel model, project type, administrative or legislative mandate, fire complexity rating, and ranking scores for natural resource values, historic importance, and wildlife habitat. Using a constant elasticity model of declining cost with increases in scale, they found that the costs of fuels treatments varied with respect to two management goals: maintaining or restoring ecosystems and hazard fuel reduction. Higher precision was found in cost estimates for traditional hazard reduction treatments compared to ecosystem management treatments.

In summary, little empirical has been done to identify the determinants of suppression cost. More studies have investigated the factors that affect prescribed fire costs, finding that treatment size, fuel model, management objectives, and the cost and availability of labor can affect treatment cost.

Methods

To relate the costs of suppressing a wildfire to the proximity of that fire to housing requires spatial information on the area burned by wildfire and housing density. Spatial data on the area burned by wildfires were obtained from Region 6 (Oregon and Washington) of USDA Forest Service. Fire managers created a GIS layer of the area burned by 58 of the largest wildfires in Oregon and Washington during the 2002 fire season. These fires varied in size from 25 acres to 499,570 acres. This GIS layer was superimposed on a GIS layer of housing density in the US—derived from 2000 census data—allowing the calculation of housing density and total number of houses within the perimeter of each wildfire. However, the number of houses within the final perimeter of a wildfire does not fully capture the effect of housing density on suppression costs. Although a wildfire may only destroy a small number of homes, it may threaten many more, affecting the suppression strategy used by fire managers and, therefore, suppression costs. To capture the influence of houses not destroyed but threatened by wildfire, we calculated the number of houses in successively larger (2, 5, 10, and 20 miles) buffers around the perimeter of each wildfire. Conceptually these variables can be thought of as spatial lag variables.

Although housing is the focus of this paper, several other factors may affect suppression costs. Therefore, the following variables were also included in the analysis: 100 hour fuel moisture; fire size; a binary variable indicating if the incident commander on the fire classified the terrain as extremely difficult; and the number of uncontained acres burning in Oregon and Washington on the day a fire started. This last variable was intended to capture the relative scarcity of suppression resources; we hypothesize that if many other large fires were burning in the region at the time a fire started, then some suppression resources may not be available, which may affect costs. Data on suppression costs were obtained from the 209 forms that fire managers are required to complete on each day of a major wildfire.

Results

The above dependent variables were regressed on total suppression costs (table 1).

Table 1--Regression results—fire size and extreme terrain on total suppression costs

Variable	Coefficient	Std. Error	t-stat	Prob.
Intercept	-129,522	1,441,778	-0.0898	0.929
Fire size	291	14.8	19.6	0.000
Extreme terrain	7,277,264	2,487,116	2.93	0.0059
Adjusted R-squared	0.926			

Unsurprisingly, the most significant determinant of total suppression costs is fire size. The only other significant variable is the binary variable denoting whether or not fire managers considered the terrain a fire was burning in extreme. The positive

coefficient on the extreme terrain variable indicates that fires burning under these conditions are more costly to suppress.

In contrast to fire size and the extreme terrain variable, none of the total housing or housing density variables was significant. In addition, standard transformations (natural log, quadratic, etc.) did not improve the explanatory power of any of the total housing or housing density variables. The 100 hour fuel moisture and resource scarcity variables were also insignificant.

To determine if housing variables better explain per acre as opposed to total costs, the above model was re-estimated with per acre costs as the dependent variable. As with the total cost model, none of the housing variables, or transformed variables, were significant. In addition, all other variables, including fire size and the extreme terrain variable, were insignificant.

Discussion

The purpose of this paper is to determine if proximity to housing affects wildfire suppression costs. Data were drawn from the 2002 fire season in Oregon and Washington and from the 2000 census. Results show that neither total housing nor housing density explained any of the observed variation in suppression costs. The only variables that were shown to influence total suppression costs are fire size and the binary variable denoting extreme terrain. Analysis of per acre costs found no significant variables. Care should be taken when interpreting the influence of fire size on suppression cost. Fire size is not an exogenous variable, but rather suppression cost and fire size are simultaneously determined.

The inability of the analysis to show a significant relationship between housing and suppression costs may have a number of explanations. The relatively small sample of 58 fires may have been a factor; a larger data set might yield more significant results.

Another factor that may be important is the correlation between housing density and road density. Areas with more housing have better road access, which may allow firefighters to reach a fire more quickly with cheaper ground based resources rather than relying on more expensive aerial resources. Therefore, although housing may affect suppression costs, this effect may be confounded by easier access.

It is possible that housing does affect suppression costs; it may be that the reason why this effect was not identified is that the sample did not contain any examples where this was not the case. In a region like the Pacific Northwest, during severe fire conditions (hot, dry, weather, and low fuel moisture) all fires may threaten housing. That is, the region is sufficiently densely populated that wherever an ignition occurs, houses will be threatened, and fire managers will suppress wildfires accordingly.

The absence of any significant variables in the per-acre cost model may have a number of causes. As with the total cost model, sample size may have contributed to the lack of significance, or we may have simply not selected the correct variables. It is also possible that the per-acre cost of a wildfire is largely determined by factors unique to that fire, and that variables common to all fires are relatively unimportant. If this is the case, there are significant policy implications. Care should be taken in designing policies to control suppression costs. If indeed per acre costs are largely

determined by factors unique to a given fire, then a generic approach to cost containment would be inappropriate and probably ineffective. Future work could valuably focus on identifying the importance of these unique factors.

References

Arno, S.F. and J.K. Brown (1991). Overcoming the paradox in managing wildland fire. Western wildfire 17(1): 40–46.

Cleaves, D.A. and J.D. Brodie (1990). Economic analysis of prescribed burning. Natural and prescribed fire in the pacific norhtwest forests. J.D. Walstad and et al. Corvallis, OR, Oregon State University Press: 271–282.

Cleaves, D.A., T.K. Haines, et al. (2000). Influences on prescribed burning activity in the national forest system. Fire and forest ecology: innovative silviculture and vegetation management, Tallahassee FL.

González-Cabán, A. (1983). Economic cost of initial attack and large-fire suppression, USDA Forest Service, PSW Research Station: 7.

González-Cabán, A., C.W. McKetta, et al. (1984). Costs of fire suppression forces based on cost-aggregation approach, USDA Forest Service, PSW Research Station: 16.

Jackson, D.H., P. Flowers, et al. (1982). Predicting prescribed fire burning costs of wildlife habitat management. Fire Management Notes 43(4): 20–22.

Rich, T. (1984). Sources of costs associated with prescribed burning on the Powell Ranger District. Moscow, University of Idaho: 56.

Rich, T. (1989). Prescribed fire burning cost variability–an analysis of four years of cost data on the Powell Ranger District, Clearwater National Forest. Prescribed fire in the intermountain region, Missoula, MT.

Rideout, D.B. and P.N. Omi (1995). Estimating the cost of fuel treatment. Forest Science 41(4): 664–674.

USDA Forest Service, F. a. A. M. (1995). Fire suppression costs on large fires. A review of the 1994 fire season. Washington D.C.

USDA, Forest Service. (2003). Large fire cost reduction action plan. Washington D.C., USDA Forest Service: 24.

Page left blank intentionally.

Wildfire Initial Response Assessment System: A Tool for Fire Preparedness Planning[1]

Marc R. Wiitala,[2] Andy E. Wilson[2]

Abstract

Recent advances in operations research and computer technologies present new opportunities to improve preseason wildland fire planning tools. In this paper, we describe the Wildfire Initial Response Assessment System (WIRAS), a stochastic simulation model that incorporates many recent technical advances and is designed to closely represent the dynamics of fire occurrence and suppression. The computer simulation model provides fire managers a powerful tool to examine operational and performance characteristics of their initial attack capabilities for planning appropriate preseason protection organizations.

Introduction

The Forest Fire Laboratory in Riverside, California is engaged in the development of a new presuppression wildland fire planning model. This modeling effort builds on knowledge gained from previous developmental efforts (Bratten and others 1981; Fried and Gilless 1999; Martel and others 1984; McAlpine and Hirsch 1999; Wiitala 1998). The model, the Wildfire Initial Response Assessment System (WIRAS), incorporates many recent advances in operations research technologies and takes several new approaches to model design. The intent in building WIRAS was to closely represent the dynamics of fire occurrence and suppression resource deployment characteristic of many federal and state protection programs in the western United States. The close correspondence of the model to reality provides an effective decision support system to help fire managers and planners better determine the appropriate size, location, composition, and use of locally controlled initial attack programs as well as evaluate nationally shared aerial resource programs. This paper provides an overview of WIRAS.

Model Building Approach

Protected federal wildlands in the western United States is the environment for model development. The variability of the timing and intensity of fire workloads in this environment can have a profound effect on performances of different presuppression organizations. Given this variability as well as other operational and environmental

[1] An abbreviated version of this paper was presented at the second international symposium on fire economics, planning, and policy: a global view, 19–22 April 2004, Córdoba, Spain.

[2] Operations Research Analyst and Resource Information Specialist, Forestry Sciences Laboratory, Forest Service, U.S. Department of Agriculture, 620 SW Main Street, Suite 400, Portland, OR 97205: email: mrwiitala@fs.fed.us; email :aewilson@fs.fed.us.

uncertainties, we selected discrete-event, stochastic simulation as an appropriate modeling methodology to design WIRAS. We adopted a process-oriented approach (Law and Kelton 1991) in using an enhanced variant of the discrete-event simulation language General Purpose Simulation System (Henriksen and Crain 1989) to build the model.

Model Structure

WIRAS distinguishes itself from other models with the ability to plan both local and national fire preparedness programs. It also pioneers the ability to conduct local planning within the context of the national fire environment. This embedded planning approach allows fire planners to design a local initial attack program while taking into account their success in competing for nationally shared aerial resources.

From a process viewpoint, WIRAS simulates the deployment and retrieval of ground and aerial resources in response to a yearly time stream of fires unique in their fire behavior, location, and time of arrival *(fig. 1)*. Initially WIRAS dispatches local and nationally available suppression resources from their home bases to fires according to user-defined rules and with regard to deployment constraints. As is the case operationally, when the first resource arrives at the fire, the simulation model, based on observable fire behavior, reassesses staffing needs to either request additional suppression units or return some of those in transit to the fire. After a fire is contained or escapes the initial attack effort, the simulation model demobilizes initial attack suppression resources to their home bases for dispatch availability on a subsequent day. As an exception, WIRAS will redeploy ground resources to on-going understaffed fires the same day of demobilization if attack times are within reason.

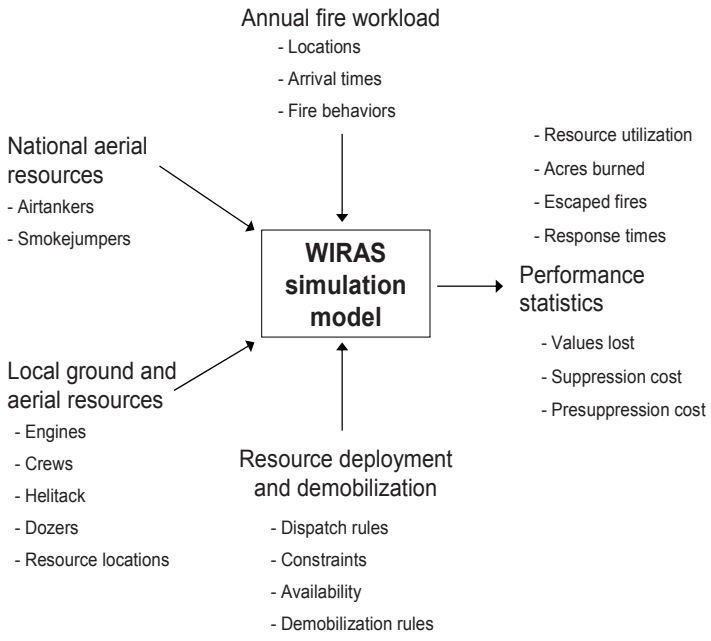


Figure 1—WIRAS overview.

Suppression Resources

WIRAS manages four classes of initial response resources. Three classes involve aerially delivered suppression capability: airtanker retardant delivery, smokejumpers, and helicopter delivered crews and water. The fourth class, ground resources, currently includes engines, crews, dozers, and water tenders. Each of the four suppression resource categories is modeled uniquely to capture important and disparate operational features (Wiitala 1998; Wiitala and Dammann 2003).

Program Performance Testing

WIRAS currently tests the performance of an initial attack organization against a set of historical fire seasons. Resource dispatching is controlled through a system of Boolean variables that mimics the rules and priorities governing an administrative unit's preplanned dispatch policies. The model is designed to favor dispatching quickest response, local ground resources provided they could be expected to reach a fire within a reasonable time; otherwise, the model attempts to dispatch aerially delivered firefighters. The first firefighters to arrive at a fire reassess the preplanned staffing needs for sufficiency and determine the need for retardant deliveries.

Several of the arguments in the Boolean variables reflect the types of information typically available to dispatchers in making deployment decisions. The simulation model maintains and updates state variables corresponding to these arguments. This system of Boolean variables is sufficiently flexible to permit planners to set, within the simulation model, the conditions for dispatching ground resources based on attack times, fire behavior potential, and protection objectives.

Travel Time Calculations

The WIRAS project is making a special effort to accurately model suppression resource response times. This is viewed as critical to the successful modeling of the initial attack system (Mees 1986). Total response time is composed of getaway, reloading, refueling, and travel time. Travel time is usually the largest component. For aircraft, distance between travel points and average airspeed are combined to calculate aircraft flight component of response time. For aerially delivered firefighters an additional amount of landing and walk time is included in total response time. In the case of airtankers, reloading and refueling times add to response times. Additionally, WIRAS models congestion at airtanker bases during periods of high fire activity which can lengthen response times when airtankers have to wait for available loading pits.

The project is making a major push to develop improved methods for estimating ground resource travel time which includes vehicle travel along a road network and off-road foot travel. The effort involves the development of a computationally efficient least-cost-path algorithm to quickly calculate travel times over a landscape (Hatfield and others, this proceedings). A study of ground resource travel times is underway to gather empirical information to validate the least-cost-path algorithm and quantify additional random travel time components (Wilson and Wiitala 2003). The simulation model presently integrates the travel time algorithm to calculate ground resource travel time from any ground resource location to any other location. The value of the algorithm in allowing WIRAS to mirror real operational practices is

particularly apparent during a simulation when a ground resource in transit to a fire becomes available for diversion to another fire. At this point in the simulation, the least-cost-path algorithm can determine the resource's current location and calculate response times to all needy fires to decide the best plan for its redeployment.

Model Outputs

Discrete-event simulation models provide great capability to collect large amounts of information on system conditions and performance over the course of a simulation. WIRAS is no exception. Examples of average annual statistics collected by WIRAS include: acres burned by fire intensity for both contained and escaped fires, numbers of fires escaping initial response, volume of delivered retardant, flight hours for aerial resources, resource dispatch and arrival lists for each fire, and fire containment time and size distributions.

WIRAS also tracks annual dispatch frequency which is an important model output that can help planners evaluate suppression resource and base utilization to improve program performance and efficiency. Underutilized suppression resources are good candidates for relocation or elimination. Utilization statistics can help identify opportunities to close bases.

WIRAS also monitors a number of queues to help identify potential bottlenecks in various service delivery processes. For example, information on the frequency and length of time airtankers must wait for retardant reloading facilities allows planners to assess the need for and value of expanding or reducing airtanker base facilities.

Operational and performance statistics produced by WIRAS provide the basic building block to examine economic trade-offs between average annual fire suppression costs and natural resource loss and the budget cost of building alternative preseason suppression organizations *(fig. 2)*.

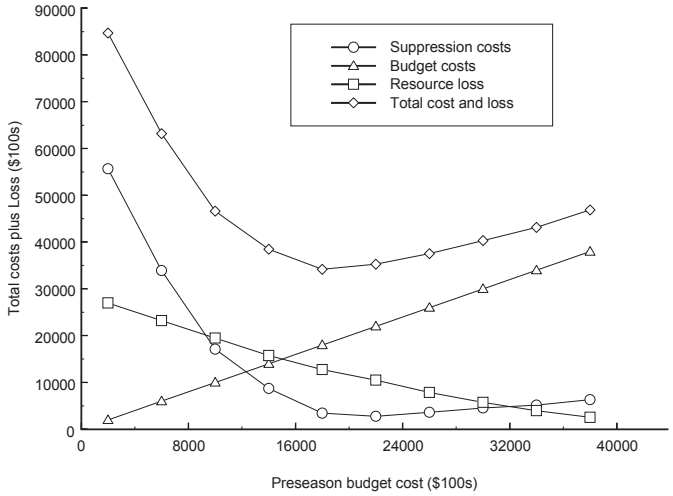


Figure 2—Economic tradeoffs associated with alternative presuppression budget levels.

Conclusions

Discrete event stochastic simulation provides a powerful operations research method for building decision support tools for planning highly complex initial attack service delivery systems. Taking a systems analysis perspective in the design of the WIRAS, the resulting initial attack simulation model can tackle a wide range of program and policy issues not previously addressable by other fire planning technologies. Not only can fire planners use WIRAS to determine the best program composition, they can also use it to improve their resource deployment and dispatch policies—locally, regionally, and nationally.

Acknowledgments

The WIRAS project is funded in part by the National Fire Plan.

References

Bratten, Frederick W.; James B. Davis; George T. Flatman; Jerold W. Keith; Stanley R. Rapp; Theodore G. Storey. 1981. FOCUS: a fire management planning system—final report. Gen. Tech. Rep. PSW-GTR-49. Albany, CA: Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture. 33 p.

Fried, Jerome S.; and J. Keith Gilless. 1999. The California Fire Economics Simulator: Version 2 User's Guide. University of California, Division of Agriculture and Natural Resources Publication 21580.

Henriksen, James O.; and Robert C. Crain. 1989. GPSS/H Reference Manual. Third edition. Wolverine Software Corporation. Annandale, Virginia.

Law, Averill M.; and W. David Kelton. 1991. Simulation modeling and analysis. McGraw-Hill, Inc., New York. 759 p.

Martell, David L., Robert J. Drysdale, Glenn E. Doan, and David Boychuk. 1984. An evaluation of forest fire initial attack resources. Interfaces 14(5), 20-32.

McAlpine, Robert. S.; and Kelvin. G. Hirsch. 1999. An overview of LEOPARDS: The level of protect analysis system. The Forestry Chronicle 75(4): 615-621.

Mees, Romain M. 1986. Locating suppression resources by travel time to wildfires. Res. Note PSW-387. U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station. 5 p.

Wiitala, Marc R. 1998. Modeling the spatial and temporal dynamics of initial attack fire suppression using GPSS. In: Proceedings of the III international conference on forest fire research and 14th conference on fire and forest meteorology, 1998 November 16-20, Lusco-Coimbra, Portugal. 2389–2403.

Wiitala, Marc R., and Carl L. Dammann. 2003. Simulating a smokejumper service delivery system. Systems analysis in forest resources. In: Arthaud, G.J; Barrett, Tara M, eds. Proceedings of the eighth symposium held September 27-30, 2000, Snowmass Village, Colorado, U.S.A., , Kluwer Academic Publishers, Dordrecht. 71–79.

Wilson, Andrew E.; and Marc R. Wiitala. 2003. Estimating travel times to forest-fires using resistance surfaces. Twenty-Third Annual ESRI International User Conference Proceedings, 7–11 July 2003, San Diego, California: Environmental Systems Research Institute, Inc., Redlands, California; unpaginated CD-ROM.

Page left blank intentionally.

Forest Fires in Mexico and Central América[1]

Roberto Martínez Domínguez,[2] Dante Arturo Rodríguez Trejo[3]

Abstract

Mexico and Central America are rich in biodiversity and contain approximately 73,000,000 ha of forest land, including ecosystems adapted to, and influenced by, fire. Nevertheless, due to excessive number of fires occurring due to poverty and a lack of forestry culture, 43 percent of causes are linked to agricultural activities with an average of 21,000 fires which annually affect 677,000 ha in the region. In 1998, some 56,731 fires affected 2,330,000 ha. Forest fires contribute to deforestation and contamination as well as influencing global climatic change, among other negative impacts. There are around 17,500 permanent fire-fighters in the region with varying levels of resources and technologies for different fire management tasks. In general fire fighting resources in the region are insufficient, although there have been important advances in many cases, with relevant support from several countries. However, the future scenario is one of more fires. It will be necessary to intensify international collaboration and also the search for finance schemes, to increase human resources and materials, training, prevention detection and fire fighting. Other possible parallel activities are the use of alternative agricultural technologies instead of fire, particularly in the tropics, and ecological integrated fire management, in appropriate ecosystems and areas and with emphasis on community participation, with the support of universities and research institutes, as well as international agencies.

Introduction

México, Central America, and the Caribbean account for 29 countries with a surface area of 264,774,000 ha, of which 79,443,000 ha (30 percent) are forest land. The rate of deforestation varies according to the country, although in general it is high. The average for the region is about a 1,037.000 ha/per annum or 1.3 percent per annum (FAO 1999). The population is 161,448,000 inhabitants.

Nevertheless, nine countries (Mexico, Belize, Guatemala, El Salvador, Nicaragua, Honduras, Costa Rica, Panama, and Cuba) account for almost 96 percent of the total surface area and 85 percent of the population. This paper will be based principally on those countries.

The natural scenario

Given the varied topography, with altitudes varying from sea level to 5,700 m, soils and climates, the region contains both tropical vegetation (such as the evergreen tropical forest, sub-evergreen tropical forest, deciduous tropical forest or savannah)

---

[1] An abbreviated version of this paper was presented in the second international symposium on the economics of fire, planning, and policy: a global view, 19–22 April, Córdoba, Spain.

[2] Deputy Director of Forest Fires, SEMARNAT-CONAFOR. Av. Progreso no. 5, México, D.F., MÉXICO. rmartinez@conafor.gob.mx.

[3] Profesor-Investigador. Forest Science Division, Universidad Autónoma Chapingo, Chapingo, Edo. de México, C.P. 56230, MÉXICO. dantearturo@yahoo.com.

and cold temperate (pinewoods, holm oak and Mexican fir, upland and alpine pastures) in addition to semi-arid zones (thorny scrub, for example). Mexico and Central America have 73,030,000 ha of forest land and plantations (*table 1*).

Table 1—*Forest resources in Mexico and Central America.*

Country	Land Surface (1000 ha)	Surface with forest (1000 ha)	Forest timber Biomass (ton/ha)
Belize	2,280	1,348	211
Costa Rica	5,106	1,968	220
El Salvador	2,072	121	202
Guatemala	10,843	850	371
Honduras	11,189	5,383	105
Mexico	190,869	55,206	54
Nicaragua	12,140	3,278	161
Panama	7,443	2,876	322
Region Total	241,942	73,030	95
World Total	13,063,900	3,869,455	109

Source: FAO (2002).

The biodiversity of the region is extremely rich. It comprises the "Meso-American biological corridor," which has important environmental, social, cultural and economic resources. Nevertheless there is strong social pressure, due to population growth and subsistence requirements of rural dwellers. In recent years greater importance is being attached to these areas by society in general, through evaluation by environmental services, greater public participation and the creation and importance of NGOs. Nevertheless, further international cooperation is required to strengthen and consolidate government efforts for the protection of forest ecosystems It should be recognised that regional management by the CCAD_CCAB and CCAP is important, in order to obtain resources from the international community. There is also a need for more determination on the part of institutions and resources to implement forestry policies in the face of the most serious environmental problem of the region: deforestation and forest fires.

The region contains vegetation adapted to fire, with frequent fire regimes (every two to ten years) and moderate regimes (superficial) as is the case of many pine woods, various holm oak woods, palm groves, pastures, savannah and wetlands. There is also vegetation with fire regimes characterised by relatively frequent fires (every 50 to 100 years) and intense, crown fires as in the case of much brushland. Finally there are catastrophic regimes which are infrequent, with fires occurring over centuries as in the Mexican fir forests (with crown fires) and the evergreen tropical forests (upland forests) and sub-evergreen (with subterranean or crown fires)

Despite the fact that there is a need for improvement in determining the causes of fire in the region, it is known that 3 to 12 percent are caused by lightning. In Mexico it is estimated that half of the 32 types of vegetation with 58 percent of forest surface, have fire regimes with return periods of up to 100 years.

Ecosystems adapted to frequent fires in Central America are those of the

savannah, palm groves and pinewoods of *Pinus tropicales, P. oocarpa* and *P. caribaea*. In the case of Mexico, Rodríguez and Fulé (2003) mention 35 species of pine with variously adapted to fire.

History of anthropic fires in the region

Due to its latitude, Mexico was the first place reached by ancient man some 40,000 years ago. From there he progressed to what are today the other countries of the region. Man used fire to clear a path in the thickets or to aid hunting by attracting game to areas of re-growth. With the discovery of agriculture in Meso-America thousands of years ago, another use of fire arose, that of cleansing the forest cover to establish cultivated crops. Over 3000 years ago the Olmecs and the Mayas evolved an efficient agricultural forest system for tropical areas, particularly those with stony shallow soils: the slash and burn method which, today, due to population increase as well as the atomisation of the land has reduced the period for which the land should lie fallow from several decades to two or three years, and it has now become a significant deforesting agent causing a risk of fire in tropical zones. Subsequent European influence included fire causes relating to pasture and with more intense exploitation of the forests. Currently the same fire causes prevail, i.e. agricultural fires.

The social factor

In all the countries of this region there is a considerable rural population engaged in agricultural, fishing and forest activities. However, poverty levels have always been high and have a tendency to rise. The Hemispheric Conference on Disaster Reduction in Costa Rica in 2001, reported that from 1990 to 1999 the number of those suffering absolute poverty in Latin America rose from 200,000,000 to 225,000,000. Twenty percent of those in the upper income bracket earn 20 times more than the poorest 20 percent , converting the region into world leader in terms of income inequality. Given the lack of options and forestry culture, the changes in the use of forest terrain into agricultural land, the burning of pastures and forests for the purpose of grazing (which in many cases may considered as overgrazing) and the practices of burning of agricultural land for the purposes of cleansing, fertilisation and disease control, as well fire used in slash and burn techniques, are very common and are the prime cause of forest fires.

In Mexico 41 percent of the surface area affected out of 32 states corresponds to Chiapas and Oaxaca, which have the two lowest development levels in the country including services, education and class differences.

Fire statistics

Each year on average some 21,000 registered fires affect approximately 677,000 ha (32.2 ha/per fire). The worst year in the history of the region was 1998, with 56,731 fires registered over 2,330,000 ha (41 ha/per fire), that is, the equivalent of 3 percent of forest surface and a surface area 2.25 times greater than the average annual deforestation rate for the zone (*table 2*).

Table 2—*Number of forest fires and surface area affected by fire and agricultural burning during 1998 in México and Central America*

Country	Number of Fires	Affected Forest Surface	Surface Affected by agricultural Burning	Total Surface Affected
Belize	656	22,960	16,400	39,360
Costa Rica	1,511	52,885	37,775	90,660
El Salvador	227	7,945	5,675	13,620
Guatemala	10,906	381,710	272,500	654,210
Honduras	9,594	335,790	239,850	575,640
Nicaragua	15,196	531,860	379,900	911,760
México	14,445	849,632	4,288,670	5,139,302
Panama	4,196	146,860	104,900	251,760
Total	56,731	2,329,642	5,345,670	7,676,312
Average 1998	7,091	291,205	668,209	959,539

Source: Forest Fires in Central America Workshop San Pedro Sula, Honduras, June 1998.

The agricultural surface affected in that same year was in the order of 5,346,000 ha, for a registered total (forest fires and agricultural burning) of 7,680,000 ha burnt, i.e. a surface area burnt equivalent to more than the total surface area of Panama.

For the whole 12 months of the year fires occur in some part of the region, although most take place between January and May. April is the month of greatest risk.

With regard to the causes, an average of 43 percent are related to agricultural activities (land cleansing, pasture burning to promote regrowth). Other important causes are smokers, bonfires, rubbish burning, deliberate fires due to disputes, hunters or other reasons, or to facilitate change of soil use which account for around 42 percent. Natural causes such as lightning vary between 3 to 12 percent according to the country. Forestry activity and other causes including unknown causes cover the remaining percentage.

One aspect of the impact of forest fire is an average emission of 1,000,000 ton CO_2/per month during the fire risk period of the tropical zones of the region (Wei et al. 1990).

Prevention

Physical, educational, and legislative prevention is implemented with varying degrees of intensity in the different countries of the region. Distribution of posters, pamphlets and educational material for schools, illustrating preventive measures as well as press and radio and television messaging, in addition to documentaries, are common measures, as are talks in schools and training and talks in rural communities including those at high risk. Opening of fire breaks is another common activity. In countries such as Honduras and México controlled burning is carried out.

As an illustration, Mexico has 1,423 dissemination activities in the guise of the Official Mexican Regulation on Fire Management, 6,846.89 printed works, television and radio broadcasts, 1,224 press, radio and television conferences and news bulletins, 4,359 activities extending to rural communities, 7,700 ha of controlled burning (mainly blacklines), 7,589 km of fire break control lines opened, and 6,656 km of maintenance of control lines.

Fire-fighting resources

In different parts of the region the following or partial means of detection are used: Civil participation, land detection (fixed and mobile), aerial and satellite detection. Mexico, for example, has 190 look out points. With respect to satellite detection, NOAA provides information on the region's hot spots via internet. In the case of Mexico, CONABIO has formed close links with CONAFOR to provide detection of hot spots which are also carried out in Guatemala and which could extend to all of Central America. The Mexican SMN is beginning to provide a similar service in Mexico.

There is no precise data for all the countries and some do not even have official fire fighting teams with the work being carried out by volunteers. Between Mexico, Guatemala, Cuba and Costa Rica, there are 16,500 permanent fire fighting forces (Martínez 2002; SIPECIF 2002; Ramos 2003; Murullo 2002). It is estimated that the region has at least 17,500 permanent fire fighters of the principal agencies responsible.

The situation is also very variable in terms of material resources, in some cases there is a lack of specialised equipment. In most countries however, although quantities vary, there is agricultural equipment, specialised manual tools, back pack sprayers, protective clothing vehicles, and radio equipment. Some countries have portable meteorological monitors

The availability of land and air vehicles is also very variable. Cuba has PZL-M18 Dromeder air tankers and pump trailers (Ramos 2003). El Salvador has two helicopters (Ibarra and Marroquín 2002). Honduras uses fire department tankers (AFE 2002).

As a more detailed example, different areas of México have almost 50,000 sets of manual and specialised tools, 3,663 specialised minor teams, 684 geopositioners 249 camps, 334 control centers, 898 vehicles for fire fighting teams, 2,786 radio equipment sets, 55 airships for detection, and 49 combat helicopters (Martínez 2002). Last year a dozen pump trailers were incorporated.

The amount spent on forest fire programmes amounts to 8,000,000 de Quetzales in Guatemala (SIPECIF 2002), 60,000,000 lempiras in Honduras, 191,600,000 pesos (including central operational costs, fire team salaries, temporary employment programme, and administration operational costs) in México (Federal government only) (Martínez 2002), corresponding to US $987,654, US $3,348,214, and US $17,461,686, for a total of US $21,797,554 in these three countries.

Fire fighting organization

The main fire fighting body in Mexico is CONAFOR, the federal government, with the participation of state and municipal governments. The Secretary of National

Defence also participates, as do the owners of forest land, forestry industry organisations, forestry service professionals, agricultural producers, civil bodies (NGOs academics, businessmen, producers), rural confederations (including CNC and CCI,) all of whom, together with personnel from protected natural areas, make up the Forest Fire Prevention Programme.

Various institutional bodies are involved in fire fighting and fire prevention. In Costa Rica (Ministry of Environment and Energy, with the National Commission on Forest Fires), Cuba (Corps of Forest Rangers of the Ministry of Interior), Honduras (State Forestry Administration, COHDEFOR), Nicaragua (National Forestry Institute), México (National Forestry Commission), and Panamá (National Environment Authority, with the National commission for fire fighting and prevention). Cases with various institutions include Belize (Forestry and Army Department), El Salvador (Fire fighting forces, National Emergency Committee), and Guatemala (National Plan for the Prevention and Control of Forest Fires of the Ministry of Environment and Natural Resources, Secretariat for Executive Coordination of the Presidency, CONRED, Army, Nation Forestry Institute and the National Council for Protected Areas).

Almost all countries have a National Operations Center although not always at a state or provincial level.

Training and Education

Training courses for instructors directed at technicians and professionals from various Latin American countries and Spain delivered by the US Forestry Service with instructors from U.S.A. and Spain, and with the support of AID, in 1984 and 1985, in Marana, Arizona, were the basis of a chain reaction in Mexico which slowly strengthened due to the interest of the federal area for prevention and control of forest fires and the continuing possible of participation of U.S.A., Spain, and Canada. Little by little the level of competence of fire fighters was raised and the type and level of courses diversified.

Mexico currently holds an international course every year for 60 participants from Mexico and other countries which has been held since 1990. There are courses for emergency management (basic or intermediate) for helibucket handlers, and also 900 basic courses held annually for ejidos and communities, and a national course for National Defence Forces in addition to two courses for Mexican Air Force pilots who receive certification from the USFS.

There has been a similar trend in other countries. In Guatemala, for instance, 103 courses of varying levels were held in 2002 (most of these were for forestry fire fighters, two for training instructors and one for emergency management)) (SIPECIF 2002). In Honduras, 28 courses were held the same year, three given by international trainers and 25 with national trainers (AFE 2002). In Nicaragua, 33 courses were held annually between 1998 and 2002, training 226 technicians and instructors and 1,615 fire fighters (INAFOR 2002).

Although with varying levels of proficiency, technical professional and postgraduate education covers the theme of forest fires in respect of various topics at a regional level. In the case of Mexico, all degree level institutions of forestry science offer a course in forestry protection or at least include the subject. For example, the Forestry Science Division of the Autonomous University of Chapingo holds a course

on Forestry Protection (which is a compulsory subject), and another on the Use of Fire (an optional subject). Since 2000 the postgraduate programme at the same university has held courses on the Ecology of Fire and the Restoration of Forest Ecosystems (from 2001) (which includes themes on fire management), and a special question on the theme of smoke from forest fires. Another program which offers courses related to the subject is UAAAN, with a course on forest fuel management.

Research

Research into the subject is increasing, particularly in terms of the ecology of fire, due largely to the interest of national or international researchers, although there is still much to be done. A case in point is the fact that Autonomous University of Chapingo, CONACYT, CONAFOR, the Government of Mexico City and the Community of Santo Tomás Ajusco, are carrying out a project on the ecology of fire and integral fire management in tall pine forests (*Pinus hartwegii*), known as the Ajusco Project (*table 3*). In addition the University of Guadalajara, the University of Washington and the INIFAP are carrying out another project with an ecological and social focus in the Manantlán Reserve, Jalisco, which includes the creation of stereoscopic guides for forest fuels.

Another field in which there has been active research is that of GIS and spatial statistics applied to the problem of fires largely due to the efforts of CONABIO, INIFAP, the University of Colima, and the College of Postgraduates among others.

Table 3—*The Ajusco project*

Antecedents. The Federal District has a surface area of 150,000 ha, 35,000 ha of which comprise pine woods, holm oak, Mexican fir, pasture, and zerophyte scrub. Among the pinewoods, the most notable is *Pinus hartwegii*, or upland pine (also present in Guatemala), found between 2,200 and 4,000 m above sea level. In terms of number of fires, the Federal District on average is third at a national level, some years with more than 1,000 fires. Nevertheless, excellent fire fighting cover by the federal and Mexico city governments, and good available access reduced the surface area affected to 20th position. Here the causes of fire are mixed, in rural areas relating to agricultural activities, principally pasture, and fires generated by the urban population, one of the most populated on the planet, (bonfires and smokers) in addition to the pressure of growth of Mexico City and contamination. Since this area has an ecosystem well adapted to fire, which is of prime importance in terms of conservation and restoration, and since it comprises high mountain terrain and includes endemic and status species, in addition to its problem of forest fires, it is an area of particular interest in the application of the project. Some of the research for this project was also done on this type of ecosystem in other parts of the Federal District or in the State of Mexico.
Objective. The aim of the project was to contribute to use of fire which reconciles its ecological role in this ecosystem, enabling it to be used for moderate livestock purposes maximising the positive impact of controlled low intensity fire (diversity of species, greater secondary growth, recycling of nutrients, creation of seed beds, reduction of danger of forest fires, among others) and reduction of the negative impact of fire, which obviously has a more dramatic effect (death of trees, disease, deforestation, erosion, pollution). As it continues to be an option for the rural land worker, it is hoped that in future he will contribute to the reduction of forest fires in the area. The project is being developed principally by researchers carrying out their postgraduate theses and degrees.

Continued…

Continuation…

Methodology and Results. At 3,500 m above sea level, these were fringe areas with low intensity fires (in March) and experimental confined fires at the peak fire risk periods (May 2002), and a test area was left unburned. Results were obtained for a year but at least three more years will be studied in order to analyse the duration of the effects found. Below the main results are detailed.

Behaviour of fire. The prescribed fire early in the period and early in the morning, against the wind, and at a gradient (55 percent) spread at no more than 1/min, with flame length of 0.5 m. The flames of the fire at the hours of greatest risk and in full fire risk period, with the wind in favour and on a gradient, reached flame length of 6 to 8 m. and with propagation speeds of up to 60 and 80 m/min.

Radial growth of *P. hartwegii*. The width and growth ring formed the year following the fire was greater than the test area when only the lower third of the crown was affected by the heat of the fire (an effect of natural pruning which eliminates the lower branches, which, having less foliage are less efficient in photosynthesis, thus more is consumed than produced, as well as fertilisation from the ashes). Those with brunt crowns from 33 percent to 66 percent had narrower growth rings than the test area. (González and Rodríguez,).

Survival and susceptibility to disease. The survival of young trees (from 2 to 6 m in height) was not statistically significant between the areas of prescribed burning in March and the test area (96 percent in both cases). In the May fires, survival was 48 percent although in most dense areas this value was 0 percent due to greater accumulation of forest litter which, when burned, transmitted greater temperatures to the superficial roots of the trees, thus killing them (Castro and Rodríguez,).

Wealth and diversity of species and species indicative of burned areas. In summer with the rains which characterise the region, 12 herbaceous and shrub species were registered in the test areas and 21 in the areas of controlled burning or of fires. The most dominant species and those indicative of the burned areas are: *Penstemon gentianoides, Senecio callosus, Lupinus montanus, Eupatorium* spp., and *Senecio tolucanus* (Martínez and Rodríguez 2003). In general the wealth of species is low due to the high altitude of the area.

Planting in burned areas. Initial survival (6 months on from planting) of trees of the species planted in the treated areas did not significantly differ statistically between the test areas and those of the controlled fire in March (with 93 percent and 88 percent). The areas burned in May had a lower level of survival (60 percent) (Ortega and Rodríguez 2003).

Smoke from fires. Emissions of NO_X, SO_2 , and CO were, respectively, 9.37 Kg/ha, 2.84 Kg/ha, and 198.69 Kg/ha. *Senecio cinerarioides*, a species which appeared abundantly in many areas of the central region, affected by past fires in 1998, is the main cause of emissions of these gases. If such areas are burned again they will contaminate more than they would have if typical superficial fuels of these pinewoods had been burned. (Contreras et al. 2003).

Germination of *Lupinus bilineatus*. Seeds of this species remain dormant. Without treatment at 20 °C during the day and 15 °C at night with 12 light hours only 18 percent germinate. With fire scarification it rises to 39 percent with significantly different statistics (Martínez and Rodríguez,).

Existing projects and Initiatives

These are as follows:

- Meso-American Cooperation Programme. With the summit meeting of heads of states of the countries which are members of the Dialogue and decision Tuxtla IV.
- Meso-American Biological Corridor for consolidation with the participation of PNUD, GEF, GTZ, DANIDA, CCAD and the governments of Mexico, Belize, Guatemala, El Salvador, Honduras, Nicaragua, Costa Rica, and Panama.
- United Nations World Food Programme. For mobilization of voluntary brigades in Honduras.
- Integrated Management of the Ecosystem in Indigenous Lands and of the in Central America. With the participation of the GEF.
- World Bank Central American Geographic Information with the participation of CATIE and CIAT.
- Regional Environmental Programme for Central America. Run by USAID.
- Emerging Plan for the Prevention and Control of Forest Fires at a national level (INAB).
- Training and Education Programme for Forest Fire Instructors (OFDA-AID).

Cooperation networks

These include:

- British-Nicaraguan Cooperation (NOAA, MARENA, INAFOR). For the detection of hot spots using satellites.
- Prevention and Control of Forest Fires in Meso-Amercia (CCAD-Tuxtla IV).
- Inter-American Information Network on Biodiversity (IABIN).
- Programme of hot spot detection using remote perception techniques. (CONABIO-CCAD).
- Central American Alliance for Sustainable Development (ALIDES).
- Working Group on Forest Fire Management (COFAN: U.S.A., Canada, and Mexico).

Future fire scenario

The future scenario, while current levels of activities and resources are maintained, is one of more fires and greater surface areas affected. This is true given existing investigation into global warming (which results in higher temperatures, less

humidity, the spread of more inflammable vegetation such as underbrush and pasture, reduction of forests, and greater presence of lighting on various areas of the planet) in addition to the effects of El Niño. In addition, given the fact that poverty is unlikely to be resolved in the region, the result is a greater presence of natural and anthropic fire.

It should be recalled that if tropical forests, a mainstay of biodiversity, are affected by fires, this will lead to a greater risk of fire until these areas are progressively converted to savannah and pasture.

Dealing with the probable scenario

Undoubtedly of prime importance in reducing the attack of fire is greater cooperation of agencies within the country itself and between countries, such as the search for financing schemes to reinforce prevention—pre-suppression and suppression with greater human, material, technical, technological and financial resources. For example, among the goals for future international cooperation: establishing regional mechanisms to ensure the contribution of technical and financial resources from the international community, for the purpose of strengthening and consolidating government efforts in the countries of the region for planning, prevention, detection and control of fires, which permits the training, and the formation of teams with specialised equipment as well as establishing systems in response to emergency management.

Another aspect is that of alternatives to fire in agricultural activity and the fact that it would be advisable to increase, particularly in tropical areas, slash and dig instead of slash and burn techniques. Another option is also greater incorporation of well-planned agricultural forest systems

However, there is an additional growing trend in various countries, through the initiative of academics and technical experts and with participation or initiative of other nations which has two components. The first is linked to the ecological role of fire, that formidable adversary which can be temporarily vanquished, but which cannot be excluded from the planet, since it has been present in vegetation for millions of years and most of the land ecosystems have developed variously depending on the frequent presence of fire or rarely its influence. Efforts are being made in scientific research and on an operational scale for the use of fire for ecological and forestry purposes.

It is also necessary to consider on one hand that man has frequently burned vegetation to excess, lowering its resistance to fire and degrading it. On the other hand, the exclusion of fire leads to an accumulation of fuel which will make the next fire more intense, more dangerous, and with a greater negative impact; in addition to being more expensive and difficult to control. A happy medium would be ideal, such as using fire but with a technical and scientific basis.

For example, TNC is starting controlled fires for ecological purposes in reserves such as La Amistad, Costa Rica; Madre de las Aguas, Dominican Republic, and Rio Bravo, Belize. In Mexico attempts are also being made in the ecological and integrated management of fire, via controlled burning of vegetation in fire regimes where fires are frequent but not intense and/or integrated fire management in the Parque Cumbres del Ajusco, and in reserves such as Manantlán, La Sepultura, La Encrucijada, El Ocote, Sierra de los Ajos, and la Sierra de Arteaga, with the

As an illustration, Mexico has 1,423 dissemination activities in the guise of the Official Mexican Regulation on Fire Management, 6,846.89 printed works, television and radio broadcasts, 1,224 press, radio and television conferences and news bulletins, 4,359 activities extending to rural communities, 7,700 ha of controlled burning (mainly blacklines), 7,589 km of fire break control lines opened, and 6,656 km of maintenance of control lines.

Fire-fighting resources

In different parts of the region the following or partial means of detection are used: Civil participation, land detection (fixed and mobile), aerial and satellite detection. Mexico, for example, has 190 look out points. With respect to satellite detection, NOAA provides information on the region's hot spots via internet. In the case of Mexico, CONABIO has formed close links with CONAFOR to provide detection of hot spots which are also carried out in Guatemala and which could extend to all of Central America. The Mexican SMN is beginning to provide a similar service in Mexico.

There is no precise data for all the countries and some do not even have official fire fighting teams with the work being carried out by volunteers. Between Mexico, Guatemala, Cuba and Costa Rica, there are 16,500 permanent fire fighting forces (Martínez 2002; SIPECIF 2002; Ramos 2003; Murullo 2002). It is estimated that the region has at least 17,500 permanent fire fighters of the principal agencies responsible.

The situation is also very variable in terms of material resources, in some cases there is a lack of specialised equipment. In most countries however, although quantities vary, there is agricultural equipment, specialised manual tools, back pack sprayers, protective clothing vehicles, and radio equipment. Some countries have portable meteorological monitors

The availability of land and air vehicles is also very variable. Cuba has PZL-M18 Dromeder air tankers and pump trailers (Ramos 2003). El Salvador has two helicopters (Ibarra and Marroquín 2002). Honduras uses fire department tankers (AFE 2002).

As a more detailed example, different areas of México have almost 50,000 sets of manual and specialised tools, 3,663 specialised minor teams, 684 geopositioners 249 camps, 334 control centers, 898 vehicles for fire fighting teams, 2,786 radio equipment sets, 55 airships for detection, and 49 combat helicopters (Martínez 2002). Last year a dozen pump trailers were incorporated.

The amount spent on forest fire programmes amounts to 8,000,000 de Quetzales in Guatemala (SIPECIF 2002), 60,000,000 lempiras in Honduras, 191,600,000 pesos (including central operational costs, fire team salaries, temporary employment programme, and administration operational costs) in México (Federal government only) (Martínez 2002), corresponding to US $987,654, US $3,348,214, and US $17,461,686, for a total of US $21,797,554 in these three countries.

Fire fighting organization

The main fire fighting body in Mexico is CONAFOR, the federal government, with the participation of state and municipal governments. The Secretary of National

SIPECIF (Sistema Nacional de Prevención y Control de Incendios Forestales). 2002. **Guatemala.** 1ª Reunión mesoamericana de Incendios Forestales. Guatemala, Guatemala. Julio 2002.

Wei Min Hao, Mei-Huey, L., and Crutzen, P. J. 1990. **Estimates of annual and regional releases of CO_2 and other trace gases to the atmosphere from fires in the tropics, based on the FAO statistics for the period 1975-1980.** In: Goldammer, J. G. (ed.). Fire in the tropical biota. Berlin: Springer-Verlag.; 440-486.

This publication is available online at www.fs.fed.us/psw/. You may also order CDs of it by sending your mailing information in label form through one of the following means. Please specify the publication title and series number.

Fort Collins Service Center

Web site	http://www.fs.fed.us/psw/
Telephone	(970) 498-1392
FAX	(970) 498-1122
E-mail	rschneider@fs.fed.us
Mailing address	Publications Distribution Rocky Mountain Research Station 240 West Prospect Road Fort Collins, CO 80526-2098

Pacific Southwest Research Station
800 Buchanan Street
Albany, CA 94710

Federal Recycling Program
Printed on Recycled Paper

PENCO