



United States
Department of
Agriculture

Forest Service

Pacific Southwest
Research Station

General Technical Report
PSW-GTR-227 (English)
November 2009



Proceedings of the Third International Symposium on Fire Economics, Planning, and Policy: Common Problems and Approaches



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Proceedings of the Third International Symposium on Fire Economics, Planning, and Policy: Common Problems and Approaches

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Pacific Southwest Research Station
Albany, California
General Technical Report PSW-GTR-227 (English)
November 2009

Abstract

González-Cabán, Armando. 2009. Proceedings of the third international symposium on fire economics, planning, and policy: common problems and approaches. Gen. Tech. Rep. PSW-GTR-227 (English). Albany, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station. 395 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 regional, national, and global vision of forest fires: common problems and approaches, theory and models for strategic fire planning, economic analysis and modeling for fire management, forest fires and sustainable forest management, public policies and forest management, hazardous fuels treatment, wildland fire use and fire suppression activities, examples of fire management plans and strategic fire resource allocation, and a round table on the role of international organizations in forest fire solutions. Representatives from international organizations with fire protection responsibilities in 12 countries presented and discussed their experiences on the same issues. Thirty-six invited and contributed papers and 18 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

The costs of wildfire management have escalated in the past decade, largely owing to increased expenditures for suppressing large wildfires. Frequent siege-like fire incidents have enormous costs in loss of life, property, and natural resources. Additionally, there is growing recognition of the futility of fighting fires in ecosystems where prior fire exclusion policies have led to dangerous fuel accumulations. This is also true in countries with significant wildland fire problems such as Argentina, Chile, Spain, Canada, and Australia, and Central American countries like Costa Rica, Guatemala, Honduras, Mexico, Nicaragua, Panama, and Colombia. In the Caribbean basin, countries like Cuba and the Dominican Republic are experiencing similar situations. In Puerto Rico, for the first time, in 2005 there were large wildland-urban interface fires in the Municipality of Mayagüez.

Political and social pressures, such as those encountered in urban interface and multiple-use areas, complicate recent shifts in agency philosophies toward managing sustainable ecosystems. The economic consequences of alternative management strategies are poorly understood. Cost-effectiveness comparisons between prescribed fire and other treatments are compounded by analytical difficulties. Expenditures on large fires may bear little relation to values at risk. Current analysis tools for justifying budgets and displaying tradeoffs rarely incorporate consideration of all relevant contributors to fire management costs and net value changes. Outside of North America (Canada and USA), and most recently Spain, very little work has been done on analyzing the economic consequences of alternative fire management strategies. Many countries have recently recognized the need for the economic analysis of their wildland fire management investments. However, few have developed the necessary tools to perform this work.

In the USA, numerous reports have recognized the importance of optimizing fire management costs, yet progress toward this end has been slow, uncertain, and elusive. Recommendations contained in several fire policy reviews following the disastrous 1994 fire season, and more recently the 1998, 2000, and 2003 fire seasons, suggest a clear need for a forum in which policymakers, natural resource managers, and fire managers and practitioners can exchange ideas and learn from mutual concerns and experiences.

In spring 2004, the Second International Symposium on Fire Economics, Planning, and Policy: A World View was held in Córdoba, Spain, to address the issues outlined here. Since then, disastrous events in the 2003, 2004, and 2005 fire seasons have exacerbated the problem. Many changes in policy have taken place in response to the new challenges. There is the need again to bring together the community of wildland fire agency managers and practitioners, natural resource managers, researchers, foresters, economists, students, and policymakers to discuss recent problems, experiences, and responses to wildland fire. The goals of the proposed symposium are (1) to bring together individuals interested in exchanging ideas regarding the economics, planning and policies of wildland fire management; (2) share the most recent developments and technologies for optimizing fire management

expenditures; (3) explore the tradeoffs among hazardous fuels treatments, wildland fire use, and suppression expenditures; and (4) share recent developments in strategic fire planning models.

Thank you!
Armando González-Cabán
Carolina, Puerto Rico
April 29, 2008

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Forest Fires in the Mediterranean Basin¹

Ricardo Vélez Muñoz²

Abstract

Forest fires in the Mediterranean Basin are not only a consequence of long periods of drought; they may also be considered an indicator of the socioeconomic differences between the diverse areas and their levels of development. The Mediterranean countries at the north of the Basin (Europe) are the ones that register the greatest number of fires as well as the largest area of burnt land, precisely as a consequence of their greater economic development.

The socioeconomic changes in the last decades influence the risk of fire by increasing combustibility in ecosystems.

To confront these risks, southern European countries have greatly improved their fire suppression resources during the last two decades at a high economic cost and apparently acceptable results. However, the possibilities to continue making large investments in order to confront these aggravations to the problem seem to be almost exhausted.

The greater part of the resources is used in the suppression of fires, following the general criteria that all fires must be extinguished. The principle of integrated suppression and the availability of economic resources have led to important improvements in providing training and equipment to personnel, as well as the generalization of employment in aerial means. Every summer, approximately 400 aircrafts intervene in forest fire suppression in Mediterranean countries in Europe.

Currently, there is no database with information about the investments on forest fire protection. However, it is estimated that the five Mediterranean countries which belong to the EU invest more than 2.5 billion euros each year in prevention and suppression, of which 60% is invested in equipment, personnel and forest fire suppression operations, and the rest is used in preventive work.

A new problem which becomes more evident with each coming summer is the risk of fire in the urban/forest interface. This problem is creating an increasing concern as communities grow into forest, coast, and mountain areas with primary and secondary homes with large city influences. Preventive legislature for this problem does not exist or is clearly insufficient, for which reason it is foreseeable that this problem might reach catastrophic gravity.

The forest fires which occurred in Greece in 2007 have served as a tragic reminder of this problem. They have also shown the possibilities of cooperation, as numerous firefighting resources were sent from the western countries of the Mediterranean to the east, in order to help in high risk areas.

1. Introduction

The fires in the Mediterranean Basin are not only a consequence of long periods of drought; they may also be considered an indicator of the socioeconomic differences between the diverse areas of the region and their levels of development. The

¹ An abbreviated version of this paper was presented at the Third International Symposium on Fire Economics, Planning, and Policy: Common Problems and Approaches; April 29 - May 2, 2008, Carolina, Puerto Rico.

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Mediterranean countries at the north of the Basin (Europe) are the ones that register the greatest number of fires as well as the largest area of burnt land. This tendency seems to begin in the northeast and spread towards the west.

Socioeconomic changes in the last decades influence the risk of fire by increasing combustibility in ecosystems. The changes with the most serious repercussions are the following:

- a) Depopulation of rural areas causes an accelerated process of abandonment of land, which is later overrun by spontaneous vegetation that is highly combustible. Also, as the remaining population grows old, the risk of fire increases due to farmers and shepherds who traditionally burn down vegetation in order to control it.
- b) The concentration of population in urban areas is spreading to the urban/forest interface. New homes, primary or secondary, are threatened by ever-growing vegetation in the surrounding areas.
- c) A change in priorities in forest policy, which used to be focused on the production of wood and other raw materials, and is currently directed toward the conservation of nature, landscape, and on leisure-related uses. The decrease in the extraction of wood and lumber in some areas has increased the accumulation of highly combustible biomass in the forest.

The low fire occurrence in the southern as well as eastern countries of the Basin (North Africa, Middle East), where these changes have not occurred, sharply contrasts with the high risks in the European countries of the Basin.

To confront these risks, the countries that belong to the “fire club” (Portugal, Spain, France, Italy, and Greece) have greatly improved their fire suppression resources during the last two decades at a high economic cost, but with apparently acceptable results. However, the possibilities to continue making large investments in order to confront these aggravations to the problem seem to be nearly exhausted. Thus, the fight against forest fires requires new approaches to improve prevention and suppression strategies.

2. Conditional Factors to the Situation

2.1 *Ecological Factors*

Meteorology, and related modifications due to climate change, cannot foresee a reduction of the long drought period (3 – 6 months) during which vegetation

flammability is very elevated. Furthermore, an increase in the frequency of dry storms has been observed during these periods which coincide with large accumulations of fine fuels in open areas due to migration from rural areas, which can start intense fires in several areas at the same time.

2.2 *Economic Factors*

Forest areas with Mediterranean climates have very low economic profitability when compared to other regions because of the slow growth of the species populating them, and due to the low demand for the products available in the area, with the exception of cork. This reduced direct economic value dissuades investors who might be able to otherwise improve productivity. In Spain, the forest sector represents only 5% of the environmental market.

The risk of forest fire is another negative factor for the economy. Thus far, it has not been possible to establish or, much less, consolidate an insurance system against fire that might make it easier to obtain credit, and therefore, investments.

Unfortunately, the environmental values of the forest areas do not attract capital seeking profitability.

2.3 *Demographic Factors*

The Mediterranean Basin is a region of the world with a growing population. In 1950, the population totaled 225 million people. In 2000, the population had reached 450 million people, and it is expected that by the year 2050 it will reach 600 million. However, the population is concentrated along the coastal areas and in some urban areas of the interior.

Because of this, the urban population in the Basin countries accounted for 60% of the entire population in 1970 and 70% in 2000. In the northern countries of the Basin, this proportion is already at 90%. In other words, the rural areas have begun to empty out, and mountainous forest areas may even be considered deserted.

Currently, the intense migration movements do not modify this situation since the migrating population tends to concentrate in urban areas and in highly productive farming areas; in other words, they migrate to areas where there are more employment opportunities.

The desertion of rural areas produces an abandonment of land, which is later overrun by spontaneous vegetation that remains highly combustible for many years. The population shortage also represents a decrease in labor in the field of forest management in general, and particularly, in protection against fires.

2.4 *Political Factors*

In view of the previously discussed points, an attractive situation that might encourage political interest in forest protection does not exist in the region. However, the urban voting population has voiced a demand for environmental protection, which has in turn contributed to the establishment of permanent protection programs as another service provided by the Welfare State. These services, however, have the kind of shortcomings that are common such a political focus. First of all, the system pays attention to urgent matters (fire suppression), but barely has the resources to attend to what is important, i.e., prevention. Second, the administrative interventions tend to generate, on the one hand, passivity on the part of the population, and, on the other, unreal expectations in situations of extreme danger that are not well understood by the population.

3. The Results of Fire Suppression

As previously mentioned, the greatest proportion of available resources is used in fire suppression, following the general criteria that all fires should be extinguished. The U.S. policy of allowing some areas to burn (prescribed natural fire) is not considered a possibility in any case.

The concentration of property requiring protection in urban areas, along with the development of firefighting services in said areas, has produced, in many cases, the transference of fire suppression responsibilities to said services, disassociating them from forest activities.

Since this transference is not supplemented by any specialization in forestry techniques, it has led to somewhat long periods of disorganization, and unsatisfactory results. Nevertheless, little by little, the concepts of forest fire behavior and specific attack techniques are becoming more generalized with a greater degree of organization between firefighting services and forest management services.

The principle of integrated suppression and, fortunately, the availability of economic resources, have led to significant improvements in providing training and equipment to personnel, as well as the generalization of employment in aerial resources. Every summer, nearly 400 aircraft intervene in the suppression of forest fires in European Mediterranean countries.

This principle means that all the available firefighting resources are gathered with the sole objective of minimizing damages at any cost, even if it if these are higher.

4. Budget Allocation for Forest Fire Protection

Currently, there is no database with information about the investments on forest fire protection. However, it is estimated that the five Mediterranean countries which belong to the EU invest more than 2.5 billion euro per year in prevention and suppression, of which 60% is invested in equipment, personnel and forest fire suppression operations, and the rest is used in preventive work.

5. New and Old Problems

The data on forest fires indicate that fires are an ongoing problem of a seasonal nature in the Mediterranean region. Despite the fact that rural areas are being deserted, most fires still originate due to traditional burning practices for agricultural and cattle raising purposes (burning of agricultural remnants, burning of dry pasture). Winter fires in the mountain areas (Cantabria, The Pyrenees, The Alps) sometimes cover large areas of land. They are forcing changes on the firefighting services' strategy, which is focused on the summer season, and are also activating mobile firefighting units in the winter.

The accumulation of fuels, which the desertion of lands produces in great proportions, triggers large fires. Also, as a secondary cause until a few decades ago, intense sunlight may increase the occurrence of large fires over these vast areas of land. The tragic seasons of 1994 in Spain, and 2003 in Portugal and France, were caused mainly because of a mix of sunlight and an extensive accumulation of fuels in mountainous areas.

Intense erosive effects appeared after the large fires, as was foreseen. This is an example of a chronic problem which has worsened in the last years.

A new problem that becomes more evident every summer is the risk of fire in the urban/forest interface. This problem, which was considered more endemic to other regions of the world (California, Australia), is creating an increasing concern as communities extend into forest, coast, and mountain areas with primary and secondary homes with many urban characteristics. Accidents resulting in the destruction of homes and the loss of human lives have become more frequent. Firefighting services find themselves forced to concentrate on the protection of housing, and must thus leave forest areas unprotected. Preventive legislature for this problem does not exist or is clearly insufficient, for which reason it is foreseeable that this problem may reach catastrophic severity.

6. International Coordination

Constitutionally, the European Union lacks a forest policy, since this issue was not addressed in the Treaty of Rome. However, in the last decade there have been some attempts to fill this vacuum, such as the approval of a Forestry Strategy by the

European Parliament and the approval of the Reforestation of Marginal Agrarian Lands Program. Also, from 1985 to 2001, a series of Forest Fire Prevention Regulations have been effective with the very small funding provided to them. These regulations have allowed for the creation of a European forest fire database (EFFIS) and have supported some preventive activities.

In 2003, a new regulation (Forest Focus 2003) was approved with reduced funding to cover a follow-up network on forest conditions, the database on forest fires, and some preventive measures. This regulation concluded in 2006.

It is necessary to point out that there is no community contribution in fire suppression operations. However, there is great solidarity among neighboring countries through bilateral agreements for mutual aid. In the last few years, the availability of aircraft has increased the frequency of these operations, which has established the need for regulation, updating treaties, and an attempt to set homogeneous coordination rules; in other words, a regional Emergency Management System. The Silva Mediterranea/FAO Committee is promoting the creation of said rules.

7. Perspectives

The identified problems and the factors that condition the situation are not forestry based. The forestry sector must simply suffer with these problems, which make themselves manifest through the sign of fire.

Global development has brought many advantages for the forestry sector, but it also poses an ever-growing threat: the great frequency of devastating fires.

Europe has a strong suppression infrastructure and an acceptable database, but it needs significant improvements in some countries. In addition, there is a small group of researchers dedicated to forest fires, despite the fact that the outcome of their work in Operational Services is quite limited.

Preventive silviculture will clearly create a deficit, as do all environmental education programs, which include programs for both rural and urban populations.

New problems at the urban/forest interface may move society to demand that more attention be paid to prevention projects, with effective actions rather than rhetorical declarations.

Another factor that might also be influential is the present level of saturation for fire suppression and related costs, which continue to rise. During the 1990s, aerial resources were developed by taking advantage of the low cost of restricted aircraft of U.S. military origin, as well as aircraft from former East-bloc countries.

New rules on aircraft security are forcing the introduction of technological improvements that favor security as well as efficiency, but create a significant supplementary cost. This limits the possibilities for further expansion of air fleets.

The more evident possibilities for systemic improvements are only found in a coordination of preventive actions, which would limit the frequency and intensity of fire through silvicultural practices aimed at reducing biomass.

Under these conditions, improvements in the quality of the firefighting services, with well-equipped, well-trained, and well-led personnel, applying specific techniques while suppressing fires, will enable us to maintain or improve overall results.

To achieve this improvement of services, it is necessary to maintain a high level of personal safety which will contribute to a generalized system of certifying personnel. This will also make possible the multilateral aid operations between countries that, in the present state of globalization, are expected to be more frequent.

Conclusions and Recommendations

- 1.- Environmental protection in Europe, the Mediterranean Basin, and the Caucasus, cannot be effective without a Regional Strategy for Fire Management, designed according to the distribution and intensity of danger, and developed in cooperation with the interested parties, public and private, from the forestry sector.
- 2.- Desertion of rural areas and the decline of the forest economy in the Mediterranean Basin, together with the outlook on climate change, may worsen the natural conditions that cause the risk of fire.
- 3.- Priority should be given to the prevention of fires that are a consequence of socioeconomic changes in rural areas, while encouraging the participation of the local population in said projects.

Asia and Australasia Wildfire Management: A Regional Perspective¹

Gary Morgan²

Abstract

These days, there are few communities in fire-prone areas in the region that believe they are successfully managing their forests and woodlands, and the inherent fire threat associated with them. Changes in philosophical and organizational approaches to wildland areas over the last forty years, the expansion of urban populations into the hinterland, and more recently the uncertainties associated with global warming present decision-makers with considerable dilemmas. Through much of the region appropriate fire regimes are critical to the survival of the rich biodiversity, and indeed, in a number of ways to the very character of many landscapes. In several Asian nations, and on many Pacific Islands, the use of fire in large-scale forest conversion and the lack of appropriate measures to prevent the spread of land-use fires into protected vegetation have led to unprecedented ecological and environmental problems and, in a number of situations, to smoke-related health crises. This paper briefly examines:

- The region's recent wildfire history in the wake of an apparent increasing frequency of devastating fires;
- Efforts being made in the region to better come to terms with the economic, policy and planning implications of fire; and
- Developments politically and the desire, in some quarters, to want to overly simplify the region's recent wildfire experience.

The paper suggests that there is considerable scope for improving the efficiency and effectiveness of the region's current approaches to forest and woodland fire management and that:

- Parts of the region currently run the risk of spending ever-greater amounts of money on wildfire suppression, while becoming even less successful in the management of fire in the landscape than is currently the case;
- In many areas it is time to rediscover the relationship between appropriate, year-round forest and woodland management and wildfires;
- There is, in many areas, a need to develop a more strategic approach to the management of growth in the rural-urban interface and a better way of sharing the

¹ An abbreviated version of this paper was presented at the Third International Symposium on Fire Economics, Planning, and Policy: Common Problems and approaches; April 29 - May 2, 2008, Carolina, Puerto Rico.

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risks and costs associated with fire management in interface areas;

- With the advent of global warming it is increasingly futile, in many parts of the region, to develop policies in areas ranging from water and biodiversity conservation, to urban planning, carbon sequestration, and the maintenance of key aspects of indigenous culture, without first critically analyzing fire management considerations; and that
- Fire and land management policy must be underpinned by quality research.

Finally, it is suggested that there is a need for an on-going international policy dialogue to broaden the understanding, among relevant policy makers and the wider community of the key issues involved, and that scope exists for greater fire-related co-operation both within the region and beyond.

Keywords: Asia, Australasia, fire management, regional perspective.

Introduction

There is a growing consensus emerging internationally, that societies that largely ignore the bush ('nature') for most of the time will, in fire-prone areas, pay a re-occurring price in terms of social disruption, damaged assets, environmental degradation and, at times, loss of human life.

Reviewing international trends in fire management in 2006, the internationally based NGO 'The Nature Conservancy' suggests that far too often "There are disconnects between fire prevention programs, suppression responses to wildfires, fire use, conservation of biodiversity, and the needs and aspirations of people who use and are affected by fire" (Myers 2006).

Humans are currently understood to have first used fire, to manipulate the African savannas, several million years ago. The thoughtful and deliberate use of fire in other parts of the world over the millennia is also increasingly being understood. The current dilemmas being faced in Asia and Australasia would, at one level, seem part of the long tradition of human adaptation to changing circumstances.

Across much of the region fire presents somewhat of a paradox - in many locations natural fires are essential to maintain ecosystem dynamics, biodiversity and productivity. Fire is also widely used as a land management tool. Each year however, fires cause widespread loss of life, ecosystem damage, and adverse economic and social impacts. They also contribute increasingly to global warming. Secondary effects of inappropriate fire can include land and mudslides, and flooding.

Despite these impacts, reliable, current information relating to key aspects of fire and fire management across the region ranges from barely adequate to non-existent. While international monitoring (using satellite technology) is increasingly in

use, in many parts of the region it is impossible to distinguish unplanned fires from land-use fires. This difficulty, when coupled with variations in the availability and nature of base data, varying population densities and vegetation types, makes comparisons within the region difficult. And without such information the development of appropriate policies, legislation and fire management plans at both the national and international level is restricted.

Nonetheless, there is evidence, in parts of the region, of increased fire numbers affecting larger areas and burning with greater severity. Complicating an analysis of these emerging trends is climate change, population pressures and associated changes in land use, and institutional constraints on sustainable forest and fire management.

Using Indonesia as an example, the past two decades has seen fire management as an increasingly important development-linked issue. The El Niño-Southern Oscillation (ENSO) has caused considerable climate variability, repeatedly bringing severe droughts (and disastrous wildfires) to the archipelago. Rapid population increase has led the country's government to re-settle people from overpopulated islands to less densely populated ones, with consequential pressures to convert rainforest to agricultural landscapes. This conversion is invariably associated with a general lack of traditional skill in using fire. Finally, the regional climate regularly traps the smoke from land-use related fires and leads to severe smog problems.

Most fire-prone countries in the region invest significant resources in fire detection and suppression, traditionally using ground-based personnel. Detection through the use of satellites, and related remote sensing technologies, and the use of aircraft in fire suppression are on the increase however. In a number of parts of the region an emerging trend sees the policy response to fire emergencies as increased investment in expensive suppression forces and technologies, at the expense of fire prevention activities and year-round land management, strategies which may have averted the emergency in the first-place.

Organizationally, the institutional arrangements for managing fire vary considerably. In fire-prone nations a national fire service is usually chartered with protecting people and property, with priority usually given to urban areas, while forest and conservation area agencies assume varying levels of responsibility in less settled areas. In a number of locations the military also provide support when other resources become limited.

Co-ordination between the various responsible organizations remains a challenge in many jurisdictions, the UN's Food and Agriculture Organization (FAO) referring for example, in its 2006 'South Asia Assessment', to a "lack of feeling of responsibility (for fire management) on both sides – government and local

population. Tackling the difficult issue of fire is postponed by national Parliaments as soon as ... the danger recedes.”

Throughout the region humans cause the overwhelming number of fires. In remoter areas however the relatively small percentage of lightning-caused fires can lead to significant areas being burnt. Conversely, in areas such as eastern Russia, where very active suppression regimes were maintained for many decades, fuel build-up has led to changes in species composition and ecosystem structure and a changed fire risk.

In summary, the region is a highly diverse one in socio-economic, cultural and environmental terms, and each country faces its own set of challenges in terms of the management of landscape fire. Any attempt to summarize the fire management situation over such a vast and diverse area of Earth must, of necessity, be dependent on the work of many others. This is certainly the case with this paper and a number of key references are listed later. I would however, and at the outset, acknowledge the value, in preparing this summary, of the FAO's *Fire management – global assessment 2006*. Without the work of the FAO, and those who supported it, this regional summary would have been much the poorer.

The Current Situation - Asia

Stretching east from the Ural Mountains and the Suez Canal, and south of the Caucasus Mountains and the Caspian and Black Seas, Asia is bounded to the east by the Pacific Ocean, to the south by the Indian Ocean, and to the north by the Arctic. It comprises about one-third of the land area on Earth and contains around 60% of the world's current human population.

As would be expected with the range of latitudes and landforms involved, the vegetation, land uses and fire regimes across the region vary enormously. As an example, in parts of northeast Asia the effect of fires on permafrost sites, which may lead to the degradation of forests due to the long restoration process, is an increasing concern. While increased numbers of fires in the boreal forests of Russia are considered to be a major threat to the global carbon budget. (Together, the temperate and boreal forests of northeast Asia are estimated by some to account for more than 2 percent of both global biomass burning and carbon emissions). Meanwhile, in central and southeast Asia, the environmental impact of fires in deep organic layers such as peat, which are difficult or impossible to control, as well as the continuing effect on human health of smoke emissions from these fires are presenting increasing problems.

In many parts of Asia the traditional role played by fire in rural economies has been altered dramatically in recent decades. Shifting cultivation cycles, as a

consequence of the pressures of changing markets, and because of increasing population pressure is seeing a greater use of slash-and-burn ‘pioneer’ agriculture, without the long fallows of more traditional agriculture. Such approaches are increasingly also practiced by populations that are either attracted to, or forced to migrate to forest (particularly tropical) areas. Burning is also essential to maintaining the cattle pastures that are replacing large areas of tropical forest.

Recurrent land-use fires that generate emissions that seriously affect the environment and human health have been a growing problem in Southeast Asia since the late 1970s. In 1999, the Association of Southeast Asian Nations (ASEAN) introduced a ‘zero-burning’ policy that has proved to be, in the view of FAO, ineffective. It is now being suggested that the role fire plays in the livelihoods of rural people is more fundamental than had been appreciated. Modified guidelines are currently being developed to allow prescribed burning by small-scale landowners, but the use of fire by shifting cultivators in developing economies still presents a considerable challenge.

In central Asia a unique challenge involves the prevention of fires in areas contaminated with radiation – around 6 million hectares of forest was polluted as a result of the failure of the Chernobyl nuclear power station in 1986. Despite these fire management efforts it is reported that each year hundreds of fires occur in these areas (which also contain peatlands and former agricultural areas) with consequential radioactive emissions being recorded as far away as Canada.

A similar problem exists in Kazakhstan, where more than 450 nuclear tests were conducted in the 40 years to 1989 and where significant areas of fire-prone pine forests are involved.

Some of the most advanced fire management systems in the region, which include the use of remote sensing for detecting and monitoring fires, are in place in China, Japan, and the Republic of Korea and in Russia. South Korea is implementing a ground-based system that uses automatic cameras for detecting forest fires – once fully operational the system will monitor 93 percent of the nation’s total forest area (some 6.4 million hectares).

In relation to suppression operations, much of the region still relies primarily on ground crews, with heavy machinery and aircraft slowly becoming more widely available. In China, however, it is understood that a number of more sophisticated technologies are in use. While in more remote parts of Mongolia traditional tools, and horses for transport continue to be used in suppression operations.

In part as a consequence of experiences in other parts of the world Russia is moving from its policy of total suppression of all forest fires. This policy shift is being complicated however by related organizational changes, resourcing and technical problems.

In parts of the region (for example, in a number of nations in South Asia) fires continue to be lit by livestock owners, shepherds and herders to promote a new flush of growth for their herds. In Nepal firewood collectors prefer saplings killed by fire and dried, to freshly cut wood because it burns slowly and produces a higher heat yield. Similarly, some farmers continue to welcome the first post-monsoon flash floods, from burned forest to their lands, because they carry organic matter, available phosphorous, potash and nitrogen.

An increasing number of fire-prone Asian nations maintain awareness-raising programs and training for local populations, as part of their fire prevention programs. In Sri Lanka, villagers in the vicinity of forest areas often have permission to gather dead wood free of charge to help reduce forest fuel loads. In return they are expected to assist authorities with fire suppression.

In a number of countries in the region the transition from centrally-planned to market-based economies continues. Often this transition is associated with moves to decentralize previously strong and highly centralized systems of forest and fire management.

In Southeast Asia, the past two decades have been notable for severe fire events that have generated considerable intraregional and indeed global concern. The search for subsistence and income (i.e. the use of fire for agriculture or plantation related matters) remain the most direct reason for fire use. Pronounced smoke haze episodes, generated by wildfires and land-use fires have occurred repeatedly, with the impacts in August 2000 and August 2005 being particularly notable.

In significant parts of the region, and particularly in Southeast Asia, major problems associated with the inappropriate use of fire include loss of habitats and biodiversity in forests, with peatland biomes being particularly threatened as a consequence of peatland conversion, by fire, to cash crop plantations, most notably for palm oil (SE Asia contains 60 percent of the world's tropical peatlands – covering some 22 million hectares. The FAO reports that more than 2 million hectares of these peatlands have been burnt in the last ten years, contributing considerably to the thick smoke mentioned previously blanketing the region).

The first legally binding ASEAN regional environmental accord – the *Agreement on Transboundary Haze Pollution* – came into force in late 2003. As yet however, not all ASEAN member nations have ratified the agreement and until all do, questions will remain about its effectiveness.

The Current Situation–Australasia

Comprising Australia, New Zealand, Papua New Guinea and the neighboring islands in the South Pacific, Australasia is again geographically diverse, with landscapes

ranging from the deserts and semi-deserts of inland Australia to the lush tropical rainforests found in parts of New Guinea and on some Pacific Islands. Some 30 million people are spread across this part of the Asia/Australasia region.

In an average year around 29 million hectares of Australia are burnt by bushfires. With seasonal fluctuations however, this area can vary to four times greater or less than this average. For example, in 1974/75, 115 million hectares or 15% of Australia was burnt.

Around 90% of the area of Australia burnt by fire each year is found north of the Tropic of Capricorn, with burning occurring during the 'dry season', generally between April and November. Most of the remaining burnt area (around three million hectares) is found in the temperate, more densely populated southern region of Australia with high fire danger generally occurring between December and March.

Significant differences feature in terms of the types of fires that occur in northern, and in southern Australia. Northern Australian fires tend to occur in savannah woodlands and in hummock grasslands. The amount of fuel in these environments is generally limited and the weather conditions in the dry season are generally stable. Maximum fire intensities in these situations rarely exceed 20,000 kW/m. During bushfires in the mountain forests of southern Australia maximum intensities can reach up to 100,000 kW/m.

The El Niño-Southern Oscillation (ENSO) mentioned previously has been responsible for a 10 year long drought in much of southern Australia. Since 2000 the country has experienced fire seasons that have been as dramatic as have been seen in the 200 years since European settlement. The impacts of these fires has led to a series of Inquiries and reviews of fire management in Australia, the key findings of which are summarized later in this paper.

As with some other parts of the region, the area subject to fire declined somewhat over the past several decades, in Australia's case as a consequence of changed land-use patterns, fire suppression practices and, and in many areas as a result of the cessation of traditional burning by aboriginal populations. In southern Australia, urban attitudes to the use of prescribed fire in more recent years have also been a factor in the decline in its use. New Zealand, which has a somewhat less diverse fire management challenge would appear, from the available data, to have achieved a more balanced approach to the 'prevention, preparedness, suppression and recovery' mix.

In Papua New Guinea and on the islands of the South Pacific the range of fire management issues reflect, to varying extents the challenges already outlined for Southeast Asia.

The period 1998-2006 has seen an unprecedented level of scrutiny of the management of bush (wild) fires in Australia. Yet despite all the reports and

recommendations however, fundamental issues appear to remain unaddressed. Over two and a half million hectares or over one-third of the State of Victoria's public land has been burnt by wildfire since late 2002. Politically, there does seem to be an increasing recognition that escalating suppression costs may, at least in part, be linked to the falling rates in the use of prescribed fire. From these State and Federal Inquiries a number of recurring themes have emerged. These include:

- *Resourcing of park and forest management.* Nationally over the last 25 years more than 11 million hectares of Australia's publicly-owned forest has been set aside as national park and related reserves, in part in response to urban-based concerns about timber harvesting. This change in status has often resulted in less 'active' land management. The creation of new 'reserves', for example, sees a gradual reduction in the access track network, reduced and somewhat de-skilled workforces, less machinery available for suppression activity and falling prescribed burning levels. In general, governments have not increased the budgets of park agencies in anywhere near same proportion as the increase in the land estate the agencies are required to manage, and with the departure of most industries from the land in question, alternate funding sources available to land managers, such as from tourism operators, fail to meet the gap;
- *The use of prescribed fire.* The role and use of prescribed fire in southern Australian parks and forests is arguably the most frequently debated fire management issue, with a 'precautionary' fire management approach tending to prevail in recent decades;
- *The extent and value of assets in the urban interface zone.* The largest loss of built assets in the urban interface zone in recent years occurred during bushfires in 2003 fires that surrounded the nation's capital. Despite the recommendations from various Inquiries for greater use to be made of the Australian Standard for the Construction of Buildings in Bushfire Prone Areas in the urban interface area, governments seem reluctant to pursue this matter for either new or existing buildings;
- *The level of fire behavior/fire weather expertise in relevant agencies.* There was considerable anecdotal and other evidence available both during the 2002/2003 and 2006/2007 fire seasons in south-eastern Australia that specialist skills in fire behavior and fire weather were diminished among firefighters and Incident Management Teams, when compared to earlier times. This skill shortage may be retarding suppression efforts and could be adding significantly to areas burnt by wildfire;
- *Fire fighter safety, risk minimization and the legal system.* There are increasing concerns within the fire and land management community that

the cumulative effect of on-going changes to occupational health and safety legislation, and the increasing involvement of the legal system in firefighting, may have moved the suppression effort ‘balance’ from a focus on ‘safety’ to one of ‘risk avoidance’. In terms of bushfires, where the aim is to bring an ‘out of control’ situation ‘under control’ as quickly and as safely as possible, this significant shift in emphasis appears to be contributing to bushfires becoming larger, burning longer, costing more to suppress and potentially placing more people at risk. A ‘risk avoidance’ attitude would seem to be neither desirable, or in the community’s best interest.

- *The escalating use of technology.* There is no doubt that technology, in many of its forms, has greatly improved the efficiency and effectiveness of bushfire management in Australia. Given the escalating cost of fire suppression, there is a need for considerable more rigour in the on-going evaluation of both the effectiveness and efficiency of the various technologies, particularly aircraft (seasonal aircraft costs are now regularly exceeding \$US100 million);
- *Climate change.* With much of southern Australia currently in the grip of a decade long drought, the role of underlying moisture deficits in the fluctuating nature of Australia’s experience with bushfire is highlighted. The political temptation to use these two factors (drought and looming climate change) to avoid scrutiny of the on-going stewardship of the management of Australia’s public lands has, at times, appeared hard to resist.

In 2003 the Australian government agreed to the establishment of a Bushfire Cooperative Research Centre which, at the time became one of 56 public-private research centres operating in Australia. The formation of the Bushfire CRC was, and remains, a major initiative of fire and land management agencies in Australia and New Zealand (the Bushfire CRC’s current funding is due to expire in 2010). Beyond this national initiative however, fire management in Australia remains largely the responsibility of State and Territory governments. The volunteer-based bushfire agencies in rural Australia remain essential to the overall fire effort and a generally high level of effective suppression still occurs in the south.

Finally, and in common with the rest of the region, Australia needs to develop an agreed, consistent data-collection process on all aspects of landscape fire management. In the meanwhile, the lack of such an approach is hindering research, operational planning and evidence-based approaches to financial management.

Potential Future Wildfire Situations and Possible Approaches

In its 2006 *Fire management – global assessment*, the UN's FAO suggests that too often "Fire prevention and suppression are reportedly hampered by unclear lines of institutional responsibility, as well as by conflicting policies and legislation in some countries..... The importance of national fire management plans that cover all aspects (of fire management) and that reconcile intersectoral considerations cannot be overstressed."

As already suggested, and notwithstanding the inadequacy of much of the current national reporting within the region evidence, in a number of locations, of higher numbers of hotter fires burning larger areas is emerging. Work as to the impact of global warming on current scenarios continues.

Fire danger rating systems and early warning systems are being increasingly used throughout the region to give advanced notice of periods of high fire risk. ASEAN's *Specialized Meteorological Centre* and the *Southeast Asian Fire Danger Rating System* have been making their information available online since 2000. Viet Nam now has a national fire danger rating system and Russia is understood to be close to implementing a similar system.

A lightning detection and monitoring system has been established to identify and locate lightning-caused fires in Japan, South Korea, and in some forested areas in parts of China and Russia.

As far as the future of community-based fire management, two distinctive trends appear to be emerging in the region. In developing economies (such as China, India, Pakistan and Nepal), 'communities of interest' are emerging to assist with the fire management effort, while in more developed economies community involvement is declining rapidly.

The FAO reports that in Northeast Asia countries "have recognized the immense pressures on forests in densely populated areas, and also that authoritarian styles of centralized forest management are neither appropriate nor effective in meeting the broader forest management objectives of today." In India community involvement is actively promoted through the creation of 'joint forest management committees' in an area of over 10 million hectares. In other parts of India however government approaches have been perceived as replacing traditional, community-based fire management systems and, as a result, have been less successful.

In Southeast Asia there have been a number of positive 'community-based' initiatives in recent years. In 2001, in Bangkok, the first international workshop on community participation in fire management occurred.

Collaboration amongst countries in the region varies considerably, there being little, for example in South Asia, but growing levels in Australasia. China and Russia

have mutual support arrangements in place, as do Mongolia and China. The Regional Northeast Asia Wildland Fire Network was established with assistance from the UN in 2004. This network is coordinated by the Korean Forest Research Institute and it is currently providing a platform for fire information dissemination and exchange.

At the International Wildland Fire Summit, held in Australia in 2003, an international agreement for the exchange of Australian, New Zealand and US fire management personnel, that been in place since 2000, was presented. The agreement was seen as a possible model for other future international agreements.

Recently, ASEAN member countries have adopted a *Peatland Management Initiative* to enhance peatland management in the region. A related strategy has been developed to guide actions to sustainably manage peatlands and reduce fires and associated haze within the framework of the *ASEAN Agreement on Transboundary Haze Pollution*. A related expert panel has also been established to undertake rapid assessment of the on-ground situation during potential or impending critical periods of fires and haze.

In terms of institutional responses to fire, there is much cause for optimism. A number of nations in the region have adopted national and/or local versions of the UN's *Agenda 21* (that relates to human impacts on the environment) and environmental progress has been achieved in most countries according to the FAO's 2006 report.

The legislative situation tends to be more problematic. Even in countries with well-defined laws, their enforcement can be quite weak.

Financial and Human Factors

The problems associated with the quality of data available across the region, already alluded to, are compounded considerably when it comes to trying to distil trends in the human and financial resource areas. In the further absence of agreed standards for the collection of data on matters like fire damage any summary in this area can at best be restricted to commenting on the limited information available.

The FAO's 2006 report provides information on the few countries and regions that had provided information on fire damage – for example, \$US107 million in India in one year, \$US4.2 billion in Russia in 1998. Northeast Asian nations recorded losses in timber from forest fires of in the order of \$US0.5-1 billion annually. Mongolia reported that over the years 2000-2004 5.1 million hectares of forest and 9 million hectares of steppe vegetation had been burnt, the fires causing an estimated \$US8.5 million of environmental damage, \$US150,000 of infrastructure damage and costing \$US600,000 to suppress.

China has estimated that between 1959 and 1998 around 100 people had been

killed in firefighting, with around 500 injured. Significant human losses were also reported in 1998 and in 2003 in Russia, while in April 2000 in South Korea property losses of around \$US83 million were recorded, with associated severe effects on forests.

The FAO has expressed doubts as to the accuracy as to the, albeit, already limited reporting of property losses. As an example it considered fires in the Russian Far East in 1998 that burnt some 2.2 million hectares of forests. Russia, at the time, reported economic losses of around \$US200 million. A subsequent recalculation however, using world market prices suggested actual losses were likely to be around \$US4.2 billion.

When it comes to prevention and suppression, most nations in the region continue to rely on early detection through the use of fire towers and patrol complimented, increasingly, by the use of aerial surveillance and satellites.

In its 2006 report the FAO indicated that a number of Southeast and Northeast Asia nations reported that although fire suppression resources are available they are often insufficient. As an example, Thailand has a nationally organized fire suppression capability, but it recognized in 2000 that it could offer coverage of only 20-30 percent of its forested lands.

A number of Southeast Asian nations reported that the use of helicopters is increasing, especially in 'first-attack' operations. The use of more sophisticated equipment and advanced technology, by more industrialized nations clearly has suppression-related cost implications. In its 2002-2003 fire season Australia reported that it spent over \$US80 million on aerial support for its suppression operations, and that this activity was becoming an increasingly significant component of its overall fire suppression costs. In its 2006-2007 fire season one south-eastern Australian State (Victoria) is understood to have spent in excess of \$US250 million on forest fire suppression.

In Australia, more generally, it is possible to extract indications of overall firefighting costs from agency annual reports and related sources. Such an analysis leaves one with the strong impression that there has been a trend involving increasing budgets for fire agencies and perhaps decreasing budgets for the management of land, including fire prevention.

Institutionally, across the region those countries, such as Australia, where fire management is largely the responsibility of States or provinces tend to have cross-border emergency management arrangements. Invariably, in multiple wildfire situations however, there occur critical gaps in the availability of adequately trained and equipped human resources, particularly for more specialized roles.

Pleasingly, the FAO notes that in much of the region forest related research and education is increasingly seen as a prerequisite for effective management of natural

resources.

The role of NGOs in much of the region, particularly in the implementation of bilateral and multilateral development projects and in facilitating dialogue and exchange continues to be important. Japan is one of the main donor countries, contributing substantially to forestry projects in the Asia and Pacific region.

Finally here, there have been several Australian attempts, over the past decade and a half, to quantify the economic benefits that flow from investment in the management of landscape fire. The first of these efforts, by a firm of actuarial and risk management consultants in 1992 concluded that considerable savings could be made by minimizing the size of the largest of the fires in each regions studied, that occurred in a given year. The consultants concluded, “that 50% of the bushfire damage (was) caused by the single largest fire in each region”.

In 1997, economists employed by the Victorian State government (Bennetton and others) concluded that “the FMP (Fire Management Program) was calculated to yield a high benefit-cost ratio (22 to one) to the State of Victoria from its investment in fire suppression and prevention through a reduction in the agricultural, capital and forest assets which would otherwise be lost to bushfires. Moreover, this return is likely to understate the true value of the FMP, as losses caused by damage to flora and fauna, public infrastructure, tourism and recreation, water quality and quantity, and human life have not been qualified.”

As to specific matters, bushfires in the 2006/2007 caused a major electricity disruption, over 8.5 hours, to Australia’s second largest city. Direct and indirect impacts of this disruption are estimated to have cost \$A500 million, with around 70,000 businesses affected, some for up to a week.

Most recently, work being done by Professor John Handmer for Australia’s Bushfire Cooperative Research Centre has identified a benefit-cost ratio of 9.75 at a 5 percent discount rate, in terms of the national economic benefits of the CRC’s fire-related research program. The ratio is considered conservative in that it excludes the benefits that flow to land management from the better management of fire.

Existing Limitations

In attempting to develop an overview of such a large area of Earth the limitations in the current availability and reliability of the available information must again be stressed. Beyond the problems associated with the currently available raw data (number of fires, areas burnt etc.), few countries provide much, if any, information by way of the environmental, social and economic costs of wildfire. This ‘data/analysis’ problem is probably the major existing limitation in developing a regional or international perspective of fire management. In terms of the extent of

fires for example, the increasing sophistication of satellite analysis is, in the view of FAO, “providing much more reliable (often several times greater) information than land-based assessments.”

More specific current limitations within the region would appear to include:

- the complexities of the issues often associated with fire (and smoke) management and the need for fundamental knowledge and training in fire ecology and management;
- the, often limited, associated technological and infrastructure resources;
- the movement of populations from rural areas to cities, resulting in less people to deal with rural fires that get out of control;
- the tendency of urban dwellers to view all landscape fires as bad resulting in political pressure to limit the use of prescribed fire;
- the movement, for lifestyle reasons, of urban dwellers into high-risk fire areas;
- problems, in many countries, in enforcing existing legal provisions and in administering existing fire prevention programs;
- the problem in dealing with arson. In Australia for example, in 2002/03, some 10,000 fires were listed as “actual or potential arson”, while there were only 43 convictions;
- the link, in some countries, between illegal timber harvesting and wildfire (for example, arson subsequently facilitating the obtaining of salvage logging permits); and
- The general lack of assessment of the ecological and environmental impacts of wildfire, which is essential to explain changes in land management practices and to support policy development, and to assist with the prioritization of post-wildfire recovery efforts.

Conclusions

Across much of the region humans have used fire for many thousands of years for cultivating and maintaining forests, woodlands and grasslands – and ecosystems have evolved accordingly. In more recent years however, fire has, too often, become a destructive agent in the human response to economic and population pressure. Human population pressures are particularly acute in the tropical and subtropical parts of the region and fire is being increasingly used in ways that either assist with the conversion of forest and woodland to agriculture, or that dramatically alters previous fire regimes, often with severe vegetation and environmental consequences.

In terms of the future, and in the face of accelerating climate change, it is suggested that the international wildland fire community should continue, and as a

priority, to focus on assisting regions and nations to, among other things:

- recognize both the positive and negative roles that fire can play in the landscape, and of the need for a holistic approach to fire management, as opposed to a suppression focused one;
- ensure that fire prevention and suppression, and land management responsibilities are clear; that relevant agencies are supported by appropriate policies and legislation; that the agencies are adequately resourced; and that appropriate regional and, where appropriate, international support mechanisms are in place;
- better focus on analyzing the economic, social and economic impact of wildfire;
- better recognize the role of community-based approaches as adaptive and sustainable elements in an holistic approach to fire management;
- make better use of the existing regional networks, and in particular those organized through the UN-ISDR Global Wildland Fire Network, and encourage the endorsement and use of FAO's *Fire Management Voluntary Guidelines*;
- develop and implement reliable and regular assessments of the extent and impact of vegetation fires that involve harmonized terminology and definitions, internationally accepted standards and procedures, and the development of appropriate regional databases; and
- Continue to focus on the importance of training and research in all aspects of landscape scale fire management.

References

- Council of Australian Governments (2004). Report of the National Inquiry on Bush fire Mitigation and Management. Australian Government. Canberra. 415 pp.
- Benetton, J., Cashin, P., Jones, D. and Soligo, J. (1997). An Economic Evaluation of Bushfire Prevention and Suppression in Victoria. Working Paper 9703. Economics Branch. Department of Natural Resources and Environment, Victoria. 53 pp.
- FAO (2007). Fire management – global assessment 2006. A thematic study prepared in the framework of the Global Forest Resources Assessment 2005. Food and Agricultural Organisation of the United Nations. Rome. 156 pp.
- Goldammer, J.G. (1997). Overview of Fire and Smoke Management Issues and Options in Tropical Vegetation. In: Transboundary Pollution in the Sustainability of Tropical Forests; Toward Wise Forest Fire Management. Proceedings of the AIFM International Conference. ASEAN Institute of Forest Management. Ampang Press, Kuala Lumpur. 437 pp.
- ITTO (2001). Fire alarm – More action is needed to address the causes and effects of tropical forest fires. The International Tropical Timber Organization. Yokohama, Japan. 8 pp.
- MIRA (1992). Fire Protection Risk Management Study for the Department of Conservation and Natural Resources. MIRA Consulting Ltd. Actuarial and Risk Management Consultants. 60 pp.
- Myers, R. L. (2006). Living with Fire – Sustaining Ecosystems & Livelihoods Through Integrated Fire Management. The Nature Conservancy. 30 pp.
- Pyne, S. (2006). The Still-Burning Bush. Scribe Short Books, Melbourne, Australia. 137 pp.
- The Brookings Institution (2005). The Mega-Fire Phenomenon: Toward a More Effective Management Model. Concept Paper. Presented to the U.S. National Fire and Aviation Board, 20th September, 2005. The Brookings Institution Centre for Public Policy Education, Washington, D.C. 15 pp.

Approaches to Protection From Forest Fires in Central and South America¹

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Abstract

There are no doubts that the region has been affected by forest fires on an ongoing basis, with important detrimental effects on economic, social, and environmental levels. Despite the efforts that have been made in recent years, the damages caused continue to be serious, leading to the need for an in-depth analysis regarding the nature of the problem, the restrictions existing in the implementation of fire prevention and fighting measures, and also, the ways in which different countries are approaching the issue of fire protection.

First of all, the dearth of information that exists in most of the countries in this region regarding the extent of losses generated by the occurrence and propagation of fires is alarming, and it undoubtedly represents a significant hurdle for developing any plans aimed at effective fire mitigation. On the other hand, a significant percentage of regional governments has promoted the formulation of protection laws and has established better institutional programs to conduct the actions of forest fire control. However, these initiatives do not seem to be successfully implemented to fulfill the ultimate objection. Furthermore, there is insufficient advancement in the training of specialized personnel, as well as few investigative developments to facilitate and support the design of technological and operational plans adequately adjusted to the respective realities and conditions of these countries.

The aforementioned aspects will be reviewed in the following presentation, with the aim of providing a foundation for some political and strategic approaches directed toward improving the protection systems in Central and South American countries.

Initial References

Latin America is threatened by forest fires on an ongoing basis. These fire events are frequently provoked by humans or natural agents and affect vast expanses of vegetation, destroying populated regions in their path, and resulting, in many cases, in the loss of human lives. Recently, in September 2007, media sources reported that a fire had destroyed, in only a few days, over two million hectares in Bolivia and another half million in Paraguay.

Forest fires can destroy up to 50% of the forest biomass, with serious but little understood effects over the existing fauna. Superficial fires can also release significant amounts of carbon dioxide into the environment causing critical effects on the global atmosphere, and significantly influencing climate change.

¹ An abbreviated version of this paper was presented on the Third International Symposium on Fire Economics, Planning, and Policy, April 29-May 2, 2008; Carolina, Puerto Rico.

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The impact of forest fires on human health can also be very serious, especially in the development of respiratory problems, as it was recently documented in 1997 when smoke from fires in Guatemala, Honduras, and Mexico covered a great part of the southern United States, forcing the Texas government to issue health warnings. Likewise, smoke coming from Bolivia in 1999 caused a great amount of air pollution in the state of Acre, Brazil, with a substantial increase in respiratory problems being recorded in Río Branco. There has also been atmospheric pollution in Paraguay due to smoke coming from Brazil's Mato Grosso.

The combination of tree cutting and frequent periods of severe drought, in tropical and temperate regions, even in virgin humid zones, leads to critical states for ignition susceptibility and, generally, given the existent high biomass, can lead to the further critical and rapid propagation of fires.

The above observations reveal the magnitude of the problem, due to the severe destruction of renewable natural resources and its impact on the economy, social development, and the environment. The conclusions reached at various FAO meetings concerning forest programs in Latin America, in which forest fires and burning are repeatedly denounced as major causes for deforestation and forest destruction, have proven this.

Although the occurrence of fires and their detrimental effects are a growing daily concern, in general, there have not been significant changes in national policies or in people's attitudes regarding this issue. And thus, there has been no significant reduction in the effects of such catastrophes. In part due to the global climate change, catastrophic events are even more frequent nowadays thus leading to increased levels of damage caused by fire propagation.

Forest fires in Latin America, as in other regions of the world, vary from country to country due to existing natural differences in climatic, vegetative, and orographic conditions, as well as those pertaining to land use, cultural levels, and human behavior. This causes forest fires to differ notably. Even when analyzing each country separately, significant geographic differences can be internally observed in terms of the magnitude and characteristics of the problem, which can also be related to seasonal fluctuations.

On the other hand, the way and effectiveness in which forest fire control are undertaken also present great differences among countries. First, economic capacities already establish a difference in the implementation of forest fire management programs, in the level of knowledge about the problem, and in the creation and application of technologies and efficient organizational plans. The importance and priority given in national policies concerning the value of forest resources and the need to protect them are also influential. Furthermore, the patterns for land use, which in many cases may be exceedingly outdated, are also quite

difficult to overcome, creating situations that are at times incomprehensible, and which limit the poorest nations from applying actions that are normally and routinely carried out in other countries.

Information about Forest Fires

In general, it is evident that in Central and South America there is a clear deficiency of records pertaining to the occurrence of forest fires and the damages caused by fire propagation. Only a handful of countries in the region have relevant national data systems that provide complete and reliable information. In some cases there are partial national antecedents coming from diverse sources which do not always coincide. On the other hand, in practically two-thirds of the countries there is either no information at all, and what does exist is subjectively interpreted.

Statistics about the occurrence of forest fires in Latin America have been made in an effort to gather antecedents, based on official reports, a range of publications, and informal means. These are shown in Table 1.

Table 1—Estimated Statistics on Forest Fires in Central and South America.

Country	Period	Occurrence (No. fires/year)	Surface Burned (ha/year)
Argentina	1990-1999	11,513	1,028,739
Belize	S/I	S/I	S/I
Bolivia	1999	31,245	12,749,475
Brazil	1990-2000	160,000	1,500,000
Colombia	1996-2002	4,137	46,080
Costa Rica	1998-2004	1,511	55,928
Chile	1981-2002	5,251	53,395
Ecuador	S/I	S/I	S/I
El Salvador	1998	5,500	87,992
Guatemala	1998-2003	652	205,781
Guyana	S/I	S/I	S/I
Honduras	1998-2003	4,564	69,609
Nicaragua	1998-2004	5,652	55,776
Panama	1998-2003	S/I	18,140
Paraguay	S/I	S/I	S/I
Peru	S/I	S/I	S/I
Surinam	S/I	S/I	S/I
Uruguay	1990-94	2,353	3,311
Venezuela	1987-99	1,394	8,230
Recorded Total		223,772	15,882,456
Estimated Actual Total		320,000	22,500,000

In addition to what is shown in Table 1, it is estimated that the average size of forest fires in the region extends to 70.3 hectares, and that the proportion of total surface land affected by fires totals 1.24% (July 2007).

Information about the origin of forest fires is even more uncertain than information regarding the occurrence and recently affected surfaces. In Table 2, related to cause, it was only possible to obtain antecedents for six of the 19 countries of the Region. Unfortunately, criteria for the classification of causes do not exist, and in some cases, significant risk agents, such as burning, appear classified under other categories (negligence, agricultural activities).

Although official statistics to clearly support this do not exist, there are no doubts that the use of fire as a working tool for agriculture and cattle raising clearly constitute the most important factor in the origin of forest fires and the devastation of forests in Latin America.

Table 2—Percentage Distribution of the Actual Estimated Cause of Forest Fires in Six Countries.

CAUSE	Argentina	Brazil	Chile	Guatemala	Honduras	Nicaragua
Rural Operations	-	3	4	-	-	40
Burning	-	32	10	36	22	32
Recreation and Bonfires	-	5	4	-	4	13
Smokers	-	10	-	-	-	-
Child Games	-	-	8	-	-	-
Railroads	-	1	2	-	-	-
Pedestrian Traffic	-	-	32	-	-	-
Natural Phenomena	11	1	0.3	-	-	-
Arson	17	41	37	23	56	5
Negligence and others	49	7	3	12	18	10
Unknown	23	-	-	29	-	-

Burning has been used for a long period of time without adopting the necessary steps or the appropriate techniques to ensure a positive and beneficial result. On the contrary, burning not only causes uncontrollable fires, destroying vegetation and other valuable resources and property, but also leads to a continuous degradation of renewable natural resources and the environment, seen in the loss of fertile land, the increase in erosive processes, the deterioration of water resources, and land, water and air pollution, and in general, various problems that affect wildlife and the quality of human life.

Burning is a complex problem, because quite often other factors enter into play which exceed the real possibilities that farmers have for using fire rationally. Generally, the greatest damage occurs in impoverished socioeconomic zones, where the rural population is represented by small landowners, plot farmers, coproprietors or indigenous groups, who have been marginalized from advancements in knowledge and technology, but still have an obvious, overriding need for survival, and thus continue to employ fire as their only means for continuing with their traditional way of using land.

There is also a cultural problem, especially on large plots and estates devoted to extensive cattle raising, where burning has always been used to improve the methods of grassing over, because ease and economy involved, and because there is little concern if fires spread over large tracts of land. In these cases, environmental impacts are even less considered.

On the other hand, various studies and reports reveal a noticeable increase in the degree of premeditation or arson in the setting of forest fires, originating for diverse reasons, but mainly as a response to the presence of greater levels of risk derived from the significant increase of undesirable attitudes from urban and rural

populations. Specifically, in areas surrounding big cities, pyromania has evolved into something of a mental illness resulting either from progress or civilization, similar to the spike that has been seen in suicide, drug addiction and alcoholism indexes.

Institutionalizing the Control of Forest Fires

As previously mentioned, Central and South American countries present important differences in a wide range of features relating to climate, topography, renewable resources, and, in general, prevailing natural environments and ecosystems. A high heterogeneity is also evident in terms of social, economic, and cultural development. This naturally means that problems relating to the occurrence and regulation of forest fire propagation are equally different, as are the existing capacities, the criteria, and the modalities applied to prevent and fight fires.

According to Fire Management-Global Assessment 2006 (FAO, 2007), a wide variety of institutions are involved in fire management in Central America. The main governmental agencies have joint responsibilities in agriculture, cattle raising, and forest activities. In addition, other agencies related to the environment and the protection of wild areas also have responsibilities. These carry out duties related to meteorology, tourism, health, infrastructure, development, legislation, national emergencies, defense and firefighters.

The same publication, when referring to South America, shows that in most countries the policy on natural resources is oriented toward the agriculture, mining, and transport sectors, since the contribution of the forest sector in the national economies is very low, with the exception of Brazil, Bolivia, and Chile. Colombia and Ecuador practically do not have any public administration for forest activities.

The political agenda for forest fires is mainly a reaction after the occurrence of catastrophic events, or it may well be connected to the interests of political parties. In general, the problem is not seen as part of developmental processes, and is thus not immediately part of any specific national agenda. There are instabilities due to changes in government and corruption, which lead to the transformation of forest land to different uses (FAO, 2007).

Regarding current guidelines and legislation, Fire Management-Global Assessment 2006 (FAO, 2007) states that the governments of the region use different legal tools for controlling fires, as well as the custom of prescribed burning. There is a lack of integration of norms that allows legislation regarding forest fires to be qualified as specialized, since these laws are promulgated by different institutions in each country. There are at least 153 national laws in South America, but only 57 of them are specifically geared toward fire control and the use of fire in rural zones, the rest are derived from laws concerned with forest or environmental issues in general

terms. However, in most countries there is a clear weakness in the application of current relevant legislation. This is due to various reasons. The legal texts are either incomplete or insufficient; the regulations that allow the application of norms have not been developed; and budgets for the oversight or compliance with laws are not allocated.

Although most of these countries share an awareness about the seriousness of the damages and effects of forest fires, there is not enough clarity about how to approach this problem. This in many ways derives an inability to make the necessary political decisions to promote an effective forest protection plan.

In view of these situations, it seems appropriate to present four observations submitted by Julio Alvear in the IV International Conference on Forest Fires, which took place in Seville in 2007.

- a) In the majority of the cases, the total responsibility of forest protection falls under government agencies. However, the forestry sector is not clearly identified or has a low hierarchy within public organizational schemes. In general terms, forest activity is considered an extension of agriculture and cattle raising, which strongly limits an in-depth analysis and assessment of the sector treatment, thus hindering the formulation of properly sustained development proposals.
- b) In practice, in view of the contingency of forest fires, which cause tremendous damage and public concern, governments turn to various organizations that have capacities for counteracting fires, such as firefighter companies, military and police squadrons, among others. These organizations normally do not have either the special techniques or the proper equipment for fighting fires, thus the result of their actions is frequently ineffective. The experience of developed countries indicates that the only effective way of fighting fires is with the aid of professional organizations exclusively or preferably devoted to this task.
- c) It should be emphasized that the issue of protection is far broader than that of fire fighting, since it entails a range of actions that must be executed simultaneously in coordination. Aspects such as fire prevention, fire detection, and even the organization of means for the suppression of fires should be dealt with on the basis of the same planning and programming scheme, if the intent is to be successful. The problem is that, whenever the activities other than fire suppression are executed, they are normally assigned to different organizations, which have different criteria and levels of preparation, and often compete among each other instead of reinforcing a cooperative and synergetic action.
- d) Finally, we should stress the tenuous nature of reliable records on forest fires in the region. This is in part due to the fact no clear identification has been made as to which organization is to bear the main responsibility for forest fires. This

seriously limits the capacity of problem analysis and hinders the correct planning of fire prevention and fighting. It is not possible to formulate asserted policies on the matter or define the corresponding strategies if there is no proper knowledge of the seriousness and the characteristics of the damage and effects that are being produced, or of the existing means and conditions for the design and implementation of control measures.

Final Comments

It is evident that the countries of Central and South America are being significantly affected by the occurrence and propagation of forest fires and that their governments have not yet been able to establish effective programs for the protection of renewable natural resources. No country should have impediments for the design and implementation of their own forest fire control plan, based on prevalent conditions and available resources.

However, this can only be attained if responsibilities are assumed and delegated for forest protection. When experts and technicians, especially those associated with forest activities, evolve from being mere spectators to being responsible actors, the conditions for adequately organizing the control of forest fires will be possible.

In this task, although external experiences can be extremely worthwhile, each country has a significant percentage of unique conditions which differ from those of other nations. This indicates that the initiative, originality, and disposition to face the problem should mainly come from the ones directly affected by the problem.

Resolving the points expressed in the previous paragraphs inevitably involves the development of effective education and training programs for all related personnel, in all instances of management and execution. Not only are the operators of the different organizations required to be properly trained for executing the activities of prevention, fighting, and use of fire, but, also, the entire magnitude of the problem must be understood on the administrative or managerial level, who should be apprized of all the resources available for protection, as well as the general and specific criteria and applicable strategies. In these countries, the limitation is not so much the availability of resources (which in general are scarce), but more the way in which these are allocated and used.

Some Latin American countries have incorporated required coursework on forest fire protection into forestry technical and engineering school programs. These cases coincide with the countries or provinces that have the best levels of fire prevention and fighting. This approach should be extended, because the experience obtained has shown that these professionals are the best trained among operational personnel, while also aiding in the formulation of policies and plans, because they are

the only ones who can effectively discuss and convince the authorities about the need to establish technically correct and feasible work plans.

Finally, it is necessary to point out that the Fire Management Guidelines, which have been recently formulated by the FAO with the support of the experiences and recommendations of various countries (FAO, 2006), although voluntary in nature, provide an important reference for the establishment and development of national forest fire protection systems.

The fundamental purpose of the Guidelines is to define the basis for fire prevention and fighting, the use of fire, and the rehabilitation and restoration of areas affected by the propagation of fire. In general, they contribute by providing concepts and arguments for the formulation and application of policies and strategies, as well as the initial steps that must be taken to achieve the institutionalized legislation required for compliance with the objectives of fire management.

The recognition and description of the strategies for national fire management plans are an important aspect of the Guidelines, since these references can be used to guide and support the operations of those responsible for forest fire protection. In this sense, we should emphasize that the strategies proposed, classified in 14 guidelines, which will be listed as follows with their respective titles, properly cover the entire spectrum of actions and tasks required to effectively reduce the effects and damage caused by forest fires.

- Resource and Fire Management Programming
- Fire Management in Protected Areas and Natural Reserves
- Fire Awareness and Education
- Fire Prevention
- Early Warning and Fire Hazard Approximation Systems
- Fire Preparation and Technical Training
- Activities Prior to Fire Season
- Fire Detection, Communication, and Initial Response of Available Means
- Initial Attack and Actions
- Suppression and Management of Great Fires
- Fuel Treatment
- Controlled Burning
- Restoration and Rehabilitation of Burned Areas
- Follow-up and Assessment

The Guidelines specifically note the diversity of special contexts and requisites that must be considered for the establishment and operation of efficient national fire management systems, given the significant differences existing between countries due to unique natural, environmental, socioeconomic, and cultural conditions. It is important to mention that the proposal of guiding principles and strategic actions in

all levels for the protection of renewable natural resources recommends considering the fundamental cultural, social, environmental, and economic contexts of each of the countries.

Bibliography

- International Tropical Timber Organization (ITTO) 1997 ITTO Guidelines on Fire Management in Tropical Forest. ITTO Policy Development Series N°6. Yokohama, 40 p.
- Julio, G. 2004 Forest Fire Protection Management in South America. Proc. II Symposium of FIRE Economics, Planning and Policy: A Global View. Environmental Department of Andalucía/USDA Forest Service/U.Córdoba. Cordoba, Spain. 11 p.
- Julio, G. 2006 Planning and Prevention of Forest Fires in Native Ecosystems – A Latin American Perspective. VIII Master in Environmental Conservation and Management. International University of Andalucía, Latin American Headquarters. La Rábida, Spain. 14 p.
- Julio, G. 2007 The Latin American Model: Studies on National Fire Management Systems. IV International Conference on Forest Fires. Seville, Spain. 7 p.
- United Nations Food and Agriculture Organization (FAO) 2006 Fire Management Guidelines: Guiding Principles and Strategic Actions. Work Document FM17S. Forestry Organization, FAO. Rome. 71 p.
- United Nations Food and Agriculture Organization (FAO) 2007 Fire Management – Global Assessment 2006. FAO Forestry Paper N° 151. Rome. 160 p.

Toward Advancing the Theory of Wildland Fire Economics¹

Douglas Rideout, Yu Wei, Andy Kirsch²

Abstract

Traditional fire programs are composed of several major components including: suppression and initial attack, prevention, fuel treatments. There are three key reasons that these components should be managed under a single program and they each are related to other components in the economic structure of fire management. These include the treatment of joint costs, the complementary or substitution effects in component productivity and the management of the components under a common budget. Considering the interactions between the components suggests an expansion of the economic theory of fire management to be more comprehensive. The probabilistic production function used here allows these program components to be unified into a common expression of performance and facilitates a simultaneous consideration across components. This theoretic structure provides a natural evolution of the generalized theory of fire economics that began with Headly and Sparhawk.

Keywords: Economic theory, fire management, probability, GIS.

Historical Context

Lovejoy and Headley (1916) formulated the economic efficiency question of the fire management programs as a problem of minimizing the cost plus net fire damage. The cost plus damage concept was later expanded and illustrated by Sparhawk (1925) in his model of least cost plus liability and expressed as the least cost-plus-loss model as represented in fig 1. As stated by González-Cabán, 2007, “The basic principle of Sparhawk’s model is to minimization of the sum of suppression costs plus resource losses (“total liability”) and protection costs (presuppression); presuppression being the independent variable determining suppression costs and damages. Total liability is inversely related to the primary protection efforts; as presuppression expenditures increase, suppression costs and damages decreases

¹ An abbreviated version of the paper was presented at the Third International Symposium on Fire Economics, Planning, and Policy: Common Problems and Approaches, April 29–May 2, 2008, Carolina, Puerto Rico.

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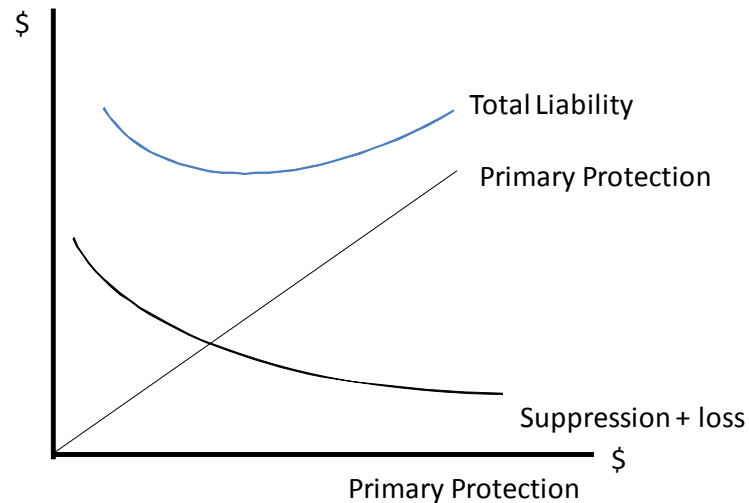


Figure 1 -- Sparhawk's illustration of the cost plus loss model of fire management.

Gorte and Gorte (1979) catalogued a stream of Sparhawk-based applications that redefine the independent variable of primary protection to take the form of arrival time, acreage and others. Paraphrasing Gonzalez-Caban (2007), until 1990 there seemed to have been no general disagreement on the usefulness and correctness of the C+NVC formulation. However, Rideout and Omi (1990) argued that an alternate expression of the economic theory of forest fire management is necessary to better account for the induced potential benefits of forest fires. They propose that a reformulation of the C+NVC as profit maximization instead of a cost minimization provides a more general model that "... allow[s] a more direct comparison between the fire problem and the economic literature (Rideout and Omi 1990: 620)." Donovan and Rideout (2003a) retake the arguments presented in Rideout and Omi (1990) and provide an analysis of what is considered inherently incorrect in the least-cost-plus-loss formulation by Sparhawk (1925) and the more recent variation of C+NVC (Mills and Bratten 1982). They argue that suppression is incorrectly modeled as model output and that suppression and primary protection (presuppression) are incorrectly modeled as negatively correlated. They further argue that these errors "... have serious implications for the model's capacity to correctly identify the most efficient level of fire management expenditures (Donovan and Rideout 2003 a: 318)." As stated by Rideout and Omi (1990) to make a correct representation of the C+NVC model presuppression and suppression should be modeled as independent inputs. In other words, they should be allowed to vary independently, using the NVC function to relate them. Rideout and Ziesler (2004) provide detail in discussing how misapplication of the C+NVC model has created some myths that have long endured

in the literature. With some exceptions, such as Simard 1976, the Sparhawk error continued through the development of operational models including the National Fire Management Analysis System (NFMAS) (USDA Forest Service 1985), and through the current architecture of the Fire Program Analysis System (FPA).

Why a New Theoretic Framework

With great interest in formulating and operationalizing a new generation of fire management models that better reflect today's new land management paradigm increased thought and effort is now applied to reaching this new frontier. There are two key reasons for establishing a new theoretic approach:

1. Previous, and some current, applications promulgate the Sparhawk error.
2. Previous theory does not integrate the range of program components expected of the new land management paradigm.

The second reason deserves some explanation. The expectation of many of today's applications is that they have the ability to properly integrate the range of fire program components such as initial attack, suppression and prevention. The graphical models, such as those based upon the Sparhawk illustration, use preparedness as a decision variable, but improperly address suppression as an outcome and they do not directly include prevention. Instead, they rely upon focusing on a single program component. Current models were not intended to directly address how the plans for initial attack and fuels treatment are affected by each other simultaneously. For example, the initial attack models used in the U.S. such as the National Fire Management Analysis System (NFMAS) and the California Fire Economics Simulator (CFES2) are specific to initial attack. Fuels models including advances designed by Hof and Omi (2003) are not intended to directly incorporate initial attack or suppression effects. In some instances these component-specific models can use the output from one component as input of the other. This sequential approach to program interaction has limitations that can be improved upon by the fully development of a system that attempts to more holistically address the problem. There are three basic kinds of interactions among the program components:

- the *budgeting* process,
- *cost* structures,
- physical interactions among the *productivity* of the components.

In *budgeting*, funds allocated to one component often reduce funds available for another component. For example, allocating more funding to prevention may reduce

funding available for suppression. This form of interconnectedness directly reflects scarcity through the fire program budget and appropriation processes. The economic principle often used to address budget scarcity across the components is to require equal improvement in each component per additional dollar spent. This is an application of what economists refer to as the equi-marginal principle. While this is an important consideration, it does not provide a singularly compelling reason for developing a unified economic theory. The reason for this is that a common budget does not directly affect the underlying benefit or cost structure of the program. Separate program component levels could be independently adjusted up or down to conform to the equi-marginal principles.

Cost analysis by component is complicated and often frustrating because fire management resources (engines, aircraft, personnel, etc.) are interrelated through the cost function. A fire management resource, such as an engine, is often used to support multiple program components. For example, the purchase cost of an engine used in both fire protection and in fuel management would be joint, making it impossible to logically divide the purchase price of the engine between these two program components. In economics this is the well-known problem of joint cost allocation. Such cost considerations are not well addressed through a separated, or sequential analysis of program components. It is unlikely that a separate consideration of the program components will enable the planning or budgeting process to take advantage of the cost savings available in fire resources that are common across components.

Interconnectedness in the *productivity* of the components has been long recognized, but it has not been well analyzed. For example, a major rationale for hazardous fuel reduction is to positively affect suppression efforts by reducing flame lengths, slowing fire growth rates, and enabling faster fireline construction. Budgeting and physical interactions among fire program components enjoy both a longstanding and consistent recognition. Sparhawk (1925) recognized the interaction between preparedness and suppression for fire management planning. Crosby (1977) addressed preparedness, suppression and prevention in assessing fire impacts. More recently, Pyne et al, (1996, page 386) stated

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This would require the potentially awkward enumeration of a full set of funding levels for each program component, each to be compared to select the optimal mix of component levels.

“All of these activities and all these levels of management require planning. Especially as fire management enters a period of consolidation, plans by which to integrate program with program, agency with agency, region with region will assume ever greater importance.”

A Unified Theory of Wildland Fire Program Components

To formulate a unified economic model of fire program analysis we assert that federal managers exhibit behavior consistent with cost minimization. While such behavior may not always reflect reality, this assertion has withstood the test of time for modeling purposes and we suggest that modeling such behavior is desirable at least as a benchmark of comparison to alternative behavior. The cost minimization assertion also aids in understanding and in recognizing a cost-effective fire program.

We define suppression broadly as the activities involved in extinguishing wildland fires while recognizing that for pragmatic purposes, suppression may be separated into initial and subsequent attack categories such as “large fire.” Focusing our discussion and analysis on two components greatly simplifies and improves our ability to illustrate the underlying economic relationships. Expanding the analysis to include additional components such as fire prevention and ecologically based fuel treatments for site condition improvement is straightforward. We also present a major departure from many previous approaches. Here, we recognize that program planning and budgeting is performed in the context of managing for future fires and fire seasons that are *unknown* with respect to fire incidence, intensity, size, etc. The usual assumption that specific individual fire events expressing a future fire season workload can be modeled from historic events has been widely used and appears in models such as the Interagency Initial Attack Analysis system (IIAA) and in CFES2 (Fried et al. 2006). It has also been customary to model placement of fuel treatments based upon assumed ignition locations such as the Monte Carlo simulations of Hof and Omi (2003) or as in FlamMap (Finney 2005).

Event-based modeling introduces a potential philosophical inconsistency between program-level and the tactics of event-level analysis. This inconsistency can be overcome by incorporating a probabilistic production function. Although future fires and fire seasons are unknown, the probability of fire occurrence by intensity and location might be able to be estimated using established probabilistic methods. Abstracting thousands of individual fire events into a probabilistic production function eliminates the potential philosophical inconsistency of modeling individual events to analyze an entire program and it better conforms to the scale of analysis often needed to address the wildfire program.

We suggest that the productivity of each fire program can be represented by changes to the landscape probability map. Representation of program productivity is essential to any production based economic analysis. Because our probabilistic approach abstracts away from the individual fire event, it symmetrically abstracts away from the individual fire resource. Finally, we recognize that spatial and temporal interrelationships are important. Spatial relationships are important because the probability of fire at a given location is influenced by conditions at neighboring locations. For example, the probability of fire in a given location (e.g., a geographic information system (GIS) raster cell) is a function of that cell's fire producing attributes and of the attributes of neighboring cells. Figure 2 shows a sample probability grid for the program component of prevention applied to a portion of a fire management in Colorado.

As prevention resources are placed on the landscape they operate to alter the wildland fire probability potential as spatially displayed. Such a surface can be integrated with an initial attack and fuels management probability surfaces. The key to unify the economics of program analysis is for each program component to “speak the same language” through the production function.

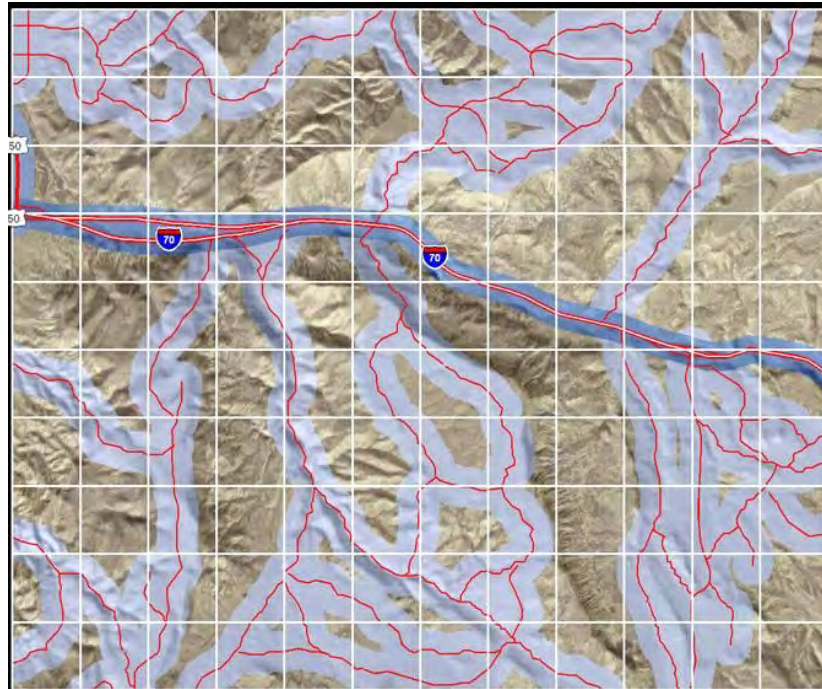


Figure 2. -- Probability surface for prevention on a forested landscape in Colorado.

While a probabilistic production function enables a more robust integration of the spatial and temporal interactions, we use a static model as a simplifying first step⁴ because our focus is on the theory. We begin with the most general structure in (1) to minimize a budget constrained expected loss from wildfire (Z) where program components, fuels (F) and suppression (S) are modeled as decision variables.

$$\text{Min}_Z = L \bullet P(F, S) + \lambda(B - \text{SCS}(S) - \text{SCF}(F) - \text{JC}(F, S)) \quad (1)$$

Where:

P(F,S) denotes the probabilistic production function for the program.

C denotes the cost function of the fire program

B denotes the fire program budget

λ (Lambda) denotes the Lagrange multiplier for the program budget constraint.

B denote an appropriation or budget

SCS denotes the separable cost of suppression

SCF denotes the separable cost of fuels

JC denotes the joint cost – cost that is not separable between the components.

Many relationships can be developed from this objective function (Rideout et al 2008), but suffice it to say that such a model formulation enables direct consideration of the joint cost structure that is so important in the fire program and for the interactions among the productivity of the program components in ways that previous formulations have not addressed as a simultaneous consideration. The general formulation provides a foundation from which many enhancements can be made including the introduction of stochastic analysis and the introduction of the beneficial considerations in wildland fire including the ability to address appropriate management response (AMR) where wildland fires are managed to provide the greatest net benefit. Here, the beneficial effects of fire are directly recognized and managed in conjunction with the detrimental effects to produce a desired outcome.

Conclusion and Discussion

Advancement of the traditional theory into a unifying probabilistic production function enables a richer analysis. Each program component can effectively

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Static formulations of the theory are customary in fire management (Rideout and Omi 1990)

communicate with each of the other program components through the language of probability. This enables a direct consideration of a holistic approach to fire program management that was not available through the historical models. In addition, the probabilistic framework enables direct use of spatial analysis through a geographical information system. For example, the probabilistic framework enables spatial analysis where raster cells effectively communicate to convey information regarding the relationship between fire spread and ignition that affect each program component.

While the probabilistic production function requires more abstraction than the traditional event based modeling, it may be better suited to strategic analysis and to integrated analysis. The challenge of this overall approach is to enable each program component to affect a change in the probability surface in a way that is directly available to the other program components. In other words, when fuels treatments are spatially scheduled, how do they change the probability surface in a way that is meaningful to the suppression or initial attack programs. While connecting changes in program component level with changes in probabilities is a challenge, the benefits of the integration of both joint costs and program productivity appear to be promising.

Application of such a departure poses many challenges, but progress in some applications has shown promise. In a first application Wei et al. (In press) showed how the probabilistic production function could be used to optimally schedule fuels treatments across a forested landscape. Although this application used a single program component, it provided a start and a demonstration. In a second and more challenging application, Wei and Rideout (see Wei and Rideout, 2008 paper in this symposium) explain development of the unifying probabilistic economic model to address the management of AMR across a Southern California landscape. This model includes a graphic user interface (fig. 3).

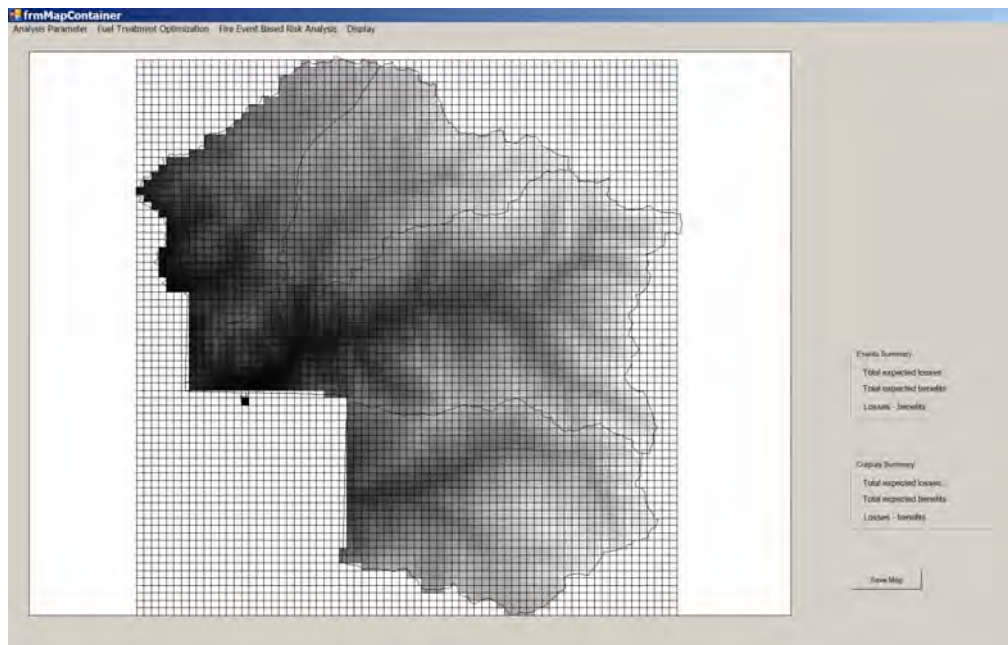


Figure 3 – The main Graphic User Interface developed to implement the unified fire economic theory in AMR analysis.

The grid map in fig. 3 applied to a key portion of the Sequoia-Kings Canyon National Park with a digital elevation map as a background. Each pixel defines an area where the probability of fire can be displayed and managed in a spatially explicit context. Given a defined set of weather, fuels and topographical conditions, the pixels in fig. 3 can be transformed into a fire probability surface like the one in fig 4. The probability surface can then be manipulated through either fuel treatment or the management of particular fires.

Of particular interest is the integration of program components facilitated by the probabilistic production function. Here we integrate fuels management with fire management together to support decisions in an AMR program.



Figure 4 -- Reported probability of burning within the study site for a particular set of weather, fuels and topographical conditions. Darker colors represent higher probability of burning.

References

- Arnold, R.K. 1949. Economic and social determinants of an adequate level of forest fire control.
- Davis, Lawrence S. 1971. The economics of fire management. In: Planning in fire management proceeding. Phoenix, AZ: Southwest Interagency Fire Council; p 60-69.
- Donovan, Geoffrey H. and Douglas B. Rideout. 2003. A reformulation of the cost plus net value change (C+NVC) model of wildfire economics. *Forest Science*. 49(2):318-323.
- Donovan, Geoffrey H.; Rideout, Douglas B. 2003a. A reformulation of the cost plus net value change (C+NVC) model of wildfire economics. *Forest Science* 49(2): 318-323.
- Donovan, Geoffrey H.; Rideout, Douglas B. 2003b. An integer programming model to optimize resource allocation for wildfire containment. *Forest Science* 49(2): 331-335
- Finney M.A. 2006. FlamMap 3.0. Missoula, MT: USDA Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory
- Finney, M.A. 2001. Design of regular landscape fuel treatment patterns for modifying fire growth and behavior. *For. Sci.* 47:219-228.
- Flint, Howard R. 1928. Adequate fire control. *Journal of Forestry* 26(5): 624-638.
- González-Cabán, Armando. 2007 Fire Management Policy and Fire Management Economic Efficiency in the USDA Forest Service. Invited Keynote lecture at the IV International Wildland Fire Conference, 13-17 May 2007, Seville, Spain.; http://www.wildfire07.es/html/in/cMagistrales_in.html
- Gorte, Julie K.; Gorte, Ross W. 1979. Application of economic techniques to fire management.
- Headley, Roy. 1943. Re-thinking forest fire control. Res. Paper M-5123. Missoula, MT: North Rocky Mountain Forest and Range Experiment Station; U.S. Department of Agriculture, Forest Service. 361 p.
- Hesseln, Hayley; Rideout, Douglas B. 1999. Economic principles of wildland fire management policy. In: González-Cabán, Armando; Omi, Philip N., technical coordinators. 1999. Proceedings of the symposium on fire economics, planning, and policy: bottom lines; 1999 April 5-9; San Diego, Ca. Gen. Tech. Rep. PSW-GTR-173. Albany, CA: Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture; 332 p.
- Hornby, L.G. 1936, Fire control planning in the northern Rocky Mountain Region. Missoula, MT: U.S. Department of Agriculture, Forest Service; 179 p.
- Lovejoy, P.S. 1916. Costs and values of forest productions. *Journal of Forestry* 14(1): 24-38.
- Mills, Thomas J.; Bratten, Frederick W. 1982. Economic efficiency and risk character of fire management programs, northern Rocky Mountains. Gen. Tech. Rep. PSW-65. Berkeley, CA:

- NWCG (National Wildfire Coordinating Group). 2001. Review and update of the 1995 federal wildland fire management policy. National Interagency Fire Center, Boise, Idaho, USA.
- Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture; 52 p.
Parks, George M. 1964. Development and application of a model for suppression of forest fires. *Management Science* 10(4): 760-766.
- Rideout, D.B., Yu Wei, Andrew Kirsch and Stephen J. Botti. 2008. (In Press). Toward a unified economic theory of fire program analysis. In: *The Economics of Forest Disturbances: Wildfires, Storms and Invasive Species* (Forestry Sciences). Thomas Holmes, Jeff Prestemon and Karen Abt. Eds.. Kluwer.
- Rideout, Douglas B. and Philip .N. Omi. 1990. Alternative expressions for the economics of fire management. *Forest Science*. 36(3):614-624.
- Rideout, Douglas B.; Omi, Philip O. 1990. Alternate expressions for the economic theory of forest fire management. *Forest Science* 36(3): 614-624.
- Rideout, Douglas B.; Ziesler, Pamela S. 2004 Three great myths of wildland fire management. In: González-Cabán, Armando, technical coordinator. 2004. 2004 April 19-22; Proceedings of the II International symposium on fire economics, planning and policy: A world view. Córdoba, Spain; Albany, CA: Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture; CD only.
- Schweitzer, D.L.; Andersen, E.V.; Mills, T.J. 1982. Economic efficiency of forest management
- USDA Forest Service. 1985. National fire management analysis system user's guide of the initial action assessment (FPL-IAA2.2). Washington, DC: U.S. Department of Agriculture, Forest Service. USDA Forest Service.
- USDA/USDI (1995). Federal Wildland Fire Management Policy & Program Review, USDA Forest Service, USDI Bureau of Land Management, USDI National Park Service, USDI Fish and Wildlife Service, USDI Bureau of Indian Affairs. Boise, Idaho, National Interagency Fire Center.
- Wei, Y, Rideout, D.B., Kirsch, A, (in press), An optimization model for locating fuel treatments across a landscape to reduce expected fire losses, *Can. J. For. Res.*
- Wei, Y., D.B. Rideout. 2008. Developing a Probability Based Approach to Support Wildland Fire Management Decisions. In: proceedings of this symposium.

The Problem of Forest Fires in Costa Rica, the Country's Volunteer System and Organizational Structure¹

Alberto Vázquez Rodríguez²

Abstract

Forest fires pose a threat to Costa Rica during dry season, which runs from January to May, but may come sooner or later depending on the climatic behavior of the different regions of the country. The areas mostly affected by this type of natural disaster are the Northern Pacific, Central, and Southern regions of the country, as well as the Northern Huetar Region, specifically the areas of Los Chiles and Upala in the province of Alajuela, which is affected to a lesser degree.

Hunting, forest and agricultural fires, invasion of land, illegal cutting, and the extraction of resources are some of the main problems that protected wild areas face.

However, forest fires are created by human activities either in an involuntary or premeditated manner, and the problem occurs both inside the boundaries of protected wild areas and in their buffer zones, where the National System of Conservation Areas (SINAC) has had to implement a series of preventive and control measures that have successfully reduced the disaster areas over the course of the years. The human activities that often lead to fires have often evolved due to social inequality, shortage of land, a lack of knowledge about forests, misguided government policies or ignorance regarding same, as well as fire management projects and proposals which fail to take into account Costa Rica's socioeconomic reality.

¹ An abbreviated version of this paper was presented at the Third International Symposium on Fire Economics, Planning, and Policy: Common Problems and Solutions, April 29 to May 2, 2008, Carolina, Puerto Rico.

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1. Introduction

The following are among the most relevant causes that set off forest fires in Costa Rica:

Agricultural burning. Agricultural producers carry out this type of regular practice, without taking the necessary precautions of patrol and firebreak, thus leading fires to spread to other zones not generally affected by fire-related disasters. In addition to this problem, there is a lack of knowledge about current legislation and the regulations concerning agricultural burning, which are out of date, not well circulated or functional, and which do not respond to the real needs of campesinos, producers, farmers, and stockbreeders, among others, when they undertake such activities.



Revenge. The result of malicious intent, and at times in retaliation for the measures carried out by forest rangers, both within the limits and surroundings of the protected wild areas, when hunters, fishermen, and lumberjack violate the respective laws concerning the environment and natural resources. A clear example of this occurred in 2002 when illegal hunters burned down the Casona de Santa Rosa (a World Heritage Site), located in the Santa Rosa National Park, leading to significant economic and historical losses for the country.

Vandalism. A criminal act, and a more significant problem every day, in which people try to destroy natural heritage sites and infrastructure within protected wild areas or private properties.

Hunting activity. The carrying out of illegal and irresponsible practices with the hope of capturing prey within protected wild areas and their buffer zones, causing the short-term disappearance of many wild species of scientific, ecological, and commercial value.

Garbage disposals. Places where solid waste is dumped without any control or appropriate treatment provided by local governments, thus creating an accumulation of methane gas, seepage of hazardous materials into the ground, and alteration of the landscape, among other problems, which can provoke fires during the dry season.

1.1. Statistics on forest fires in Costa Rica

In Costa Rica, according to statistical records from SINAC, forest fires have affected an average of 351,276.24 ha. (Table 1) in the last years (1998-2007), within the boundaries of protected wild areas as well as in their buffer zones.

Table 1—record of areas affected by forest fires inside and outside protected wild areas, period 1998 – 2007.

Year	Affected Area Inside PWA	Affected Area Outside PWA	Total Area (ha.)
1998	8,011.55	56,881.90	64,893.45
1999	857.00	10,334.50	11,191.50
2000	2,390.82	34,505.48	36,896.30
2001	9,540.70	47,970.00	57,511.40
2002	3,150.00	47,187.00	50,337.00
2003	6,287.05	26,495.50	32,782.55
2004	4,706.00	30,522.22	35,228.31
2005	3,175.24	11,647.00	14,822.24
2006	4,220.10	10,971.50	15,191.60
2007	4,849.67	27,572.22	32,421.89
Total	47,188.22	304,088.02	351,276.24
Percentage (%)	13.43	86.57	100.00

Source: P.N.M.F./SINAC –MINAE, 2007

In 1998, the greatest area affected by forest fires totaled approximately 64,893.45 ha., and in 1999, the least affected amounted to 11,191.50 ha. (Table 2). However, grassland areas are often among the most affected by forest fire disasters, comprising an average area in 1998 of 64,893.45 and between 2006- 2007 of 32,421.89 ha.; in general, grassland, scrubland, densely thicketed areas, and secondary forests were the type of vegetation most affected.

Table 2 presents the specific geographical areas affected by forest fires, according to each conservation area, from 1998 until 2007, where the ones most affected by fire disasters have been: Tempisque Conservation Area, which was the most affected region, and Central Volcanic Mountain Range Conservation Area, the least affected, which means most of its territory has climate characteristics unfavorable for the propagation of forest fires.

Table 2—forest fire affected areas, in terms of conservation area, period 1998 – 2007.

Conservation Area	Average Area (1998 – 2007)	Average (%)
Arenal – Tempisque	42,730.06	10.84
Tempisque	154,048.40	43.61
Northern Huetar	29,816.75	9.22
La Amistad Pacific	21,398.60	6.04
Guanacaste	62,117.31	17.87
Central Pacific	37,564.57	11.29
Osa	3,280.50	1.03
Central Volcanic Mountain Range	320.05	0.10
Total	351,276.24	100.00

Source P.N.M.F./SINAC-MINAE, 2007

Graphic 3—Conservation Areas in Costa Rica.

Among the Conservation Areas with the greatest incidence of forest fires: Guanacaste Conservation Area (ACG), Tempisque (ACT), Arenal Tempisque (ACA – T), Northern Huetar (ACA-HN), Central Pacific (ACOPAC), and Amistad Pacific (ACLA –P), most of which are located along the Pacific Coast of Costa Rica. All of these conservation areas have their own organizational structure for the extinction of forest fires.

2. Volunteer Participation in Forest Fires

Currently, Costa Rica, specifically the National System of Conservation Areas (SINAC, for its Spanish acronym), has a support system referred to as **“Volunteers for the Control of Forest Fires,”** which has been a pillar for the participation of society in the protection and conservation of the environment and natural resources, an effort which is consolidated and strengthened during the dry season (January to June each year).

The first forest fire control volunteer brigade was created in April of 1991 in the province of Guanacaste, specifically in the Lomas de Barbudal Biological Reserve and in Palo Verde National Park. This resulted from the need to strengthen response capacities against fire disasters within the boundaries and buffer zones of protected wild areas, both state and private. Later, support was extended to the reforestation projects which have environmental services, biological corridors, aquifer recharging areas, and other areas of community or municipal interest, among others.

A voluntary forest firefighter is defined as, **“A person who participates in the prevention, mitigation, control, and suppression of fire, one who is able and trained to work in an efficient and safe manner.”**

A forest brigade is defined as, **“An active team within the response system for the prevention and management of forest fires, which is organized under administrative regulations and an appropriate structure; it has work plans, protocols, and operational procedures under an Incident Command System.”** A brigade is made up of a brigade chief, a squadron chief, and two squadrons of forest firefighters consisting of up to 12 people. Their work is based on the prevention, mitigation, fire management (control and prescribed burning), detection, surveillance, and suppression, as well as community participation, management of resources, management and maintenance of equipment and tools, and training.

The brigade’s operational mechanism is carried out by means of free voluntary work. Each time there is a fire event, the fire management program coordinator from each conservation area requests support from brigade leaders and coordinates a range of logistical factors— including food supply, transport, lodging, tools, etc.— for the control of each disaster.

Since 1998, the Firefighters Corps of the National Insurance Institute annually sponsors, during fire season, the **“Basic Accident Policy,”** which is given to forest firefighters organized in brigades at a national level. Table 4 details the amount of brigades registered under this policy.

Table 4—record of forest firefighters in terms of brigade and conservation area 2005 – 2007.

Conservation Area	Number of	Quantity of Forest Firefighters

	brigades	
Northern Huetar	10	115
Arenal – Tempisque	21	255
Guanacaste	16	178
La Amistad Pacific	15	178
Central Pacific	14	170
Central Volcanic Mountain Range	5	95
Osa	5	49
Tempisque	67	744
Total	153	1784

Table 5—record of volunteer forest firefighters registered under the basic accident policy period 1998 – 2006.

Year	Number
1998	570
1999	706
2000	688
2001	700
2002	861
2003	802
2004	797
2005	847
2006/07	984
Total	6,955

2.1 Brigade Operation Requirements

In order for the MINAE to authorize the operation of volunteer brigades it must first follow a series of actions so that these brigades, which are essentially voluntary and not fully systemized, comply with certain procedures and requirements, such as:

- Execution and control of annual inventory of resources;
- Diagnostic of the current state of the brigade;
- Drafting and execution of the annual work plan;
- Training processes for brigade members;
- Accident records;
- Capacity for the formulation of projects and funding;
- Annual internal assessment mechanisms;
- Regionalized work and inter-institutional coordination;

- Application of work protocols;
- Have a local and regional database of active members and contacts;
- Collaborate with conservation areas in the detection, communication, and control of forest fires;
- Have internal regulations.

2.2 Profile of a brigade member

With the aim of facilitating the formulation of the voluntary's line of work and making possible the design of education and training plans, as well as establishing criteria for proper selection, a brigade member profile has been established as the following:

- Committed to environmental protection ;
- Solidarity and ability to work in teams;
- Respect for co-workers and fellow brigade members;
- Job availability;
- Ability to assume responsibilities and answer for his/her acts;
- Respond sensibly when faced with social and environmental needs;
- Good discipline and ability to work under authority;
- Good physical and health conditions in order to participate in forest fire control processes;
- Ability to establish and maintain cooperative relations with fellow brigade members;
- Ability to humbly recognize his/her own capacities and limitations;
- Ability to respond patiently to the limitations of fellow brigade members;
- Committed to an ongoing process of learning;
- Loyalty to team members.

2.3 Accreditation of Forest Volunteer Brigades

The accreditation of a brigade should comply with the following requisites:

- Committed and responsible participation of community and institutional volunteers;
- Brigade members with an adequate capacity to deal with forest fire prevention and control processes;
- Participants experienced in dealing with forest fire control situations;
- Brigade composed of men and women with an appropriate gender equality ratio;
- Consolidated organizational structure geared toward environmental management processes;
- Available resources for the effective tackling of forest fire prevention and control processes;

- Adequate coordination and communication system;
- Permanent processes for the exchange of experiences and the development of organizational and personal capacity;
- Effective work planning, execution, and monitoring system;
- Brigade able to identify, formulate, manage, and execute alternative projects for the channeling of resources;
- Brigade trained in the administration of work in situations of forest fire prevention and control;
- Brigade properly aware of its corresponding conservation area.

3. Organizational Structure of Fire Management in Costa Rica

In order to achieve an adequate level of coordination on national, regional, and local levels, the country has developed an organizational structure to confront the problem of forest fires, allowing for the simultaneous integration of various participants, and with the MINAE maintaining, through the SINAC, responsibility and leadership for the development of actions related to fire management.

The organizational structures consist of a National Forest Fire Commission (CONIFOR, for its Spanish acronym), made up of a series of governmental entities and a Technical Committee (COTENA), which is represented by the coordinators of the Fire Management Program of the Conservation Areas most vulnerable to fires, Regional Commissions, Cantonal Committees, and forest fire protection brigades.

3.1 National Forest Fire Commission (CONIFOR)

The National Forest Fire Commission was created in 1997 by Executive Decree No. 26399 – MINAE, published in Official Gazette No. 206 of 1997 and ratified by Executive Decree No. 29149 – MINAE in December of 2000. CONIFOR is an authority assigned to and coordinated under the National System of Conservation Areas (SINAC) of the Environment and Energy Ministry (MINAE), which has been operating on an ongoing basis since its creation.

The commission is in charge of the formulation, management, support, assessment, and follow up of inter-institutional actions related to this area. It is made up of the following entities:

- The National System of Conservation Areas (SINAC), which coordinates CONIFOR;

- The Firefighters Corp of the National Insurance Institute (INS), managed by the Office of the Executive Secretary;

- The Ministry of Agriculture and Cattle Farming (MAG);

The Ministry of Public Education (MEP);

The National Risk Prevention and Emergency Readiness Commission (CNE);

The Ministry of Public Safety (MSP);

The Institute of Agrarian Development (IDA);

The Costa Rican Electric Energy Institute (ICE);

The Costa Rican Water and Sewer Institute (AA);

The National Meteorological Institute (IMN);

The Red Cross of Costa Rica (CRC);

A representative from the Association of Volunteers for Protected Forest Areas (ASVO).

Each entity that forms CONIFOR has its own budget for the execution of actions (preventive, training, environmental education, and operation, among others), which are established in the operating plan they create and which CONIFOR approves for each participating entity. They also provide necessary support to the SINAC, when requested, whether it be for level three and four activation reasons (the suppression of forest fires), application of the Command Incident System, or other pertinent measures.

3.2 Regional Commissions

CONIFOR depends on the actions taken by these regional commissions that the MINAE establishes through the SINAC, according to the recommendations put forward by the National Technical Committee of Forest Fires on the approval of said commission.

These commissions are responsible for the proper coordination, support, execution, and follow-through of the actions established in the fire management programs existing in the different regions or conservation areas.

3.3 National Forest Fire Technical Committee

This committee answers to the coordinating needs of the SINAC, and is composed of the coordinators of the Fire Management Program from the most vulnerable Conservation Areas.

Its basic function is to achieve satisfactory fulfillment of the objectives set forth under the Fire Management Plan and National Strategy. This committee provides technical support for decision-making in this area by SINAC, while also coordinating support and follow-through for the actions that the specific Conservation Areas define, establish, and develop through their own plans or programs.

3.4 Cantonal Committees

These committees provide coordination, support, and local management, under the auspices of specific Conservation Areas or sub-regional offices. Actions are aimed at fostering the active participation of institutions, local organizations, and society in this field.

3.5 Forest Fire Brigades

Forest fire brigades are made up of forest firefighters, who are supported and maintained by employees from government entities, private companies, non-governmental organizations, or by volunteers who have been trained for such situations.

These brigades form part of the national fire management structure, as established by the National Strategy, as part of the operative development of actions, thus allowing for coordination with inter-institutional regional commissions, as well as with local emergency committees.

Seasonal Predictions for Wildland Fire Severity¹

Shyh-Chin Chen², Haiganoush K. Preisler³, Francis Fujioka², John W. Benoit², and John O. Roads⁴

Abstract

The National Fire Danger Rating System (NFDRS) indices deduced from the monthly to seasonal predictions of a meteorological climate model at 50-km grid space from January 1998 through December 2003 were used in conjunction with a probability model to predict the expected number of fire occurrences and large fires over the U.S. West. The short-term climate forecasts are ongoing experimental products from the Experimental Climate Prediction Center at the Scripps Institution of Oceanography. The probability model uses non-parametric logistic regression with spline functions for evaluating relationships between covariates and probabilities of fires. The 2-meter relative humidity and the Forsberg fire weather index, along with NFDRS indices of the Keetch-Byram drought index and energy release, were previously found to produce more significant information for the observed big fire events than all the other stand-alone fire weather variables.

Utilizing this previously determined regression relationship between historical fire information and the nowcast fire indices, these predicted indices were skillful in generating fire severity forecasts at monthly and seasonal time-scales. However, certain meteorological model biases, due to a known drying-up defect of the climate model, needed to be removed from the predicted indices before being used as input to the probability model. It was shown that the probability model using the bias-corrected fire danger indices outperformed the one with historic information only. The inter-annual fire frequency variability was predicted particularly well. This dynamical-statistical hybrid climate forecast application demonstrates a potential predictive capability (with specified precision) for the resulting economic impacts with a lead-time varying from a month to a season.

Keywords: Fire severity, NFDRS, seasonal prediction, semi-parametric logistic.

¹ An abbreviated version of this paper was presented at the Third International Symposium on Fire Economics, planning, and Policy: Common Problems and Approaches, 29 April – 2 May, 2008, Carolina, Puerto Rico.

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Introduction

Wildland fire has been a major worldwide problem affecting million of hectares forest shrub lands. In the U.S.A. alone, 2.5 million hectares of wildland has been affected per year between 2000 and 2004 with an annual average suppression cost of \$1.2 billion, more than twice that of the previous 5 years (González-Cabán 2005). Part of the cost increase might be due to the increased interface between wildlands and urban areas in today's community (Shafran 2006), but part of it might be the increase of wildland fire frequency and hence the burned area. While the level of affected burned area and associated suppression costs are challenging the national capability to confront the problem, ineffective use of the suppression costs could potentially impede society's willingness to maintain financial support for wildfire management programs.

Therefore, if a management system with the ability to project potential losses due to the impact of wildfires can be developed, it would represent a direct benefit to society and to those agencies with fire suppression responsibility. However, such a management system would require quantified predictions for fire severity and a prediction for the number of fires of different size classes with specific precision, not just fire danger.

Currently there is no operational objective long-range forecast for fire severity. The outlooks for national fire weather and fire danger at weekly to seasonal time scales are provided by the National Interagency Coordination Center (NICC), which is the nation's support center and home to seven federal agencies including the Forest Service, for wildland firefighting. The outlook and assessment are currently done by considering standard National Weather Service seasonal forecast products of temperature and precipitation (see Brown et al. 2003) along with other indicators, and carefully exercised human judgment. Therefore the current decision-making support for wildfire management is rather inadequate. Even the support for long-range fire danger forecast, which requires skillful climate prediction, is at best qualitative.

However, with the constant improvement of knowledge and understanding of climate variations, various numerical climate models have demonstrated their potential capability to offer required fire danger and fire weather predictions to the fire science community. For example, Roads et al. (2005) evaluated experimental forecasts of National Fire Danger Rating System (NFDRS) indices at weekly to seasonal scale using a meteorological model as weather input. They showed that these indices could be well predicted at weekly time scales when appraised against the validation indices deduced from the model 1-day forecasts. Some indices have skill even at seasonal scales, especially over summertime seasons in the western U.S. However, despite the high skill in predicting NFDRS indices, Roads et al. (2005) showed that there was only a weak relationship between their validation indices and

the observed fire counts/acres burned.

Preisler et al. (2004, 2007), took a statistical approach to reevaluate the relationship between the model derived NFDRS indices and the observed fire characteristics. They adopted a probability model using non-parametric logistic regression with spline functions to evaluate relationships between fire indices and probabilities of fire occurrence and size. They showed that the probability model outperformed the persistence model based on historic averages alone, and the geographical maps of wildland fire probability were reasonably well matched to the actual fire events. This method paves a feasible way to use climate forecast output from a dynamical meteorological model with a statistical model to forecast the probability of wildland fire severity with specified precisions.

In this study, we will adopt this hybrid-model concept to examine the predictability of fire severity using climate model predicted fire danger indices in Roads et al. (2007) as the input to the statistical probability model proposed in Preisler et al. (2007). The climate model predicted fire danger variables as well as the fire occurrence data will be given in the next section, followed by the description of the statistical probability model, the evaluation result, and discussions.

Data

Predicted fire danger variables

The fire danger variables in this study were adapted from Roads *et al.* (2005), in which a global to regional meteorological forecasting system developed at the Experimental Climate Prediction Center (ECPC) (Roads *et al.* 2003) was used. The modeling system consists of a global spectral model (GSM) and a regional spectral model (RSM). The RSM, originally developed at National Centers for Environmental Prediction (NCEP) (Juang and Kanamitsu 1994; see also Juang *et al.* 1997), is a regional extension of the GSM (Kalnay et al 1996). In particular, the RSM provides an almost seamless transition from the GSM to the higher resolution region of interest (Chen et al. 1999) and thus avoids a common regional model problem when using incompatible physics between the driving global model and the nested regional model (Chen 2001). The GSM is a frozen version of the operational NCEP global model. Descriptions of the GSM and RSM and the model setup used in this study can be found in Roads et al. (2003).

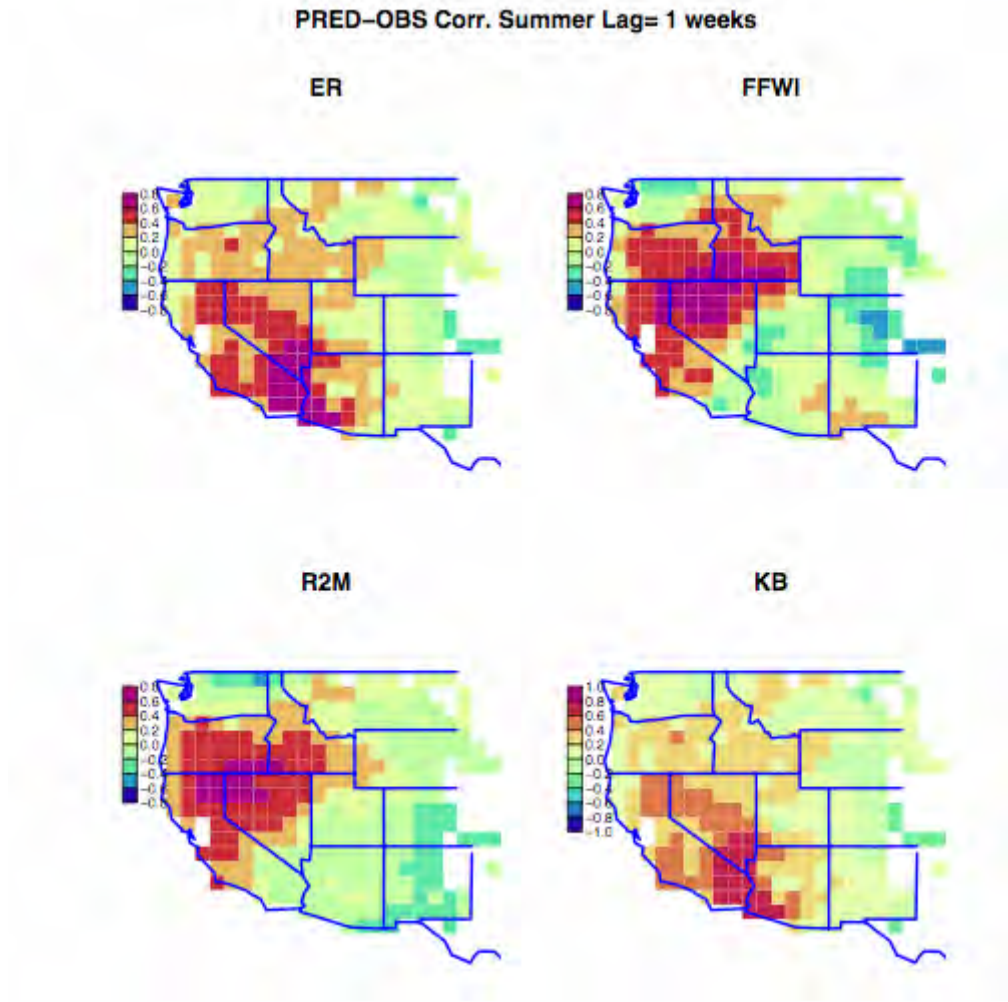
The model system used operational 00 UTC analyses from the NCEP Global Data Assimilation as initial conditions. The forecast evaluation period was from January 1, 1998 through December 31, 2003 with a 16-week forecast launched on each Saturday initialized by 00UTC analysis. The initial sea-surface-temperature and sea ice anomalies were persisted throughout each integration. The 4 times daily

output of the GSM was subsequently used as initial and lateral boundary conditions for the RSM. Horizontal grid spacing of RSM was 60 km. The forecasted surface weather variables, including temperature, two-meter relative humidity (R2M), wind speed from the model, and top 10-cm soil moisture content along with the precipitation, fuels and slope, were the input for the NFDRS indices computation (Burgan 1988) and Fosberg fire weather index (FFWI; Fosberg 1978; Fujioka and Tsou 1985). The major difference of our NFDRS calculation from the standard one is the use of the meteorological model forecast output, instead of weather station observations. Not all fire danger indices are useful to us in this study. Preisler et al. (2007) concluded that only FFWI, R2M, and two indices from NFDRS, i.e. energy release component (ER) and Keetch-Byram (KB) drought component, were important for the statistical model to be described later. Adding other indices increased only negligible skill. Therefore throughout this study, we use these four variables as input fire danger variables for the statistical model.

To initially evaluate the skill of the meteorological model in producing these fire danger indices, a set of model deduced indices from 1-day GSM/RSM forecasts was produced, and is called ‘validating’ indices. Similar to Roads et al (2005), these monthly mean indices are used as surrogates for ‘observed’ values, since 1-day forecasts have been found to be very skillful when compared to observations. Interested readers should refer to Roads *et al.* (2005) for detailed descriptions and a comparison of these indices.

All 16-week forecasts were arranged into monthly mean according to their respective calendar month. For example, outputs of the 16-week forecast starting from June 27, 1998 were grouped and averaged into monthly forecasts of lag 0 of July 1998, lag 5 of August 1998, and lag 9 of September 1998. Therefore for each target month, there are independent monthly forecasts with lead-times from 0 to 11 weeks. These monthly forecasts were further averaged into seasonal forecasts with 3 possible lags, i.e. 0, 1, and 2 weeks. These long-range forecasted indices do possess prediction skills as seen in the temporal correlation maps (*fig. 1*) for the 1-week lag seasonal forecast against those “observed”. As described in Roads (2005), these “observed” indices were actually calculated from a series of 1-day forecasts of the modeling system. Since 1-day forecasts have been found to be very skillful when compared to observations, these validating indices were used as surrogates for the “observations.” This evaluation was done over the entire fire season from May through October of each year. Therefore a total of 36 independent forecasts were used. It can be seen that all 3 indices and R2M are highly skillful at seasonal scale over the U.S. West region with the highest correlation of FFWI over the Great Basin and California area. However, the forecast skills of these variables are somewhat deteriorated over the northern boundary of the U.S Northwest and the eastern portion

of the U.S. Southwest. Since precipitation has been recognized as the most difficult



meteorological variable to predict (e.g. Chen et al. 1993), it is not surprising to see that the model fire danger prediction is skillful over the climatologically dry regions.

Figure 1. —Seasonal correlations for the input fire indices (ER, FFWI and KB) and 2-meter relative humidity (R2M). “Observed” and 1-week lag forecasts for May through October from 1998 to 2003 are used. Grid points with correlation coefficients larger than 0.32 passed 95% confidence level student t-test.

Fire Occurrence Data

This work relied on fire history datasets over the western U.S. Westerling et al. (2003) compiled a gridded one-degree latitude/longitude (317 grid cells) dataset of monthly fire starts and acres burned from approximately 300,000 fires reported by the USDA Forest Service, the USDI’s Bureau of Land Management and Indian Affairs, and the National Park Service for 1980-2003. However, we only used the data from January 1998 through December 2003 to match the period of the meteorological model-derived fire danger indices. As in Preisler et al. (2007), the fire starts and acres

burned have been merged into a set of data with large fire events (area burned > 400 ha $\approx$ 1000 acres). Throughout this study, all model derived fire danger variables (*fig. 1*) were interpolated to the same one-degree latitude/longitude grids as the fire data.

Statistical Methods

Adopting a semi-parametric logistic regression approach (Hastie et al. 2001, Preisler and Westerling 2007), a probability model of fire has been developed using historic monthly fire occurrence data as the dependent variable and meteorological model output derived fire danger indices as the explanatory (or independent) variables. The regression model estimates two fire danger probabilities: probability of fire occurrence and conditional probability of large fire event. Probability of fire occurrence was defined as the probability of at least one fire of any size occurring in a given one-degree grid cell during a given month of a year. The probability of a large fire event was defined as the probability of the occurrence of a burn area greater than 400 ha ($\approx$ 1000 acres) given at least one fire occurrence in the one-degree cell during a given month of a year. The product of the above two probabilities was used as a measure of danger for a big fire event. The 400 ha cut-off for large fires, although arbitrary, aligns with size class F fires. The same methods might be used to estimate probability spectrum of area burned, if the historic dependent as well as explanatory variables were sufficient.

The explanatory variables used in the regression model were the modeled fire danger indices described above in addition to a purely temporal variable (month-in-year) and a geo-spatial vector variable (latitude and longitude of the one-degree grid cell). The temporal variable (month) was included in the model as a proxy for annual cyclical patterns of fire occurrence and large fire events that may not have been properly captured by the indices. The geo-spatial vector (latitude, longitude) was included in the regression as a surrogate for variables with spatial patterns (e.g. vegetation type, elevation or human activities) that do not change over time. Interested readers should refer to, e.g., Brillinger et al. (2003), Preisler et al. (2004), and Preisler et al. (2007) for details.

Two probability models from Preisler et al. (2007) were used in this study. The first one is the historic (climatologic) model (or H-model). There are no fire danger variables used in this model, except month-in-year and location (latitude, longitude). With this model each grid has a different probability for each month of the year, but the probabilities do not change from year to year. The H-model is in fact a spatially and temporally smoothed function of the observed large fire frequency at each grid cell. The second probability model is the combined indices model (or C-model). The explanatory variables in this model were spatial location, month and a combination of

four fire danger variables, i.e. FFWI, ER, KB and R2M. Therefore, by feeding the C-model with a set of predicted monthly fire danger variables, a map of predicted probability of large fire events over the U.S. West will be created.

Results

Since we trained the C-model using ‘validating’ meteorological 1-day forecasted fire danger variables (Preisler et al. 2007), some care had to be taken when the monthly forecasts described above were to be used as input to the C-model. Numerical meteorological models are never perfect, and are prone to having defects, such as a tendency to drift to a biased state when they are integrated for a long period of time. The meteorological model we used in this study is no exception. It had a dry bias such that the model soil moisture was depleted somewhat and the precipitation reduced as the integration continued (Roads and Chen 2000; Chen and Roads 2005). To partially counter this bias and perhaps other not-so-obvious defects, we first constructed the monthly mean of each forecasted fire danger variable at each corresponding lag. The differences of these monthly mean climatologies of the 12 lag forecasts and the corresponding monthly mean 1-day “validating” fire danger variables were subsequently removed from the original forecasted fire danger variables before feeding them to the C-model.

Although the forecast evaluation period covered only 6 years, meaning there were only 6 monthly maps to compute a respective monthly climatology, this correction appeared to be quite effective in removing the known dry bias of the weather input as suggested by the goodness-of-fit of the reliability diagrams (*fig. 2*). These were done by grouping together all cells from the monthly forecasts with similar predicted probabilities within a certain bin for each lag forecast, and the fraction of how many of these cells were observed with fires were computed over the entire space and time. If a forecast was perfect, the observed fraction of cells with fire to the total cell number would be identical to the predicted probability of fires, and thus a point would be on the diagonal line. The ranges of 95 percentiles from the binomial distribution with respective probability and size of sample were represented with two dashed curves. The wider ranges at high probability resulted from fewer cell numbers. As can be seen, the scattered points for the un-corrected C-model are mostly under the diagonal line, indicating over-predicted fire danger, presumably a response to fire danger indices from a dry environment. This over-predicted fire danger is not only true for cases at extreme probability; the over-prediction becomes severe even at lower probability at larger forecast lags. The bias-corrected C-model, on the other hand, effectively removed most of the over-prediction, especially at lower fire probability.

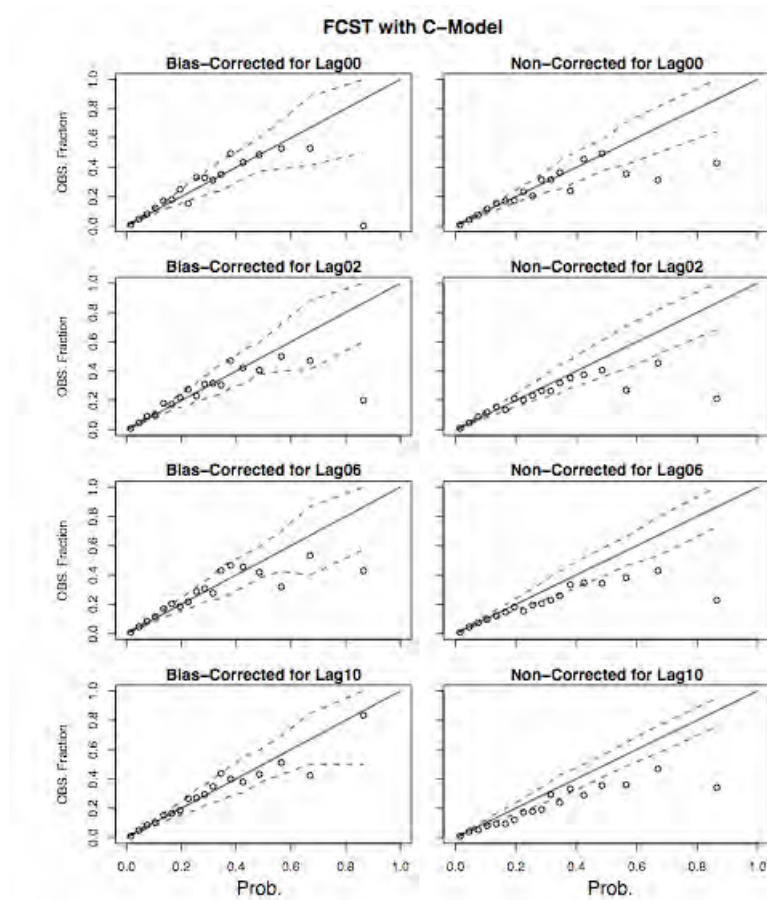


Figure 2 . — Reliability diagrams for the forecasted probability C-model with the respective forecast lags. Left side panels are those from bias-corrected indices, and right side panels are those using uncorrected outputs. Reliability diagram shows the observed fraction of large fire events plotted against predicted probability from the C-model. The two dashed curves mark the 95 per centiles for binomial distribution with respective size (number of cells) and probability.

To better compare the goodness-of-fit, we computed χ^2 for the bias-corrected and un-corrected C-models alongside that of the H-model (*fig. 3*). Smaller χ^2 indicates better fit to the diagonal line in the reliability diagram; larger χ^2 demonstrates either worse prediction or cases when the temporal and spatial distributions of cells with fire were off from observed, again presumably caused by the dry biased weather prediction. For forecasts at short lags, there are small differences between corrected and un-corrected C-models. Both models predicted fires with statistical distribution no different from that observed and were better than the H-model (the constant thin solid line) at 95% confidence level. But at longer lags, with increasing χ^2 , the uncorrected C-model apparently diverged statistically from the corrected one, or most importantly from the observation.

Although we can pretty much draw a preliminary conclusion that we should use the corrected C-model based on the reliability diagram and its χ^2 , the analysis so far

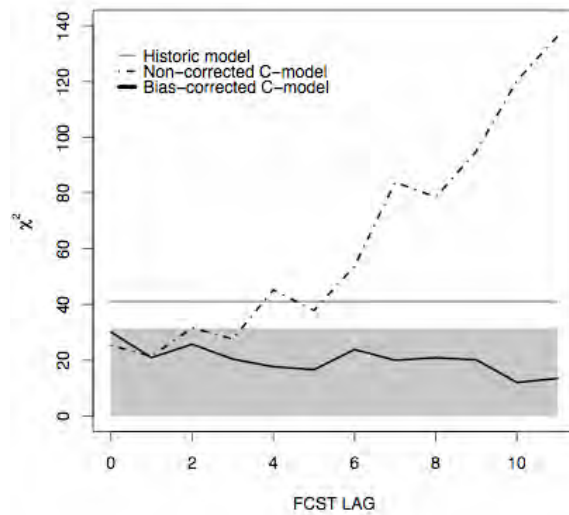


Figure 3. χ^2 of the observed and predicted fire cells as a function of forecast lags. Solid thin line is the Historic model, dotted line and solid heavy lines are for uncorrected and corrected C-models. 95% and higher confidence levels are shaded.

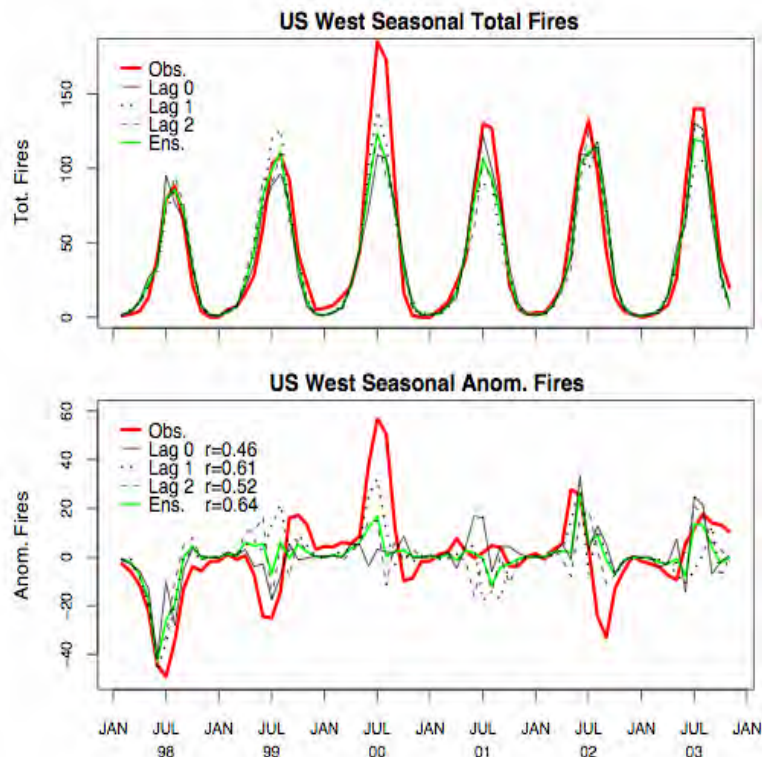


Figure 4. —3-month (seasonal) sum of the total (top) and anomalous (bottom) time series. The observed 3-month running sums are in heavy red lines, while the predicted fire numbers are in thin solid, dotted, and dashed lines for forecasts with 0, 1, and 2-week lags with respective temporal correlations (d.o.f 70) of 0.46, 0.61, and 0.52. The ensemble mean forecasts are in green lines with a correlation of 0.64.

only demonstrated that the predicted fire severity possessed similar statistical properties to those of observed fire events. They revealed little information regarding

how skillful the predictions were. To examine the prediction skill, we constructed some time series of the predicted number of fires and displayed them with the observations (*fig. 4*). The predicted number of fires was done by taking the area sum of the probability of each predicted map produced from the C-model. The observed number of fires was simply the sum of cells with fire. The top panel shows the total fire number over the entire evaluation domain from January 1998 through December 2003, the bottom panel is the anomalous time series for the same period with their respective climatology removed. Each seasonal sum was made by taking the sum of 3 consecutive monthly predictions from the same forecast, and was plotted at the center of the 3 months. Three possible forecast time series could be made with forecast lags of 0, 1 and 2 weeks. Since these three sets of forecasts were cast with initial conditions 1 or 2 weeks apart, they practically formed a “poor-man” 3-member ensemble forecast and the ensemble mean was given in green curve. As shown in the top panel, the observation shows intense annual cycles for the total number of fires, with a peak around July. There was also a slight increasing trend for the summertime peaks. All 3 sets of forecasts, including the ensemble mean, in general, followed the observed annual cycle quite well. They even reproduced the slight upward trend as observed. However, the true forecast skill of this hybrid model can only be tested with the anomalous plot in the bottom panel. Except for the high positive anomaly in the summer of 2000, all three forecasts and the ensemble mean fairly predicted the peaks and valleys in summertime with temporal correlations exceeding the 95% confidence student-t test (70 d.o.f.). There was even one forecast that somewhat caught the extreme positive anomaly at summer of 2000. These are skillful forecasts, and are obviously much better than forecasts made with climatology (H-model), which would have been a constant zero in the bottom panel.

Summary and Discussion

A statistical method of estimating probabilities of large wildland fire events has been applied to the monthly to seasonal fire danger indices forecasts produced by the numerical climate prediction model from the ECPC. Specifically, following Preisler et al. (2007), the predicted monthly mean fire danger indices, FFWDI, KBDI, ER, and R2M, were used as input variables for the statistical probability model to estimate monthly probabilities of large fire events over the western United States. The predicted probabilities were then compared with observed frequencies of large events in order to assess the skill of this dynamical-statistical hybrid modeling system. The evaluation period was from January 1998 through December 2003. Despite the use of persistent sea-surface-temperature and sea ice anomalies for the climate model, it is encouraging to see that the prediction of the fire danger indices from the climate

model was quite useful in generating the projected wildland fire severity.

From this preliminary study, we found that special attention to the prediction data was needed to counter the drift or bias of the climate prediction model. This was simply done by removing the differences between the forecast and validating (1-day forecast) climatologies from the predicted fire danger indices before feeding them to the probability model. The procedure was straightforward but the apparent dry bias and hence the over-estimated fire severity prediction was effectively corrected. This is particularly true when compared to the observed fire events. The resulting statistical characteristics of fire probability prediction were not only improved over the bias un-corrected set, they were also superior to using the fire climatology only. Thus the inter-annual variability of the predicted fire frequency was predicted fairly well. Furthermore, the prediction seemed to be particularly useful if ensemble forecast mean was taken.

While the fire severity prediction over the U.S. West might be useful in quantifying fire danger to fire managers, a more useful application might be the ability to forecast monthly or seasonal fire frequency over a region in a probabilistic manner. For example, a fire severity forecast over the juridical area of a regional operation center of the Geographic Area Coordination Center (GACC; <http://gacc.nifc.gov/>). However, to evaluate the skill of the forecast over such a small area is not an easy task using the prediction data presently available to us. In this study, since we have only 6 years of prediction and validating analysis, we had to compensate the shortage of temporal points with the abundant spatial points for the statistics to be meaningful. Future study should address the use of longer periods of climate forecast data (e.g. Roads et al. 2007) and fire data (e.g. Westerling et al. 2003) to examine the predictability of fire severity. Using such datasets, not only could we focus our analysis on a smaller GACC region, we would also not be limited to only two classes of fire, i.e. no fire or large fire, as in the analysis of this study. Instead, a probability spectrum (sizes of fires) could be readily produced.

Probability models, such as the one described here, are not only practical in producing maps of fire danger, they are also useful in assessing the skill of each fire danger in estimating and/or forecasting frequencies of wildland fire events. However, the indices in NFDRS were probably originally designed to support firefighting tactics on a daily basis. Some of the indices, such as SC, BI and IC, are sensitive to short-term variations of weather components, especially wind speed. These indices, therefore, might lose their high frequency characteristics when a long-term (e.g. monthly) average is taken, as was the case in this study. Thus a future extensive re-evaluation of those indices excluded from Preisler et al. (2007) and this study is needed. In particular, we will focus on how to best accumulate the daily information given in these wind-sensitive indices into monthly or even seasonal variables.

References

- Brillinger, D. R.; Preisler, H. K.; Benoit, J. W. 2003. **Risk assessment: a forest fire example.** In D. R. Goldstein Editors. Science and Statistics, Institute of Mathematical Statistics Lecture Notes. Monograph Series; 177-196.
- Brown, T. J.; Barnston, A.; Roads, J. O.; Martin, R.; Wolter, K. E.; 2003. **2003 Seasonal Consensus Climate Forecasts for Wildland Fire Management.** Experimental Long-Lead Forecasts Bulletin 12 (1); 6 p.
- Burgan, R. E. 1988. **1988 Revisions to the 1978 National Fire-Danger Rating System.** USDA Forest Service, Southeastern Forest Experiment Station Research paper SE-273; 39 p. (Asheville, NC).
- Chen, S. -C.; Roads, J. O.; Alpert, J. 1993. **Variability and predictability in an empirically-forced global model.** J. Atmos. Sci. 49; 443-463.
- Chen, S. -C.; Roads, J. O.; Juang, H. -M. H.; Kanamitsu, M. 1999. **Global to regional simulations of California wintertime precipitation.** J. Geophys. Res.-Atmos. 104(D24); 31517-31532.
- Chen, S. -C. 2001. **Model mismatch between global and regional simulation.** Geophys. Res. Lett. 29 (5); 4.1 – 4.4.
- Fosberg, M. A. 1978. **Weather in wildland fire management: the fire weather index.** Proceedings of the Conference on Sierra Nevada Meteorology, South Lake Tahoe, NV. p. 1-4.
- Fujioka, F.M.; Tsou, T. -H. 1985. **Weather in wildland fire management: the fire weather index.** Proceedings of the Conference on Sierra Nevada Meteorology, South Lake Tahoe, NV. p. 1-4.
- González-Cabán, A. 2005. **Economic impact of wildland fires.** Paper presented at the Southern California Academy of Sciences annual meeting, Loyola Marymount University, Los Angeles, CA, May 21, 2005.
- Hastie, T. J.; Tibshirani, R.; Friedman, J. 2001. **The Elements of Statistical Learning: Data Mining, Inference, and Prediction.** Springer, New York. 533 p.
- Juang, H. -M. H.; Kanamitsu, M. 1994. **The NMC nested regional spectral model.** Mon. Wea. Rev. 122; 3-26.
- Juang, H. -M. H.; Hong, S.; Kanamitsu, M. 1997. **The NMC regional spectral model. An update.** Bull. Amer. Meteor. Soc. 78; 2125-2143.
- Kalnay, E. M. and coauthors 1996. **The NCEP/NCAR 40-year Reanalysis project.** Bull. Amer. Meteor. Soc. 77; 437-471.
- NWCG Fire Weather Working Team; **National fire danger rating system weather station standards.** Publication of the national Wildfire Coordinating Group, PMS 426-3; 30p. (http://www.fs.fed.us/raws/standards/NFDRS_final_revmay05.pdf)
- Preisler, H. K.; Brillinger, D. R.; Burgan, R. E.; Benoit, J. W. 2004. **Probability based models for estimating wildfire risk.** International Journal of Wildland Fire 13; 133-142.
- Preisler, H. K.; Westerling, A. L. 2007. **Statistical model for forecasting monthly large wildfire events in Western United States.** Journal of Applied Meteorology and Climatology 46(7); 1020–1030.
- Roads, J. O.; Chen, S. -C.; Fujioka, F.; Kanamitsu, M.; Juang, H. -M. H. 1995. **Global to regional fire weather forecasts.** International Forest Fire News [BAHC] 17; 33-37.

- Roads, J. O.; Chen, S. -C.; Kanamitsu, M. 2003. **US regional climate simulations and seasonal forecasts.** J. Geophys. Res. –Atmos. 108 (D16); 8606; doi:10.1029/2002JD002232.
- Roads, J. O.; Fujioka, F.; Chen, S. -C.; Burgan, R. E. 2005. **Seasonal fire danger forecasts for the USA.** International Journal of Wildland Fire 14; 1-18.
- Roads, J. O.; Tripp P.; Juang H.; Wang J.; Fujioka F.; and Chen S. C. [In press]. **NCEP/ECPC Monthly to Seasonal US Fire Danger Forecasts.** International Journal of Wildland Fire.
- Shafran, A. 2006. **Risk externalities and the problem of wildfire risk.** J. Econom. Literature 44; 1-33.
- Westerling, A. L.; Gershunov, A.; Cayan, D. R. 2003. **Statistical Forecasts of the 2003 Western Wildfire Season Using Canonical Correlation Analysis.** Experimental Long-Lead Forecast Bulletin 12(1,2).

Do Repeated Wildfires Change Homebuyers' Demand for Homes in High-Risk Areas? A Hedonic Analysis of the Short- and Long-Term Effects of Repeated Wildfires on House Prices in Southern California¹

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Abstract

Unlike most hedonic studies that analyze the effects of a one-time event, this paper analyzes the effects of forest fires that are several years apart in a small geographical area. We find that repeated forest fires cause house prices to decrease for houses located near the fires. We test and reject the hypothesis that the house price reduction from the first fire is equal to the house price reduction from the second fire. The first fire reduces house prices by about 10%, while the second fire reduces house prices by nearly 23%, a statistically significant difference.

Keywords: Economic impacts of wildfires, hedonic property models, nonmarket valuation, temporal effect of wildfires, wildfire risk.

Introduction

The occurrence of a natural disaster increases the public's perceived risk of such an event. Earthquakes, floods, wildfires and hurricanes are covered in depth by local and national media, and residents of nearby communities feel exposed to the risks of natural disasters after an event occurs. Public policy that addresses natural disasters should take into account public perception of risk. If buyers and sellers decrease the value of homes in high-risk areas, then this decrease in value will be signaled by

¹ An abbreviated version of this paper was presented at the Third International Symposium on Fire Economics, Planning, and Policy: Common Problems and Approaches, 29 April – 2 May, 2008, Carolina, Puerto Rico.

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decrease in house prices. By intervening and giving financial aid to victims of natural disasters, the government may provide a subsidy for living in high-risk areas.

A lack of information on natural disaster risk may also contribute to the public's inaccurate perception of the probability of loss due to natural disasters. A market failure occurs in the housing market if a homebuyer has an inaccurate view of the risk profile associated with a purchased home. Because information on natural disaster risk has public good characteristics, government intervention may be needed to provide information and prevent market failure.

Wildfires cause billions of dollars of losses in the United States each year. Our study area is Southern California, a densely populated region prone to wildfires because of decades of wildfire suppression. In 2003, the state of California suffered their worst wildfire season on record. From October 21 to November 3, 2003, there were 14 wildfires in 5 Southern California counties. Twenty-four lives were lost. Over 750,000 acres were burned, and 3,710 homes were destroyed, causing billions of dollars worth of insured losses, and costing Federal, state, and local governments millions for emergency assistance. It is important that local, state, and federal policymakers have an accurate measure of the damages caused by wildfires so that policies can correctly address issues surrounding wildfires such as prevention and disaster assistance. Although the immediate effects of wildfires have been estimated in previous studies, the long-term effects should also be considered when making policy decisions. In this study, we use the hedonic property method to analyze both the immediate and long-term effects of repeated wildfires on house prices in Los Angeles County to understand how the public responds to wildfires. In particular, do first wildfires have a different effect than second wildfires on the demand for housing and hence house prices in high-risk areas?

The hedonic property method is commonly used to model housing markets, and is often used to measure the value of environmental amenities or dis-amenities proximate to the home, including: open space (Irwin 2002), water quality (Leggett and Bockstael 2000), nuclear waste transport (Gawande and Jenkins-Smith 2001), and maintaining adequate lake water levels (Loomis and Feldman 2003)⁵ In addition, several studies use hedonic property models to estimate the marginal willingness to pay for reduced risk of natural disasters. For example, Bin and Polasky (2004) used a hedonic model to estimate the effect of flooding on residential property values. They found that houses located within a floodplain have lower prices than houses located outside a floodplain. Furthermore, they found that the price differential increases after a major hurricane caused severe flooding. Bin and Polasky conclude that recent flooding causes an increase in perceived risk due to flooding. The results of Bin and

⁵ See Boyle and Kiel (2001) for a comprehensive survey of hedonic studies on environmental externalities.

Polasky's study indicate that after a natural disaster, increased risk perception causes a decrease in the value of houses located in high-risk areas.

Previous studies have also found indications that homebuyers have inaccurate information on the risk of natural disasters. After failure to find significant evidence of a flood risk discount in a hedonic study, Chivers and Flores (2002) surveyed homeowners in an area that has very high risk of flooding to investigate the possibility of market failures due to lack of information. Their survey results indicate that most homebuyers were unaware of the actual flood risk of their homes until after they made an offer. In another hedonic study Beron and others (1997) found that the hedonic price of reduced earthquake risk decreased after a major earthquake in Northern California. Beron and others attributed the surprising decrease in the hedonic price of risk to inaccurate perception of earthquake risk. They contend that homebuyers over-estimated the risk of damage due to earthquakes, and after experiencing an earthquake, re-evaluated their risk profiles. So, even though the hedonic price of earthquake risk was reduced after an earthquake, Beron and others' study indicates market failure due to imperfect information. Hence, previous research on natural disasters indicates that lack of information on natural disasters can cause market failures in the housing market.

Previous research on the effect of wildfires on house prices finds a negative initial impact on house prices. A recent study by Loomis found that house prices in an unburned community 2 miles from a Colorado wildfire decreased by 15% after the fire (Loomis 2004). In addition, a study by Price Waterhouse Coopers in New Mexico found that house prices in Los Alamos decreased by 3 to 11% after the Los Alamos wildfire (Pricewaterhouse Coopers 2004). Both of these wildfire studies investigate what happens to house prices immediately following a wildfire, but neither study analyzes the long-term effect of the wildfires. Performing a broad temporal analysis is one of the objectives of our study. Both wildfire studies also assess the effect of a single wildfire on house prices. Another objective of our study is to assess the effect of repeated wildfires.

Model specification

We used the hedonic property model first proposed by Rosen (1974). The dependent variable is the log of real sale price adjusted using the housing price index for Los Angeles, Riverside, and Orange Counties (1983 base year). A log-linear specification allows the marginal effect of each independent variable to vary with the level of the independent variables. Thus, with our specification, the marginal effects of independent variables on the price of a house depend upon the characteristics of the house.

To address the temporal effects of wildfires on house prices, a sale date for each house is required. The recorded sale date is not the date when the actual purchase decision was made. Offers on house purchases are made one to two months in advance of the recorded sale date. Since homebuyers are locked into their offers once an offer is made, the time element of our model is represented by a decision date defined as 60 days prior to the recorded sale date. For example, if a sale date is April 30, 1998, the decision date is March 1, 1998.⁶

The independent variables of interest are wildfire indicator variables and the rate of change of house prices after each wildfire for houses located near and selling after wildfires. Controls for housing structure and neighborhood demographics are included. The general model is as follows:

$$P_{it} = f(E_{it}, S_i, N_i, M_{it})$$

where P_{it} : Sale amount at decision date t , with sale amount deflated using the annual housing price index for Los Angeles, Orange, and Riverside Counties (1983 Base Year).

The choice of included independent variables for our first stage hedonic property model was based on prior research, data availability, and data characteristics (i.e. correlations). Including irrelevant variables in an OLS regression results in large standard errors for the coefficient estimates, therefore, increasing the probability of type II errors (failing to reject the null hypothesis when the null is false). Furthermore, including several highly collinear explanatory variables in a regression may result in unreliable parameter estimates. Failure to include relevant variables, however, results in biased coefficient estimates (Taylor 2002). The following are the environmental variables of interest we chose to include in our empirical specification:

After One Fire: An indicator variable that equals one if a house sold after and is located within 1.75 miles of at least 1 wildfire, otherwise zero

After Two Fires: An indicator variable that equals one if a house sold after and is located within 1.75 miles of at least 2 wildfires, otherwise zero

Days Since First Fire: Number of days since the first wildfire, if the house sold after and is located within 1.75 miles of at least one wildfire

Days Since Second Fire: Number of days since the second wildfire, if the house sold after and is located within 1.75 miles of at least 2 wildfires

Our empirical specification is as follows:

$$\begin{aligned} \text{Log (Real Sale Amount)} = & \beta_0 + \beta_1 * (\text{After One Fire}) + \beta_2 * (\text{After Two Fires}) + \beta_3 * \\ & (\text{Days Since First Fire}) + \beta_4 * (\text{Days Since Second Fire}) + \beta_5 * (\text{Square Feet}) + \beta_6 * \\ & (\% \text{ with no High School Degree}) + \beta_7 * (\text{Median Household Income}) + \beta_8 * (\text{Distance} \\ & \text{to U.S. Forest Service Land}) + \beta_9 * (\text{Unemployment Rate}) + \beta_{10} * (\text{Elevation}) \quad (1) \end{aligned}$$

⁶ Our timing adjustment is similar to the adjustment used in Loomis and Feldman (2003)

We want to analyze both initial and long-term effects of wildfires on house prices. The After One Fire and After Two Fires variables measure the initial effect of first and second wildfires on house prices, but the After Fire variables do not measure long-term effects of wildfires on house prices. Including the Days Since First and Second Fire variables allows house prices to change after an initial shock, and also allows the rate of change of house prices to differ after first and second wildfires. Distance to USDA Forest Service owned land is a proxy for distance to open space or forested land. The elevation of a house lot serves as a proxy for vegetation type (higher elevations have more flammable vegetation). Houses located at higher elevations and nearer to forests have a higher risk of burning from a wildfire. The distance to downtown Los Angeles is included in the model because Los Angeles is the biggest employment center in the area, and people commute to Los Angeles for work.

Several measures of housing characteristics were available. Square feet is the most commonly used approach in hedonic property models to control for housing structure, and therefore is the structural characteristic we decided to include. Neighborhood characteristics commonly included in hedonic models are school district quality and household income (Taylor 2002). A direct measure of school district quality is unavailable within our data, so a measure of the percent with no high school degree in a neighborhood is used as a proxy for the relative level of educational attainment in a particular community. Neighborhoods with high percentages of educated people generally have higher quality schools. Median household income is also included as a proxy for neighborhood desirability. The California unemployment rate is included in our model to control for market fluctuations that may shift housing demand.

Data and sampling methodology

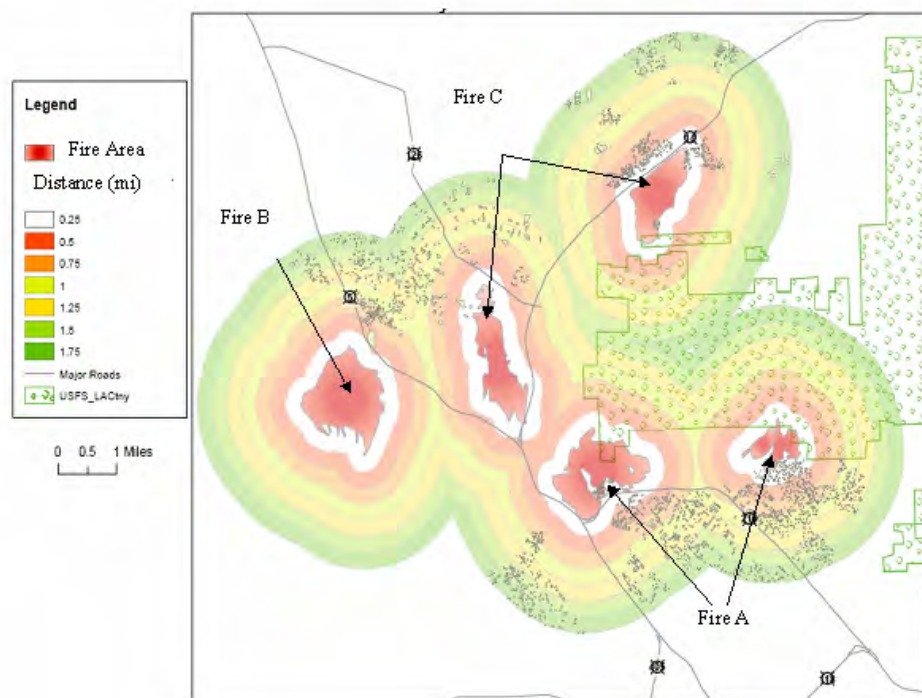
Several datasets obtained from various sources are merged to form a database that includes housing parcel sale date, sale amount, location, demographic characteristics, fire distances, and distance to employment centers. Each housing parcel is a single-family residence located within 1.75 miles of a relevant wildfire. All parcels sold at least once between 1989 and 2003.⁷

There were over 54,000 single-family residences to sample from. After outliers were removed, the sample was stratified by distance to wildfire and sale date. Each wildfire was mapped with a series of quarter mile rings from the fire center, until the last ring, which is 1.75 miles from the fire center. A target of 25 houses for each

⁷ We know only the most recent sale date of a house.

distance strata and each year was used. Houses were randomly sampled when there were more than 25 houses for a given distance and sale date.⁸

Figure 1-- Map of Fire Area



Wildfires that occurred in the 1990's were chosen for analysis to ensure we have sufficient data after each wildfire to analyze long-term effects. Los Angeles County was selected because there were numerous wildfires within the wild-land urban interface in the county during the 1990's. The study area is composed of five fires and is approximately 5.25 miles across. See Figure 1 for a map of the fire area. The darkest areas are our fire perimeters. The gray shaded colored areas represent 0.25-mile rings mapped out from each fire perimeter. The tiny gray shapes represent housing parcels. The Sylmar and Polk fires occurred within three days and just a few miles of each other and are considered one fire (Fire A) for purposes of this analysis. The Sierra fire occurred less than 60 days after the Placerita fire, also within miles of the Placerita fire. For purposes of this analysis, the Placerita and Sierra fires are also counted as one fire (Fire C). The Towseley fire is treated as one fire (Fire B). All three wildfires are of comparable size—Fire A burned 937 acres, Fire B burned 818 acres, and Fire C burned 977 acres.

⁸ No houses were lost to fire in our fire area.

Each house in the study area is located within 1.75 miles of at least one of the fires, but may have sold before the nearest fire. A house within our sample is considered to experience a wildfire if it sells after and is located within 1.75 miles of the wildfire. That is, our After First Fire variable is equal to one for the first wildfire that a particular house sold after and was located within 1.75 miles of. Alternatively, houses that sold before all fires located within 1.75 miles of the house are coded with After One Fire = 0, and are treated as a control group.

The Days Since First Fire variable equals the number of days since the first wildfire for houses with After First Fire equal to one. After Second Fire equals one for the second wildfire for houses that sell after, and are located within 1.75 miles of two wildfires. The Days Since Second Fire variable equals the number of days since the second wildfire for houses with After Second Fire equal to one. Hence, houses selling on different dates and located in different areas will have different values for the After Fire and Since Fire Variables. Some houses are located near only one of the three wildfires in our area, some houses are located near only two wildfires in our area, and some houses are located near three wildfires in our area. By allowing different wildfires to be the “first” wildfire for different houses, we reduce the likelihood that our estimates are biased by spurious correlation with other events.⁹

The parcel data were obtained from Los Angeles County through Nobel Systems.¹⁰ The data contain the geographic location, sale date, sale price, and structural characteristics of housing parcels in Los Angeles County. Demographic variables were attached to each parcel using Geolytics software. We decided to include median household income (measured in year 2000 dollars) and percent with no high school degree in our models. Both demographic variables are proxies for overall neighborhood quality. Including demographic characteristics in the model will control for differences in house prices due to variation in neighborhood quality, allowing a more accurate measure of the effects of wildfires on house prices. GIS was used to measure a series of different distances for each parcel.¹¹ The geographic data include Distance to fire center for all wildfires (kilometers) and Distance to edge of nearest USDA Forest Service owned land. Sale price data is deflated using an annual Housing Price Index for Los Angeles, Orange, and Riverside Counties.¹² Annual unemployment rates for the state of California were also obtained from the Bureau of Labor Statistics website.¹³ Annual mortgage rates tied to the buyer’s decision date were also included in the model. Table 1 shows summary statistics for

⁹ Due to the small number of houses that experience a third fire (only 34 houses), we do not analyze the effect of a third fire.

¹⁰ We thank Shil Niyogi of Nobel Systems for his assistance with the Los Angeles County parcel data.

¹¹ We are very grateful to Nate Peterson, our GIS expert, for his contributions to this project.

¹² The annual Housing Price Index was obtained from the Bureau of Labor Statistics website (<http://data.bls.gov/cgi-bin/srgate>) and typing in the series id CUURA421SAH.

¹³ The website is <http://data.bls.gov/cgi-bin/srgate>, with the series id LAUST06000003.

the variables included in the final empirical model.

Table 1-- *Summary statistics*

Variable name	# Of Observations	Mean	Standard Error
<i>Real sale amount (year 1983 dollars)</i>	2520	151,907.10	3,026.06
<i>Log of real sale amount</i>	2520	11.85	0.24
<i>After one fire</i>	2520	0.73	0.01
<i>After two fires</i>	2520	0.50	0.01
<i>Days since first fire</i>	2520	1,450.00	28.90
<i>Days since second fire</i>	2520	693.00	13.81
<i>Square feet</i>	2520	1,842.00	36.70
<i>% with no high school degree</i>	2520	21.76	0.43
<i>Median household income (year 2000 thousands)</i>	2520	65.68	1.31
<i>Distance to USFS. land (kilometers)</i>	2520	2.83	0.06
<i>Elevation (meters)</i>	2520	1,426.00	28.40
<i>Unemployment rate</i>	2520	6.77	0.13

Results

Our estimation results are reported in Table 2. The coefficient on the After One Fire variable is negative and statistically significant, indicating that house prices drop approximately 9.71% after one wildfire. The coefficient on the After Two Fires variable is also negative and statistically significant, indicating that house prices drop an additional 22.68% after a second wildfire. The coefficients on the Days Since First Fire and Days Since Second Fire are also statistically significant, but they have different signs.

Table 2-- *Regression Results for an OLS regression with log of deflated sale price as the dependent variable. The absolute values of t-statistics are reported in parenthesis, * indicates significance at the 5% level, ** indicates significance at the 1% level, and errors reported are robust standard errors.*

	Regression Results	Mean of Independent Variable
<i>After one fire</i>	-0.09706 (5.53)**	0.73
<i>After two fires</i>	-0.22681 (11.88)**	0.50
<i>Days since first fire</i>	-0.00004 (3.70)**	1451.00
<i>Days since second fire</i>	0.00024 (15.36)**	693.00
<i>Square feet</i>	0.00035 (38.44)**	1,842.00
<i>Median household income</i>	0.000963 (2.78)**	65.68
<i>% no high school degree</i>	-0.00435 (7.75)**	21.76
<i>Distance to USFS land</i>	0.00000565 (1.60)	2.83
<i>Elevation (meters)</i>	-0.00025 (5.72)**	1426.00
<i>Unemployment rate</i>	-0.02691 (6.82)**	6.77
<i>Constant</i>	11.85281 (128.67)**	
<i>Observations</i>	2520	
<i>R-squared</i>	0.64	

The estimated model from Equation 1 allows us to calculate marginal implicit prices for a first fire and a second fire. We have a log-linear specification, therefore the estimated implicit price is a function of the estimated coefficient on the After Fire variable and the mean house price. Therefore,

$$\text{Marginal Implicit Price} = \hat{\beta} \cdot \bar{y} \quad (2)$$

Where, $\hat{\beta}$ is the estimated coefficient on the After Fire variable and $\bar{y}$ is the mean sale price.

Table 3 shows the marginal and cumulative effects of a wildfire for the average priced house in our sample. The mean deflated sale price over all years in our sample is \$151,907. Hence, the marginal effect of the first wildfire within 1.75 miles is an initial decrease in house price of \$14,744. A second wildfire within 1.75 miles will cause an additional decrease of \$34,453 in house prices. The cumulative effect of two wildfires on the selling price of an average house is a \$49,198 drop. Since the coefficients on the After Fire variables are both statistically different from zero, we

also tested the null hypothesis that the coefficients on the After Fire variables are

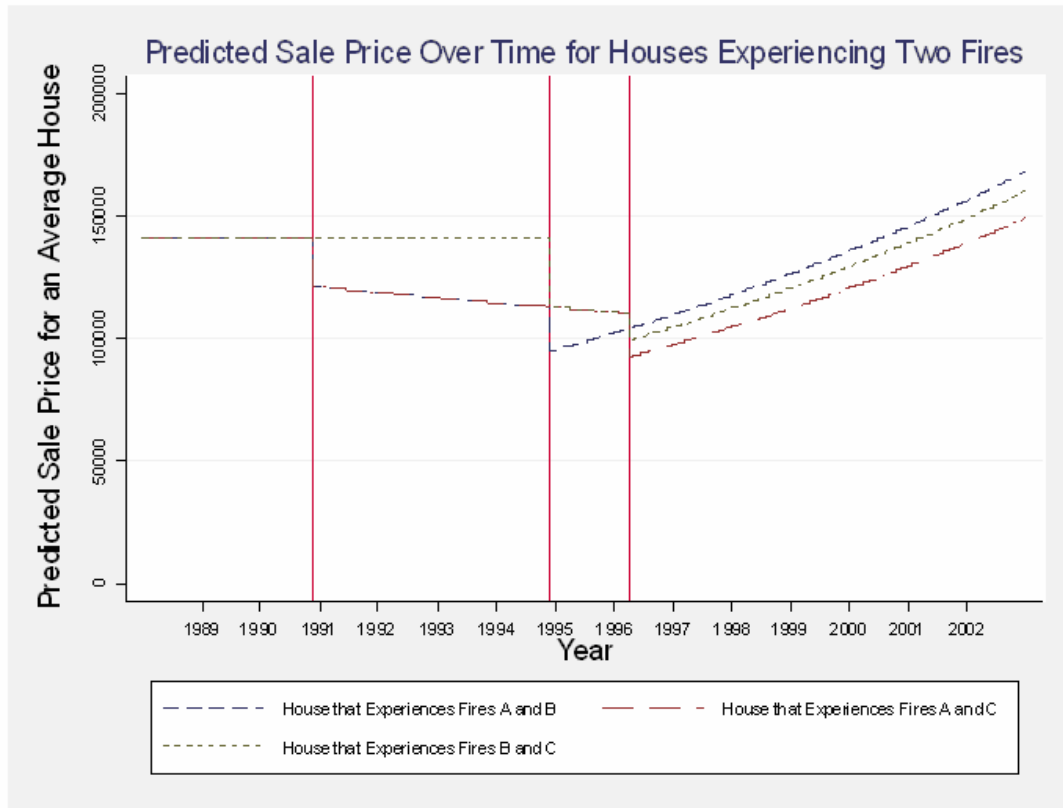


Figure 2: *Predicted sale price over time for a house that experiences two fires*

equal to each other. The test had a p-value of 0.0001, indicating that we reject the null hypothesis that the coefficients on the After Fire variables are equal to each other. We conclude that a second wildfire has a different initial effect than the first wildfire.

Table 3-- *Marginal and Cumulative Effects of First and Second Fires*

	Estimated Coefficient	Marginal Effect	Cumulative Effect
<i>One Fire</i>	-0.0971	-\$14,744.59	-\$14,744.59
<i>Two Fires</i>	-0.2268	-\$34,453.54	-\$49,198.13

In addition, the coefficients on the Days Since Fire variables are statistically different from zero in our regression. However, they have different signs. The first wildfire causes an initial drop followed by a continued decrease in house price, but the second wildfire causes an initial drop followed by a subsequent increase in house

prices. The exact length of time it takes for the house price to recover after the second fire depends upon the length of time between the first and second fires. Recall that different houses can experience different combinations of fires within our area. Figure 2 illustrates the time path for an average-priced house over time in the three possible fire event combinations. It takes between 5 and 7 years for house prices to recover after a second fire. The time frame for recovery seems reasonable. Within a few years, the natural vegetation near the house will have regenerated. In addition, if several years pass without a fire, people may begin again to forget about the risk of fire.

Conclusions

A striking result from our estimation is that a second wildfire causes a larger initial decrease in house price than the first wildfire. One explanation of the observed difference in impacts is that a single wildfire may not be a sufficient stimulus to cause homeowners to move, while a second wildfire causes more risk-averse homeowners to move to areas less prone to wildfire. A homeowner may think that the first wildfire is going to be the only nearby wildfire for an extended period of time and hence remain living in a high-risk area after one wildfire. However, house prices continue to decrease after the first wildfire because of diminished surrounding landscape amenities due to wildfire damage. Then, a second wildfire occurs, causing more devastation, and another update in perceived wildfire risk. Because homeowners did not expect another wildfire for a prolonged period of time, the second wildfire causes a more devastating initial shock than the first wildfire. As a result of the second wildfire, highly risk-averse homeowners may be replaced by less risk-averse homeowners. As new homeowners move in, house prices begin to recover, explaining the subsequent recovery of house prices after a second wildfire. In other words, it takes more than one wildfire to induce a permanent reaction (in the form of moving) from current homebuyers.

Our results indicate that demand for houses located near wildfires decreases immediately following each wildfire, and that demand decreases more after repeated wildfires. This means that many homebuyers do not want to live in areas with repeated wildfires, and that perhaps homebuyers purchase homes in high risk areas without being fully aware of actual wildfire risk. Hence, policymakers could decrease losses due to wildfires by increasing wildfire risk awareness through public information campaigns. Such a campaign was initiated in Colorado where fire risk maps, including high hazard designated “red zones” were publicized in local newspapers and based on the research of Donovan, et al (2007) appears to be successful in changing house buyer awareness of wildfires.

References

- Beron, Kurt J.; Murdoch, James C.; Thayer, Mark A. 1997. **An analysis of the housing market before and after the loma prieta earthquake.** Land Economics 73 (1):101-113.
- Bin, Okmyung;;Polasky, Stephen. 2004 **Effects of flood hazards on property values: evidence before and after hurricane Floyd.** Land Economics 80 (4):490-500.
- Boyle, Melissa A.; Kiel, Katherine A. 2001. **A survey of house price hedonic studies of the impact of environmental amenities.** Journal of Real Estate Literature 9(2):117-144.
- Chivers, James; Nicholas Flores. 2002. **Market failure in information: the National Flood Insurance Program.** Land Economics 78 (4):515-521.
- Donovan, G.; P. Champ; D. Butry. 2007. **The impact of wildfire risk on housing price: a case study from Colorado springs.** Land Economics 83 (2):217-233.
- Pricewaterhouse Coopers 2001. Federal Emergency Management Agency. **Post-fire residential property value in Los Alamos.**
- Gawande, K.; Jenkins-Smith, H. 2001. **Nuclear waste transport and residential property values: estimating the effects of perceived risks.** Journal of Environmental Economics and Management 42 (2):207-233.
- Irwin, Elena. 2002. The effects of open space on residential property values. Land Economics 78 (4):465-480.
- Leggett, C.; Bockstael, N. 2000. **Evidence of the effects of water quality on residential land prices.** Journal of Environmental Economics and Management 39 (2):121-144.
- Loomis, John B.; Feldman, M. **Estimating the benefits of maintaining adequate lake levels to homeowners using the hedonic property method.** Water Resources Research 39 (9): 1-6.
- Loomis, John B. **Do nearby forest fires cause a reduction in residential property values?** 2004. Journal of Forest Economics 10 (3) :149-157.
- Rosen, S.1974. **Hedonic prices and implicit market: product differentiation in pure competition.** Journal of Political Economy 82:34-55.
- Taylor, Laura. 2002. **The Hedonic method.** In: P. Champ, T. Brown, and K. Boyle editors. A Primer for Non-Market Valuation, AA Dordrecht, The Netherlands: Kluwer, 331-394.

The Total Cost of Fire in Australia¹

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Abstract

Fire, an ever present threat in Australia, causes approximately 100 fatalities and over 3,000 injuries per annum. Significant resources are allocated to mitigate the threat. In this study we estimate the total cost of fire in Australia for 2005 at AUD\$12,000 million or 1.3% of GDP. Breaking this total down into its components, we find 56% relates to costs in anticipation of fire, 29% for response activities and the remaining 15% stem from the consequences of fire. This estimate shows that the investment in mitigation (85% of the total costs), is over 5 times the consequences (15%) and raises the question as to whether the current investment strategy adopted in Australia is efficient and effective. As a first step in exploring the efficiency of the current system, a structured expert judgment exercise was undertaken. Twenty six experts responded, and the outcomes suggest that the current system is not optimal, and that there is no net benefit in increasing investment, however there may be a net benefit in reducing investment in anticipation and/or response.

Key Words: Australia fire cost.

Introduction

In Australia, fire is a significant hazard to people, property and the environment. Each year there are approximately 100 fatalities and approximately 3000 injuries from structure fires (Productivity Commission 2007). Over the last century, the loss of residential homes from bushfire (wildland fires) averaged 83 homes per year (McAneney 2005). The year-to-year variance about the mean figure is large from no homes lost in 40% of years to 2,500 buildings in the Ash Wednesday bushfires, Victoria (1983) (McAneney 2005), which also killed 75 people (Bureau of Meteorology 1984). In other Australian fires, the 1974/75 rangeland fires in the Northern Territory destroyed 117 million hectares (Australian Bureau of Statistics 1995); the Longford Gas explosion cost the Victorian economy an estimated AUD\$1,300 million (The Age 2002); the Childers Hostel fire,

¹ An abbreviated version of this paper was presented at the Third International Symposium on Fire Economics, Planning, and Policy: Common Problems and Approaches, April 29-May 2, 2008, Carolina, Puerto Rico.

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Queensland, killed 15 people, and the 2003 Canberra bushfires destroyed 500 properties, killed 4 people and cost AUD\$300 million (M^cLeod 2003).

While much debate takes place in Australia about fire, particularly in regard to bushfire, very little of this is informed by an understanding of its true cost to the nation. In fact, to our knowledge, only one analysis of the total cost to the national economy has been undertaken (Ashe and others 2007) who estimated the total cost (2003 as the base year) to be AUD\$8,500 per annum.

This study firstly attempts to revise and update the earlier work of Ashe and others (2007) on the total cost of fire in Australia (using 2005 as the base year). In our view, defining the Australian system is a necessary first step to enlightening debate on all matters that may have an impact on the prevalence and severity of fires. While fires may stimulate the economy in some cases, and while the economic multiplier effect of recovery activities, such as rebuilding, may on occasions be significant, it is useful to focus on the costs alone. These are a measure of losses and expenditures that if all fires were prevented could be invested elsewhere in the economy. The total cost has been divided into three components: costs in anticipation of fire, cost of response to fire and the cost of consequences arising from fire.

Having a breakdown of the costs of fire is also an essential prerequisite before examining the cost effectiveness of alternative strategies of allocating resources to fire prevention. With this in mind, this paper also takes a first look at whether or not the current allocation in Australia is optimal. Due to complexity of the issues, the limited data available and absence of robust relationships between anticipation / response and consequences, a structured expert judgment approach was adopted to estimate the impacts of hypothetical changes (from the current system) in investment into anticipation and response.

System definition - Cost of Fire in Australia

The first task is to define the cost of fire in Australia. Before doing so we consider overseas studies undertaken with a similar view. We briefly review these now.

The UK Home Office report (Roy 1997) concluded that the cost of fire in 1993 to be over £4,500 million or around 0.9% of GDP in England and Wales. Weiner (2001) provided revised estimates and, for the first time, separated the average cost for different types of fires by location and cost type. The total cost of fire was estimated to be £6,900 million, with commercial fires accounting for over 40% of this sum.

In the USA, Hall (2004) explored the total cost of fire based on analysis of a reporting schedule that has been running for 10 years and which also underpinned a number of assumptions relating to the cost of fire made by Roy (1997) for the UK.

The cost of fire in the USA (NFPA 2002) was estimated at between US\$187,000 million and US\$251,000 million, or approximately 2% of GDP.

The most detailed study originates from Canada where Schaenman (1995) found the cost of fire to be around CAN\$11,600 million in 1991 (again about 2% of GDP). In Denmark, Moller (2001) determined that the socio-economic cost of fire was in the region of 1% of GDP.

The most recent study in its kind was undertaken in New Zealand (BERL 2005) with the objective of quantifying the scope, scale and incidence of economic costs relating to fire risk management. The total cost of fire was estimated to be about NZ\$1,000 million per annum, or about 0.79% of GDP. The largest costs were associated with fire protection measures in buildings; the cost of public fire emergency services; fire damage to property, and injury costs as a consequence of fire events.

Methodology

The impacts of fire are many and varied, and a wide range of methods could have been employed to categorize its component costs. This study adopts the same logic as research into the costs of crime in the UK (Brand 2000). Costs are broken down into three categories:

- Costs in anticipation – predominately costs incurred by protection and preventative measures undertaken by or for the benefit of potential victims of fire;
- Cost as a consequence – costs incurred as a result of fire and due to the exposure to fire of property, individuals, private firms and society; and
- Costs in response – those costs associated with extinguishing fire and clearing up afterwards, costs that are for the most part are borne by society.

In reporting on estimates for the various cost components, it is important to bear in mind that while based on the best available information, and where possible data, there are many ways where the costs could be refined. Because of the uncertainty and between season variation in the loss of dwellings due to bushfire, only average costs have been assumed here. In other cases, we have resorted to a first order extrapolation of comparable overseas figures after making appropriate adjustments for population differences, exchange rates and inflation.

The following sections describe costs of the three categories.

Cost in Anticipation

‘Cost in anticipation’ has been divided into seven components.

A1 Fire safety in buildings

Building regulations for fire safety help protect life but increase the cost of construction. The cost is divided into: (a) the cost of building regulations for new domestic and commercial buildings; and (b) the cost imposed upon existing buildings. The latter is often referred to as retrospective regulation and the practice of “retrofitting”.

This cost component also includes the purchase of equipment such as automatic fire detection and portable fire-fighting equipment, which may not be a requirement of fire safety legislation, as well as the cost of smoke alarms in domestic premises.

The cost of these measures can be uncovered either at the time of construction when they represent an identifiable proportion of the building cost, or as forming part of the rental value of buildings (Roy, 1997). Overseas research favours the first approach: Table 1 present estimates of the proportion of total construction costs that have been attributed to fire protection in a number of studies.

Table 1—*Protection as a percent of construction costs. (Hall 2004, NFPA 2002, Schaeman 1995, Roy 2004)*

Occupancy US	A	USA	Canada	UK	Ranges
Residential 2.	5	2.5	4.9	0-2.5	0-5.0
Industrial 9.	0	12.0	6.0	5.0	5.0-12.0
Commercial 9.	0	12.0	6.0	5.0	5.0-12.0
Institutional 4	.0	4.5	4.5	5.0	4.0-5.0
Other 3.	0	3.0	3.0	5.0	3.0-5.0

The table also presents cost ranges as implied by these four studies. These ranges may reflect a host of genuine cross-country differences such as building regulations, construction materials, and overall industrial composition; differences may also reflect variations in the estimation procedures adopted.

The only Australian study in this area was undertaken by the Warren Centre, University of Sydney. The Warren Centre (1989) found that the cost of fire protection in Australian buildings accounted for 3% of the total cost of a typical apartment block and 6% for a typical office building.

Australia Construction Handbook (Rawlinsons 2006) is the leading authority with respect to cost of construction components. Table 2 provides an estimate of the cost proportion of fire safety measures in Australian buildings. The definition of fire services in this table covers elements that detect and/or extinguish fires: sprinklers and other automatic extinguishing systems; automatic fire alarm installations; fire-fighting equipment; hydrant installations and hose reels. Exclusions include fire

doors and fire proofing and to account for this a further 1% has been added.

Table 2—*Percentage of fire services, fire doors and fire proofing in Australian buildings (Rawlinsons 2006)*

Building type	Fire services	Fire doors & proofing	Total
Administration 0.	7-3.5	1.0	1.7-4.5
Banks 0.	7-2.5	1.0	1.7-3.5
Educational 0.	4-0.7	1.0	1.4-1.7
Hospital/health 0.	5-2.5	1.0	1.5-3.5
Hotels/motels 0.	4-4.3	1.0	1.4-5.3
Industrial 0.	9-7.0	1.0	1.9-8.0
Offices 0.	8-8.6	1.0	1.8-9.6
Parking 0.	2-6.4	1.0	1.2-7.4
Recreational 0.	2-0.6	1.0	1.2-1.6
Religious 0.	2-1.0	1.0	1.2-2.0
Residential 0.	0-2.4	1.0	1.0-3.4
Retail 0.	5-6.9	1.0	1.5-7.9

The total annual value of new residential construction in Australia for 2005 was AUD\$38,000 million, with non-residential construction (commercial) estimated at AUD\$24,000 million (ABS 2005). From the data available, the cost of fire safety in residential buildings is assumed to be ~2% of the construction value of residential construction (the majority of new residential construction are houses), and 5% of commercial construction assuming a mid-point between the 1 to 9% range (Table 2).

The above relates to the cost of fire safety in new or renovated buildings. Retrospective fire safety changes to existing buildings are rare in Australia and are only likely after a major fire event. For this study an annual figure of AUD\$20 million is assumed.

Combining the cost of retrospective regulations and the cost of fire safety in new construction is estimated at AUD\$1,740 million for 2005.

A2 Fire safety measures in structures and infrastructure

This component covers tunnels, bridges, power stations, roads, rail, waterworks, oil and gas facilities etc. As one example, fire fighting flow requirements are often a major factor in sizing water mains and determining associating pumping needs. The cost of using larger pipe and pumps than would be needed just to provide drinking water and sanitation can be attributed to fire protection.

The Australian Bureau of Statistics valued engineering construction in Australia

in 2005 at AUD\$37,000 million (ABS 2005). In Canada, Schaenman (1995) estimated that the cost of fire safety in structures and infrastructure to range from 0.1% for roads, 10% for oil refineries to 20% for water systems. In the USA, Hall (2004) estimated the figure to be between 9 and 11% for similar structures. Given the absence of similar studies in Australia, a mid-range figure of 5% was adopted in this study. The cost of fire safety measures in structures and infrastructure is estimated at AUD\$1,850 million in 2005.

A3 Fire safety education and training

A variety of activities can be classed under fire safety education and training; for example, fire brigades undertake inspections of certain types of property to ensure enforcement of fire safety regulations and employees may be trained on fire safety as part of induction courses or health and safety training.

For the UK, Weiner (2001) estimated that the cost of fire education and training to be £40 million. It is assumed that the majority of this figure is accounted for in the fire service. We have assumed a nominal AUD\$20 million is used to cover fire safety education and training not undertaken by the fire service.

A4 Insurance administration

Insurance administration represents a loss to society resulting from fire and includes commissions paid by agents as well as the cost of setting up policies and investigating and administering claims. Payment of claims for fire losses are regarded as a wealth transfer between policy holders and are not included in the cost of fire to the nation.

Due to the lack of Australian data, this study considered the insurance administration costs estimated in the UK (Roy 1997) and adjusted these for Australia using population and exchange rates. This equates to a sum of AUD\$400 million. Converting equivalent Canadian results (Schaenman 1995), we obtain a figure of AUD\$250 million. For this study a mid-range figure of AUD\$325 million is assumed.

A5 Fire safety in consumer items

Every civilian aircraft, vehicle and train has fire safety designed into it and virtually all flammable liquids have to be stored in special containers. Heaters have cut-outs to prevent over-heating. Such examples of additional protection increase the costs of the item, a cost that is very difficult to quantify since many of the additions are multi-purpose: how much do circuit breakers, for example, exist to prevent fire and how

much to prevent electrocution?

In the absence of any data from Australia, we are compelled again to look overseas. Given that a high proportion of consumer goods are imported, these figures have relevance. The Canadian study (Schaenmann 1995) estimated the cost of fire safety in consumer to be CAN\$2,300 million, a figure which converts to approximately AUD\$1,700 million in Australia after adjusting for population and exchange rates. In the USA, Meade (1993) estimates that the cost of fire safety in consumer items can be as high as 20% of the total cost of fire, a figure that translates to approximately AUD\$1,500 million. Both the USA and Canadian studies imply remarkably similar figures for Australia and we adopt a conservative mid-point figure of AUD\$1,600 million.

A6 Fire research

While the aggregate cost of fire research is unavailable for Australia, two research programs provide a guide to this cost. The Fire Code Reform Centre was provided with AUD\$5 million over a 5 year period, and the Bushfire Cooperative Research Centre (2003) has funding of approximately AUD\$15 million per annum. Further work is carried out in Universities not funded through the Bushfire Cooperative Research Centre. Given this information, the average cost of fire research in Australia is taken here as AUD\$20 million per annum.

A7 Maintenance of fire safety equipment and measures

Most fire safety equipment requires ongoing maintenance to maintain its effectiveness. The most comprehensive coverage of this cost comes from Canada (Schaenmann 1995) where it was estimated that the cost of maintenance of fire safety measures equated to 8% of the cost of the annual built-in fire safety measures. Importantly, this estimate only covers new in-built systems and not previous generations of in-built systems. Using the 8% figure for Australia (cost component A1 and A2) suggest a cost of maintenance of AUD\$287 million per annum. As this figure does not account for the previous generations of in-built systems, we consider it to be low. Consider, for example, the adoption of the same amount of fire safety measures over a 5-year period. This would eventually require an annual maintenance bill of approximately AUD\$1,436 million.

Rawlinsons (2006) estimates that maintenance of fire safety systems cost 1% of the net lettable area per annum (a figure that includes sundry fees, repairs and maintenance). In 2005, the rental value of non-residential buildings in Australia has been estimated to be AUD\$200/m²/annum, which equates to a maintenance cost of

AUD\$2/m²/annum.

Assuming that Australia's requirements are similar to those in the USA, the information derived from the Commercial Building Energy Survey (Australian Building Codes Board 2006) can be used to estimate the total overall floor space requirements. It suggest that Australia's average floor space requirements for commercial purposes is 27.5m² per capita, giving a total of 500 million m² in 2005. This figure equates to a total national maintenance cost of AUD\$1,000 million. This figure does not account for the maintenance cost of the fire safety equipment and measures in structures and infrastructure.

Considering the two independent methods of estimating the cost of maintenance of fire safety equipment and measures for buildings, structures and infrastructure, the mid-point figure of AUD\$1,200 million is adopted.

Cost as a Consequence

'Cost as a consequence' has been divided into six components.

C1 Cost of injury due to fire

Nationally, there were 110 deaths in 2005 (Productivity Commission 2007). Exposure to smoke, fire and flames accounted for 86 deaths, followed by 21 fire deaths from intentional self-harm. Nationally, the three year average fire death rate was 6.4 per million people for the years 2002-2004. Nationally, the fire injury rate is 160 per million people for 2005, or approximately 3,300 fire injuries per annum.

It has been argued that it is impossible to place a value on casualties and its specification remains controversial (Slayter 2001). Nonetheless, such values are implicit in choices made every day: for example, a political decision on whether to fund a new hospital or to target fire prevention in domestic dwellings over say public buildings places an implicit value on casualties.

The emotional and physical suffering of victims is also a significant cost and difficult, but not impossible, to quantify. We may, for example, derive the cost of trauma to victims of incidents by consideration of the value society places on preventing this incident occurring.

Three studies have quantified the cost of injury due to fire in Australia. One at a national level (Moller 1998), one for New South Wales (Potter-Forbes 2003) and another relating the Western Australia (Hendrie 2005). All adopt a similar methodology that sums the direct resource costs of the injury, the indirect costs associated with loss of wages and loss to household productivity, and the reduction in the quality of life loss from injury morbidity and mortality. Table 3 summarises the results of each study.

Table 3—*Cost of injury due to fire – Australian studies*

Jurisdiction B	ase year	Total
National 19	96	AUD\$330 million
NSW 1	999	AUD\$75 million
WA 2	003	AUD\$38 million

After converting the NSW and WA estimates in Table 3 to equivalent national values for 2005 by adjusting for population and its growth by State, estimates range between AUD\$300 million and AUD\$430 million. This study assumes a mid-point figure of AUD\$370 million.

C2 Property losses

One of the most obvious costs of fire is the cost of repairing or replacing damaged property. For many people fire losses will be covered by insurance, but the insurance payments only represent a transfer of payment of insurance premiums from those who do not suffer losses to those who do. For this reason insurance payments are not included in the cost of fire. However, the destruction of the original property is a cost to society.

Building occupants may have to move out whilst damage is repaired, local authorities must remove burnt out cars and repair road surfaces. These are just a few of the possible costs of cleaning up. Clean-up costs are included in this cost component.

Every year the Australian Productivity Commission undertakes a 'Report on Government Services' (2007) in which it outlines that the median dollar losses and the total property loss from structure fires. Structure fires are those affecting housing and other buildings. Nationally, the total property losses to structure fires was AUD\$40 per person or approximately AUD\$824 million for Australia. It is assumed that this figure considers other fire losses from structures and infrastructure: however it does not include losses reported by rural fire services. As the majority of property in Australia is in areas covered by the urban fire services, the property losses have been increased by 20% to account for rural property losses to obtain an estimate of AUD\$990 million.

C3 Loss of business

Fire can result in significant business losses in terms of lost production, market share and customer goodwill. Even a minor fire at crucial stages of production may mean

very large losses for individual firms. In addition fire resulting in the closure of firms could have significant effects on staff. However, losses are rarely large for the country as a whole with lost output of one firm often resulting in a gain for another: a fire in a local supermarket means that customers will simply go to another. In this particular case, the only cost to society is the increased travel time to reach an alternative supermarket. In the same way, a company that gains business may employ more staff to meet the increased demand and so the effect on net employment may be muted. The only loss to the country from fire is in the case where output is lost and not compensated by increases in production by other firms. Foreign competitors may have to pick up the shortfall, or where the goods are unique, society will have to go without until the fire-damaged premises are back in business or substitute products are found.

Information on the losses of business due to fire in Australia is hard to find. Due to the lack of information, this study adopted an estimate from the UK of £40 million (Roy 1997), a figure that translates to approximately AUD\$50 million for Australia.

C4 Environmental costs

Environmental costs are caused by polluting the atmosphere with the products of combustion, or ground water with the run-off of chemicals from a fire, often from water sprayed on the fire.

Fires, including bushfires, produce fine particulates leading to atmospheric haze. These particles can exacerbate respiratory and cardiovascular illnesses, such as bronchitis, pneumonia and asthma, leading to increased hospital admissions and emergency room visits. Particulate matter has also been linked to deaths. A study undertaken in 2003 by the NSW Department of Environment and Conservation (2005) estimated an annual mid-point health cost of AUD\$893 per capita related to air pollution in the Greater Sydney Metropolitan Region. For this study, it is assumed that the products of combustion from fires impact 20% of the Australian population every year, and that accidental fire contributes 10% of the fire particulates in the atmosphere. This results in an estimate of AUD\$195 million for 2005. Other environmental costs, such as run-off and chemical pollution are assumed to be incorporated into this sum.

C5 Heritage and cultural costs

Fire can destroy or damage property with unique cultural or heritage value. It is difficult to replace or repair these pieces, and their loss has a greater value to society than the simple replacement cost: a recent example was the loss of the historic Mount

Stromlo Observatory in the 2003 Canberra fires (The Age 2003).

Information on the annual heritage and cultural costs in Australia due to fire is unknown. In the UK, the October 1992 Windsor Castle fire is an example of a heritage and cultural loss. It took 5 years and £37 million (AUD\$100 million) to renovate (Royal Windsor 2005). Rebuilding the 1942 Mount Stromlo Observatory after the 2003 Canberra bushfires has been estimated cost at AUD\$50 million (The Age 2003). For this study we have used an annual figure of AUD\$100 million, assuming two Stromlo type events every year.

C6 Wider economic distortions

Fire and arson, in particular, may affect local communities. Large numbers of burnt-out cars and buildings can discourage new business and residents. There exists little information on this cost for Australia: here we assume a nominal figure of AUD\$100 million.

Cost in Response

‘Cost in response’ has been divided into four components.

R1 Fire service response costs

Fire services perform a variety of duties, some of which are legislative requirements. These include:

- Responding to emergency calls, including special service incidents and false alarms;
- Carrying out regulatory inspections, and
- Providing community fire safety advice and education.

Special service incidents (such as the response to a flood emergency) have not been deemed a cost of fire. In contrast, the cost of false alarms is an explicit cost of fire, as in the absence of fire there would be no false alarms. A significant proportion of all calls for assistance are found, upon investigation, to be false alarms. However, fire service organizations are required by legislation to respond to all calls, and an incident cannot be deemed to be a false report until the fire service organization has responded and investigated the incident.

Fire service organizations are the primary agencies providing emergency management service for fire events. A range of other agencies may also be involved including ambulance and police services. Nationally, 16,920 full-time equivalent paid personnel were involved in the delivery of fire services in 2005-06 (Productivity

Commission 2007) and 537 fire incidents per 100,000 people were attended (Productivity Commission 2007), with numbers generally declining over the period since 2002-03. Although structure fires are relatively uncommon in comparison with landscape (bush and rangeland) fires, for example, they impose a significant threat.

The total cost of funding fire services in Australia according to the 'Report on Government Services' (2007) was AUD\$1,900 million in 2005 (excluding funding for land management agencies). Since fire services in Australia also undertake tasks not related to fire and we need to account for this. Fire statistics for the New South Wales fire brigade (2003), suggests that 70% of the fire services efforts are directly related to fire safety. This results in an estimate of AUD\$1,330 million for this component cost.

R2 Volunteer fire service

Many thousands of Australian's give their time to the volunteer fire services, particularly rural and bushfire brigades. This is a huge contribution and a significant opportunity cost to the national economy.

The Council of Australian Governments (COAG) Inquiry into bushfires (2004) investigated the impact of the volunteer fire service. In 2005, 222,000 fire volunteers contributed millions of hours assisting the Australian community. The unpaid contribution of these volunteers is large: estimates from Victoria put the annual contribution of voluntary fire services at AUD\$460 million for 58,000 volunteers (Hourigan 2001). Extrapolating this figure nationally, the annual contribution approaches AUD\$2,000 million.

R3 Private fire brigade response

Only relatively large or remote organizations have their own fire brigades. Examples include oil, gas and mining operations. The majority of their personnel are drawn from within the organization and only a small part of their time is attributable to fire protection.

Information on this cost item is limited. For this study, the cost of providing private fire brigades in Australia is put at a notional AUD\$100 million per annum, to mainly account for significant mining operations in remote regions of Australia.

R4 Criminal justice costs

Many fires result in some police effort to control traffic and crowds. Police also investigate fires, particularly arson fires. Crime laboratories detect accelerants and perform investigation services. Coronial inquiries investigate major fires and demand significant resources: NSW, for example, has had at least seven bushfire inquiries

since 1994.

In the absence of explicit information on this cost component, we adopt an aggregate figure of AUD\$50 million per annum.

System definition – Total Cost of Fire Australia 2005

Table 4 summarizes the estimates of the cost components identified above to establish a national cost of fire.

Table 4—*Summary of cost components*

Cost component	Total cost (\$ million)	% of total
Fire safety in buildings	1,740	14
Fire safety measures in structures / infrastructure	1,850	15
Fire safety education and training	20	<1
Insurance administration	325	3
Fire safety in consumer items	1,600	13
Fire research	20	<1
Maintenance of fire safety equipment and measures	1,200	10
Cost in anticipation	6,735	56
Cost of injury due to fire	370	3
Property losses	990	8
Loss of business	50	<1
Environmental costs	195	2
Heritage and cultural costs	100	<1
Wider economic distortions	50	<1
Cost as a consequences	1,755	15
Fire service response costs	1,330	11
Volunteer fire service	2,000	17
Private fire brigade responses	100	<1
Criminal justice costs	50	<1
Cost in response	3,480	29
Total cost of fire in Australia 2005	11,990	100

The total cost of fire equates to 1.3% of Australia's GDP. To put the cost of fire in context, it is useful to compare it with other cost components in the Australian economy. The most recent OECD statistical profile of Australia 2005 (2005) states that Australia invests 1.5% of GDP on research and development and 6% on education. Clearly then, the cost of fire to Australia is significant.

System optimization

Now that the system has been defined, the next task is to consider whether the allocation of funds in Australia is optimal. Given that the current system invests 85% of AUD\$12,000 million to manage consequences that equate to 15%, it is natural to pose the question as to whether the current investment is optimal. A priori we expect that if the investment in anticipation and response were reduced, consequences would increase; but by how much? And are there a better ways of prioritizing the investment?

In order to evaluate whether the current system is optimal, it would be necessary to derive relationships between anticipation, response and consequences, and the interactions between the various cost components. This is a challenging task as these relationships are complex and not necessarily understood. As a first step, we conducted a simple expert elicitation. We discuss this approach now.

Structured Expert Judgement

Expert judgement elicitation is a method of data collection that is used when traditional research techniques are unfeasible or inappropriate (Otway 1992). Judgements are inferences or evaluations that go beyond obvious statements of fact, data, or the conventions of a discipline. Expert judgement has always played a significant in science and engineering; increasingly, it is recognized as just another type of scientific data, and methods have been developed for treating it as such. Like any scientific measurement, the acquisition, use and validation of expert judgement data must proceed in a traceable way according to rigorous methodological rules.

Elicitation process

In order to evaluate the viability of structured expert judgement for this particular research, a pilot exercise was undertaken. Twenty experts were identified from relevant professional and industry sectors. Ten responded to the initial request. Evaluation of the pilot exercise confirmed that use of structured expert judgement may assist in system optimization.

A further forty experts were invited to participate in the exercise, and an additional sixteen responses were received, giving a total of twenty six responses. All respondents were promised anonymity. Experts came from various backgrounds, including fire services, fire protection and fire engineering professions, facility managers, science and the insurance sectors.

Each expert was asked to estimate the impact of increasing and decreasing investment of anticipation and response on the consequences from fire. In addition to the mode, the experts were also requested to provide minimum and maximum estimates. Figure 1 is the table provided to the experts using anticipation as the

variable. A similar table was provided using response as the variable.

Figure 1— *Table provided to experts (2003 costs)*

Anticipation as the variable parameter					
Response Anticipation	Anticipation		Consequences*		
(\$ billion)	(\$ billion)	% of current	Minimum	Mode	Maximum
			(lower bound)		(upper bound)
2.5	0.5	11%			
2.5	1.5	33%			
2.5	2.5	56%			
2.5	3.5	78%			
2.5	4.5	100%	100	100	100
2.5	5.5	122%			
2.5	6.5	144%			
2.5	7.5	167%			
2.5	8.5	189%			

* 100 refers to the current system and allocation of funding

In addition, each expert was asked the following questions to evaluate his or her level of knowledge in the relevant area:

Table 5— *Questions used to evaluate the expertise of the expert*

Question
1. What is the proportion of reported fatalities that occur in residential buildings (houses, apartments etc.)?
2. What is the proportion of reported fire fatalities caused by self-harm / deliberate actions?
3. Estimate the proportion of reported fires that self-control prior to the arrival of the fire service?
4. Estimate the proportion of reported fires that result in approximately 50% of fire consequences (financial consequences)?
5. In terms of the total cost of fire, what proportion is taken up by anticipation / response / consequences?
6. Estimate the % (of construction costs) that relates to the mandatory fire safety requirements (anticipation) for offices?
7. What is considered to be the bushfire intensity at which suppression (via ground based fire service) is likely to fail?

The experts were provided with four possible answers to each question (one which was the correct answer). Each answer was scored on the proximity to the correct answer.

Only one expert obtained a score less than 50%, thirteen experts scored between 50% and 75% and twelve experts greater than 75%.

Results

As expected, all experts predicted an increase in consequences if the investment in anticipation and / or response were reduced. Also, if investment in anticipation and/or response is increased consequences will decrease.

In order to evaluate whether there is an economic benefit accompanying an increase or decrease in investment, we introduce the concept of *net benefit*. The following example explains the concept. If the investment in response were to increase by \$100 million and consequences were to reduce by \$150 million, we infer a net benefit of \$50 million. Likewise if the experts expected consequences to reduce by \$20 million, a net loss of \$80 million would result. The same logic is also applied to a decrease in investment.

Figure 2 and 3 illustrates the estimate (mode) from all experts together with the zero net benefit for a given level of investment (illustrated with the heavy line). This is the point at which an economist would be indifferent to the change in investment.

All experts agreed that there is no net benefit to be obtained from increasing investments in anticipation of or response to fire (Figures 2 and 3). In other words, these experts believe the current system to be saturated. All but one agree that there would be a net benefit to decreasing investment. However, if investment in anticipation were to be significantly decreased (<AUD\$4 billion) four respondents predicted a net loss. This would represent a 40% decrease in the investment in anticipation and we were surprised to find only four respondents predicting this outcome.

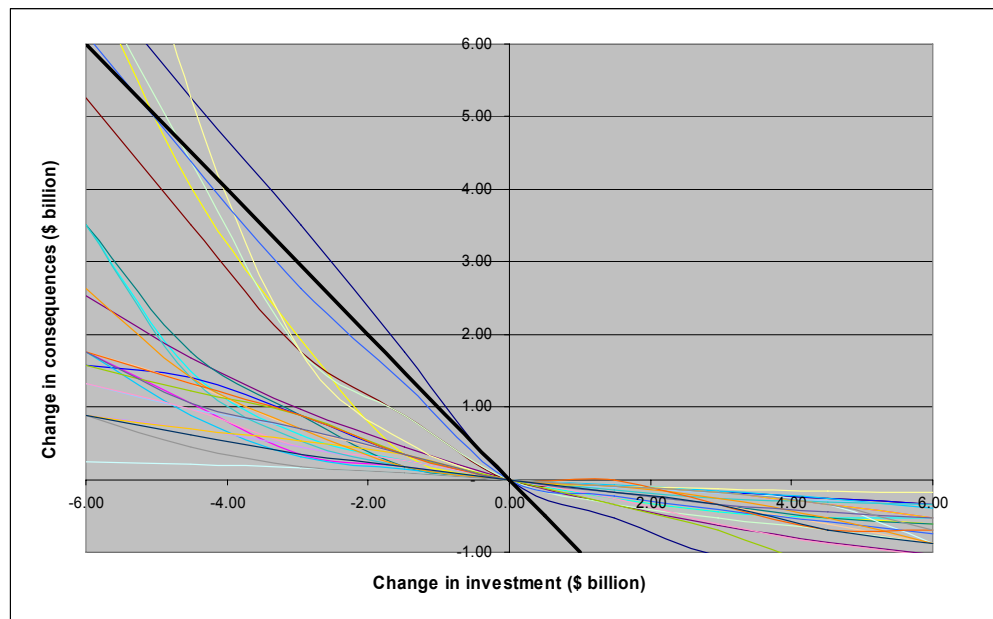


Figure 2— Expert judgements of outcomes associated with changes in investment in to the anticipation of fire. The position of zero net benefit is the 1-1 line shown in heavy black.

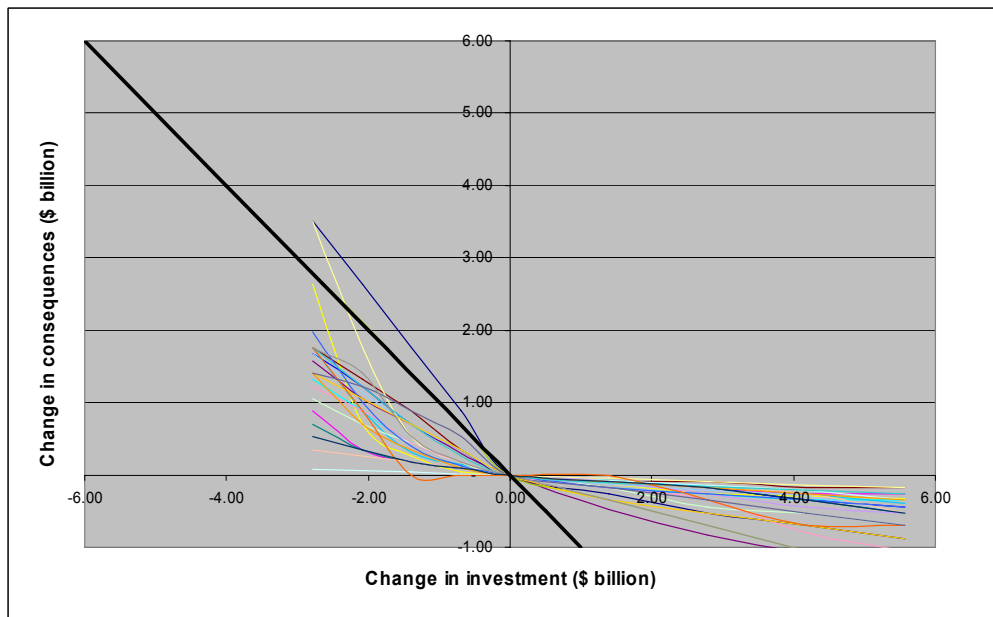


Figure 3— Expert judgements of outcomes associated with changes in investment in the response to fire. The position of zero net benefit is the 1-1 line shown in heavy black.

The average results in Figure 4 suggest a net loss to the system will result if an increase in investment and a net benefit if investment is decreased.

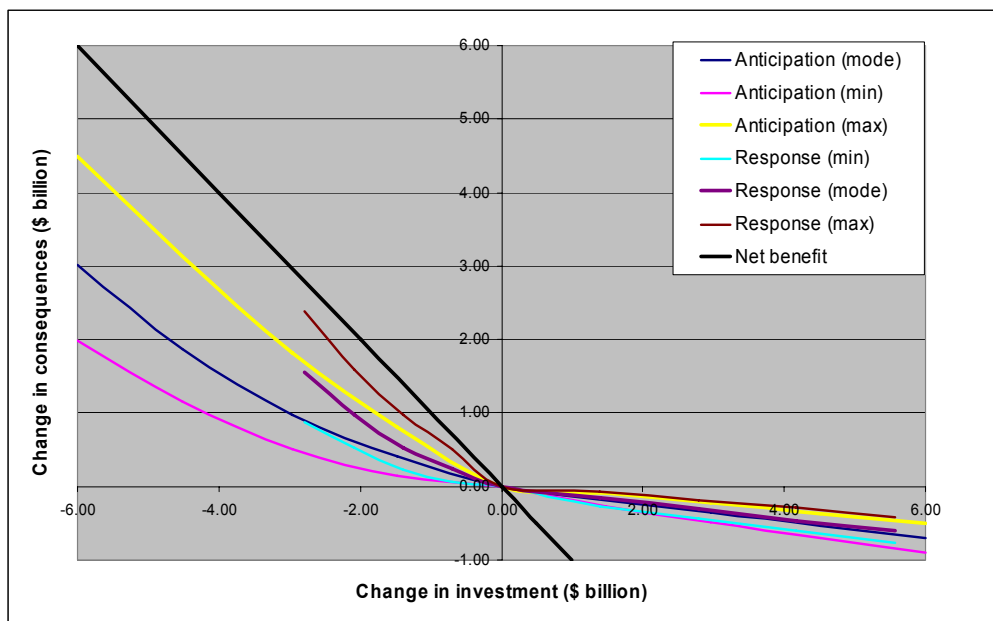


Figure 4—Average minimum, mode and maximum opinions provided by experts

The implications of Figure 4 assuming that the respondents, all fire professional in one way or another, have successfully captured the sensitivity of the system to

changes in funding are as follows. Assuming the modal anticipation and a total cost of the current system of AUD\$12,000 million, then if investment in anticipation were to increase by AUD\$ 4,000 million, for example, consequences are anticipated to only decrease by AUD\$500 million giving a net loss of AUD\$3,500 million. On the other hand, if the investment in anticipation were to decrease by AUD\$4,000 billion, consequences are anticipated to increase by AUD\$2,000 million; the total cost then decreases to approximately AUD\$10,000 million giving a net gain of AUD\$2,000 million. Of course, the decreased investment is predicted to result in increased (negative) consequences, however, from a strictly economic perspective, the reduced investment out-weighs the increase in consequences by approximately AUD \$2,000 million.

The results of the exercise were also assessed in relation to the strength of the experts' response to the evaluation questions. Although the general conclusion did not alter, it was evident that an expert's score increased (the more knowledgeable the expert), the relationship moved closer towards the position of cost-benefit neutrality, i.e. no net benefits.

Conclusions

We have defined the system and quantified the cost of fire in Australia. Our estimate is that the total cost of fire to Australia is approximately AUD\$12,000 million or 1.3% of Australia's Gross Domestic Product. The results also show that Australia is investing approximately AUD\$10,200 million (or 85% of the total cost of fire) to manage a loss of approximately AUD\$1,755 million (or 15% of the total cost of fire), a result that raises questions as to the most effective and efficient investment of approximately AUD\$580 for every Australia. Structured expert judgement has been used as a first step to investigate whether the current system is optimally positioned in terms of investment. None of the experts who responded believed a increase in investments in anticipation or response would be cost effective. Moreover, most suggested that decreases of investment in anticipation and /or response although delivering a net benefit to Australia would be accompanied by an increase in consequences.

Acknowledgments

We thank the experts who responded to our request.

References

- Ashe, B.S.W, McAneney, K.J., Pitman, A.J. 2007. **The Cost of Fire in Australia**. Cost of Fire conference, Conferenceworld, 29 May 2007, Sydney, Australia.
- Australian Building Codes Board. 2006. **Regulation Impact Statement – BCA Energy Efficiency requirements for Class 5-9 buildings**. RIS 2006-2, Canberra, Australia.
- Australian Bureau of Statistics. 2005. **Year Book Australia**. Canberra, Australia.
- Australian Bureau of Statistics. 1995. **ABS Year Book Australia, (1301.0)**. ABS, Canberra, Australia.
- Blong, R. 2004. **Residential building damage and natural perils: Australian examples and issues**. Building Research and Information 32(5):379-390.
- Brand, S., Price, R. 2000. **The economics and social costs of crime**. Home Office Research Study No. 217, London Home office.
- Building Regulation Review Task Force. 1991. **Microeconomic Reform: Fire regulation**. National Building Fire Safety Systems Project of the Building Regulation Review Task Force, May 1991.
- Bureau of Meteorology. 1984. **Report on the meteorological aspects of the Ash Wednesday fires**. 16 February 1983. Australian Government Public Service. Canberra. 143pp.
- Bushfire Cooperative Research Centre. 2003. **The Bushfire CRC Officially Launched**. Media Release, 9 December 2003.
- Business and Economic Research Limited. 2005. **The cost of managing the risk of fire in New Zealand**. BERL ref#4278, May 2005.
- Council of Australian Governments. 2004. **National Inquiry on Bushfire Mitigation and Management**. 31 March 2004, Commonwealth of Australia.
- Department of Environment and Conservation, NSW. 2005. **Air Pollution Economics – Health Costs of Air Pollution in the Greater Sydney Metropolitan Region**. ISBN 1-74137-736-6, November 2005.
- Hall, J.R. Jr. 2004. **The total cost of fire in the United States**. National Fire Protection Association, Quincy, MA, USA.
- Hendrie, D. 2005. **The Cost of Injury in Western Australia during 2003: An overview of Total and Health System Costs**. ISBN 0-9756937-6-x, Perth, Western Australia, Western Australia, Government.
- Hourigan, M. 2001. **The value of the volunteer contribution**. Consultants report to the Victorian Country Fire Authority – cited in the CFA submissions to the Economic Development Committee of the Parliament of Victoria.
- McAneney, K.J. 2005. **Australian bushfire: Quantifying and pricing the risk**. In Proc. Of Workshop on Planning for Natural Hazards – how can we mitigate the impacts?. Wollongong University, 2-5 February, 2005.
- McLeod, R. 2003. **The inquiry into the Operational Response to the January 2003 Bushfires**. http://www.cmd.act.gov.au/mcleod_inquiry/report.htm.
- Meade, W. 1993. **A first pass at computing the cost of fire in modern society**. The Herndon Group, March 1993; prepared for Center for Fire Research, National Institute of Standards and Technology, Gaithersburg, Maryland.
- Moller, J. 1998. **Estimated cost of injury by fire, flame and burns, Australia 1995-96**. National Injury Surveillance Unit, Flinders University of South Australia, <http://www.nisu.flinders.edu.au/pubs/injcost.burns.html/>.

- Moller, K. 2001. **The socio-economic costs of fire in Denmark**. Danish Emergency Management Agency, Birkerød, Denmark. ISBN 87-89121-90-2.
- National Fire Protection Association. 2002. **The high cost of fire in the United States**. NFPA Journal, May/June 2002, pp. 28.
- New South Wales Fire Brigade. 2003. **NSWFB Annual Statistical Report 2001/02 – Table 2 Total responses and primary incidents by region, region and station**. State Government of New South Wales, 2003.
- Otway, H, von Winterfeldt, D. 1992. **Expert Judgment in Risk Analysis and Management: Process, Context, and Pitfalls**. Risk Analysis, Vol. 12, No. 1, 1992.
- Organisation of Economic Co-operation and Development. 2005. **OECD statistical profile of Australia – 2005**.
- Potter-Forbes, M., Aisbett, C. 2003. **Injury costs: A valuation of the burden of injury in New South Wales 1998-1999**. NSW Injury Risk Management Centre, UNSW, ISBN 0-9580633-1-1.
- Productivity Commission. 2004. **Reform of Building Regulation – Research Study**. December 2004, Canberra, Australia.
- Productivity Commission. 2007. **Report on Government Services 2005**, Canberra, Australia.
- Rawlinsons. 2006. **Australian Construction Handbook 2006**. Edition 24, Rawlinson Publishing Pty. Ltd, Perth, Western Australia, ISSN 0810-8064.
- Roy, D. 1997. **The cost of fires – A review of the information available**. Home Office Publications Unit, London. ISBN 1 85893 932 1.
- Royal Windsor.com. 2005. **The definitive Winds or castle guide**. <http://www.royal-windsor.com/winsorcastle.htm>.
- Schaenman, P., Stren, J., Bush, R. 1995. **Total Cost of Fire in Canada: An Initial Estimate**. National Research Council of Canada, February '95, ISBN 0-660-15949-X.
- Slayter, T. 2001. **Economic Costs of Natural Disasters in Australia**. Bureau of Transport Economics, Report 103, ISBN 0-642-45633-xs, Commonwealth of Australia.
- The Age. 2003. **Mount Stromlo to rise from the ashes**. 1 February 2003.
- The Age. 2002. **Coroner blames Ess for Longford disaster**. 15 November 2002, <http://www.theage.com.au/articles.2002/11/15/1037080898920.html?oneclick=true>.
- The Warren Centre for Advanced Engineering. 1989. **Fire Safety Engineering**. The University of Sydney, December 1989, ISBN 0-86758-403-3.
- Weiner, M. 2001. **The economic costs of fire**. Home Office Research Study 229, Home Office Research, Development and Statistics Directorate, Department of Transport, Local Government and the Regions, London.

Health and Economic Impact of Wildfires: Literature Review and Impact Assessment¹

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Abstract

This review study synthesizes available literature in epidemiology, economics and wildfire-related studies to provide essential information for the valuation of health costs associated with wildfire events. We review three areas within these literatures: key health outcomes to be evaluated, association between wildfire smoke and health outcomes, and valuation of health effects. We find that the key health outcomes are mortality, restricted activity days (including work days lost), hospital admissions, respiratory symptoms, and self-treatment. Our review shows somewhat inconsistent results between the conventional and wildfire-related PM epidemiology studies. We summarize the recent estimates of per unit cost of mortality and morbidity and present recommendations for evaluators.

Keywords: Wildfire, health impact, health valuation, epidemiology studies, particulate matters.

Introduction

The potential health risk from diminished air quality during wildfire events is a serious social concern. Many studies document that wildfires produce various air pollutants and often report that the ambient concentration of particulate matters (PM) increases substantially during a wildfire period. Epidemiology studies report significant morbidity and mortality impacts of PM, suggesting a potential for considerable health risks from wildfires. Evaluating the social cost associated with the health damage due to wildfire events is critical to determine the optimal wildfire management policy. Assessing this economic cost consists of multiple steps. First, the change in the air quality level due to the wildfire event must be evaluated. Second, the relationship between changes in air quality and the health impacts in

¹ An abbreviated version of this paper was presented at the Third International Symposium on Fire Economics, Planning, and Policy: Common Problems and Approaches, April 29 – May 2, 2008; Carolina, Puerto Rico.

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wildfire-smoke affected communities must be established to estimate the total change in morbidity and/or mortality due to wildfires. Third, the estimated change in morbidity and/or mortality must be measured in monetary terms. Each aspect of the economic analysis requires specific procedures and data.

This review study synthesizes available literature in epidemiology, economics and wildfire-related studies to provide essential information for the valuation of health costs associated with wildfire events. We focus on three issues: the health outcomes to be evaluated, whether epidemiology studies of urban air pollution are applicable to evaluate wildfire smoke health damages, and recent findings from health valuation literature. We constrain our epidemiology literature review to the major pollutant of wildfires, PM.

Health outcome coverage

The U.S. Environmental Protection Agency (U.S.EPA) lists the wide range of potential health outcomes from PM exposures (U.S.EPA 1999).⁶ While wildfires may result in wide range of health outcomes, there are limited studies that examine the distribution of health outcomes resulting from wildfire events. Anaman (2001) surveyed a community in the southeastern Asian country of Brunei affected by a large wildfire that occurred in Indonesia during 1997 and 1998 (hereafter we call this event 1997 Southeast Asian Haze). Based on 102 randomly selected households, the author finds that 2 percent of the households experienced hospitalization of a household member, and 22.5 percent experienced outpatient care of a household member due to the haze. Six percent of the sample reported some kind of self-treatment and 57 percent reported that a household member took leave of absence from school or work. To our knowledge, there has not been such survey of general population in the U.S. following a wildfire.

Table 1 summarizes previous studies that evaluated the economic cost of wildfires. All tables in this paper are available at www.fs.fed.us/rm/value/puertoricowildfire.html. None of these studies cover all health outcomes listed in the 1999 U.S.EPA report, but rather select the health outcomes based on the available information. The cost estimate of health effects due to smoke from wildfire events ranges from \$0.26 million to \$1,201 million⁷ depending on the scale of the fire, and health outcomes considered.

⁶ Potential health impact of PM exposure listed in U.S.EPA (1999) include: mortality, bronchitis (chronic and acute), new asthma cases, cardiorespiratory-related hospital admission, emergency room visits, lower and upper respiratory illness, respiratory symptoms, minor restricted activity days, restricted activity days, work lost days, moderate or worse asthma status, neonatal mortality, changes in pulmonary function, chronic respiratory diseases, morphological changes, altered host defense mechanisms, and cancers.

⁷ All monetary values in this paper are converted to 2007 US\$ value using the consumer price index.

The studies summarized in *table 1* identify that there are several key health outcomes. The first important health outcome is mortality. Rittsma and others (2005) estimate that a short, moderate scale forest fire in Canada contributed to 2.6 additional mortality cases at a cost of \$11 million. This mortality cost accounts for more than 90 percent of total health-related costs associated with that particular forest fire. Since other economic studies listed in *table 1* do not include the mortality cost, they may underestimate the health cost substantially.

Work days lost, restricted activity days and minor restricted activity days contribute substantially to total morbidity-related costs, and account for 36 to 74 percent of the total cost. Hospital admissions, respiratory symptoms and self-treatment are other major health costs. If every possible health outcome associated with a wildfire cannot be measured, at least mortality and these major morbidity effects should be evaluated.

Epidemiology studies: urban air pollution vs. wildfire smoke

There are a considerable number of PM-related health studies. However, most studies evaluate the health impact of persistent low to moderate levels of PM emitted from urban air pollution sources, such as fossil fuel burning (hereafter we call these PM studies conventional PM studies). Wildfires often cause short, but high levels of PM due to the vegetation burning. Whether there are different health risks from PM exposure due to urban air pollution versus wildfires is an important research question. If there is no difference, we can simply use previously estimated dose-response functions from conventional PM studies to estimate the level of health damages from wildfires.

To examine this issue, we will compare the study results from conventional PM studies and wildfire health studies in the next sections. Since conventional PM literature is substantial, we rely mainly on the U.S.EPA's extensive PM literature review (U.S.EPA 2004) as well as Pope and Dockery (2006), as references for the conventionally considered health impact of PM for mortality, hospital admissions and emergency department (ED) visits.

Conventional PM studies

Table 2 summarizes the selected study results of health effect of a short-term exposure to PM₁₀⁸ in the U.S.EPA (2004) and Pope and Dockery (2006). Conventional PM studies generally find a statistically significant impact of mortality, cardiorespiratory-related hospital admission, and asthma related ED visits from a

⁸ PM₁₀ is the particles less than 10 micrometers in diameter.

short-time exposure to PM₁₀, although the estimated impact is fairly small. The health impact is age-specific, and also illness specific. Generally, the impact of PM₁₀ exposure on respiratory-related illnesses is higher than on cardiovascular-related illnesses. Within respiratory-related hospital admissions, asthma and pneumonia show a higher risk than chronic obstructive pulmonary disease (COPD) from the PM exposures. The excess risk for asthma-related ED admission is also significant as PM₁₀ levels increase.

There are limited studies that examine the relationship between restricted activity days and the PM level. Ostro and Rothschild (1989) use the National Health Interview Survey data, a continuous survey of the health status of the U.S. population collected by the National Center for Health Statistics. They find that a 1 µg/m³ increase of fine particulate matter results in a 1.58 percent increase in restricted activity days (RRAD),⁹ and a 0.82 percent increase in minor restricted activity days (MRAD)¹⁰ among an 18 to 65 year old sample.

Wildfire health impact studies

Tables 3, 4 and 5 present the epidemiology studies that examine the association between wildfire events and mortality, hospital admission and ED visits, respectively. We only include studies that examine the statistical significance of the results.¹¹ In the tables, studies are listed by the estimation method and the order of the maximum PM level recorded during the wildfire event (from the lowest to the highest). While conventional PM studies reviewed in this paper use the daily time-series analysis method, wildfire health impact studies use the time-series analysis as well as the historical control method. The historical control method compares the total or average level of health effect during the event period to a similar duration of the control periods.

While conventional PM studies find a statistically significant positive mortality and morbidity impact from a short-time exposure to PM, not all wildfire health impact studies find statistically significant health impacts. Among mortality impact studies (table 3), only two of six studies find a significant mortality increase of the

⁹ RRAD is defined as “any day on which a respondent was forced to alter his or her normal activity and an acute respiratory condition was reported. It includes days of work lost or bed disability as well as more minor restriction” (p 239)

¹⁰ MRAD is defined as “a restricted activity day that does not result in either work loss or bed disability and therefore involves more minor conditions and reductions in activity.” (p 239).

¹¹ Naeher and others (2007) also provide comprehensive review of epidemiology studies of vegetation fires as well as controlled laboratory studies of wood smoke, health effect of residential wood burning, toxicology, chemical and physical nature of wood smoke. Our study expands their epidemiology literature review of mortality, hospital admission and ED visits by adding studies that are not included as well as by adding the analytical structure.

mortality level during a wildfire event.¹² As for hospital admissions studies (*table 4*), while all studies that considered respiratory-related effect find a significant impact, only two out of six studies that considered asthma-related effects find a significant increase attributable to a wildfire event. One of the two studies that considered cardiovascular effects finds a significant increase of hospital admissions during wildfire events. Among ED visit studies (*table 5*), seven out of the thirteen studies that considered asthma-related effects, nine out of the thirteen studies that considered respiratory related effects, and none of the three studies that considered cardiovascular effects find a significant increase in ED visits during wildfire events.

Since many wildfire healths impact studies use different units to present the health impact of wildfire smoke exposures, their results are not generally comparable with the PM health impacts reported in the U.S.EPA (2004). We will briefly discuss the studies that show comparable results.

Sastry (2002) studies the mortality impact of the 1997 Southeast Asian Haze on the Malaysian population using the daily time series model. The author finds a significantly positive association between PM and mortality levels among the elderly. The magnitude of the mortality effect is compatible with conventional PM studies. However, the mortality impact is found to be significant only after very high pollution days (daily PM = 200ug/m³). Including days with lower levels of PM substantially weaken the results. This is in contrast to the fact that conventional PM studies find a significant mortality impact even at lower levels of PM.

In general, we have very limited evidence of mortality impacts associated with wildfire events. Kunji and others (2002) also report a weaker mortality impact from the wildfire smoke than the urban air pollution. Kunji and others observe 527 deaths during the 1997 Southeast Asian Haze episode in haze-affected areas in Indonesia while the conventional PM studies employed in the World Health Organization guideline predicted 15,000 deaths.

Johnston and others (2002) and Chen and others (2006) study the effect of prolonged bushfire events on ED visits and hospital admissions in Australia, respectively. Both studies find a higher health impact during the bush fire periods as compared to results from conventional PM studies. However, Chen and others (2006) also find a relatively high PM risk level during a non-bushfire period, which indicates the potentially higher PM health impact in Australia as compared to the U.S. Cançado and others (2006) study the effect of a sugar cane burning event on hospital admissions and find a significant impact among children and the elderly. Chen and others (2006) and Cançado and others (2006) also find a higher health risk during fire

¹² If author(s) uses different analysis methods, multiple study locations or different samples (except different age group categories) within one study, we count each estimation result as if they come from separate studies.

periods than non-fire periods.

Hospital admission and ED visit based studies provide mixed evidence of the health risk from wildfire smoke. Several studies do not find a significant health impact, while some studies suggest a more hazardous nature of wildfire smoke. Lastly, Sastry (2002) and Johnston and others (2002) find a non-linear health impact of wildfire oriented PM exposures, where significant health impacts are found only when PM levels exceed certain levels.

Difference between conventional and wildfire PM studies

Vedal and Dutton (2006) and several researchers discuss the potential reasons for inconsistencies between conventional PM studies and wildfire health impact studies. Following five explanations may be particular importance: 1) choice of statistical models, 2) chemical composition, 3) non-linearity of PM dose-response function, 4) averting behavior, and 5) perception about health risk. We briefly discuss each explanation.

The first explanation for the inconsistent results between conventional PM studies and wildfire studies is the use of different statistical methods. The conventional PM studies often use daily time-series models with a long observation period. A large sample size likely enables researchers to detect a small health impact from a short-term PM exposure.¹³ The historical control method, often employed in wildfire health impact studies, compares a total or average health outcome level between the study and control periods. When health outcomes show a small variation over time, it would be difficult to detect a small health impact from this method. In fact, none of the historical control studies that evaluate the impact of mortality and asthma-related hospital admission finds significant results, potentially because of the lack of statistical power.

Even with time series models, conducting a wildfire related health impact study is challenging. Wildfire events are generally short, and it is difficult to study a separate health impact of wildfire events using the daily time-series model due to the small number of observations of interest. The studies that find a significant increase in mortality and hospital admissions during wildfire periods tend to use long observation periods (Sastry uses 13 to 33, and Chen and others use 452 smoke affected days).

The second explanation is that there exists a different chemical composition between urban air pollution and wildfire smoke. Vedal and Dutton (2006) argue that the fossil fuel combustion usually contains toxic particles such as metal, and may be more hazardous than vegetation burning. However, Mar and others (2000) did not

¹³ See also Vedal and Dutton (2006) for the discussion of potential bias in conventional time series PM models.

find significantly different health impacts of PM from fossil fuel and vegetation burning. The difference they find is that the burning vegetation shows a longer lagged mortality effect.¹⁴

The third issue is the potential non-linearity of the PM dose-response function. Wildfires cause a relatively short, but high level of PM, while urban air pollution causes persistent low to moderate levels of PM. The U.S.EPA (2004) concludes that the PM dose-response function is linear at low to moderate levels. However, the functional form is still uncertain at high PM exposure levels. As several wildfire health impact studies indicate, it is possible that we have a non-linear PM dose-response function at high levels of PM exposure. If this is the case, applying the dose-response function obtained from low-to-moderate level PM exposures to estimate the health impact of high levels of PM exposures would substantially bias the results.

The fourth issue is the potential different averting behaviors among residents in smoke affected areas during wildfire events. Studies find individuals, particularly those who are sensitive to air pollution, take averting measures when the air pollution level is high (Bresnahan and others 1997, Künzli and others 2007). Since large wildfire events are highly publicized by mass media and/or local officials, and smoke is highly visible, individuals may take more measures to avoid air pollution exposures than usual. If individuals take more averting actions during wildfire events than non-wildfire events, the actual PM exposure level is lower, and results in less health impacts at a given level of outdoor PM.¹⁵

The fifth reason is a potentially different perception of health risk towards urban air pollution versus wildfire events. Lipsett and others (1994) find that about four times as many people without physical evidence of illness visited an ED during a large urban fire event than usual. This finding indicates that the perception of seriousness of illness dramatically increases during a large fire event. This factor will not affect the level of mortality and would not likely affect the level of hospital admissions. However, other relatively minor health outcomes, such as ED visits and perceived symptoms of cardiorespiratory illness, may be affected substantially by the overestimation of health risk from wildfires.

¹⁴ A related issue is the different sizes of particles between urban air pollution and wildfire smoke. Wildfire smoke mainly contains fine particles which are less than 2.5 micrometers in diameter (Ward 1999). Some studies suggest that fine particles are more hazardous than coarse particles (2.5-10 micrometers in diameter) (U.S.EPA 2004). If this is the case and urban air pollution contains larger proportion of coarse particles than wildfire smoke, wildfire smoke would be more hazardous than urban air pollution.

¹⁵ See also Vedal and Dutton (2006) for the discussion of the effectiveness of averting behaviors during wildfire events.

Future research

There is still significant uncertainty about the health risk of wildfire smoke. Many mortality studies and several hospital admission and ED visit studies find no significant impact on health outcomes, even though conventional PM studies predict significant impacts. When significant results are found in wildfire health impact studies, results are somewhat inconsistent with results from conventional PM studies.

The level of PM health impact would be affected by not only the PM levels, but also by the characteristics of the affected population and study design. The strict comparison between results from previous conventional PM studies and wildfire health impact studies is difficult due to the different population samples and study designs. Future studies should evaluate the health impact of wildfire smoke and urban air pollutions with the same study design using the same samples. Such studies have been done by Chen and others (2006) and Cançado and others (2006) using Australian and Brazilian samples, but no such study has been conducted with a U.S. sample. Studying the health impact of large prolonged (or repeated) wildfires near urban areas could be a key to obtaining meaningful results, since the health outcome variation may not be large enough during the short and small scale wildfires.

Using the daily time series model is a preferred approach to evaluate the wildfire health impact. This model is more likely able to detect significant small changes of health outcomes during the wildfire period than the historical control method. The time series model can test different hypotheses about which of the five factors addressed above play critical roles in the observed difference in the health impact from wildfire smoke and urban air pollution. Another benefit of using time-series analysis is that the dose-response function obtained from this method is easily used to evaluate the health impact of different wildfire events. However, this method requires a minimum of “wildfire day” observations, which may make the application difficult.

Another potentially useful study would be a meta-regression analysis using various wildfire health impact studies. The estimated total wildfire health impact would be the dependent variable, and outdoor PM and other pollutants levels, affected population characteristics, and type of fuels, would be independent variables. This approach would enable researchers to estimate the future wildfire health impact after adjusting to the different affected population characteristics and fuel types. To obtain a good meta-regression model, we need to accumulate more wildfire health impact studies in North America with consistent presentation of health impact results.

Surveying communities about experience with cardiorespiratory symptoms and averting behaviors during wildfire events, as well as risk perceptions associated with wildfires, will help us estimate the potential health impact in terms of cardiorespiratory symptoms and restricted activity days associated and improve our understanding of the potential disparity of health impacts due to wildfire smoke and

urban air pollution.

Economic evaluation

The health damage from wildfire events incurs direct and indirect costs to society. Freeman (2003) divides the health damage associated cost into four categories: 1. medical cost, 2. labor loss, 3. averting cost and 4. utility loss (discomfort, suffering) associated with health damage. From the economic efficiency standpoint, the total cost associated with health damage should be estimated by the individual's willingness to pay (WTP) to avoid such health damages. The U.S.EPA (1999) uses the health valuation literature to list the plausible value of per unit costs of health outcomes, as in *table 6*. In this section, we review more recent health valuation literature and discuss whether the U.S.EPA list should be modified.

Mortality valuation

The monetary value of preventing mortality is measured as the value of a statistical life (VSL). The VSL is society's aggregated willingness to pay to save one anonymous person's life. Viscusi (1992) provides a comprehensive review of VSL literature. The U.S.EPA (1999) uses the average value of Viscusi's selected 26 VSL estimates, \$7.6 million, to evaluate the mortality benefit of air pollution control. Out of 26 VSL estimates, 21 estimates are based on the labor market data, and 5 estimates are based on the survey studies. Later, the U.S.EPA updated the VSL to \$6.8 million based only on the labor market studies (U.S.EPA 2005).

Recent studies find that labor market studies used in the U.S.EPA (1999, 2005) analysis likely overestimate the actual VSL due to incorrect model specifications. Kniesner and others (2006) and Kochi (2006) correct the bias and report the revised VSL of \$5.4 million and \$2 million, respectively. Other recent studies find that the VSL is not age dependent but health status dependent among the U.S. population (Alberini and others 2004). The mean VSL estimated in Alberini and others (2004) is between \$0.87 and \$5.99 million for the U.S. population.

In conclusion, these recent studies suggest that the plausible range of the VSL would be \$1 million to \$6 million with an adjustment for the part of the population with existing health conditions.

Morbidity valuation

The morbidity valuation is more complicated than the mortality valuation due to the various potential health outcomes with different levels of severity and duration. The detailed review of morbidity valuation methodologies is available in Tolley and others (1994) and Dickie and Gerking (2002). The U.S.EPA (1999) lists per unit cost

of morbidity outcomes estimated based on the Cost of Illness (COI) method or the contingent valuation (CV) method. The COI method only estimates the direct expenses associated with illness, such as the medical cost and lost wages to treat the illness. The CV method measures individual's willingness to pay (WTP) to prevent a hypothetical occurrence of illness.

The U.S.EPA (1999) uses \$10,000 to \$15,000 as per cardiorespiratory-related hospitalization cost based on the conventional COI that includes direct medical cost and labor loss during the hospitalization. A recent study by Chestnut and others (2006) finds that the time lost during the recovery period at home is about five times longer than the time lost from work during hospitalization among cardiorespiratory patients. Adding COI values incurred during recovery period, lost household production, and cost associated with caregivers increases the conventional COI estimate by 9 to 32 percent.¹⁶

The estimated COI needs to be converted to the WTP measure. A widely used WTP/COI ratio is 2 to 3.¹⁷ In a hospital admission event, most of the medical expenses are paid by the insurance company, and some patients have sick leave benefits. The conversion to WTP should be based on the out-of-pocket expenses associated with hospitalization, not based on the expenses paid by a third-party. Thus, the final economics measure of hospitalization should be the COI accounting for the third party payment plus the individual WTP as presented in Chestnut and others (2006).

These issues also apply to the economic cost estimation of ED visits. The U.S.EPA (1999) uses the conventional COI measure. This measure excludes expenses associated with caregivers, cost incurred during the recovery period, and utility reduction. Since no study has evaluated this part of the cost of ED visits, the results from Chestnut and others (2006) may be utilized to obtain the full COI values. In addition, COI measures should be converted to the WTP measure.

Dickie and Gerking (2002) list selected studies that estimate WTP to prevent acute cardiorespiratory symptoms using the CV method. *Table 7* modifies Dickie and Gerking's list by including slightly different set of studies and estimates. As noted by Dickie and Gerking (2002), WTP values used by the U.S.EPA (1999) are generally lower than recently estimated values. For example, the U.S.EPA uses \$75 per acute bronchitis case. Dickie and Messman (2001) estimate the WTP to prevent a 6-day long acute bronchitis case¹⁸ as \$201 (median value) and Navrud (2001)¹⁹ estimates

¹⁶ The COI per hospitalization also depends on the age of the patient and category of illness. Elderly (over 65) have lower COI than younger individuals due to the smaller value of lost work days.

¹⁷ Hrudey and others (2004) suggest to use the WTP/COI ratio of 2 to 3 to estimate the benefit of air pollution control in Canada. Hon (1999) and Ruitenbeek (1999) use the WTP/COI ratio of 2.

that the WTP to reduce 14-day acute bronchitis symptoms as \$82 (mean value). The mean WTP to reduce one asthma attack episode used by the U.S.EPA is \$50. Navrud (2001) reports the mean WTP to reduce one asthma attack episode as \$236.

The U.S.EPA uses \$28 as the WTP to avoid acute respiratory symptoms per day, while Dickie and Messman (2004) estimate it as \$90. The U.S.EPA uses \$8 as the WTP to avoid one day of shortness of breath, chest tightness or wheezing. Dickie and Messman (2004) report the mean WTP to avoid 6-day shortness of breath and chest tightness as \$130 (\$22 per day) and \$101 (\$16.8 per day), respectively. Navrud (2001) estimates \$39 (mean value) and \$15 (median value) to avoid one day of shortness of breath.

It is not clear why older studies report generally lower WTP estimates than more recent studies. However, recent studies incorporate methodological advances of morbidity evaluation, and should be given more weight to determine the morbidity value to evaluate the health-related policy. Thus the U.S.EPA's morbidity value list should be updated to reflect these new findings. Maybe the best way to incorporate results from different studies is to estimate a meta-regression model using existing morbidity valuation studies. The meta-regression model would enable researchers to obtain the WTP for each morbidity outcome for different severity and durations, after accounting for the different study design among existing valuation studies (Van Houtven and others 2006).

Finally, Dickie and Messman (2002) and Navrud (2001) consistently find that the WTP to prevent children's morbidity is substantially higher than adult's morbidity. This indicates the importance of valuing the adult and children morbidity impacts separately.

Recommendation

In this paper, we review three important issues in the economic analysis of the effect of wildfires on health: key health outcomes, association between wildfire smoke and health outcomes, and valuation of health effects. We find that the key health outcomes are: mortality, restricted activity days (including work days lost), hospital admissions, respiratory symptoms and self-treatment. Our review of the conventional and wildfire-related PM epidemiology studies poses an important question of whether or not conventional PM epidemiology results can be used to evaluate the health impact from wildfire events.

¹⁸ Authors find that the average acute bronchitis symptom lasts an average of 7-days among the sample.

¹⁹ Navrud (2001) uses samples in Norway, and authors caution that the estimation results of this study may underestimate the WTP for the U.S. population due to different health care systems.

We do not recommend applying conventional PM epidemiology results to evaluate the mortality impact of wildfire events at this point. Although the conventional PM epidemiology studies generally show statistically significant mortality increases associated with short-term PM exposures, the majority of wildfire-PM studies do not find similar results. Simply using the conventional PM epidemiology results may substantially overestimate the mortality health cost associated with a wildfire event.

Since mortality is associated with a very large social cost, the estimation of the mortality impact due to wildfire events requires extreme caution. If the scale of the wildfire is relatively small and short, evaluators may want to assume that there is no mortality impact from the wildfire smoke while noting that there is a potential underestimation of the cost by excluding the mortality impact, or conduct an original epidemiology study. We recommend using the VSL estimate of \$1 million to \$6 million to evaluate the social cost of mortality, if there is any.

To estimate the changes of key morbidity outcomes from wildfire events, evaluators may want to use the results from conventional PM epidemiology studies for now, or conduct original epidemiology studies. We do not have studies that evaluate the impact of wildfire on restricted activity days in the U.S. We have some hospital admission studies and a few cardiorespiratory symptoms studies (not discussed in this paper) related to the wildfire events. However, it is difficult to derive the general association between a wildfire event and these morbidity outcomes due to the limited study design of previous findings. It is important to remember that the health impact of urban air pollution and wildfire events may be different, and the morbidity impact analysis based on conventional PM studies are still subject to this uncertainty.

We recommend using per unit cost of hospital admission and cardiorespiratory symptoms that reflect the recent findings with an emphasis on U.S. studies. Hospital admission should be based on the total medical expenses and labor loss during the hospital stay and recovery period. To convert COI values to WTP values, evaluators may want to use 2 to 3 WTP/COI ratios. Evaluators may want to use per unit values of respiratory symptoms estimated in Dickie and Messman (2004) when available. This study estimates comprehensive per unit values of respiratory symptoms with an improved health valuation method using a relatively large U.S. sample. Evaluators may also want to conduct a meta-regression analysis based on previous morbidity studies to determine the appropriate value for each severity and duration of symptoms after controlling for differences in the study design. Since the health impact and health costs are likely to be different between children and adults, evaluators should conduct the health impact study and valuation study separately for children and adults.

References

- Alberini, A.; Cropper, M.; Krupnick, A.; Simon, N.B. 2004. Does the value of a statistical life vary with age and health status? Evidence from the US and Canada. *Journal of Environmental Economics and Management*. 48: 769-792.
- Anaman, K.A. 2001. Urban householder's assessment of the causes, responses, and economic impact of the 1998 haze-related air pollution episode in Brunei Darussalam. *ASEAN Economic Bulletin* 18(2): 193-205.
- Bresnahan, B.W.; Dickie, M.; Gerking, S. 1997. **Averting behavior and urban air pollution. *Land Economics*. 73(3): 340-357.**
- Cançado, J.E.D.; Saldiva, P.H.N.; Pereira, L.A.A.; Lara, L.B. L.S.; Artaxo, P.; Martinelli, L.A.; Arbex, M.A.; Zanobetti, A.; Braga, A.L.F. 2006. **The impact of sugar cane-burning emissions on the respiratory system of children and the elderly.** *Environmental Health Perspectives*. 114(5): 725-729.
- Chen, L.; Verrall, K.; Tong, S. 2006. **Air particulate pollution due to bush fires and respiratory hospital admissions in Brisbane, Australia.** *International Journal of Environmental Health Research*. 16(3): 181-191.
- Chestnut, L.G.; Thayer, M.A.; Lazo, J. K.; Eeden, S.K.V.D. 2006. **The Economic Value of Preventing Respiratory and Cardiovascular Hospitalization.** *Contemporary Economic Policy*. 24(1): 127-143.
- Dickie, M.; Gerking, S. 2002. Willingness to pay for reduced morbidity. Unpublished manuscript prepared for the workshop, "Economic valuation of health for environmental policy: assessing alternative approaches"; 2002 March 18-19; Orlando, FL.
- Dickie, M.; Messman, V.L. 2004. **Parental altruism and the value of avoiding acute illness: Are kids worth more than parents?.** *Journal of Environmental Economics and Management*. 48: 1146-1174.
- Freeman, A.M. III. 2003. **The measurements of environmental and resource values: Theory and methods.** RFF Press.; 420p.
- Hrudey, S.E.; Adamowicz, V.; Dales, R.; Hale, B.A.; Krupnick, A.J.; Lippman, M.; McConnell, J.; Renzi, P. 2004. **Report of expert panel to review the socio-economic models and related components supporting the development of Canada-wide standards (CWS) for particulate matter (PM) and ozone to The Royal Society of Canada.** *Journal of Toxicology and Environmental Health. Part B*. 7: 147-266.
- Hon, P.M.L. 1999. **Singapore.** In: Glover, D.; Jessup, T., editor. *The cost of catastrophe*. Singapore: Institute of Southeast Asian Studies; 51-85.
- Johnston, F.H.; Kavanagh, A.M.; Bowman, D.M.J.S.; Scott, R. K. 2002. **Exposure to bushfire smoke and asthma: an ecological study.** *The Medical Journal of Australia*. 176: 535-538.
- Kniesner, T.J.; Viscusi, W.K.; Woolck, C.; Ziliak, J.P. 2006. **Pinning down the Value of Statistical Life.** Unpublished manuscript.
- Kochi, I. 2006. **Essays on the value of a statistical life.** Atlanta, GA: Georgia State University; 161p. Ph.D. dissertation.
- Kunji, O.; Kanagawa, S.; Yajima, I.; Hisamatsu, Y. 2002. **The 1997 Haze disaster in Indonesia: Its air quality and health effects.** *Archives of Environmental Health*. 57(1): 16-22.
- Künzli, N.; Avol, E.; Wu, J.; Gauderman, W.J.; Rappaport, E.; Millstein, J.; Bennion, J.; McConnell, R.; Gilliland, F.D.; Berhane, F.; Lurmann, F.; Winer, A.; Peters, J.M.

2006. **Health effects of the 2003 Southern California wildfires on children.** American Journal of Respiratory and Critical Care Medicine. 174(11): 1221-1228.
- Lipsett, M.; Waller, K.; Shusterman, D.; Thollaug, S.; Brunner, W. 1994. **The respiratory health impact of a large Urban Fire.** American Journal of Public Health. 84(3): 434-438.
- Naeher, L.P.; Brauer, M.; Lipsett, M.; Zelikoff, J.T.; Simpson, C.D.; Koenig, J.Q.; Smith, K.R. 2007. **Woodsmoke health effects: A review.** Inhalation Toxicology. 19: 67-106.
- Mar, T.F.; Norris, G.A.; Koenig, J.Q.; Larson, T.V. 2000. **Associations between air pollution and mortality in Phoenix, 1995-1997.** Environmental Health Perspectives. 108: 347-353.
- Navrud, S. (2001). **Valuing health impacts from air pollution in Europe.** Environmental and Resource Economics. 20: 305-326.
- Ostro, B.D.; Rothschild, S. 1989. **Air pollution and acute respiratory morbidity: An observational study of multiple pollutants.** Environmental Research. 50: 238-247.
- Pope III, C.A.; Dockery, D.W. 2006. **Health effects of fine particulate air pollution: Lines that connect.** Journal of the Air & Waste Management Association. 56: 709-742.
- Rittmaster, R.; Adamowicz, W.L.; Amiro, B.; Pelletier, R.T. 2006. **Economic analysis of health effects from forest fires.** Canadian Journal of Forest Research. 36: 1-38.
- Ruitenbeek, J. 1999. **Indonesia.** In: Glover, D.; Jessup, T., editor. The cost of catastrophe. Singapore: Institute of Southeast Asian Studies; 86-129.
- Sastry, N. 2002. **Forest fires, air Pollution, and mortality in Southeast Asia.** Demography. 39(1): 1-23.
- Smith, M.A.; Jalaludin, B.; Byles, J.E.; Lim, L.; Leeder, S.R. 1996. **Asthma presentations to emergency departments in western Sydney during the January 1994 bushfires.** International Journal of Epidemiology. 25(6):1227-1236.
- Tolley, G.S.; Kenkel, D.; Fabian, R. 1994. **Valuing health for policy: An economic approach.** University of Chicago; 422p.
- U.S. Environmental Protection Agency. 1999. **The benefits and costs of the Clean Air Act 1990 to 2010.** Washington D.C.: USEPA.
- U.S. Environmental Protection Agency. 2004. **Air quality criteria for particulate matter.** Washington D.C.: U.S.EPA.
- U.S. Environmental Protection Agency. 2005. **Regulatory impact analysis for the final Clean Air Interstate Rule.** Washington D.C.: U.S.EPA.
- Van Houtven, G.; Powers, J.; Jessup, A.; & Yang, J.C. 2006. **Valuing avoided morbidity using meta-regression analysis: What can health status measures and QALYs tell us about WTP?** Health Economics. 15: 775-795.
- Vedal, S.; Dutton, S.J. 2006. **Wildfire air pollution and daily mortality in a large urban area.** Environmental Research. 102: 29-35.
- Viscusi, W.K. 1992. **Fatal tradeoffs: Public and private responsibilities for risk.** New York: Oxford University Press; 306p.
- Ward, D.E. 1999. **Smoke from wildland fires.** In: Background paper for Health Guidelines for Vegetation Fire Events; 1998 October 6-9; Lima, Peru; WHO; 70-85.

Developing a Probability-Based Approach to Support Wildland Fire Management Decisions¹

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Abstract

This research developed a probability-based approach to support the wildland fire management decision processes regarding fuel treatment locations and appropriate fire management. Spatial fire behavior data such as fire spread directions and relative fire probability distributions can be created through fire simulations. A directed graph was used to represent the potential fire spread directions between different locations. Combined with concerns such as fire losses and benefits, decision makers can use this approach to determine the best fuel treatment locations and analyze tradeoffs between alternative fire management decisions. Independent from specific fire events, fuel treatment will focus on landscape level expected fire losses or potential benefits from fires. Upon the occurrence of a particular fire event, specific impacts of fire can be analyzed across time to determine the appropriate management strategies.

Keywords: Fire management, probability, GIS.

Problem description

The 1995 Federal Wildland Fire Management Policy and Program Review (1995) and the federal interagency fire management policy set the stage for the development and implementation of appropriate management response (AMR) to enable the consideration of fire management in ways that both protect valuable resources that may be in harm's way, and to facilitate the natural role of fire in the ecosystem to mitigate the increased fire risk caused by continuous fuel accumulations. The new challenges and opportunities in fire management have promulgated increased efforts including the development of new analysis and decision support tools that can integrate spatial and temporal information to provide benefit and cost based tradeoff analyses for public fire planning units.

Strategic fire management is often performed under the context of managing for future fires risks that are unknown with respect to fire incidence, intensity and size

¹ An abbreviated version of this paper was presented at the III International Symposium on Fire Economics, Planning, and Policy: Common Problems and Approaches, April 29-May 2, 2008, Carolina, Puerto Rico.

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etc. Although the future fires events are uncertain, the probability of fire occurrence by intensity and location can often be estimated through established probabilistic methods and modeling techniques. We developed this decision support system based on strategically creating, analyzing and manipulating the spatially explicit maps including fire probability distributions, the fire intensity distributions, and the expected fire losses and benefits. Events based fire behavior simulation is used to generate information used in the strategic planning but we won't emphasize the management of specific fire incidents.

Basic functions of the modeling system

We designed this model with the primary objective of helping fire managers decide the suitable places to schedule prescribed or controlled burns to strategically reduce the future expected fire losses. The location of fuel treatments and fire use need also be designed to promote the benefits from fires. To integrate both fire losses and fire benefits together, an economically sound evaluation system also needs to be developed and embedded into this modeling system. Since current decisions are likely to have long term impacts to future landscape fire risk distributions, this system is also designed to support tradeoff analysis across temporal dimensions between different fire management strategies.

Decisions in wildland fire management often need to be made promptly upon the occurrence of a fire event. In many cases, if the tradeoffs between fire suppression and utilization are unclear, the safest option will be “full suppression” since the loss of the fire will be immediate but the benefit from fire use is often realized in the future. To encourage the use of current fire to reduce the fire risk in the future, we designed this system to enable the pre-analysis (or the concept of “playbook”) by providing comprehensive information regarding the fire probabilities, potential fire losses and benefits across time and space.

Fire management and associated analysis are usually complicated due to the existence of many determining factors such as weather conditions, evolution of fuel conditions, benefits and costs associated fire suppression and fuel management programs. The recent development of geographic information system (GIS) and operations research modeling software provide us a unique opportunity of developing a user friendly interface to integrate information and also demonstrate the results so that the managers and public can visualize the fire management decisions and associated consequences.

Graphic User Interface

We developed a graphic user interface (GUI) by using Visual Basic.net. Managers can easily conduct different analysis types through this simple GUI. The main GUI

includes a map frame in which the basic information including the boundary of each fire management unit, the elevation and the raster cells that this system will based the analysis on in the future. This user interface will also be able to summarize the changing of the expected fire benefits and cost upon the decision of fuel treatment has been decided or the footprint of each fire is predicted.

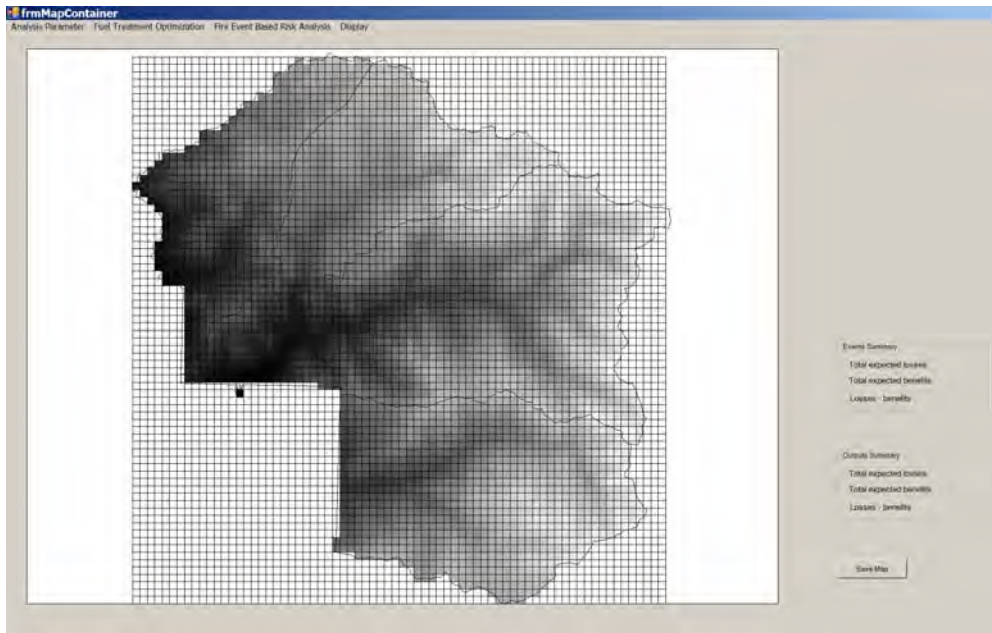


Figure 1 – The main Graphic User Interface (GUI) used in this modeling approach.

The model will also provide users with choices in determining their management decision context. Through the two general input forms (fig. 2), managers can select different combinations of weather conditions, predefined fire durations, and benefits and losses information.

The user selected inputs also include the assumption of fire return interval. Ignition risks can either be considered as following a uniform distribution across the landscape or they can be redistributed by referring the historic ignition records. Managers also have the option of selecting the number of cells in which fuel reduction program should be conducted. In Sequoia National Park, previous research has classified the landscape into different priorities in conducting fuel treatment. From low to high, the fuel treatment priority was classified into seven categories with the highest priority represented by seven. To give managers a choice to incorporate this information, we added in a user choice to filter out cells that were not considered as higher priorities during fuel reduction program by the local managers. This function provides flexibilities for managers to select at what extent they want their

decisions to be made based on the previous analysis performed at the management unit.

Both benefits and losses of fire within each cell were determined by the different attributes to be protected within each cell. These attributes include wildland urban interface (WUI), social concerns, forest, sequoia forest, and wilderness. Fire benefits in each cell are determined by whether the fire will be used to restore the desired vegetation types or simply maintain the current vegetation types. Managers can select the benefits and losses associated with each specific attributes at different intensity levels before running the model.

Figure 2 -- (a) and (b) fire behavior assumptions and benefit and lost assumptions

Preliminary Results

The recent development of fire behavior models such as FlamMap (Finney 2006) can simulate thousands of fires in a landscape by considering factors such as wind direction, wind speed, fuel type, fuel moisture, slopes, aspects and elevations etc. We use the direct simulation to calculate the relative burning probability in each of the raster cells under user designed assumptions. For example, under the assumption of southwest wind directions (wind direction 225 degree), 11 miles per hour wind speed, moderate fuel moisture, if we randomly simulate 18000 fires in the four FMUs, we can create a map of relative fire probability (fig. 3) for each cell through FlamMap. How to select the assumption for fire simulation time is considered as part of the model tuning process and information from the judgment of the local fire managers can be useful. After acquiring the relative fire probability distribution map,

based on the historical fire return interval, we will convert it to the absolute fire probability distribution map.

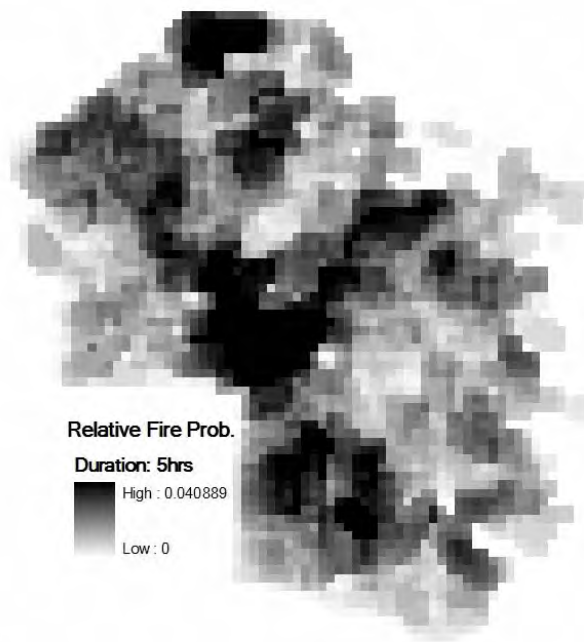


Figure 3 -- Reported relative probability of burning by FlamMap within the study site under the assumption of southwest wind direction, 11mph wind speed. 18,000 fires were simulated in the landscape to create the maps.

We also used a fire behavior model to determine the major fire spread direction within each cell within a target landscape. Fire spread direction can be used to identify the spatial connections between adjacent cells. Based on the connection between cells, a directed graph can be built to represent the spatial relationships between cells following the major fire spread direction in each cell. The directed graph will be used as the basis to connect different raster cells together through an integer programming model (Wei and others, in press).

Both the expected fire losses and benefits in the current period and in the future are important considerations built in to our system to support fire management decisions. A recently developed fuel succession diagram in Sequoia National Park was used to create the succession path for each unique fuel types across a forty year time period. Along with the change of fuel type and its spatial distributions across a landscape, the associated fire behaviors elements of fire intensity, the rate of fire spread can also change, which can impact the distribution of fire probabilities and require managers to select different fire management strategies.

With suppression resources, the spatial allocations of fuel reduction program will play an important role in fragmenting the fuel complex and therefore increase the

likelihood that suppression will be effective (Finney 2001). Prescribed fire is the most commonly used hazard fuel reduction approach. The primary utilization of this probability based fire management decision support system is to help managers identify the best locations for fuel treatments to minimize the potential fire losses across a landscape. Fig. 4a shows a set of six cells suggested by the model to schedule fuel treatment to efficiently break the fuel complex. Upon the selection of cells for fuel treatment, the models results can be combined with other important map layers to further understand the logic behind the model selections. Fig. 4b shows all suggested fuel treatment locations within the boundary of the wildland urban interface; four of the six suggested cells are around the existing locations of giant Sequoias. This type of post analysis provides managers more information about the logic used by the model to suggest the locations for fuel treatment reduction program.

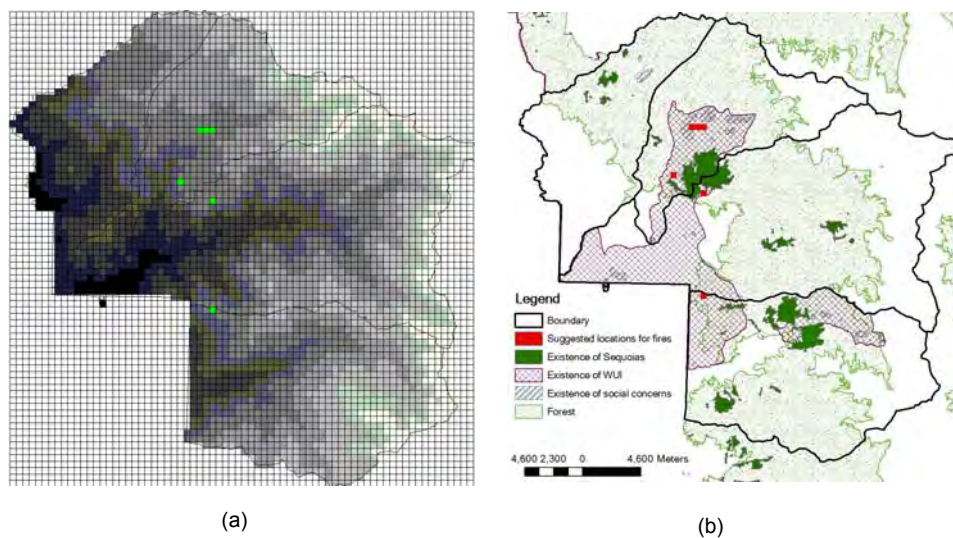


Figure 4-- (a) Model selected locations for prescribed fire. Background of (a) is the elevation map. Darker areas within the four FMU represent lower elevations. In (b), we integrate the model suggested fuel treatment locations with other GIS layers including existence of WUI, Sequoia forest, social concerns and commercial forest for further analysis. (b) Provides managers with the rationale for the locations of fuel treatment.

Each fire event usually will create resource losses and introduce ecological benefits. Since each fire will consume fuels accumulated from the past, it will alter the fuel distributions across a landscape and therefore influence the fire risk distributions both in the current time and in the future. Both the direct losses and benefits from a specific fire event and its long term impacts to the expected benefits and losses in the future are important for fire management decisions. Accurately predicting fire footprint is difficult since fire can develop in different ways and into various sizes. This system will predict a set of potential footprints for each fire event

and treat each footprint as potential future fuel breaks that would influence the future fire risk accumulations.

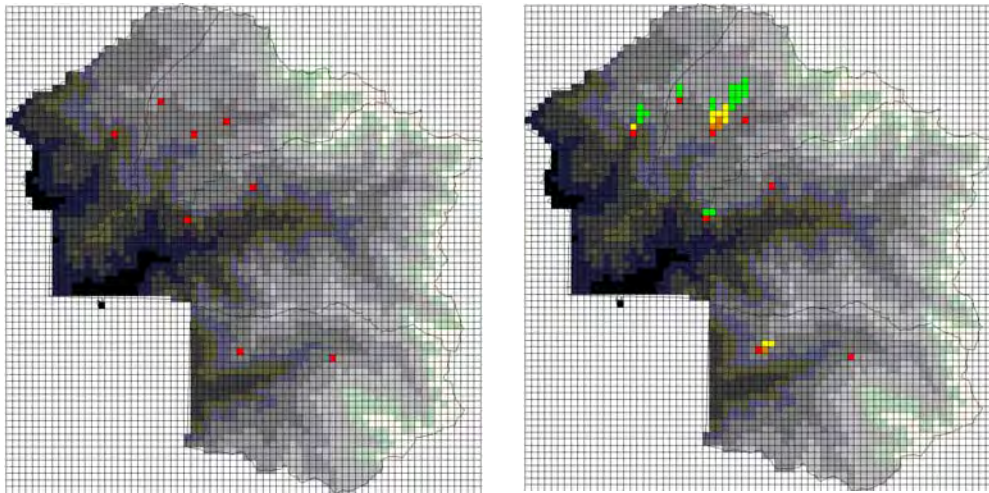


Figure 5 -- Red cells in (a) demonstrate the current fire locations. In (b), orange cells have a fire probability between 0.5 and 1; yellow cells have a fire probability between 0.25 and 0.5; green cells have a fire probability less than 0.25.

Based on analyzing the possible footprints from each fire we can calculate the benefits and losses associated with different scenarios and we can estimate the roles that each fire can potentially play in reducing the fuel accumulation and mitigating fire risk in the future. If a desired footprint associated with each fire can be identified through tradeoff analysis across time, it can also be used to provide suggestions for fire suppression efforts.

Discussion and Conclusion

We developed a probability based fire management decision support system to accomplish three types of analyses in AMR associated with fuel treatment locations, fire footprints prediction and benefits and losses analysis.

Fuel treatment location is considered important in changing fire behavior, manipulating fire risk distributions and preventing catastrophic large fires. A primary objective of this decision support system is to provide suggestions for the suitable locations of fuel treatment or fire use. Preliminary test results show the modeling system can provide logical suggestions regarding the location of fuel treatment. The locations of fuel treatment can be determined by many interrelated factors. We defined some of the factors as user inputs, which including weather conditions, assumption of fire durations and per cell based fire losses and fire benefit. This

provides flexibility for the fire managers to determine the specific decision making environments.

We included the prediction of alternative potential footprints of the individual fire event by tracking fire probability contours. This provided us with the ability to consistently analyze how individual fire events could influence the current and future landscape fire risk distributions under the same fire probability framework. However, event based fire simulation is not the primary objective of this research; instead, the footprints based on probability contours are used to enable strategic level guidelines to support fire management decisions.

Assumptions of weather conditions, fire behavior parameters and fire benefits and losses were all built as user input and each had significant impacts to model outputs and decision suggestions. However, these assumptions are stochastic factors instead of fixed model inputs. The future development of this system will require enhancing the model structure to systematically include these stochastic factors into the decision making processes.

Acknowledgement

The authors have benefited by comments and suggestions made by Jeff Manley, NPS Deputy Fire Program Planning, Tom Nichols, Deputy Chief, Division of Fire and Aviation National Park Service National Interagency Fire Center and from Stephen Botti, former Fire Program Manager, National Park Service.

References

- Finney, M.A. 2001. **Design of regular landscape fuel treatment patterns for modifying fire growth and behavior.** For. Sci. 47:219-228.
- Finney M.A. 2006. **FlamMap 3.0.** Missoula, MT: USDA Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory
- USDA/USDI (1995). **Federal Wildland Fire Management Policy & Program Review,** USDA Forest Service, USDI Bureau of Land Management, USDI National Park Service, USDI Fish and Wildlife Service, USDI Bureau of Indian Affairs. Boise, Idaho, National Interagency Fire Center.
- Wei, Y, Rideout, D.B., Kirsch, A, (in press), **An optimization model for locating fuel treatments across a landscape to reduce expected fire losses,** Can. J. For. Res.

A Mixed Logit Model of Homeowner Preferences for Wildfire Hazard Reduction¹

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Abstract

People living in the wildland-urban interface (WUI) are at greater risk of suffering major losses of property and life from wildfires. Over the past several decades the prevailing view has been that wildfire risk in rural areas was exogenous to the activities of homeowners. In response to catastrophic fires in the WUI over the past few years, recent approaches to fire management and prevention in the WUI have emphasized activities that can be taken by landowners and communities to reduce the risk of catastrophic wildfires. These activities include fuel reduction via mechanical thinning and controlled burning of forests surrounding communities and the creation of defensible space around homes. Promotion of community and homeowner-based risk reduction activities represents a new direction in wildland fire management and prevention. We developed a survey instrument to evaluate the value to homeowners in Florida of public and private programs to reduce wildfire risk. A random stratified random sample was drawn to evaluate potential differences in preferences between people living in low, medium, and high fire risk zones. A choice experiment was designed that allowed respondents to choose between public and private fire risk reduction programs that varied across three attributes: wildfire risk, economic loss, and program cost. The survey was implemented using a phone-mail-phone protocol. Results show that people living in communities they considered to be at high risk of wildfires were willing to pay a substantial premium for public wildfire mitigation programs, but had modest willingness-to-pay (WTP) for fuel reduction programs on their own property. Risk preference is related to demographic characteristics, and households that are risk seeking are more likely to make risky choices regarding wildfire mitigation programs. The results suggest that low income households, households without homeowners insurance, and African-American households living in the WUI may be good candidates for assistance.

Introduction

Wildfires pose a risk of catastrophic loss of life and property to people living in the wildland-urban interface (WUI). The increasing frequency and severity of wildfires in residential neighborhoods in the United States has caused fire managers and policy-makers to emphasize the role of homeowner and community mitigation activities to reduce the hazards associated with wildfires. Mitigation activities include fuel reduction via mechanical thinning and controlled burning of forests surrounding communities and the creation of defensible space around homes. In

¹ An abbreviated version of the paper was presented at the Third International Symposium on Fire Economics, Planning, and Policy: Common Problems and Approaches, April 29–May 2, 2008, Carolina, Puerto Rico.

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some locations, fuel reduction activities are currently being subsidized through federal cost-sharing programs.

The promotion of homeowner and community hazard reduction activities represents a new direction in wildland fire prevention and management. However, little is known about the efficacy of these approaches and the degree to which homeowners and communities are willing to invest time, effort, and money in hazard mitigation. Further, community-based wildfire hazard mitigation programs represent a weakest-link public good wherein each member of a community has a “kind of veto power over the extent of collective achievement” (Hirshleifer 1983, p. 373). Just as the strength of a chain depends upon its weakest link, or the protection provided by a system of levees depends upon its lowest height, the aggregate provision of wildfire protection is compromised by forest landowners within a community who fail to take hazard mitigation actions, thereby increasing the risk for other forest landowners in the community. Understanding the economic factors that influence decisions of whether, and how much, to invest in wildfire risk mitigation activities will help to identify obstacles to efficient and effective fire mitigation in the WUI.

In this paper, we investigate homeowner preferences and willingness-to-pay (WTP) for public and private wildfire risk reduction programs in Florida using an attribute-based choice experiment. Following the introduction we review the economic literature that has used stated preference methods for estimating homeowner WTP to mitigate the risk of catastrophic losses to private property, including losses from wildfires. We then present the survey sampling methods we used followed by a description of the empirical model used to analyze homeowner preferences for wildfire hazard mitigation. The paper continues with a presentation of the empirical results and a conclusions section.

Literature Review

The risk of a wildfire damaging or destroying a home in the WUI is very low, and yet very consequential to the homeowner.⁵ Low-risk, high-consequence (LRHC) events have posed problems for expected utility (EU) theory. This limitation was recognized by Morgenstern (1979), one of the early designers of EU theory:

... one should now point out that the domain of our axioms on utility theory is also restricted... For example, the probabilities used must be within certain plausible ranges and not go to 0.01 or even less to 0.001, then to be compared with other equally tiny numbers such as 0.02, etc. (Morgenstern 1979, p. 178).

In a meta-analysis of 23 data sets, Harless and Camerer (1994) present a test for conformance of actual choices with EU theory. Their results confirm that decision-making under conditions of low risk are not consistent with the predictions of EU theory, and suggest that “nonlinear weighting of small probabilities is empirically important in explaining choice behavior” (p. 1285).

The failure of EU theory to explain and predict economic decisions for events in the range of wildfire risk faced by homeowners in the WUI suggests that people respond in ways that are not well understood. Camerer and Kunreuther (1989)

⁵ In temperate forests, natural disturbances (e.g. fires, insect epidemics, windstorms) affect, on average, about 1% of the forest landscape per annum, a value that ranges between about 0.5% and 2% across a variety of ecosystems (Runkle 1985).

showed that, under conditions of low risk, people tend to use ad hoc decision rules. Some people tend to discount the risk entirely, thinking that “it can’t happen to me”. Other people tend to overestimate or exaggerate the risk. Both types of responses have been identified in research on perceived wildfire risk subsequent to an actual wildfire event.⁶

Similar behavioral responses to LRHC events were observed by McClelland et al. (1993) in a laboratory economic experiment where a sample of university students were instructed to bid on a fixed number of insurance policies that, although costly, would protect their wealth if a catastrophic event did in fact occur. Expected bids were close to their expected value except at the lowest probability of 0.01, at which a bimodal distribution of values was observed. These results are consistent with the idea that some people tend to ignore very low risks, while others worry too much about them.

Experimental economic methods were also used by Ganderton et al. (2000) to investigate insurance purchasing decisions for disaster-type risks. To begin, the authors hypothesized that the bimodal value distribution reported by McClelland, Schulze, and Coursey (1993) might be attributable to dual focal points. That is, when people are confronted with low probability, high consequence events, some people might focus on the probability that the event will occur, and will tend to ignore low probability events if the risk falls below some threshold. Other people might focus on the magnitude of the potential loss, and decide that the consequences are worth avoiding even at a large cost. Data from this experiment were analyzed using a binary logit model (subjects purchased insurance or not). The authors found that subjects were more responsive to the variation in loss probabilities than the variation in loss amounts. Also, they were unable to identify a bimodal distribution of values – perhaps because subjects were focusing primarily on loss probabilities and not loss amounts.

Economists have used contingent valuation methods for estimating WTP for measures that mitigate wildfire hazards. Winter and Fried (2001) asked households how much of an increase in property taxes they would pay for a 50% reduction in the probability of a wildfire. On average, households were willing to pay \$57 per year. Talberth et al. (2006) conducted a CVM study that elicited homeowner WTP for private land fire risk reduction, neighborhood fire risk reduction, and public land wildfire risk reduction. The annual WTP amounts were greatest for protecting one’s house (\$240), followed by protecting other homes in the neighborhood (\$95) and, finally, protecting public forests (\$64). Loomis and González-Cabán (2008) evaluated WTP for wildfire risk mitigation in the wildland-urban interface in 3 states – Montana, Florida, and California. The statistical results suggest that households have a substantial WTP for a prescribed burning or mechanical fuel reduction program that would decrease the number of acres burned by wildfires in their respective states by, at least, 25 percent. In particular, average WTP by household ranged from approximately \$400-\$500 in California, from \$250-\$400 in Florida, and from \$190-\$300 in Montana.

⁶ For example, Cortner et al. (1990) found that homeowners surveyed in a California community recently impacted by fire perceived less risk of future fires than another community not impacted by fires. In contrast, Abt (1990) reported that homeowners surveyed in Palm Coast, Florida after a wildfire impacted their community thought that future wildfires were the greatest threat facing their community.

Empirical Methods

Based on the literature review, a choice experiment was designed to estimate homeowner WTP for programs that reduce the (separable) risks and economic losses from wildfires. We designed our study to test the hypothesis that homeowner preferences regarding risks and losses are heterogeneous. In particular, we test the hypothesis that preferences regarding the risk and economic consequences related to wildfire mitigation programs reflect underlying attitudes towards risk, and that some people in the population are risk seeking, while others are risk averse. Such a distribution of preferences would be consistent with a bimodal distribution of preference parameters for LRHC events.

The theory of risk preference, based on expected utility theory, generally categorizes decision-makers as either risk averse, risk neutral, or risk seeking. To clarify these concepts, consider a lottery with an equal probability of receiving \$100 or nothing. A decision-maker is risk averse if they would accept a payoff of less than \$50 with certainty rather than entering the lottery. The decision-maker is risk seeking if they accept the certain payment only if it exceeds \$50. If the decision-maker is indifferent between entering the lottery and accepting \$50, they are risk-neutral.

Barsky et al. (1997) speculated that attitudes towards risk might be quite heterogeneous across the population and devised a series of utility theoretic questions that would identify an individual's risk attitude from their responses to a series of stated preference questions regarding gambles over lifetime income. Further, they sought to link stated risk preference with observed behavior. We used a simplified version of the series of risk preference questions posed by Barsky et al. (1997) to isolate respondents in our survey who were risk seeking. We then tested whether respondents identified as risk seekers had statistically different preference parameters regarding risk and loss from wildfires than respondents we identified as risk averse. The identification of structurally different preferences regarding wildfire hazard mitigation programs thus constitutes a test of the McClelland et al. (1993) finding that WTP for risk reduction has a bimodal distribution.

In particular, we identified respondents as risk tolerant based on their response to the following utility theoretic question:

Suppose that you are the only income earner in the family, and you have a good job guaranteed to give you and your current family income every year for life. You are given the opportunity to take a new and equally interesting job. The new job may be better (a 50-50 chance that it will double your family income) or it may be worse (a 50-50 chance that it will cut your family income by one-half). Would you take the new job?

1. YES
2. NO

A respondent is risk seeking, according to the definitions given above, if they respond YES to the above question, because

$$\frac{1}{2}U(2c) + \frac{1}{2}U(0.5c) > U(c) \quad (1)$$

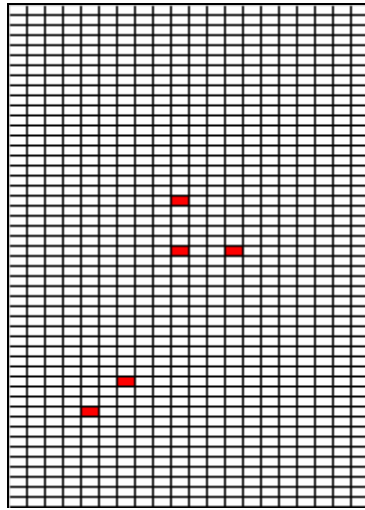
where U is a utility function and c is the stream of current income.

One of the difficulties associated with evaluating heterogeneous preferences regarding risk, alluded to above, is the fact that the risk of a home being damaged or destroyed by wildfire is very low. Fortunately, survey methods have been developed by economists studying WTP for mortality risk reduction where the risk of mortality is very low. In particular, we reference the research conducted by Krupnick et al. (2002) who developed a contingent valuation format to study of the impact of age and health status on WTP for mortality risk reductions. They used an innovative, visual method for communicating baseline risk of death (on the order of 10^{-3}) and risk changes (on the order of 10^{-4}) using a rectangular grid containing 1,000 squares where white squares represented a healthy state and red squares represented death. We modified this format by posing a situation where the risk of a home being damaged by a wildfire was represented, on a 1,000 square lattice, by a red square and the risk of being undamaged was represented by a white square. Further, to simplify the conceptualization of the risk of a wildfire damaging a home, we asked respondents to consider the risk of various wildfire risk mitigation programs that would be in effect during the subsequent 10 years. This approach (Figure 1) was used to convey to respondents the actual risk that their home might be damaged by wildfire during the next decade.

Our experimental design varied the risk of private property damage during a 10 year period over five levels, from 1-5%, where 5% was the baseline risk associated with no investments in hazard reduction activities. Damages from wildfires were posed in terms of economic losses to real property values (e.g., homes, cars, landscape trees), and dollar amounts ranged from \$10,000-\$100,000. Two types of wildfire mitigation programs were included in the experiment: (1) a public program, and (2) a private program. The public program would include three activities for managing vegetation and reducing fuels throughout the community where the respondent resided (prescribed burning, mechanical treatment, and herbicide treatment), and would be funded by a tax increase. The private program would increase the defensible space on the respondents' property by managing vegetation, such as removing trees close to the house. The cost of these programs varied from \$25-\$1,000 for the public program and from \$50-\$1,000 for the private program.

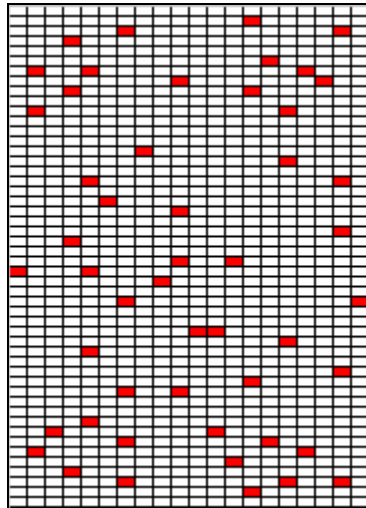
Figure 1. Chance grids used to depict wildfire risk

(1) UPPER CHANCE GRID: Annual chance



One way to illustrate the Average Annual Chance of a wildfire damaging your house is shown in the diagram to the left. The “chance grid” shows a neighborhood with 1000 houses, and each square represents one house. The white squares are houses that have not been damaged or destroyed by wildfire, and the red squares are houses that have been damaged or destroyed. Consider this to be a typical, or average, occurrence each year for this neighborhood. To get a feeling for this chance level, close your eyes and place the tip of a pen inside the grid. If it touches a red square, this would signify your house was damaged or destroyed by wildfire.

(2) LOWER CHANCE GRID: Ten year chance



The chance that your house will be damaged by wildfire during a **ten year period** is approximately 10 times the chance that it would be damaged or destroyed in a single year. The Average Ten Year Chance is shown for the same neighborhood over a ten year period, where red squares represent houses that have been damaged or destroyed during a ten year period and white squares are houses that have not been damaged or destroyed.

A completely randomized experimental design was used in constructing the choice sets (Holmes and Adamowicz 2003). An example of a choice question used in the questionnaire is shown in Figure 2. A status quo alternative, representing the typical current situation, was provided for each choice scenario. A series of three choice questions were asked to each respondent.

Figure 2. Example choice question

Question 20	Alternative #1	Alternative #2	Alternative #3
	Public Fire Prevention	Private Fire Prevention	Do nothing additional
Chance of your house being damaged in next 10 years	40 in 1,000 (4%)	10 in 1,000 (1%)	50 in 1,000 (5%)
Damage to property	\$40,000	\$80,000	\$100,000
Expected 10 year loss = Chance x damage	\$160 during 10 years	\$800 during 10 years	\$5,000 during 10 years
One time cost to you for the ten-year program	\$300	\$100	\$0
I would choose: Please check one box	☐	☐	☐

To investigate the importance of preference heterogeneity in stated preference responses to wildfire hazard mitigation programs, we used a mixed (random parameters) logit model for analysis. Mixed logit (ML) is a generalized form of the standard multinomial logit (MNL) model, and allows for random variation in preferences, unrestricted substitution patterns, and correlations among unobserved factors (Train 2002). The ML model can be motivated from a utility function

$$U_{nj} = \sum_{k=1}^K \beta_{nk} x_{jnk} + \varepsilon_{jn} \quad (2)$$

where x_{jnk} is a vector of K explanatory variables observed by the analyst for alternative j and respondent n , β_{nk} is a vector of preference parameters, and ε_{jn} is an unobserved independent and identically distributed (IID) stochastic variable that is distributed extreme value type I across respondents and alternatives. Because the IID assumption is restrictive in that it does not allow the error components of various alternatives to be correlated, this restriction may be relaxed by introducing additional stochastic components to the utility function through β_n . These components allow the preference parameters for the x_{jnk} explanatory variables to be heterogeneous and correlated over the sample. In particular,

$$\beta_{nk} = \beta_k + \Delta z_{nk} + \Gamma v_{nk} \quad (3)$$

where β_k is the mean value for the k^{th} preference parameter, z_{nk} is a vector of demographic or other data observed for respondent n , v_{nk} is a random variable with zero mean and variance equal to one, Δ is a vector of parameters providing an estimate of how the observed data z shift the mean of the distribution of the preference parameter, and Γ is a lower triangular matrix that provides an estimate of the standard deviation of the preference parameter across the sample and the correlation with other preference parameters.

Probabilities in the mixed logit model are weighted averages of the standard logit formula evaluated at different values of β , where the weights are determined by

the density function $f(\beta)$. Let P_{ni} be the probability that an individual n chooses alternative j from set J , such that

$$P_{ni} = \int L_{ni}(\beta) f(\beta) d\beta \quad (4)$$

where

$$L_{ni}(\beta) = \frac{e^{V_{nj}(\beta)}}{\sum_{j=1}^J e^{V_{nj}(\beta)}} \quad (5)$$

and $V_{nj}(\beta)$ is the observed portion of utility (Train 2002). The model's name comes from the statistics literature, where a weighted average of several functions is called a mixture function.

The function $f(\beta)$ can be simulated using random draws from various functional forms. For the analysis reported in this paper, we use 500 Halton (intelligent) draws from the normal distribution to estimate Γ for the random parameters associated with the *risk* and *loss* variables. Further, a dummy variable was created using responses to the risk attitude question. The influence of risk attitude on the mean of the preference parameters for the *risk* and *loss* variables was evaluated by estimating Δ . The parameter estimate on the *cost* variable for wildfire mitigation programs is treated as non-random in the analysis reported here. We specify alternative-specific constants for the public (*public-program*) and private (*private-program*) wildfire mitigation programs. Because the value of these programs may vary according to the respondents' subjective evaluation of the fire risk they face in their community, we created a dummy variable to identify respondents who indicated that they perceive that their home is located in a high (versus medium or low) fire risk area. This variable is then interacted with the alternative specific constants to create two new variables (*hi-risk-public*, *hi-risk-private*).

Survey Sample

A stratified random sample of households was drawn from the population of households in Florida. Because it was thought that people living in areas that have a higher risk of damage from wildfires would be both more aware and more concerned regarding wildfire mitigation programs, the sample was stratified to sample more heavily from high and moderate risk areas. The weighting scheme used was 1-2-3, where for each household sampled from low risk communities (as defined by the Florida State Fire Management Agency), two households were sampled from medium risk communities, and three households were sampled from high risk communities. Households were recruited using random digit dialing, and basic information was recorded during the initial phone call. Then, households that were willing to participate in the survey were mailed a survey booklet. Within two weeks of receiving the booklet, a return phone call was made to households and responses to the survey questions were recorded by the phone interviewer. For this stage of the research, 395 interviews were completed.

Empirical Results

Responses to the stated preference question regarding a gamble over lifetime income indicated that about 21 percent of the sample had risk seeking preferences. Attitudes towards risk are shown in table 1, broken down by various demographic categories. Tests of independence were conducted using the χ^2 statistic. Results of these tests indicated that households with lower levels of income and who do not have home insurance are risk seeking. Because very few observations were available for African-American and Hispanic households, we were unable to conduct a full statistical analysis of the influence of race and ethnicity on risk tolerance.⁷ None-the-less, the results in table 1 indicate that risk preferences are heterogeneous across the population – a conclusion similar to that found by Barsky et al. (1997).

The results of the multinomial logit (MNL) and mixed logit (ML) models are reported in table 1. As expected, the parameter estimate on the cost, risk and loss variables were negative and statistically significant in the MNL model. These results suggest that, on average, respondents preferred wildfire hazard mitigation programs that decreased both risk and economic loss.

Implicit prices (marginal WTP estimates) are computed by dividing the parameter estimate of an attribute by the absolute value of the parameter estimate on cost. Using this formula, the implicit price of a one percent decrease in the risk of wildfire damage to a private home in Florida, using the MNL parameter estimates, is \$146.25. Recall that this is a one-time payment for a program that would reduce fire risk for 10 years from the baseline risk (5 percent). Thus, the annual implicit price is roughly \$14.63 for a one percent reduction in risk from the baseline. Homeowners would be WTP roughly \$36.58 for a 50 percent reduction in wildfire risk from the baseline (from 5 percent to 2.5 percent). This is smaller than, but similar to, the estimated annual WTP (\$57) to reduce wildfire risk in Michigan by 50 percent reported by Winter and Fried (2001).

The implicit price of damage reduction in the MNL model is roughly \$7.50 for a \$1,000 reduction in losses. Is this reasonable? The average annual home insurance premium in Florida is \$786/year and the median house price (in 2004) was \$170,800. Thus homeowners were paying about \$4.60 for every \$1,000 in home value protected. As our implicit price estimates are for a 10 year program, annual WTP to reduce damage by \$1,000 would be about \$0.75. Of course, there are other risks to homes besides wildfires (hurricanes, domestic fires), so we might expect the annual WTP to reduce wildfire damage would be less than the total WTP to reduce damages from all potential sources of risk.

⁷ The sample included 18 African-American households and 9 Hispanic households. A plausible interpretation of the data suggests that African-American households are risk seeking, whereas Hispanic households are risk averse. A more rigorous test of this hypothesis awaits further data collection.

Table 1. Risk profiles by demographic categories

Variable	Risk averse (%)	Risk tolerant (%)
Homeowner insurance***		
No	33	67
Yes	82	18
Household income***		
\$22,500-\$37,499	50	50
\$37,500-\$67,499	67	33
\$67,500-\$82,499	71	29
> \$83,000	88	12
Race (NA)		
African-American	0	100
Not African-American	80	20
Ethnicity (NA)		
Hispanic	100	0
Not Hispanic	76	24

Chi-square values for tests of independence: * denotes significance at the 0.10 level, ** denotes significance at the 0.05 level, *** denotes significance at the 0.01 level. NA indicates that the chi-square test was not applicable because of zero values in some of the cells.

The sign and statistical significance of the parameter estimates on the attribute-specific constants in the MNL model indicate that, in communities viewed as low or medium fire risk by households residing there, respondents preferred the do-nothing, status quo alternative to either a public program or private program for mitigating wildfire hazards. However, the parameter estimates indicate that households residing in subjectively-valued high fire risk areas preferred a public program to the status quo, but were neutral regarding their preference for a private program. Mean willingness to pay for a 10-year public program of wildfire mitigation by residents living in subjectively-valued high fire risk communities, holding other attribute levels constant, was \$550. This value “premium” is similar to, but somewhat larger than, the WTP value reported in the contingent valuation study discussed above for Florida households (Loomis and González-Cabán 2008).

An examination of the parameter estimates for the ML model (table 2) show that the parameter estimates for the risk and loss variables are heterogeneous across the sample, as indicated by the statistically significant parameter estimates for the standard deviations of these parameters. Although the estimates for the mean parameter values for these variables are negative and statistically significant (which is consistent with the MNL model), the estimated wide dispersion on the risk parameter estimate indicates that a substantial proportion of the respondents were risk tolerant. The estimates of the Δ parameter estimates show that respondents who were identified as risk seeking, based on the stated preference question regarding a lottery over lifetime income, were risk seeking in their choices regarding wildfire hazard mitigation programs. Thus, the responses to the risk attitude question were consistent with respondent choices regarding risk-loss tradeoffs in wildfire mitigation.

Table 2. MNL and ML preference parameters for wildfire hazard mitigation programs

Variable	Multinomial logit model	Mixed logit model (mean)	Mixed logit model (std. dev.)
risk (%)	-0.117*** (0.033)	-0.138*** (0.045)	0.335** (0.136)
risk _{risk_seeking} (%)	--	0.203** (0.084)	--
loss (\$1,000)	-0.006*** (0.002)	-0.004** (0.002)	0.009 (0.006)
loss _{risk_seeking} (\$1,000)	--	-0.006* (0.003)	--
cost	-0.0008*** (0.0001)	-0.0008*** (0.0001)	--
public_program	-0.28** (0.13)	-0.074 (0.17)	--
private_program	-0.45*** (0.14)	-0.26 (0.18)	--
hi_risk_public	0.72*** (0.22)	0.83*** (0.27)	--
hi_risk_private	0.45* (0.24)	0.55* (0.29)	--
N	395	395	--
pseudo-R ²	0.042	0.056	--

Note: standard errors in parentheses. * indicates significance at the 0.10 level, ** indicates significance at the 0.05 level, *** indicates significance at the 0.01 level.

The identification of risk-seekers in the sample induces a bimodal distribution of preferences regarding risk – which is consistent with results reported by McClelland et al. (1993) – and a bimodal distribution of preferences over economic losses. The risk-loss trade-offs exhibited by risk averse respondents were very different than the trade-offs exhibited by risk seeking respondents. Clearly, the ML logit model provides a much richer description of preferences regarding risk than does the MNL model.

Conclusions

WTP estimates for reductions in risk and economic losses from wildfires were estimated from a choice experiment and were found to be roughly consistent with WTP estimates derived from contingent valuation studies and from estimates of home insurance premiums. People living in communities that they considered to be at high risk of wildfires were willing to pay a substantial premium for public wildfire mitigation programs, but had modest WTP for fuel reduction activities on their own property. This dichotomy may be due to the visual impact of fuel reduction programs close to ones home.

Economic surveys can be used to identify segments of the population living in fire prone landscapes that may be reluctant to support fire hazard mitigation programs due to their risk preferences. Our analysis revealed that roughly 20 percent of the respondents to our survey were risk seeking, while roughly 80 percent were risk averse. We found that risk preferences are related to demographic

characteristics, and that households that are risk seeking are more likely to make risky choices regarding wildfire mitigation programs. These households might be considered the weak-link in the provision of community wildfire protection programs. Consequently, our results suggest that a special effort should be made to assist those segments of the population that may be reluctant to participate in wildfire mitigation programs in order to strengthen the weakest links to wildfire protection. Our results suggest that low income households, households without homeowner insurance, and African-American households living in the WUI may be good candidates for assistance.

References

- Abt, R., M. Kuypers, and J. Whitson. 1990. Perceptions of fire danger and wildland/urban policies after wildfire. In, *Fire and the Environment: Ecological and Cultural Perspectives, Proceedings of an International Symposium*. (eds. S. Nodvin, and T. Waldrop). Asheville, NC: Southeastern Forest Experiment Station. Pp. 257-259.
- Barsky, R.B., F.T. Juster, M.S. Kimball, and M.D. Shapiro. 1997. Preference parameters and behavioral heterogeneity: An experimental approach in the health and retirement study. *Quarterly Journal of Economics* 112(2): 537-579.
- Camerer, C. F., and H. Kunreuther. 1989. Decision processes for low probability events: policy implications. *Journal of Policy Analysis and Management* 8: 565-592.
- Cortner, H., P. Gardner, J. G. Taylor. 1990. Fire hazard at the urban-wildland interface: what the public expects. *Environmental Management* 14(1): 57-62.
- Ganderton, P. T., D. S. Brookshire, M. McKee, S. Stewart, and H. Thurston. 2000. Buying insurance for disaster-type risks: experimental evidence. *Journal of Risk and Uncertainty* 20: 271-289.
- Harless, D. W. and C. F. Camerer. 1994. The predictive utility of generalized expected utility theories. *Econometrica* 62: 1251-1289.
- Hirshleifer, J. 1983. From weakest-link to best-shot: The voluntary provision of public goods. *Public Choice* 41:371-386.
- Holmes, T.P. and W. Adamowicz. 2003. Attribute-based methods. In, *A Primer on Non-market Valuation* (P. Champ, K. Boyle, and T. Brown, eds.). Dordrecht, The Netherlands: Kluwer Academic Publishers.
- Krupnick, A., A. Alberini, M. Cropper, N. Simon, B. O'Brien, R. Goeree, M. Heintzelman. 2002. Age, health and the willingness to pay for mortality risk reductions: a contingent valuation survey of Ontario residents. *Journal of Risk and Uncertainty* 24: 161-186.
- Loomis, J. and A. González-Cabán. 2008. Contingent valuation of fuel hazard reduction treatments. In, *The Economics of Forest Disturbances: Wildfires, Storms, and Invasive Species*, (T. Holmes, J. Prestemon, and K. Abt, eds.). Dordrecht, The Netherlands: Springer-Verlag.
- McClelland, G. H., W. D. Schulze, and D. L. Coursey. 1993. Insurance for low-probability hazards: a bimodal response to unlikely events. *Journal of Risk and Uncertainty* 7: 95-116.
- Morgenstern, O. 1979. Some reflections on utility theory. In, *The Expected Utility Hypothesis and the Allais Paradox*, (eds. M. Allais and O. Hagen). Dordrecht: D. Reidel.
- Runkle, J. R. 1985. Disturbance regimes in temperate forests. In, *The Ecology of Natural Disturbance and Patch Dynamics* (eds. S. T. A. Pickett and P. S. White). San Diego: Academic Press, Inc.
- Talberth, J., R. Berrens, M. McKee and M. Jones. 2006. Averting and Insurance Decisions in Wildland-Urban Interface: Implications of Survey and Experimental Data for Wildfire Risk Reduction Policy. *Contemporary Economic Policy* 24(2): 203-223.
- Train, K.E. 2002. *Discrete Choice Methods with Simulation*. Cambridge University Press.
- 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.

A Choice Modeling Approach to Value a Fire Prevention Program in Catalonia (Spain)¹

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Abstract

In Catalonia forest fires have an important environmental, economical and social impact. Due to some extreme fire sessions in the past decade, the problems of forest fires have attracted significant attention in the media and amongst policy makers, leading to an increasing public concern. In the present study the welfare effect of the implementation of a program of additional forest fire prevention measures is estimated. The proposed program would diminish the average area of forests burnt per year and the severity of forest fires, expressed by tree mortality. A contingent choice method was applied to elicit the marginal values of two forest fire impact attributes (area burnt and dead trees). In addition, the respondents were also able to select the preferred prevention type, by selecting whether the majority of the work would be done by prescribed burning or physical fuel reduction. The implications of the present study may be of interest for policy makers to support decision-making on fire prevention programs considering social preferences.

Keywords: Catalonia, forests, contingent choice method, physical fuel reduction, prescribed burning, social valuation, fire prevention program.

Introduction

Catalonia is located in the north-east of the Iberian Peninsula. The majority of Catalonia is dominated by a Mediterranean climate, with cold and moist winters and dry and hot summers (Piñol and others 1998). Further, approximately 61% of Catalonia is covered by forest and shrublands. The forests, occupying almost 38% of the territory, are dominated by different pine (e.g. *Pinus halepensis*, *P. sylvestris*, *P. nigra*) and oak (*Quercus ilex*, *Quercus suber*, *Q. humilis*) species (Gonzalez 2006).

As in other parts of the Mediterranean region, one of the major environmental concerns is the occurrence of devastating summer wildfires which can cause

¹ An abbreviated version of this paper was presented at the Third International Symposium on Fire Economics, Planning, and Policy: Common Problems and Approaches, 29 April – 2 May, 2008, Carolina, Puerto Rico.

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important ecological and economic damages. The number of forest fires and the area affected vary considerably from year to year (e.g. see EFFIS 2006). However, it seems that in the last decade the frequency of disastrous fire years is increasing. The driving factors for such a development are manifold; e.g. changing climate conditions (Piñol and others 1998), abandonment of rural areas, expansion of fast growing species that are highly inflammable, tourism growth and development of extensive wildland-urban interface areas (Xanthopolus and others 2006). Therefore the problem of forest fires is attracting more attention, reflecting the increasing public concern for this issue.

The authorities try to cope with this problem by redesigning policies⁵ and increasing the financial means, with the intention of increasing the efficiency of fire extinction and to reduce the occurring damages. For example, in 2006 the Spanish government increased the budget for prevention and extinction measures by approximately 10% when compared to the year before (MMA 2006, MMA2007). However this financial means are still very low when compared to the damages caused by wildfires. According to the Spanish annual report on forest fires for 2005, the total damage caused by fires amounted to approximately 505 million €, while in the same year the total budget for forest fire related action was only 63,5 million €⁶ (MMA 2006). Would it be worth to invest more money? Would such additional investments be supported by the society?

Another question is how to invest the money for fighting the forest fire problem. Most of the Mediterranean countries responded to the emerging wildfire problem, by increasing their extinction potentials. In Spain, for example, in 2005 around 70% of the above mentioned budget, was devoted to extinction measures. Such an approach might help to reduce the burned area in a “mild” fire season, but might, because of fuel accumulation, lead to devastating fire events in more difficult seasons (Xanthopolus and others 2006). Therefore more efforts should be directed towards fuel reduction measures. Several methods for fuel reduction exist. They can be broadly divided into physical removals of biomass and prescribed burning. Physical removals are widely applied in Southern Europe, while prescribed burning is still less known. In Spain, for example, prescribed burning is regulated and applied only in some regions (e.g. Andalusia), while in some others it is slowly getting introduced (e.g. Catalonia) or even totally banned (e.g. Madrid) (Xanthopolus and others 2006).

Legal limitations, missing experience in its appliance, and significant restrictions regarding smoke management, liability issues and safety, are some of the main reasons that prescribed burning is not a standard fuel reduction approach in the Mediterranean region (Xanthopolus and others 2006). In addition, most of the

⁵ For example in Spain (BOE 2005).

⁶ This amount does not include the budgets of the autonomous regions.

awareness raising and prevention campaigns were based on the paradigm, that in a forest any fire is bad and dangerous. Therefore, forest managers are concerned that using fires for fuel management might provoke confusion or even protests of the local population. Would the society in the Mediterranean area accept the application of prescribed burning as a prevention method?

To answer the above stated questions the social preferences regarding forest fire prevention measures investments and the use of different fuel reduction methods should be explored.

According, to our knowledge, for the Mediterranean region only Riera and Mogas (2004) conducted a study estimating the social value of a program that would reduce the fire risk. They applied a pure referendum method for evaluating from the social point of view the acceptance for a proposed program that would reduce by 50% the risk of forest fires in Catalonia. Their study showed that 63% of the sampled population would be willing to pay the estimated extra-cost of 6 € per person and year to finance the program.

Hence, it was decided to launch a study to explore (i) whether the public would be willing to contribute additional money to support a program that would reduce damages caused by forest fires and (ii) whether the society has any preferences how the program should be implemented. The study was conducted for the region of Catalonia in Spain.

Economic methods, such as choice experiments, contingent valuation method, hedonic pricing and others, were developed to evaluate the social value or desirability for a certain good or service (Manisfield and Pattanayak 2007). In this study the contingent choice method was used as the valuation methodology.

The next section, of this paper, describes the case study. Section three outlines the main results, by a discussion, on the main results, in the last part of the paper.

Methodology

Stated preference methods

Different stated preference methods can be used for eliciting preferences for environmental goods. Over the last decade attribute-based methods have been developed (Louviere and others 2000, Hanley and others 2001). The three most popular approaches of these ABMs are: (i) Contingent ranking; (ii) Contingent rating, and (iii) Contingent choice. These valuation methodologies are consistent with the welfare economic theory (Unsworth and Bishop 1994, Holmes and Adamowicz 2003, Louviere and others 2000, Bennett and Blamey 2001).

In this study the contingent choice method was applied. This method requires that respondents compare two or more alternatives simultaneously from a choice set

and then choose their preferred alternative. This choice simulates the actual market behavior; like choosing a brand of coffee from among brands with different attributes. The alternatives to choose from are described in a questionnaire that details the attributes to be considered, the changes in quantity or quality levels that may occur, and a proposed payment. This payment can be seen as a contribution towards obtaining a desired change or avoiding an undesirable one. In this way, more than one attribute of a good is taken into account at the same time.

Contingent choice is based on the random utility maximization model (RUM) (McFadden, 1973). This model assumes that the individual's utility is the sum of systematic (v) and random (ε) components and can be expressed as

$$(1) U_j = v(x_j, p_j; \beta) + \varepsilon_j$$

where U_j is the true, but unobservable, indirect utility associated with the alternative j , x_j is the vector of attributes associated with alternative j , and ε_j is a random error term with zero mean. The error term represents the influence on the individual's choices that are known to the individual, but unobservable to the researcher.

The probability (P) that an individual will choose the alternative j from a choice set containing competing alternatives can be expressed as:

$$(2) P(j|C) = P(U_j > U_k) = P(v_j + \varepsilon_j > v_k + \varepsilon_k), \forall j \neq k \in C$$

where C contains all of the alternatives in the choice set. Most often the choice probabilities are estimated using the conditional logit model (McFadden, 1973). The regression model is then estimated using a maximum-likelihood approximation (Hensher and Johnson 1981).

Survey scenario

Before asking the respondents to choose their preferred alternatives, the choice context or scenario should be explained. In this study the survey scenario explained that due to land abandonment and changes in the use of forests, the propagation and intensity of forest fires in Catalonia might increase in the future. Therefore the regional government proposes to implement additional forest fire prevention measures that would decrease the propagation and severity of forest fires in Catalonia. Further the scenario explained that the additional prevention activities would be implemented by fuel reduction. This reduction could be achieved by applying different methods (i) prescribed burning and (ii) physical reduction.

To describe the effects of forest fires and of application of prevention measures,

propagation and intensity of forest fires were used. These indicators were selected, since rate of spread and fire intensity are two primary descriptors of fire behavior and their prediction is crucial to achieve effectiveness in both wildfire control and application of prevention measures (Martins Fernandes 2001). However for the purpose of this study, these indicators had to be expressed in terms, which would be understandable to the general public.

Tree mortality was found to be a suitable indicator for expressing the fire intensity, since it can be related to fire behavior indicators such as intensity (González and others 2007). When tested in focus groups and in personal interviews it was found, that tree mortality was clear and well understood by the participants. According to González and others (2007) the tree mortality in the past forest fires in Catalonia, was around 45%. This value was used to characterize the situation which may occur in 10 years time without the implementation of additional prevention measures.

In the case of fire spread it was decided to use the average forest area affected by fires per year. This indicator was already applied by Riera and Mogas (1994) in their study. They found that it was suitable and well understood by the respondents. To estimate base line situation the average burnt area of forest per year for Catalonia was estimated. According to the fire statistic for the period 1968-2006, the mean number of hectares affected each year is around 11,000 or 1% of the total forest area of Catalonia (GENCAT 2007). The current tree mortality was used to present the situation which may occur in 10 years time if no additional prevention is applied. Not to overestimate the future situation, it was decided to use conservative estimates of the development, of both attributes, during the next 10 years.

Choice sets

A contingent choice experiment consists of several choice sets, each containing two or more alternatives. The alternatives is represented by a set of attributes and each attribute can take one of several levels. In this study three attributes were used, namely: (i) burned forest area; (ii) tree mortality, and (iii) annual payment to finance the fire prevention measures.

Each attribute had four levels, as shown in Table 1. For the “business as usual” or *status quo* situation, it was assumed that no additional fire prevention measures would be applied. Therefore the levels for burned area and tree mortality were kept as in the current situation. For the case of applying additional prevention measures, the levels of area burned and tree mortality were estimated according to simulations conducted in other studies (e.g. Gonzalez 2006) and according expert opinions. When tested in focus groups it was found that the attribute levels appeared realistic and plausible. Payment levels were determined after personal interviews and focus groups

in which respondents stated the maximum amount they were willing to pay for different scenarios; the extra cost for the *status quo* option was set to zero.

Table 1. The three attributes and levels used in the contingent choice exercise.

Attribute	Description	Levels
Burned forest area	The average of burned forest area per year in 10 years time will be	10 hectares per 1000 (<i>status quo</i>) 7 hectares per 1000 6 hectares per 1000 5 hectares per 1000
Dead trees	The average percentage of dead trees in forests affected by fires in 10 years time will be	45 dead trees per 100 (<i>status quo</i>) 30 dead trees per 100 25 dead trees per 100 20 dead trees per 100
Payment	The required payment per person per year for an additional fire prevention program	0 euros (<i>status quo</i>) 15 euros 30 euros 50 euros

Figure 1: Example of a choice set presented to respondents in the contingent choice survey

Which of the following alternatives do you prefer?

Alternative 1	Alternative 2	Alternative 3
Without additional prevention Annual Payment 0 €  10 hectares burned per 1000  45 dead trees per 100	Additional prevention mostly by prescribed burning Annual Payment 30 €  7 hectares burned per 1000  20 dead trees per 100	Additional prevention mostly by physical fuel reduction Annual Payment 15 €  5 hectares burned per 1000  30 dead trees per 100

Each combination of attribute levels constitutes an alternative. There were 27 (3^4) possible combinations or alternatives, excluding the *status quo* levels. These were randomly grouped into blocks of 2+1 (*status quo*). Each compound block of three alternatives contained (i) the *status quo* alternative, (ii) the alternative where the

majority of additional prevention measures would be conducted by prescribed burning and (iii) the alternative where the majority of additional prevention measures would be implemented by physical reduction of fuels. Three different choice sets were presented to each respondent and for each the surveyed individuals were asked to select the alternative they prefer the most within a choice set. Figure 1 reproduces a typical choice set.

Application and questionnaire

The population under study comprised 200 members of the general population in Catalonia. The strata followed the age and gender structure of the population, according to the population data for the year 2006 (INE 2007). The interviews were conducted face-to-face at the respondent's residences in June 2007. The selection of the respondents followed a random route procedure to select a household, and then the age and gender quotas to select the particular individual in the household.

The first part of the questionnaire was devoted to the presentation of the attributes to be valued, and the way of payment and consequences of it. The central part contained the choice exercise as well as some debriefing questions. The final part of the questionnaire was designed to collect some socio-economic data of the respondents.

In the introduction the questionnaire informed about the current average area of burned forest and tree mortality caused by forest fires in Catalanian forests. Further it showed the expected variation of these attributes in 10 years, if the current trend would continue and no additional measures would be taken. Next, the questionnaire informed that by implementing additional fire prevention measures, the future fire propagation and intensity levels could be modified. Three alternative levels, apart from the *status quo* option, were offered for each attribute (Table 1). To further familiarize individuals with possible levels of change, they were asked to select the most preferred level, regardless of the cost to achieve it. In this way, it could be detected whether an attribute was considered as a good or a bad, and whether the choices to be made later were consistent. In the last part of the introduction, the different prevention methods, namely prescribed burning and physical fuel reduction, were presented.

In the central part of the questionnaire, the monetary attribute was introduced. It was stated that the Catalan government was considering implementing an additional forest fire prevention program. The achievements of this program would depend on the amount of money devoted to it. The participants were told that the amount of resources would depend on their answers to the questionnaire. If on average the population would be willing to contribute an amount money to support the program,

payments would be collected annually and indefinitely from the citizens, and the money given to a foundation to be created for this purpose.

Then the respondents were presented the choice sets and asked to select their preferred alternatives. At the end, this part also contained some debriefing questions.

Finally, the questionnaire inquired about the socio-economic characteristics of the respondent.

The questionnaire was administrated in paper and read by the interviewer. To better explain and present some of the topics, pictures and graphics were shown on separate cards. The average time of the interviews was approximately 15 minutes.

Data treatment

The regression analysis was completed by using NLOGIT 3.0 software (Green 2005) and SPSS version 15.0 statistical package (SPSS 2006).

Results

A total of 207 completed questionnaires were used in the analysis. However, before turning to the discussion of the main results it should be noted, that 52 respondents (25%) always selected the *status quo* option. Most of those, selecting this alternative, where protesting to pay for a program, which in their opinion should be financed by the government. These “protest answers” were omitted from the analysis; where only positive and genuine zero bids were included.

The results of three different models estimated by the regression analysis are given in Table 2. In all of them the signs of the estimated coefficients were as expected and most of the variables are statistically significant at the 99% confidence level.

Table 2-- Results of the multi-nominal logit regression analysis

Attribute	Model I	Model II	Model III
Area burnt	-0.361*** [0.071]	-0.361*** [0.071]	-0.361*** [0.071]
Tree mortality	-0.334*** [0.079]	-0.334*** [0.079]	-0.334*** [0.079]
Annual payment	-0.422*** [0.074]	-0.422*** [0.074]	-0.422*** [0.074]
ASCSQ	-	-1.462*** [0.393]	-2.087*** [0.489]
ASCPB	1.462*** [0.393]	-	-
ASCPR	1.725*** [0.353]	0.266**[0.112]	-0.345 [0.310]
NOPB			0.507** [0.243]
Log L	- 377.99	-377.99	-375.771
Adj. Pseudo R ²	0.266	0.266	0.271

(1) Standard error in parenthesis (2) ** Denotes significance at 5% level; *** Denotes significance at 1% level

Note: the pseudo- R^2 value in MNL functions is similar to R^2 in conventional analysis except that significance occurs at lower levels. Hensher and Johnson (1981) comment that values of pseudo- R^2 between 0.2 and 0.4 are considered extremely good fits.

The negative sign in the burnt area, tree mortality and payment variables indicate that in average the Catalan population considers that higher values of these attributes decrease their welfare; i.e. less burnt area and dead trees are preferred.

The different estimated models are further exploring the preferences for applying a certain type of fuel reduction methods. These preferences, along with any other systematic unobserved effects, are captured by the alternative specific constants (ASC) (Blamey and others 2000).

In total three different models were estimated. In Model I the alternatives of applying prescribed burning (ASCPB) and physical fuel reduction (ASCPR) are compared to the *status quo* alternative. Both ASCs are statistically significant (i.e. different from zero) and positive. Meaning that both alternatives, where additional prevention measures are applied, are preferred to the alternative without additional prevention.

Model II intends to estimate whether the respondents have any preferences regarding the type of methods applied to conduct the additional forest fire prevention measures. Therefore the alternative of applying prescribed burning was compared with other two alternatives. Also in this model both ASC were statistically significant. The negative sign of the *status quo* constant (ASCSQ) confirms the result of Model I, that conducting additional prevention measures by prescribed burning is preferred to the option of no additional prevention. The positive value and statistical significance of the physical fuel removal alternative (ASCPR) is indicating that this alternative is preferred to the prescribed burning alternative.

To further inquire what might be the reason for this preference Model III was estimated. It was based on Model II by adding the dummy variable indicating respondents' knowledge about prescribed burning (NOPB). This variable takes value 1 if the respondent, before conducting this questionnaire, was not familiar with the prescribed burning method and 0 if he was. There are no changes with regards to the *status quo* alternative, which remains less desired as the prescribed burning alternative. However, the alternative specific constant of the physical removals is no longer statistically significant. This means that this alternative is not preferred compared to the prescribed burning alternative. The explanation is given by the NOPB variable. This variable is statistically significant at 95% confidence level and negative. It expresses that individuals who were not familiar with the prescribed burning method are less likely to select this alternative.

Table 3-- *Marginal values*

Attribute	Marginal value (€)
Burned forest area	-0.85 [-1.121,-0.63]
Dead trees	-0.79 [-1.041,-0.524]

(1) 95% confidence intervals in brackets; (2) Marginal values are expressed in 2007 Euros

Table 3 reports the marginal values, along with their standard errors, for the burned area and tree mortality attributes. This marginal value can be inferred by calculating

$$(3) p_a = -\beta_a / \alpha$$

where β_a is the regression coefficient of the attribute to be valued and α the coefficient of the attribute expressed in monetary units (i.e. price) (Louviere and others 2001). The confidence intervals for the marginal value for each attribute were calculated using the Krinski and Robb (1986) procedure with 2000 repetitions.

The values indicate that (i) for a decrease of burned forest area by 1 hectare per 1000 the individual, on average, would be willing to contribute 0.85 euros per year, and (ii) for a decrease in the average tree mortality caused by forest fires of one percentage point (e.g. from 30 to 29 dead trees per 100), on average, the respondents would be willing to pay 0.79 euros per year.

These values might be used to estimate the value of applying different prevention scenarios. However, it should be noted that some limitations exist. The values were estimated using given levels for each attribute (Table 1). It is uncertain if using different levels, outside this range, would result in same estimated values, since respondent's perception might vary.

Discussion

In this study it was intended to explore (i) what values people place on changes of burned forest area and decreased share of tree mortality caused by forest fires, and (ii) what are respondents' preferences related to applying different fuel reduction measures.

Regarding the first point the marginal value of the two attributes was estimated. For both we obtained negative marginal values. This was expected, since an increase in burned area or tree mortality was considered as having negative influence of the individual's utility. The results are consistent with the answers obtained in the introduction to the questionnaire. There respondents were asked to select their preferred situation with regards to different levels of burned area and tree mortality. For both attributes approximately 94% of the respondents selected the lowest levels. Based on this results it may be concluded, that the implementation of an additional

forest fire prevention program would increase the welfare of the Catalan population and that in average the population would be willing to pay for its implementation.

The second purpose of this study was to obtain the preferences the Catalans have, regarding the application of different fire prevention methods, namely prescribed burning and physical fuel reduction. This question was of particular interest, since prescribed burning is still not widely accepted and applied in Spain. Furthermore, most of awareness campaigns described any type of fire in the forest as bad. Therefore, the concerned exists that using fire for fuel management might be rejected by the public.

However, the regression analysis results demonstrated that the public is indifferent which method is used to implement additional prevention. This is consistent with the responses to additional questions, where no differences were detected between the shares of respondents supporting the use of physical fuel reduction methods and prescribed burning. Also when explicitly asked to select which method the respondents prefer, 24% replied prescribed burning, 36% physical removal and 26% were indifferent.

However, the results also clearly demonstrated, that a part of the population is still not informed about the possibilities of applying fire as a management tool. Therefore it is necessary to put more efforts on information and education campaigns, before widely applying prescribed burning.

One final remark should be put on how the respondents perceived the scenario applied in this study. Fire prevention measures and the benefits of applying them might be less known among the general population. This might cause, that respondents overestimate the effects of the application of such measures and express their support based on wrong assumptions. We tested this by asking the respondents which, in their opinion, is the possibility that a forest fire occurs after prevention measures have been applied. Only around 4% of the respondents answered that it is not possible at all, while the rest considered that even after the prevention measures have been applied forest fires may can occur.

In summary, this study showed that the Catalan society considers the implementation of additional forest fire prevention as beneficial and would be supporting it. It also showed that both of the proposed methods for the implementation of such program (i.e. prescribed burning and physical fuel removal) are considered as acceptable by the society. However more efforts should be devoted to inform the population about the possibilities and benefits of applying new types of prevention methods, such as prescribed burning.

Acknowledgments

This study was supported by the EU financed project FIRE PARADOX: *An Innovative Approach of Integrated Wildland Fire Management Regulating the Wildfire Problem by the Wise Use of Fire: Solving the Fire Paradox* (FP6-018505).

We would also like to thank Dr. José Ramón González for his suggestions, explanations and comments.

References

- Bennett, Jeff W.; Blamey, Russell K. 2001. **The choice modelling approach to environmental valuation**. Cheltenham, UK: Edward Elgar Publishing.
- Blamey, Russell K.; Bennett, Jeff W.; Louviere, Jordan J.; Morrison Mark D.; Rolfe, John. 2000. **A test of policy labels in environmental choice modelling studies**. *Ecological Economics* 32: 269-286.
- BOE. 2005. **Real Decreto-Ley 11/2005, de 22 de julio, por el que se aprueban medidas urgentes en materia de incendios forestales**. Official Journal of Spain 175 (2005): 26341 - 26348.
- GENCAT. 2007. **Estadístiques d'Incendis**. Barcelona: Generalitat de Catalunya, Generalitat de Catalunya, Departament de Medi Ambient i Habitatge; available from: http://mediambient.gencat.net/cat/el_medi/incendis/
- EFFIS 2006. **Forest Fires in Europe 2005**. Ispra, Italy: European Commission – Joint Research Centre.
- Gonzalez, Jose R. 2006. **Integrating fire risk in to forest planning**. Joensuu, Finland: University of Joensuu; Ph.D. dissertation.
- Gonzalez, Jose R.; Trasobares, Antoni; Palahi, Marc; Pukkala, Timo. 2007. **Predicting stand damage and tree survival in burned forests in Catalonia (North-East Spain)**. *Ann. For. Sci.* 64: 733–742.
- Green, William H. **NLOGIT 3.0** [Computer program]. 2005. Plainview, NY: Econometric Software Inc.
- Hanley, Nick; Mourato, Susana; Wright, Robert E. 2001. **Choice modelling approaches: A superior alternative for environmental valuation?** *Journal of Economic Surveys* 15:433-460.
- Hensher, David A.; Johnson, Lester W. 1981. **Applied discrete choice modelling**. New York: John Wiley and Sons.
- Holmes, Thomas P.; Adamowicz, Wiktor L. 2003. **Attribute-Based Methods**. In: Camp, Patricia A.; Boyle, Kevin J.; Brown, Thomas C., editors. *A Primer on Nonmarket Valuation*. Dordrecht: Kluwer Academic Publishers; 171-220.
- INE. 2007. **Cifras de población**. Madrid: Instituto Nacional de Estadística; available from: <http://www.ine.es>
- Krinsky, Itzhak; Robb, Leslie. 1986. **On Approximating the Statistical Properties of Elasticities**, *The Review of Economics and Statistics* 68(4): 715-719.
- Louviere, Jordan J.; Hensher, David A.; Swait, Joffre D. 2000. **Stated choice methods: Analysis and applications**, Cambridge, UK: Cambridge University Press.
- Manisfield, Carol; Pattanayak, Subhrendu. 2007. **Getting Started**. In: Kanninen, Barbara, J., editor. *Valuing Environmental Amenities Using Stated Choice Studies – A Common Sense Approach to Theory and Practice*. Dordrecht: Springer-Verlag; 1-20.
- Martins Fernandes, Paulo A. 2001. **Fire spread prediction in shrub fuels in Portugal**. *Forest Ecology and Management*: 144: 67-74.
- McFadden, Daniel L. 1973. **Conditional logit analysis of qualitative choice behavior**. Pages 105–142 in P. Zarembka, editor. *Frontiers in econometrics*. Academic Press, New York, New York, USA.
- MMA 2006. **Los incendios forestales en España durante el año 2005**. Madrid, Spain: Spanish Ministry of Environment: 119 p.

- MMA 2007. **Los incendios forestales en España durante el año 2006 – Draft Report**. Madrid, Spain: Spanish Ministry of Environment: 26 p.
- Piñol, Josep; Terradas, Jaume; Lloret, Francisco. 1998. **Climate warming, wildfire hazard, and wildfire occurrence in coastal eastern Spain**. Climatic Change 38: 345-357
- Riera, Pere; Mogas, Joan. 2004. **Evaluation of risk reduction in forest fires in a Mediterranean region**. Forest Policy and Economics 6:521 – 528.
- Riera, P., J. Peñuelas, V. Farreras and M. Estiarte. 2007. Valuation of climate-change effects on Mediterranean shrublands. Ecological Applications: 17:91–100.
- SPSS. 2006. **SPSS 15.0** [Computer program]. Chicago, IL: LEAD Technologies Inc.
- Unsworth, Robert E.; Bishop, Richard C. 1994. **Assessing natural resource damages using environmental annuities**. Ecological Economics 11 (1):35–41.
- Xanthopolus, Gavriil; Caballero, David; Galante, Miguel; Alexandrian, Daniel; Rigolot, Eric; Marzano, Raffaella. 2006. **Forest Fuels Management in Europe**. In: Andrews, Patricia L.; Butler, Bret W., comps. Fuels Management – How to Measure Success: Conference Proceedings. 28-30 March 2006; Portland, OR. Proceedings RMRS-P-41. Fort Collins, CO: U.S. Department of Agriculture Forest Service, Rocky Mountain Research Station; 29-46.

The Impact of Fire and the Socioeconomic Vulnerability of Forest Ecosystems: A Methodological Approach Using Remote Sensing and Geographical Information Systems¹

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Abstract

The growing demand from agencies and institutions involved in forest and land management for cartographic products integrating descriptive forest resource variables, implies an increase in the research and development of tools based on geographical information systems. The operational capacities that are offered by employing thematic cartography applied to strategic planning, and the ease with which modifications and adaptations can be made according to the specific needs and types of natural resource management, have transformed digital cartographic information into a highly useful working tool in forest fire management programs.

Thorough knowledge and evaluation of forest ecosystems are basic elements in the planning and research of the measures needed for protection against forest fires in a given territory. By extending diagnostic studies from the conceptual vantage point of vulnerability, this paper will present the methodological procedures which have been developed to recognize, evaluate, calculate and integrate the results obtained of the specific forest resources in the study area from an economic standpoint, using this economic analysis within the framework of potential levels of fire intensity that a standard fire can generate, by also factoring in historical weather and topographical influences. The integration of such mathematical algorithms with these cartographic interpolation and processing tools will facilitate the creation of maps that allow us to follow through with fire protection activities taking into account specific spatial and temporal factors adjusted to each of the resources identified in the forest, as well as the integral value of the resources existing in each of the units under evaluation. By incorporating evaluations of post-fire effects through the treatment of satellite images (Modis), we can adjust the results of the standardized indices for vegetation and fire intensity levels, thus obtaining percentage

¹ An abbreviated version of this work was presented at the Third International Symposium on Fire Economics, Planning and Policy: Common Problems and Approaches, 29 April to 2 May 2008, Carolina, Puerto Rico.

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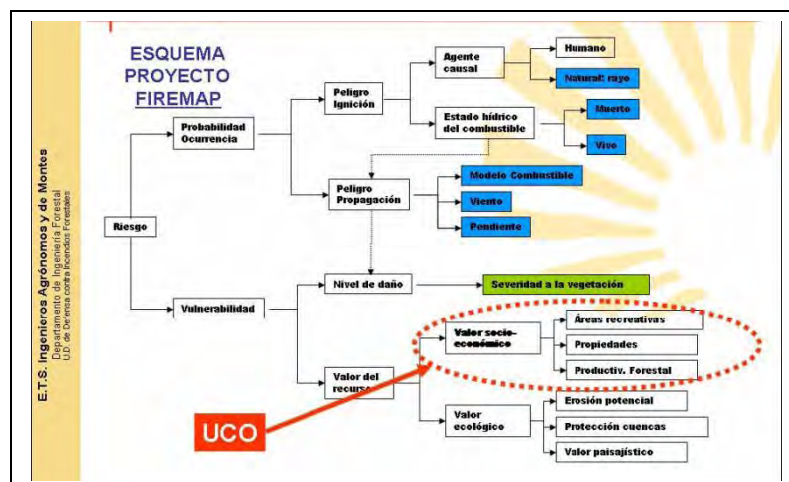
ratios to determine the economic depreciation that will be produced in forest resources due to the direct impact of forest fires.

The results from socioeconomic vulnerability analyses will be integrated into the framework of the FIREMAP research project (with financing from Spain's Ministry of Education and Science), in which, together with the algorithms providing occurrence probability and ecological vulnerability, an index of the synthetic risk of forest fires will be determined through the integrated analysis of the economic and ecological evaluation tools, SIG and remote sensing.

Keywords: Vulnerability, fire intensity level, geographic information systems, remote sensing, forest fire protection planning, risk assessment.

Introduction

This paper discusses the determination of socioeconomic vulnerability when faced with the impact of forest fires within the context of a research Project called “Integrated forest fire risk analysis using remote sensing and geographic information systems” (financed by the Ministry of Education and Science of Spain). This project responds to the coordinated project modality, and has, as its objective, the integration, with a synthetic risk index, of a set of variables, which are sensitive to the impact of forest fires. This includes ecological and socioeconomic vulnerability, as well as variability in the humidity of fuels analyzed with indexes derived from the treatment of satellite images, the incidence of rays, the risk of fire due to human impact or presence, and the description of fire behavior. The determination of an algorithm integrating all of these factors, and the automation of calculation and management by means of geographic information systems, constitutes the central axis for the project, based on the fundamental premise of providing a versatile tool to be used during operational management by the entities and government institutions responsible for forest fire protection. The overall structure and the relations between the variables discussed herein are outlined in Figure 1.



Procedure and Methodological Structure Developed to Obtain Forest Fire Socioeconomic Vulnerability.

Socioeconomic vulnerability has been determined through the development of a set of algorithms that make it possible to evaluate the consequences of forest fires on both tangible and intangible natural resources. A spatial cell of 10x10km has been established for the geographically referenced determination of variables in interpreting economic evaluation; the information is later rasterized into cells of less than 1x1km. The size of the 10km cell is justified by the connection with the national database on forest fire statistics, which uses this dimension to spatially reference the occurrence of forest fires.

The general structure that has been used has firstly been for contacting and identifying the set of variables needed to create algorithms, and has simultaneously identified the existing digital coverage which makes it possible to obtain, link, and interpolate the variables that have been selected for the calculation of the dependent variables, which provide the solution to the algorithms developed. Subsequently, a set of explicative variables on the socioeconomic valuation has been integrated within a representative vulnerability model for the specific cell; finally, the cartography provides a forest fire socioeconomic vulnerability map for each one of the studied territorial units, the operational model, and the architecture of the calculation employed. It has been focused on making easier the adaptation and application of the procedure in other areas, different from those which were selected for the experimentation of the development model. (Rodríguez y Silva, et al., 2007) (figure 2).



Figure 2— Representation of the key elements of the designed system.

Work Stages

1. The first stage was initiated with a state-of-the art bibliographic review for each of the blocks (1 through 5):

1.1. Socioeconomic evaluation of the landscape and recreational capabilities.

1.2. Socioeconomic evaluation of the production of forestry systems.

1.3. Analysis of the environmental interrelationships, and the protection provided by the forestry systems.

1.4. Socioeconomic evaluation of the services provided by the forestry systems.

1.5. Socioeconomic evaluation of the present state of the forest.

2. In the second stage, the viability of the most widely accepted evaluation methods was analyzed, tackling, when needed, the adaptation or development of tools and/or mathematical expressions that best match the economic evaluation to the natural resource being analyzed. In this sense, and in cases of intangible natural resources, economic evaluation methods have been contrasted, such as “contingent evaluation” and “travel cost method” applied to the blocks (1 through 5).

3.- The third stage involved the demarcation and inventory of the required variables in the area of study, taking into consideration that there might be a varied representation of the forestry resources for the designated area, with the aim of strengthening the integrating model of the different evaluations, making it possible to apply this method in different areas, aside from the one being used to conduct these experiments.

4.- The fourth stage proceeded with determination of fire intensity levels according to historic occurrence and the spatial characteristics with which they might potentially originate and evolve, thus establishing the necessary relationships between the impact of energy emissions on the respective forestry resources. Simulations made with the “Visual Cardin-Nuatmos” program revealed the spatialized behavior of potential fires, using as complementary tools the precedents of past fires and the analysis of impact with the treatment of satellite images. The availability of the geographically referenced impacts made it possible to effectively evaluate the economic extent of potential damage.

5.- The fifth stage involved studying and determining the economic valuation of the revenue generated by the forest environment and the economic valuation of the damage according to potential fire intensity levels for each area, as well each of the thematic blocks indicated, with the exception of block (5).

In the socioeconomic valuation by cell, the qualitative and quantitative determination of the environmental, leisure and recreational, and natural resources,

landscape, and present condition have been considered in a differentiated way. Within the natural resources group, the following blocks have been integrated to the model: wood, cork, fruit, lumber, game and fish, and other less significant products (apiculture, mushroom cultivation, etc.). Species that are classified as protected, as well as natural monuments, have also been recognized, evaluated, and included within the model.

In the block for environmental aspects, the inherent particularities for carbon fixing and loss, erosion, and lack of use have been analyzed and evaluated. The growing importance of landscape resources provided motivation for keeping this factor under consideration and developing an algorithm for the socioeconomic evaluation and valuation, which recognizes that today's society values it. For this reason, the following aspects have been analyzed: quality and fragility, completing the analysis in three stages, the intrinsic landscape, the immediate surroundings, and the scenic background (figure 2).

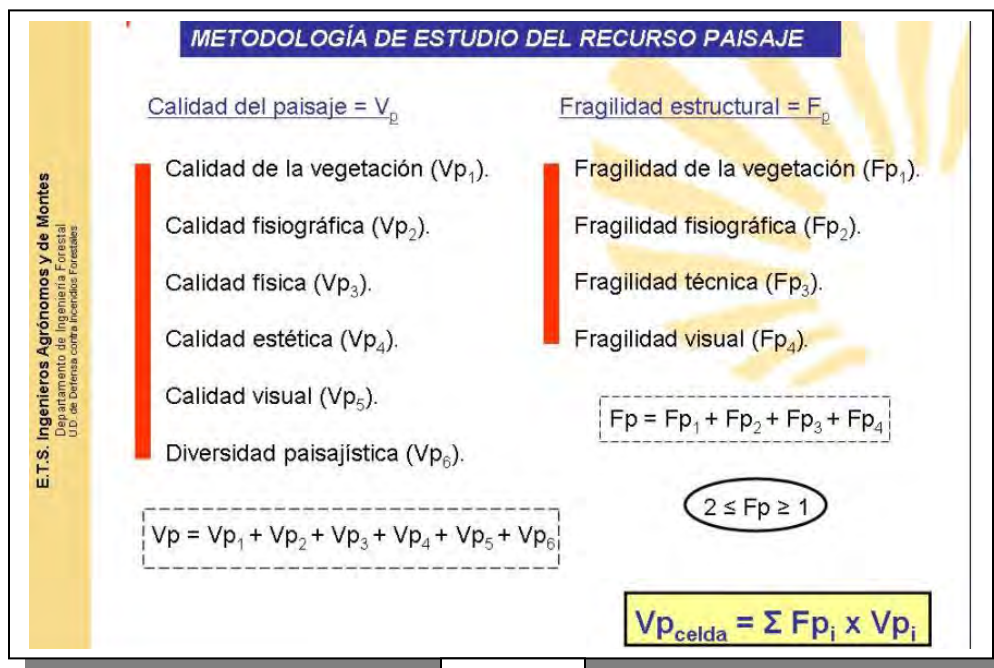


Figure 3

Figure 3—Methodology of the landscape resource study.

The allocation of the quantitative valuation of landscape resources has been obtained through the use of econometric techniques of contingent valuation (figure 4).

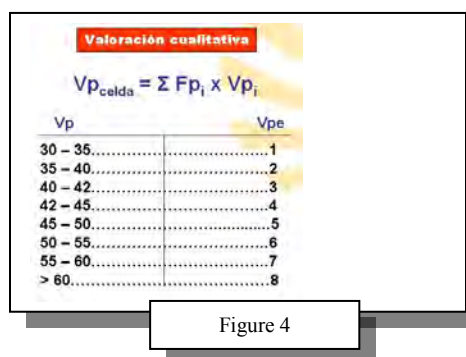


Figure 4— Qualitative valuation of the landscape resource.

The study and valuation of leisure and recreational resources has been obtained by integrating the representation and quality of the landscape with the use of the “travel cost” method (Riera 2000), so it may thus acquire the demand function that makes it possible to economically assess visitor preferences in relation to the greatest or smallest capacity that the natural surroundings present (figure 4). The economic valuation obtained through the demand function has been considered with a factor that links it the quality of landscape, from which its valuation is analyzed in relation to the quality of the region it belongs to.

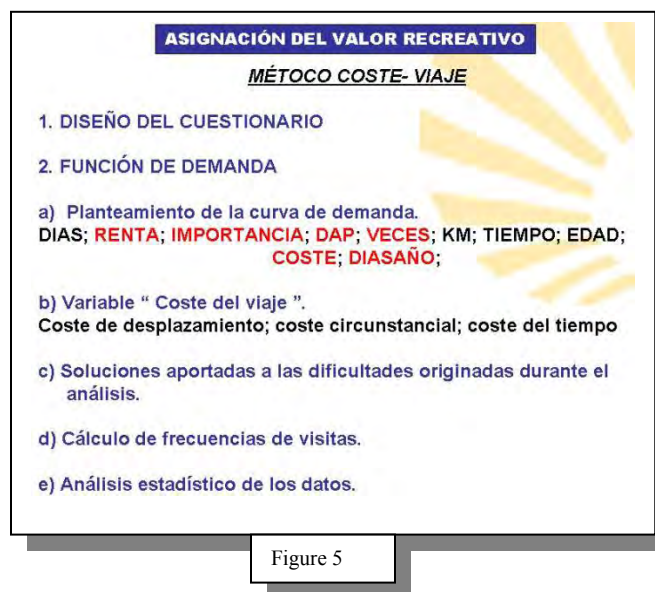


Figure 5—Allocation of the recreational value using the travel cost method.

The demand function used is the following:

$$D_{ij} = f(C_{ij}, R_{ij}, V_{ij}, E_{ij}, I_{ij})$$

While **D** is the number of days per year which visitor “i” spends in place “j,” **C_{ij}** is the cost it poses on person “i” to travel to “j.” **R** is the income of visitor “i,” who adopts 4 values obtained from the interview. **V_{ij}** are the times per year in which visitor “i” goes to place “j.” **E** is a fictional variable that acquires a value of 1 if the interviewee is willing to pay a cover charge, and a value of 0 if he or she is not. **I** represents the importance that individual “i” places on forest areas; it acquires a value of 4 if it is given maximum importance and 1 if it is given minimal importance.

Once the curve of demand is known, the calculation for the economic value of the place can be estimated with the following formula (Bishop 1983):

$$VET = \frac{DIAVISITA^2}{2 \times \alpha}$$

Where **VET**: is the total economic value, **DIAVISITA** is the time the visit lasts in half days, and **α** is the estimated coefficient in the regression equation for the cost variable.

Applying this formula to each of the influence areas, a total economic value is obtained per area and visitor. Finally, the frequency of visitors in each of the areas was used to measure the definite value per visitor, and was multiplied by the number of visitors per year.

The valuation of forest products was made while keeping in mind the maturity level of mass as well as the remote and immediate products, and making a detailed revision of the existing coverage with the use of digital cartography. The products used were:

- Spanish Forestry Map
- Forestry Map of Andalucía
- Land cover Uses and Vegetation Coverage (2003 revision)
- II National Forestry Inventory
- Digital Orthophotography
- Digital Terrain Model

Valuation was determined according to forest product cataloging (Martínez Ruiz 2005) using a generic algorithm to which modifications have been incorporated as required by the product and median age of the mass in which it is found. Afterwards, the net change in the value of the resources was corrected with the forestry productivity map (figure 5).

$$\text{Final Valuation} = \varphi \times K \times S$$

While, ϕ is the harmonization function, K is the canopy cover fraction, and S is the affected area for each species due to fire.

The harmonization function is:

$$\phi = \frac{a \times E \times B}{E + b \times B}$$

While, a , b are coefficients, E is the variable according to growth cycles, and B is the variable adapted to Mediterranean ecosystems.

Application Variable for each Fire Intensity Level (FIL) and species:

$$B = \left[\frac{V \times P^* \times c^n}{1.04^n} \right] \times \left[1 - \left(\frac{c}{1.04} \right)^e \right] \times [1 + X \times h \times t]$$

Where, B is the variable to be estimated, V is the volume to be cut m^3/ha (future forecast), P^* is the price of the m^3 of cut wood (Euros), c is the coefficient, n is the number of years left until the next cutting cycle arrives, e is the real age of the mass, X is the mortality coefficient which in turn depends on t , h is the percent of immature and mature mass of species (i) in the total mass, and t is the percent of affected mass at a fire intensity level (FIL) expressed as a function of the longitude of the forecasted flame according to fire behavior.

The calculation method for X and T is shown in detail later on.

Variable E according to growth cycles:

$$E = Co * t * K [i^e + g(i^e - 1)] + A [i^e - 1]$$

Where E is the variable according to growth cycles, Co is the cost of repopulating one hectare of land (Euros/ha.), t is the percent of the affected mass at a fire intensity level (FIL) expressed as a function of the longitude of the forecasted flame according to fire behavior, K is the tree canopy cover fraction, i , g are the interest rates that fluctuate depending on the mass cycle, a is the value of a hectare of land (Euros/ha.), and e , is the real age of the mass.

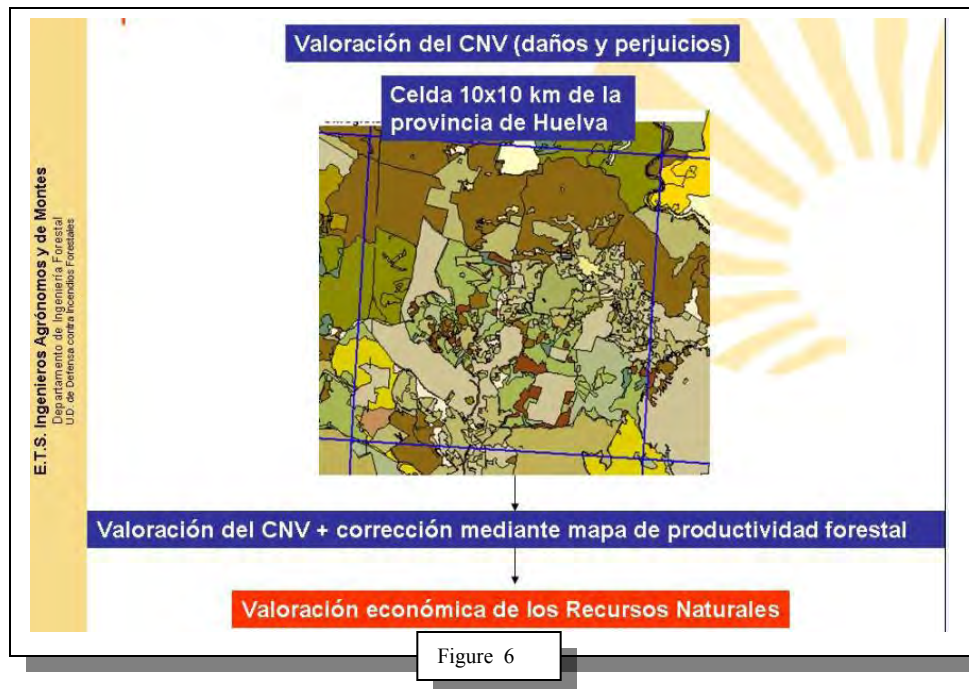


Figure 6—Economic valuation of natural resources.

The application of the algorithm with geographic tools (Walpole et al. 2005) provides interpretative maps on the socioeconomic valuation of the forest product. In the context of the FIREMAP project, detailed studies have been carried out in five regions in the province of Huelva, from which the corresponding collection of digital cartography has been created (figure 7).

Game activity is presented as a sustainable resource during the period in which it has market valuation, given that game animals have a commercial transaction price. In order to value this resource, the procedure is to obtain a value for each ecosystem as the sum of the updated, annual hunting revenue, and the stock producer:

$$V = R / i$$

Where, V is the value for game effects, R is the sustainable game revenue per year, i is the type of update. An annual game revenue has been allocated for R , for each base and height (Spanish Forestry Map), so that the graticule game value can be obtained as the sum of the value for each of the colored map units. In order to obtain this valuation, it was necessary to establish the average percentages of the tree and shrub canopy cover fraction by stratum, and for each of the 10 x 10 Km. graticules in which the region is divided.

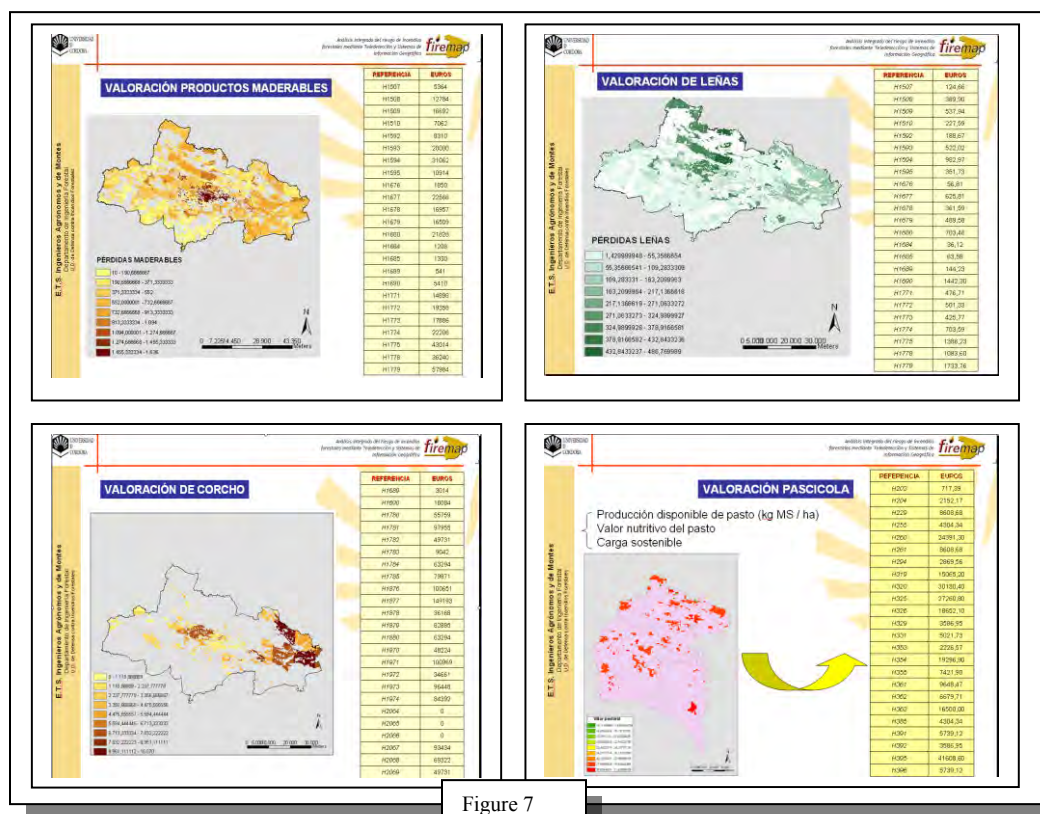


Figure 7

Figure 7—Digital Cartography of the valuation of different resources in provinces of Huelva, Spain.

The percentage of the tree cover fraction is obtained with the data that appear on the II National Forestry Inventory. With the diameter of feet by plot and stratum, the tables that link diametric classes and the average size of the tree top can be accessed. The number of feet by plot and stratum are also known; when multiplied by the average size of tree tops, the percentage of tree canopy coverage for each stratum by plot is obtained.

The data obtained was geographically referenced and interpolated as stratum and graticule with the ArcGIS 8.3 program. After said process, a median was obtained from the data of each stratum; thus, the average value of each tree canopy cover per graticule was calculated. When the stratum consisted of a mix of several species, calculations were made according to the previously mentioned process, considering all the data separately for each of the species.

Once the representative value of the tree and shrub canopy cover was obtained for each graticule, it was multiplied by the sum of the game revenue and by the area of every graticule within the region, and the final result was obtained. In order to go through the entire calculation process by graticule, a model of tables like the one

shown below was used (table 1), in which graticule E06 of the province of Huelva (Spain) is presented as an example (figure 8).

CUAD	Pcto. Arbust	Pcto. Arbor	S base	S vuelo	Tot-suma	SUP	TOTAL
E06	0,12	0,88	18,00	54,00	49,64	184,54	9.159,77

Table 1—results of the economic losses of hunting (Euros).

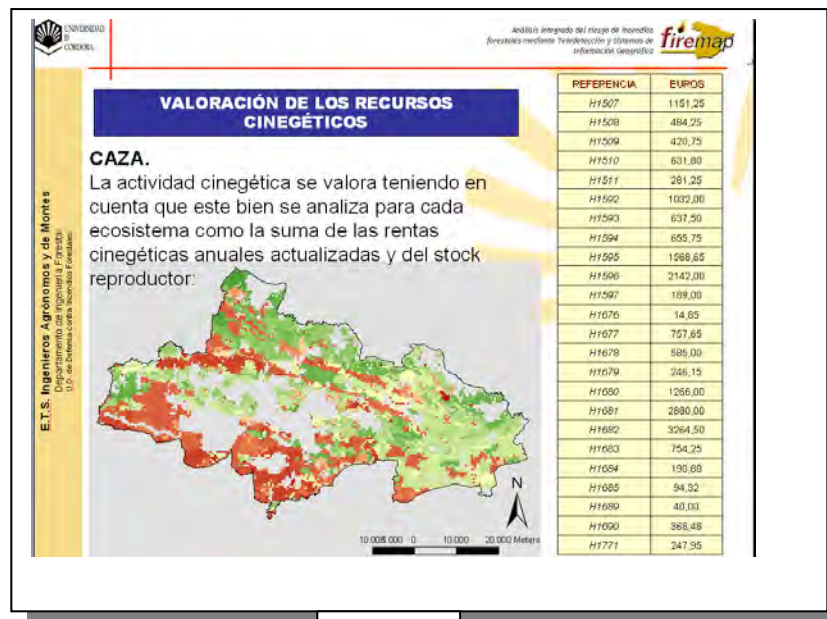


Figure 8

Figure 8—Valuation of game resources.

While, **Cuad** is the studied graticule, **Pcto. Arbust** is the average percentage per graticule of shrub strata, **Pcto. Arbor** is the average percentage per graticule of tree strata, **S base** is the sum of the game incomes associated with the bases in each graticule (Euros), **S vuelo** is the sum of the game incomes associated with the heights in each graticule (Euros), **Tot-suma** is the partial sum (Euros/ha), **Sup** is the area of each graticule (ha), and **Total** is the total sum (Euros).

With the availability of the complete results provided by the different algorithms developed for the evaluation and measurement of each of the variables belonging to the previously indicated blocks, the determination of the depreciation that can develop by the impact of fire, which is more frequent in the area (fire behavior), can be approached. For this purpose, combustibility and its spatial dynamic were analyzed, allocating the energetic particularities of fire propagation for each studied

cell. From the information obtained, and through the establishment of fire intensity levels (classification based on the longitude of flames), a depreciation coefficient matrix has been determined which makes it possible to identify the scope of fire impact on the different natural resources existing within the region (figure 9).

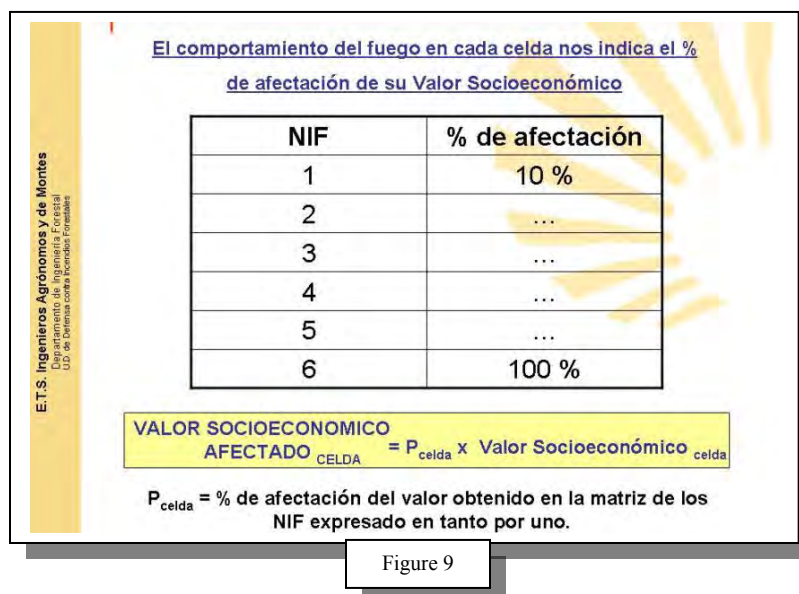


Figure 9—fire behavior by intensity level indicates the percent of change of its socioeconomic value.

A methodology based on the use of satellite images of forest fires has been developed in order to determine and validate the percentages of decrease or depreciation of the economic value of the different natural resources per hectare included in the valuation. The process includes obtaining the percental value of change as a function of two independent variables:

Average linear intensity of the front of the flames (kw/m) of the analyzed pixel, generated by the combustion emitted by the forest vegetation. This variable was later translated to its equivalent in flame longitude (m).

Normalized vegetation index (quotient of radiometric information, obtained with the difference which corresponds to the near infrared waves and the red, divided by the sum of both values)

$$NVDI = \frac{NIR - RED}{NIR + RED}$$

The range of variation of the NVDI, varies between (-1) and (+1)

- Water, snow, and clouds. -1 → 0, Reflect more red radiation than

infrared radiation.

- Rocks and bare soil. ≈ 0
- Vegetation. $0 \rightarrow 1$, Positive values.
- High vitality state ≈ 1
- Fires and high stress. Low, but positive values.

During the treatment of the analyzed images, pre- and post-fire scenarios have been considered in order to determine vegetation response, comparing the results on the same pixel in order to identify the behavior or the index.

For this first methodological approach, field research has been made on two forest fires which occurred in 2006 in the provinces of Huelva (the Alajar fire) and Malaga (the Gaucin fire). Both covered over 500 hectares and a great diversity of forest vegetation. This situation has allowed the results to be extended to a larger combination of forest fuels.

The studied images correspond to the ones obtained with the MODIS sensor, located on the Terra and Aqua satellites (NASA). The spatial resolution of the images is 250x250 meters.

The process included locating a set of plots that identify the severity in each of the forest resources, of which its socioeconomic valuation had been previously determined, in the areas affected by the fires. The severity was measured in function of the scorch height (in the case of the tree canopy) and in function of the percent of consumed vegetation (in the case of brush).

In each cell or grid of 250x250 meters, 9 circular plots of 10 meters in diameter were measured. Between the centers of the plots, a distance of 125 meters was established, and the transect sampling was done following perpendicular lines. The center of each plot was identified with its geographic coordinates, measured with the GPS (with differential correction). The information considered on the grid was the type of dominant vegetation coverage (more than 75% of the surface area), with the objective of extending the results on the severity of the measurement to the groups of brush, conifers, lush woods, and mixed woods.

Subsequently, a study on the reconstruction of the fire behavior was made, determining the average flame longitude for each plot, which caused the propagation of the fire. During this calculation process, the simulators Visual-Cardin and Visual-Behave were utilized (Rodríguez y Silva 1997, 2002). With the obtained data, an integrated matrix was elaborated with the results from each pixel of land in which the percentage of severity (in terms of the mortality of the affected vegetation) the fire intensity level (depending on the flame longitude), and the normalized vegetation index (NDVI) were interrelated (figure 10).

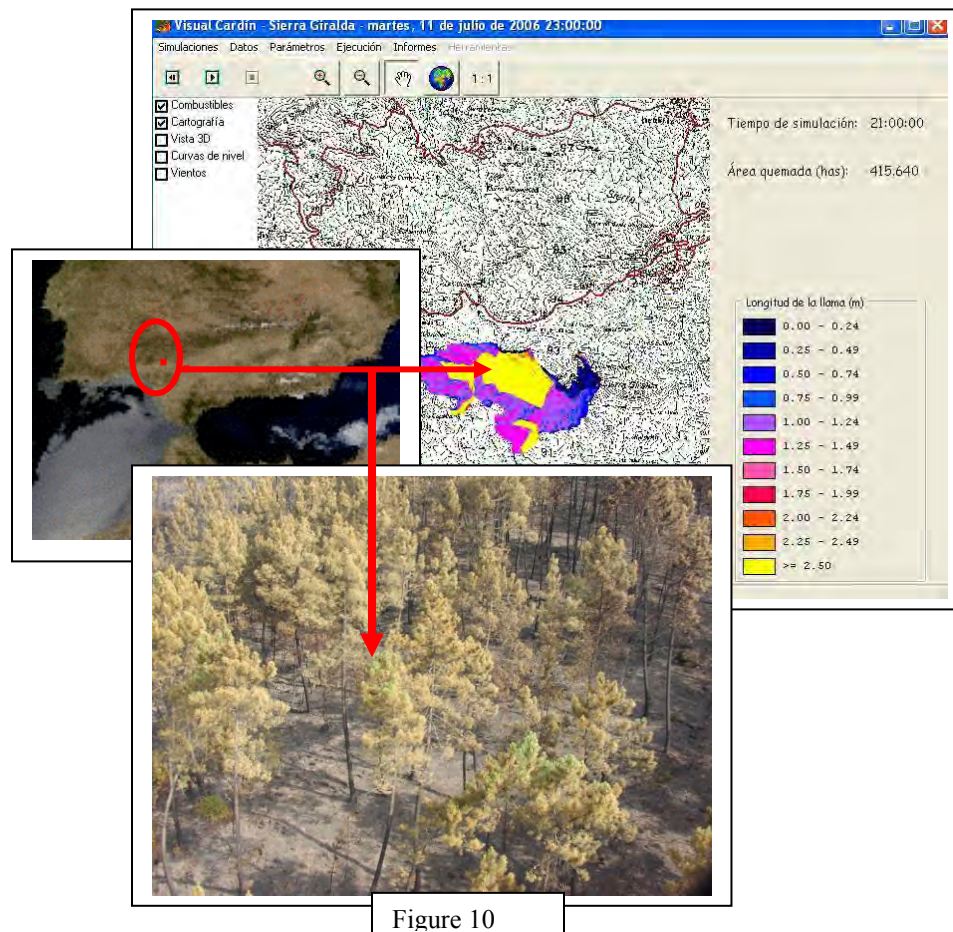


Figure 10

Figure 10 —reconstruction of fire behavior, with average flame longitude which propagated the fire determined for each plot.

Prior to these studies, a multivariable regression equation that provides the percentage of depreciation was acquired, which, applied to the initial socioeconomic value, provides the losses caused by the forest fire, as well as the residual economic value of the vegetation that was not affected by the fire.

The regression model presents the following equation:

$$\%Dep = 0,38648 + 0,0795303\phi - 0,524952\beta; \text{ con } R^2 = 0,89$$

While, %Dep represents the percentage of depreciation of the economic value of the forest resource (vegetation coverage), Φ represents the average fire intensity level in the pixel (FIL), and β represents the value obtained for the normalized vegetation index in the analyzed pixel.

The use of an empirical table on the percentages of depreciation, according to the fire intensity level (FIL) determined in each pixel, has been temporarily proposed

until a final model of the depreciation for each of the resources is acquired (figure 10). Currently, studies are being developed in order to obtain the algorithms and validation on a scenario of 2.500 hectares affected by a great fire which lasted from 29 July 2007 to 31 July 2007 in the province of Córdoba (Córdoba-Obejo fire).

NIF	Vrm madera	Vrme frutos	Vrc corcho	Vrp pesca	Vrca caza	Vrpai paisaje
I	10%	5%	20%	1%	10%	5%
II	20%	10%	45%	5%	25%	15%
III	40%	20%	65%	10%	45%	35%
IV	60%	45%	85%	25%	65%	55%
V	80%	65%	95%	35%	85%	85%
VI	90%	75%	100%	45%	100%	100%

Figure 11

Figure 11—Empirical table of depreciation percentages according to the fire intensity level (FIL) determined for each pixel.

Finally, the conversion to risk ratio or socioeconomic vulnerability index was determined with a conversion matrix of monetary units into qualitative indexes which classify the potential severity that the impact of possible forest fires might generate in the region of study, facilitating at the same time the connection with other indexes originally from other valuations within the framework of the FIREMAP project (figure 12).




Análisis integrado del riesgo de incendios forestales mediante triangulación y sistemas de información geográfica

Cada variable económica de recurso específico, tiene asociada su tabla de selección del **Índice de riesgo socioeconómico** correspondiente

Variable → Tabla de intervalos de valoración → Índice de Riesgo SEC

Determinado el NIF, se seleccionan los porcentajes de afectación de la Valoración económica obtenida por la existencia de cada uno de los recursos en la celda analizada. El valor económico reducido se lleva a la Tabla individualizada de conversión para obtener el peso de cada índice

Intervalos de Valoración Económica de la Variable: Madera (V_{MAD}) €/ha	Índice de Riesgo Socioeconómico Madera (I_{MAD})
< 4.000	1
4.001-6.500	2
6.501-8.500	3
8.501-10.500	4
> 10.501	5
Intervalos de Valoración Económica de la Variable: Ocio y Recreo (V_{OCOR}) €/ha	Índice de Riesgo Socioeconómico Ocio y Recreo (I_{OCOR})
< 2	1
2,1-5,5	2
5,6-7,5	3
7,6-9,5	4
> 9,6	5

Figure 12

Figure 12—socioeconomic vulnerability risk index.

Acknowledgments

The authors of this work wish to express their gratitude to the FIREMAP project of the Ministry of Education and Science (CGL2004-06049-C04-03/CLI) and to the autonomous public organizations.

References

- Bishop, R., Heberlein, T., Kealey, M.J. 1983. Contingent Valuation of Environmental Assets: Comparisons with a Simulated Market. *Natural Resources Journal*, 23: 619-633.
- Martínez Ruiz, E. 2005. *Manual de Valoración de Montes y Aprovechamientos Forestales*. (Spanish). Madrid: Ediciones Mundi-Prensa; 184 pp.
- Riera Font, A. 2000. Mass tourism and the demand for protected natural areas: A travel cost approach. *Journal of Environmental Economics and Management* 39(1): 97-116.
- Rodríguez y Silva, F. Molina JR. Herrera M. Zamora R. 2007. Vulnerabilidad socioeconómica de los espacios forestales frente al impacto de los incendios, aproximación metodológica mediante sistemas de información geográficos (proyecto Firemap). IV International Wildland Fire Conference. Proceedings. Seville. (www.wildfire07.es)
- Riera Font, A. 2000. Mass tourism and the demand for protected natural areas: A travel cost approach. *Journal of Environmental Economics and Management* 39(1): 97-116.
- Walpole, S.C., Sinden, J.A., 2005. BCA and GIS: integration of economic and environmental indicators to aid land management decisions. *Ecological Economics* 23: 45-47.

Willingness-to-Pay Function for Two Fuel Treatments to Reduce Wildfire Acreage Burned: A Scope Test and Comparison of White and Hispanic Households¹

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Abstract

We estimate a marginal benefit function for using prescribed burning and mechanical fuel reduction programs to reduce acres burned by wildfire in three states. Since each state had different acre reductions, a statistically significant coefficient on the reduction in acres burned is also a split sample scope test frequently used as an indicator of the internal validity of contingent valuation surveys. In this paper the dichotomous contingent valuation method is used to test for scope of the sensitivity of respondent's willingness to pay for prescribed burning and mechanical fire fuel treatment programs to the acreage reduction of wildfires. The logit models were estimated for white and Hispanic households in California, Florida and Montana. The results of logit regressions show that the acreage reduction variable is statistically significant at the 1% level among proposed programs and groups of people. The positive sign of this variable means that the more acreage reduction is proposed, the more likely people would like to pay for the fire fuel reduction programs. Because of the significance of acreage reduction variable in the willingness to pay function, this function can be used to evaluate the incremental benefits of different forest fire management plans that reduce additional acres burned. These benefits could be used as budget justification for prescribed burning and mechanical fire fuel reduction programs to protect forests from wildfires.

Keywords: California, cotingent valuation, Florida, mechanical fire fuel reduction, Montana, prescribed burning, scope test, willingness to pay.

¹ An abbreviated version of this paper was presented at the Third International Symposium on Fire Economics, Policy and Planning, April 29 to May 2, 2008, Carolina, Puerto Rico.

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Introduction

On August 20, 2002 President George W. Bush approved the Healthy Forests Initiative to restore the health of forests and rangelands in the western United States, particularly on public lands and areas of the wild land urban interface. As part of this Initiative, natural resource agencies will increase the use of two fuel treatment methods: the prescribed burning and the mechanical fire fuels reduction. The prescribed burning method is defined as the controlled application of fire to existing naturally occurring fuels under specified environmental conditions following appropriate precautionary measure (Florida Division of Forestry, 2000). The mechanical fire fuel reduction method consists of mechanically removing smaller trees and vegetation. This mechanical fuel reduction method is especially effective at lowering the height of vegetation, which reduces the ability of fire to climb from the ground to the top or crown of the trees.

On public lands there are not market signals that reveal the demand or value for these fire fuel reduction programs. Providing this type of information would allow the program managers and policy makers to determine the efficient level of prescribed burning and mechanical fire fuel reduction programs (hereafter RX and Mech programs) in each state. To estimate this value, the contingent valuation method is often used and willingness to pay of the respondent to proposed programs is elicited.

Contingent valuation method is a direct survey method where any biases on the part of interviewers, the design and implementation of the survey or the respondent, can jeopardize the reliability and validity of the willingness to pay (WTP) estimates. One way the internal validity can be assessed is from the answer to a question: Does the willingness to pay vary with factors that would be expected to influence it under economic theory? (Arrow and others 1993). One of the logical checks is that the WTP should increase when more of the “good” is offered. This is usually termed a scope effect or scope sensitivity analysis. Scope sensitivity is considered a necessary condition for the validity of the WTP. Thus, the scope test, to measure the sensitivity of the WTP in accordance with the change in levels or extent of the public program, has attracted substantial research and it has been viewed as a critical test for a contingent valuation study. The scope test could be internal to the respondent or external to the sample. The internal scope test is used to test for differences in WTP for different levels of the good for the same respondent; the external test measures the change in WTP for separate respondents across the sample at different levels of the public good.

There have been scope tests conducted in CVM using in-person interviews (Carson, Wilks and Imber 1994), and a few mail surveys (Loomis and Ekstrand 1997). Carson (1997) indicates that while some CVM surveys do not pass a scope test that many do. Scope tests have been evaluated for environmental quality and visibility assessments (Smith and Osborne 1996) and in developing countries (Memon and Matsuoka 2002), but to our knowledge there have not been external scope tests for forest/forest fire management, nor for Spanish speaking respondents.

Study objectives

The purpose of this study is to conduct a scope test to determine whether the willingness to pay per household for prescribed burning and mechanical fire fuel reduction programs increases with the number of acres of forest protected among white and Hispanic households. To our knowledge this is one of the first scope tests of Hispanic respondents taking survey in Spanish. In addition, we provide WTP functions relating to WTP for acres of forests that are protected from wildfires that would be useful to managers and policy makers.

Regression equation and hypothesis of scope test

In our study of the fire fuels reduction programs, we carry out the scope test on the impact of a reduction in acreage of forest fires on willingness to pay. We expect that this acreage reduction variable should be significant and the sign of the coefficient is positive; specifically, the greater reduction in acreage of forest burned the more people would be willing to pay. We are able to conduct an external scope test because the amount of acreage reduction varies across the three states of California, Florida and Montana, and we control for differences in demographics and attitudes across states.

First we define the odds of voting for the prescribed burning program as: $A = P_i/(1-P_i)$ and then take the log for the logit model:

$$\ln(A) = \beta_0 + \beta_1 \text{AcreReduction} + \beta_2 \text{RXBid} + \beta_3 X_3 + \dots + \beta_n X_n + u_i \quad (1)$$

Similarly for the mechanical fire fuel reduction program:

$$\ln(A) = \beta_0 + \beta_1 \text{AcreReduction} + \beta_2 \text{MechBid} + \beta_3 X_3 + \dots + \beta_n X_n + u_i \quad (2)$$

To control for any differences across the states, we include respondent demographic and attitudes variables shown in table 1.

Table 1-- variables in the logit willingness to pay model

Variables	Variable explanation
VoteRXPr	Dependent variable: 1 if respondent votes for RX program, 0 otherwise
VoteMechPr	Dependent variable: 1 if respondent votes for Mech program, 0 otherwise
Acre Reduction	Acreage reduction in burned forest
Age	Age of the respondent
Educ	Education level of the respondent
Expsmoke	Dummy variable: 1 if the respondent experienced smoke from a wildfire or RX, 0 otherwise
Income	Household income of the respondent
Ownhome	Dummy variable: 1 if respondent owns a home, 0 if respondent rents
Resprob	Dummy variable: 1 if respondent suffers from respiratory or breathing problems, 0 otherwise
RXBid	Monetary amount respondent is asked to pay for RX program
MechBid	Monetary amount respondent is asked to pay for Mech program
Witnessfire	Dummy variable: 1 if respondent witnesses a wild fire, 0 otherwise

The scope test involves testing whether the sign of acreage reduction variable is positive or not. Therefore the null hypothesis is:

$$H_0: \beta_1 = 0 \text{ and } H_A: \beta_1 > 0.$$

One tailed t- statistic test will be conducted.

Survey design

A survey booklet was developed to provide the respondent with the basic information of proposed programs prior to eliciting the WTP. The booklet began by discussing large wildfires in the three states in the previous year. It contained information and drawings contrasting wildfires and prescribed burning fire as part of the description of the public program. Then the wildfire acreage reduction and costs of prescribed burning program were described in more detail. After voting on the prescribed burning program, the mechanical fire fuel reduction was introduced as an alternative. The same elements like those in the RX program were described for this program; in particular the reduction in acreage burned by wildfires. The following WTP elicitation question was used for the prescribed burning program:

If the Expanded Prescribed Burning Program was undertaken in your county and state, it is expected to reduce the number of acres of wildfires from the current average of approximately A acres each year to about B acres for 25% reduction.

Your Chance to Vote: *Your share of the Expanded Prescribed Burning Program would cost your household \$X.....a year. If the Expanded Prescribed Burning Program was on the next ballot would you vote: In favor Against.....*

The \$X was replaced by the monetary bid amounts for prescribed burning, which were \$10, \$20, \$30, \$40, \$60, \$90, \$120, \$150, \$250, and \$350. The bid amounts of the mechanical fire fuel reduction are on average \$10 higher than those of the prescribed burning program. The similar question also was used for the mechanical fire fuel reduction program. Table 2 shows the acreage reduction in each state.

Table 2-- *current acres burning and reduced acres burning by RX and Mech programs*

States	Current wildfire acres burned-A	Wildfire acres burned with program-B	Acreage Reduction	
			RX program	Mech program
California	362,000	272,500	89,500	89,500
Florida	200,000	150,000	50,000	50,000
Montana	140,000	105,000	35,000	35,000

Data collection and survey mode

To get a representative sample, random digit dialing of the population was used. The use of random dialing assures that nearly all households are eligible to be interviewed. The surveys were conducted using phone-mail-phone approach. The initial phone interview lasted about five minutes with questions focusing on the introduction of the survey purposes, and obtaining mailing addresses to send the in-depth survey booklet. The individuals were asked to read the booklet prior to the scheduled date of the phone WTP interview. The phone interviews were conducted in English with the white households and Spanish for Hispanic households in California (CA) and Florida (FL), and only in English in Montana (MT).

The survey response percentages in three states CA, FL and MT in the in-depth WTP interview are similar (72.8%, 72.2% and 72.9%, respectively). A chi-square test indicates they are not statistically different.

Statistical analysis of WTP responses

We pool data across three states to estimate the scope test model for RX and Mech programs controlling for any demographic or attitude differences among households of the three states. We test whether acreage reduction of

forests burned affects the probability of saying yes to the proposed bid amount.

Results for White Households

The initial regression is specified with demographic and attitude variables to control for any differences across states. The **Acre Reduction** variable is statistically significant at 0.01 and 0.1 level for both RX and Mech program respectively (table 3). The positive sign of this variable tells us that white households in these states would be willing to pay more for a larger reduction the number of acres of forests burned. The null hypothesis of no effect of acreage reduction is rejected and WTP is sensitive to reduction of burned forest acreage, i.e., sensitivity to scope is supported.

Table 3-- *logit regression results of scope test for white households*

Variables	RX program		Mech Program	
	Coefficient	t-statistic	Coefficient	t-statistic
Constant	1.4638	(1.84)	0.021	(0.03)
Acre Reduction	1.17E-05	(2.4) ***	6.37E-06	(1.65) *
RXBid	-0.00449	(-6.36) ***		
MechBid			-0.003	(-4.49) ***
Age	-0.00323	(-0.51)	0.0039	(0.73)
Educ	-0.0472	(-0.99)	-0.0117	(-0.29)
ExpSmoke	0.0247	(0.08)	-0.3698	(-1.45)
Income	2.81E-06	(0.91)	5.40E-06	(2.13) ***
OwnHome	0.0228	(0.09)	-0.2139	(-0.96)
RerspProb	0.268	(1.14)	0.1095	(0.55)
WitnessFire	-0.07	(0.06)	-0.192	(-0.98)
McFadden R-squared	0.0735		0.0438	
Total observations	583		673	

* Significance at 10% ** significance at 5% *** significance at 1%

Results for Hispanic Households

For Hispanics, from the positive sign of the **Acre Reduction** variable and its significant t-statistic in table 4, we can see that the larger the acreage reduction of forest burned is proposed, the more likely the Hispanics say yes to the bid amounts. The **Acre Reduction** variable is statistically significant at 0.01 level; therefore we accept the alternative hypothesis with $\beta_1 > 0$ at this level. The scope or change in the amount of reduction in burned forest is statistically significant and therefore WTP is sensitive to amount of acreage reduction.

Table 4-- *logit regression results of scope test for Hispanic households*

Variables	RX program		Mech Program	
	Coefficient	t-statistic	Coefficient	t-statistic
Constant	1.493	(1.32)	1.7872	(1.83)
Acre Reduction	2.27e-05	(3.4) ***	1.47E-05	(2.63) ***
RXBid	-0.002716	(-3.26) ***		
MechBid			-0.001152	(-1.65) *
Age	-0.0069	(-0.89)	-0.000218	(-0.03)
Educ	-0.088	(-1.49)	-0.1766	(-3.47) ***
ExpSmoke	0.2527	(0.96)	0.08188	(0.37)
Income	-4.28E-06	(-0.92)	1.11E-06	(0.28)
OwnHome	-0.2388	(-0.93)	-0.0989	(-0.46)
RerspProb	-0.095	(-0.33)	-0.2344	(-0.94)
WitnessFire	0.166	(0.61)	0.1355	(0.59)
McFadden R-squared	0.0779		0.06042	
Total observations	478		601	

Reduced form logit model

To estimate a more policy relevant WTP function for acreage reduction, we eliminated variables that were not consistently significant in order to focus the impact of significant variables on the probability of voting to pay the bid amounts. This model will exclude variables that are insignificant as inclusion of these will unnecessarily inflate the variance, reducing power of statistical tests to detect scope, and make the model more cumbersome for managers to use.

Table 5 presents the reduced form logit models for white households. Scope is even more evident for the mechanical program as the statistical significance of the acreage reduction variable is now significant at the 1% level. These logit equations can be reparameterized into benefit or willingness to pay functions for reductions in acreage burned by following the procedure of Cameron (1988) to yield a

straightforward WTP function for reducing acres burned. By dividing the constant and acres by the absolute value of the bid coefficient we therefore obtain WTP per white household as a function of the reduction in acres burned from using the prescribed burning program:

$$\text{WTP per household} = \$174.06 + .002578 (\text{Acre Reduction})$$

Table 6 presents the reduced form logit models for Hispanic households. Given the statistical significance of acres burned, scope continues to be evident for both the RX and Mechanical programs. For the mechanical program, although the bid amount is negative, it is not statistically significant.

Table 5— *reduced logit regression results for white households*

Variables	RX program		Mech Program	
	Coefficient	t-statistic	Coefficient	t-statistic
Constant	0.7899	(3.04) ^{***}	-0.4819	(-2.16) ^{**}
Acre Reduction	1.17E-05	(2.7) ^{***}	1.05E-05	(2.9) ^{***}
RXBid	-0.004538	(-6.91) ^{***}		
MechBid			-0.00311	(-4.96) ^{***}

Table 6— *reduced logit regression results for Hispanic households*

Variables	RX program		Mech Program	
	Coefficient	t-statistic	Coefficient	t-statistic
Constant	-0.2229	(-0.6249)	-0.9574	(-3.09) ^{***}
Acre reduction	2.50E-05	(4.69) ^{***}	2.03E-05	(4.69) ^{***}
RXBid	-0.00247	(-3.19) ^{***}		
MechBid			-0.000649	(-1.02)

Conclusion

The scope test conducted in this paper shows that willingness to pay for prescribed burning and mechanical fire fuel reduction programs among the whites and Hispanics is sensitive to the amount of reduction in acreage burned. The more acreage reduction proposed, the more people would likely pay. This finding is true for both white households taking the survey in English and Hispanics taking the survey in Spanish. The case study expands our stocks of knowledge regarding the scope test for evaluating the validity of the contingent valuation method. The resulting logit equations can be converted into benefit functions for each fuel treatment program for use by fire managers to evaluate the economic benefits of reducing forest fire acreages.

Acknowledgement

We would like to thank Lucas Bair and Hayley Hesseln for assisting in developing the data used in this analysis.

References

- Arrow, Kenneth, Robert Solow, Paul R. Portney, Edward E. Leamer, Roy Radner, and Howard Schuman. 1993. **Report of the NOAA panel on contingent valuation**. U.S. Department of Commerce, Federal Register 58 (10): 4602-4614.
- Bush, George W. 2002. **Healthy forest: An initiative for wildfire prevention and stronger communities**. Assessed at www.whitehouse.gov/infocus/healthyforests.
- Cameron, Trudy. 1988. **A new paradigm for valuing market goods using referendum data: Maximum likelihood estimation by censored logistic regression**. *Journal of Environmental Economics and Management* 15: 355-379.
- Carson RT. 1997. **Contingent valuation surveys and tests for insensitivity of scope**, in R.J. Koop, W. Pommerhene and N. Schwartz, eds., *Determining the value of non-marketed goods: Economic, Psychological, and Policy Relevant Aspects of Contingent Valuation Methods*. Boston: Kluwer 127-163.
- Carson RT, L Wilks and D Imber. 1994. **Valuing the preservation of Australia's Kakadu conservation zone**. *Oxford Economic paper* 46: 727-749
- Florida Division of Forestry. 2000. **Prescribed fire position paper**. Assessed at www.fl-dof.com/Enr/rx/html.
- Loomis John and Ekstrand Earl. 1997. **Economic benefits of critical habitat for the Mexican spotted Owl: A scope test using a multiple-bounded contingent valuation survey**. *Journal of Agricultural and Resource Economics* 22 (2): 356-366.
- Memon Muchtaq Ahmed and Shunji Matsuoka. 2002. **Validity of contingent valuation estimates from developing countries: scope sensitivity analysis**. *Environmental Economics and Policy Studies* 5: 39-61.
- Smith V K and L Orborne. 1996. **Do contingent valuation estimates pass a scope test? A meta analysis**. *Journal of Environmental Economics and Management* 31: 287-301

Effects of Risk Attitudes on Extended Attack Fire Management Decisionmaking¹

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Abstract

Fire management inherently involves the assessment and management of risk, and decision making under uncertainty. Although organizational standards and guides are an important determinant of how decision problems are structured and framed, decision makers may view risk-based decisions from a perspective that is unique to their background and experience. Previous research has shown that individual differences in risk attitudes of fire managers exert a significant effect on fire management practices. Within the USDA Forest Service, Extended Attack (EA) incidents are those not contained within the first burning period after ignition. Simulation-based methodologies offer a potentially viable approach for improving our understanding of the role that risk attitudes and problem framing play in determining key decisions associated with EA incidents, and particularly on the decision to disengage, re-engage after disengagement, and transitioning to a higher level of incident command. Scenario-based exercises in which Type 3 Incident Commanders respond to simulated incident conditions provide an opportunity to study decision behavior based on current theories and models of decision making that point to the role of problem framing and incentive structures as key decision drivers.

Keywords: Decisionmaking, extended attack, fire management, risk assessment.

Introduction

Fire management inherently involves decision making under uncertainty, and the role of human decision makers is central to the accomplishment of fire management goals and objectives. To provide a context for decision making, the USDA Forest Service (as well as other Federal land management organizations) has established organizational policies, plans and directives that provide guidelines to orient decision

¹ An abbreviated version of this paper was presented at the Third International Symposium on Fire Economics, Planning, and Policy: Common Problems and Approaches. April 29 –May 2, 2008; Carolina, Puerto Rico.

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makers toward fundamental institutional priorities. In the case of wildland fire management, agency priorities concerning firefighter and public safety, and the protection of private property are reference points that offer contextual guidance as to how alternative managerial actions should be evaluated.

In recent years, it has become more apparent that the role of the individual managerial decision maker, while central to achieving the agency's mission and goals, represents a source of poorly-understood variability in accounting for decision outcomes. Sometimes this variability is expressed in terms of differences in "risk aversion" or risk-taking propensities of individual managers. At other times, it is expressed as a problem of incentives and incentive structures within which individual managers evaluate decisions and experience the outcomes. Empirical research along these lines requires the development of study approaches that provide opportunities to observe decision behavior in contexts that simulate actual decision-making situations. The development of such approaches requires integrating relevant theories and models from decision-making research with a contextual model of fire management decision making.

Preliminary Research

Individual Risk Attitudes and Fire-related Decision Behavior

Although organizational factors are an important determinant of how decisions are framed and structured, decision making is ultimately accomplished by human managers who may view decisions problems from a different (or modified) perspective than that of institutional policies and plans. Evidence for this comes from a number of managerial studies that have examined how senior managers' risk attitudes influence their decision behavior in the context of prescribed fire decision making. Cortner, Taylor, Carpenter, and Cleaves (1990) found that, in the context of prescribed fire, individual risk-taking propensities varied greatly as revealed in decision-making scenarios that involved varying levels of risk associated with conducting a planned burn, as evidenced by allocations of personnel and equipment.

González-Cabán (1996) presented prescribed fire managers with a set of realistic prescribed fire problems for which they were to provide elements relevant to plan implementation, such as ignition patterns, containment strategies, mopup classifications, season and time of burn, and estimates of equipment and personnel. Results indicated that the largest portion of the variance in estimates of burn costs was accounted for by individual differences between the prescribed fire managers, not associated with their education or experience, the location of the burn, or features of the burn site. Self-ratings of risk-taking propensity revealed that respondents who judged themselves to be risk-averse had lower average prescribed fire costs than

those who judged themselves to be risk-takers.

An in-depth interview-based study by MacGregor (1997) examined the risk attitudes of senior-level prescribed fire managers. The results indicated that the concept of risk was perceived as a complex interaction of a number of factors relating to prescribed fire and its use as a resource management tool, and that prescribed fire managers seek to manage a range of risks that are distributed over time. However, risk management strategies were variable and depended upon individual risk orientations and experiences.

Risk and Regret in Fire Management Decision Making.

An important concept that has come to play a significant role in understanding risk-related attitudes at the managerial level is the precautionary principle (Sandin 1999; Graham 2001). In essence, the precautionary principle is a “better safe than sorry” perspective that orients individuals toward taking self-protective action. The precautionary principle can be interpreted as a corollary of a general propensity for individuals to respond more extremely to decision outcomes that involve losses than those that involve gains (Kahneman and Tversky 1979).

One effect of prospective evaluation and response to decision outcomes is *anticipated regret*. Regret theory has been given central importance as a factor that exerts a strong influence on decision behavior (e.g., Bell 1982; Loomes and Sugden 1982, 1983, 1987). According to regret theory, a decision maker *anticipates* the experience they may have as a result of decisions or choices they make; regret is the psychological experience associated with having chosen an alternative that is less satisfying than an alternative that is foregone. Thus, regret is a function of the satisfaction not obtained from the alternative chosen but that would have been obtained from one or more other alternatives. As result, decision makers seek to minimize regret by anticipating decision outcomes and choosing the alternative with the least possible regret.

Regret theory can be modeled in the context of fire management decision making by examining decisions in terms of two contexts: a *prospective context* in which a decision is analyzed and made, and a *retrospective context* in which a decision is justified and evaluated (*fig. 1*). These two contexts differ in terms of important features. Prospectively, decisions and outcomes are linked probabilistically and numerous outcomes are possible given a chosen alternative. Retrospectively, a particular outcome is experienced and the tendency is to perceive the outcome as causally or deterministically linked to the decision maker’s actions. A decision pertaining to the assignment of a Type 3 versus a Type 2 Incident Management Team to a fire can be represented in terms of a *Prospective Context* that involves decision making about the appropriate level of IMT to assign to a fire, and a *Retrospective Context* that represents a post-outcome evaluation or justification of the decision.

Each of the four cells in a 2 x 2 payoff matrix is associated with each of four outcomes. Two of the cells represent a “Correct” Decision; these are the outcomes for which the prospective choice of IMT matches the level of IMT actually required. These are correct decisions in the sense that a post-decision evaluation of the IMT selection would indicate that the appropriate level of IMT was chosen.

		<i>Anticipated Retrospective Context (Decision Justification)</i>	
		Type I Team Required	Type II Team Required
<i>Prospective Context (Decision Making)</i>	Type I Team Selected	<i>“Correct” Decision</i>	<i>Excess \$\$ costs to the Organization Small Competence Risk</i>
	Type II Team Selected	<i>Inadequate Suppression Mortality & Morbidity Risks Large Competence Risk Career Risks</i>	<i>“Correct” Decision</i>

Figure 1 - Hypothetical payoff matrix for deciding the level of IMT to assign to a fire.

For the two remaining cells, a discrepancy exists between the level of IMT chosen prospectively and the level of IMT justified retrospectively given the outcome of the incident. In the case where the higher level of IMT (Type 2) is selected prospectively, but the lower level of IMT (Type 2) would have been appropriate, two potential payoffs are: (a) excess monetary costs to the organization due to the higher cost of the Type 2 team, and (b) a small (potential) competence loss to the decision maker accruing from their overestimation of the level of resources required for management of the incident. In the case where the lower level of IMT (Type 3) is selected, but the higher level of IMT would have been appropriate, payoffs include (a) inadequate suppression of the fire, (b) potential mortality and morbidity risks, (c) relatively large competence risks to the decision maker, and (d) perceived or actual career risks.

For the diagonal represented by the two correct decisions, the decision maker has no anticipated regret since the managerial decision concerning level of IMT assignment is perceived to be consistent with the outcome. All of the potential regret in the decision is associated with the two outcomes where there is a disparity between the level of IMT assigned and the level that could be perceived as required or justified in hindsight. An asymmetry exists between the value of the two negative

payoffs, with the larger negative payoff associated with a decision to use a lower level of IMT. A decision maker who wishes to minimize their maximum possible regret in such a decision situation would tend choose the higher level of IMT unless other contextual factors intervened to alter their choice.

Sunk Cost Effects in EA Decision Making.

Sunk-cost effects occur when current decisions are influenced by options in which the decision maker has already invested time, money or other resources, even if it is not the best option (e.g., Arkes and Blumer 1985). According to rational economic theory, current decisions should consider only future costs and benefits. Empirical studies of decision making have demonstrated that people often make decisions based on what they have already expended (e.g., Gourville and Soman 1998). In a fire management context, sunk-costs can be manifest in terms of decisions that favor protecting the expenditures associated with line construction, even if such a decision poses greater risks and costs than would be the case if the sunk-cost was not present. One result of sunk-cost decision making is a tendency toward *escalation of commitment* to a suboptimal course of action, based on an investment already made (Staw 1976). Some evidence suggests that sunk-costs effect due not endure indefinitely and that the tendency toward the biasing effects of prior investments diminishes over time (Thaler 1999). How sunk-cost effects specifically manifest themselves in EA decision making and how such effects if present can be de-biased or attenuated are open questions.

Production Systems in EA Decision Making

Production systems are a general class of decision models that described the relationship between humans and the tasks that they perform. In the simplest terms, production systems represent human performance in terms of inputs, system processes and outputs that are connected through a feedback loop that affects the environment within which the system operates (Sheridan and Ferrell, 1981; Wickens and Hollands, 1999). The analogy to fire management is direct.

In a prototypical production system, the inputs include *scheduled and expected events* that serve as *triggers* to system processes (*fig. 2*). The various system processes (e.g., procedures, plans, internal communications) result in *products* that are outputs of the production system. These outputs include decisions, actions and communications that are intended to have an effect on the environment within which the system operates (for example, a fire incident). The impact of the production system on the environment acts as a closed-loop feedback to the input of the system, thereby controlling its actions (Powers 2005). Essentially, production systems are a form of *cybernetic control system* (Wiener 1948) for which output from the system serves as a basis for the evaluation of how well system processes (e.g., fire

management decisions) are meeting the goals and objectives of the system, such as perimeter control.

System processes can be perturbed or altered by human factors, such as physical or mental fatigue and stress. More generally, system processes are influenced by an on-going assessment of capabilities; changes (Δ) in capabilities can alter how the system responds to inputs and how the various processes are implemented with a resulting effect on system outputs. Changes in human resource capabilities can also influence how critical decision cues are recognized and processed (Klein, Calderwood and MacGregor 1989).

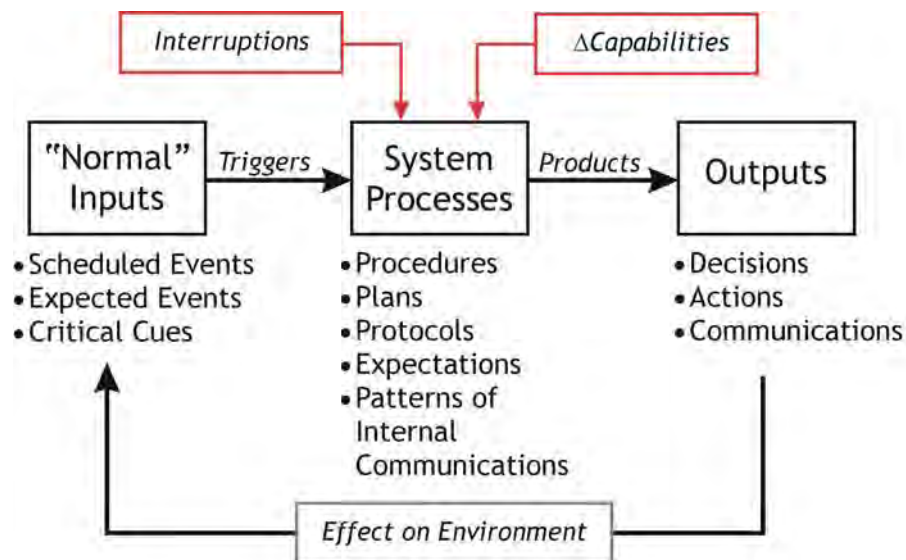


Figure 2 - Prototypical production system decision model.

Alteration can also occur due to interruptions; these are unanticipated events or situations that are external to the system and that prevent the completion of organized actions or sequences. Understanding how interruptions influence the dynamics of production systems is critical to improving their functioning and making them more resilient against degradation and collapse (Rudolph and Repenning 2002).

Method

Characteristics of Extended Attack Incidents

The research approach applied here involves the development of a methodological framework for studying the effect of individual managerial risk attitudes and incentive structures on fire management decision making in the context of Extended Attack (EA) incidents. Within the USDA Forest Service, EA incidents are those that are not contained within the first burning period after ignition. A typical EA incident

is staffed by a Type 3 Incident Commander, or ICT-3, as well as suppression resources. Incident command may also include subordinate staff members who occupy roles associated with logistics, operations, plans, finance and information, depending on the complexity of the incident, availability of personnel, and the management style and/or preferences of the ICT-3.

Extended attack fires can range in size from a few acres (e.g., Class B) to a hundred acres or more (e.g., Class C or small Class D). The actual size of the fire is less relevant than its complexity (e.g., fuel conditions), and guidelines are currently in place by which a ICT-3 can gauge whether or not continuing to manage an incident as a Type III incident is an appropriate management response. Key checklist factors include fire behavior, firefighter safety, organizational capabilities, and values to be protected (NWCG, 2007).

EA incidents are particularly challenging on several grounds, not the least of which is firefighter safety. As an incident goes beyond the capabilities of a Type 5 or Type 4 organization, it grows in size and complexity, and becomes an emerging fire for which a precise characterization of its risks is difficult owing largely to its dynamic nature. Essentially, an EA incident is an incident in transition and for which a locally-organized management response may be effective at averting a much larger and more costly fire, or it may not - the outcome depending in large part on the quality of decision making that occurs during the management of this critical incident stage. Moving too quickly from EA to a Type 2 or Type 1 may incur unnecessary costs if the fire could have been managed effectively as a Type 3 incident. On the other hand, continuing to manage an incident as a Type 3 could expose firefighters to excessive safety risk and increase the likelihood that valuable resources will be needlessly lost.

Extended attack can be characterized as an ongoing decision making process in which the Type 3 organization evaluates both the fire situation and the organization's capability to manage the incident with the resources at hand. In some circumstances, the Type 3 organization may disengage from the incident to assess its capabilities and to assess its likelihood of success if it re-engages the incident. Recurrent decisions concern whether or not the organization can accomplish meaningful objectives with respect to the fire, and/or whether they should conduct a holding action until more resources arrive or conditions improve. Complicating the decision process are human factors such as the mental and physical state of personnel. In essence, the Type 3 organization is often at the limits of its capabilities and operates in a short time frame decision cycle whereby it is constantly adapting its management approach according to a rapidly evolving and dynamic fire situation.

Simulating a Type 3 Decision Making Environment

For training and qualification purposes, Type 3 environments are simulated in two general ways. One way is to give trainees the “feel” for the rapid pace of setup, operations and management associated with a Type III environment where their responsibilities include establishing a management organization as well as monitoring and responding to a dense communication environment that includes multiple channels of radio traffic. Monitoring and updating situation awareness is also a critical aspect of Type 3 management.

A second approach is to simulate the strategic decision making aspects of the Type 3 environment. These include development of staff positions, preparation of an Incident Action Plan (IAP), identification of primary and secondary control objectives, acquiring and positioning suppression resources, and engaging in monitoring activities associated with the production cycle of incident management (*fig. 2*).

The present research uses a strategic context within which to study decision making on EA-type incidents. The simulation environment includes a combination of materials supported by a PC-environment as well as checklists and structured protocols that pose situations and call for responses from study participants.

The simulation environment poses a scenario involving a fire start that has been managed by an ICT-4, but is transitioned to an incoming ICT-3. The scenario develops over a four-day (four burning period) time frame. Within each simulated burning period, the respondent receives information pertaining to the current situation, including topographic maps showing the current fire perimeter, location of resources, status of resources on order, weather conditions, location of value at risk (e.g., residences, wildlife). The respondent then assesses a number of factors associated with the incident, including location of primary and secondary control objectives, probabilities of success for each objective, factors and resources on which success is dependent, probability of containment within 24 hrs., probability of disengagement within 24 hrs., and probability of transitioning to a higher level (e.g., Type 2). A final section of the exercise elicits background information from the respondent, including their fire experience as an ICT-3, cost issues in fire management, and legal liability issues.

Overall, the simulation is designed to represent a wildland fire that emerges into a situation that is marginally manageable as a Type 3 incident. Over the course of the four-day simulated time frame, the incident progresses from one that has a moderate probability of achieving containment to one that continues to elude containment. The intent of the exercise is to focus the respondent on a key set of decisions pertaining to disengagement/re-engagement and transitioning to a higher level of incident management. Simulation variables are constructed to pose situations in which the

respondent is faced with the possible loss of constructed line, allowing an examination of sunk-cost effects. In the context of the situation, risk attitudes are assessed in terms of a range of variables, including probabilities of success/loss, positioning of primary and secondary control objectives, resource ordering and utilization, as well as respondent background and general perceptions of risk-based decision making in Type 3 operations.

Acknowledgements

This research is supported by Agreement #04-JV-11272165-448 between the USDA Forest Service, Pacific Southwest Research Station, and MacGregor-Bates, Inc. We thank Aaron Ortega (Fuels Specialist, Comanche and Cimarron National Grasslands), Shane Greer (FMO, Pike-San Isabel NF), and Jay Perkins (FMO, Klamath NF) for their help and expertise in developing this research approach.

References

- Arkes, H.R., & Blumer, C. (1985). The psychology of sunk cost. *Organizational Behavior and Human Decision Processes*, 35, 125-140.
- Bell, D. E. (1982). Regret in decision making under uncertainty. *Operations Research*, 30, 961-981.
- Cortner, H. J., Taylor, J. G., Carpenter, E. H., & Cleaves, D. A. (1990). Factors influencing forest service fire managers' risk behavior. *Forest Science*, September, 531-548.
- González-Cabán, A. (1996). Managerial and institutional factors affecting prescribed burning costs. *Forest Science*, 43, 535-543.
- Graham, J. D. (2001). Decision-analytic refinements of the precautionary principle. *Journal of Risk Research*, 4, 127-141.
- Gourville, J.T., & Soman, D. (1998). Payment depreciation: The behavioral effects of temporally separating payments from consumption. *Journal of Consumer Research*, 25, 160-174.
- Kahneman, D., & Tversky, A. (1979). Prospect theory: an analysis of decision under risk. *Econometrica*, 47, 263-292.
- Klein, G. A., Calderwood, R., & MacGregor, D. G. (1989). Critical decision method for eliciting knowledge. *IEEE Transactions on Systems, Man, and Cybernetics*, 19(3), 462-472.
- Loomes, G. and Sugden, R. (1982). Regret theory: An alternative theory of rational choice under uncertainty. *Economic Journal*, 92, 805-824.
- Loomes, G. and Sugden, R. (1983). A rationale for preference reversal. *American Economic Review*, 73, 428-432.
- Loomes, G. and Sugden, R. (1987). Some implications of a more general form of regret theory. *Journal of Economic Theory*, 41, 270-287.
- MacGregor, D. G. (1997). Assessing risk attitudes of prescribed fire managers. Final report. Project No. OM-43-91S8-5-3325. USDA Forest Service, Pacific Southwest Research Station, Riverside, CA.
- NWCG (2007). Incident Response Pocket Guide. National Wildland Fire Coordinating Group, Washington, DC.
- Powers, W. T. (2005). *Behavior: The control of perception*. New Canaan, CT: Benchmark Publications.
- Rudolph, J. W. & Repenning, N. R. (2002). Disaster dynamics: Understanding the role of quantity in organizational collapse. *Administrative Science Quarterly*, 47, 1-30.
- Sandin, P. (1999). Dimensions of the precautionary principle. *Human and Ecological Risk Assessment*, 5, 889-907.
- Sheridan, T. B., & Farrell, W. R. (1981). *Man-machine Systems: Information, control, and decision models of human performance*. Cambridge, MA: The MIT Press.
- Staw, B.M. (1976). Knee-deep in big muddy: Study of escalating commitment to a chosen course of action. *Organizational Behavior and Human Performance*, 16, 27-44.
- Thaler, R. (1999). Mental accounting matters. *Journal of Behavioral Decision Making*, 12, 183-206.
- Wickens, C.D., & Hollands, J. G. (1999). *Engineering psychology and human performance*. Prentice Hall.
- Wiener, N. (1948). *Cybernetics*. New York: Wiley.

What Ignited Forest Service Interest in Nonmarket Valuation in Fire Economics?¹

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Abstract

This paper traces the origin and evolution of the application of nonmarket valuation techniques to fire management within the USDA Forest Service. The motivation for contingent valuation (CVM) studies that quantify existence value is traced to the need for monetary benefits of protecting spotted owl old-growth forest habitat from fire in the early 1990s. Two large scale general public surveys successfully demonstrated that CVM could be used to estimate both state level and national level benefits for fire prevention and fire suppression of endangered species critical habitat. By the late 1990s the large-scale wildland urban interface fires resulted in the need to measure what the general public would pay for prescribed burning and mechanical fuel reduction programs. With the advent of conjoint and choice experiments joining CVM as applicable tools for estimating the nonmarket benefits of preventing and suppressing wildland fires, economists' capabilities have grown extensively. Due to the expense and time consuming nature of conducting these surveys, the greatest remaining challenge is formal and systematic incorporation of these types of use and non-use values into wildland fire planning and resource allocation models. Drawing upon the past results, we offer benefit transfer of the existing results as a plausible interim technique to estimate the public's nonmarket benefits from fire prevention and suppression. We also offer some insights as to the next frontiers in CVM application.

Keywords: Contingent valuation, endangered species, mechanical fuel reduction, prescribed burning, willingness- to-pay.

¹ An abbreviated version of this paper was presented at the III International Symposium on Fire Economics, Planning, and Policy : Common Problems and Approaches, April 29 to May 2, 2008, Carolina, Puerto Rico.

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Introduction

The early 1990s saw a rapid change in forest management from an overwhelming emphasis on timber management and viewing the forest as a collection of multiple uses to viewing the forest as an ecosystem. A major catalyst for the change was the listing of the Northern Spotted Owl under the Endangered Species Act, and the designation of more than 4 million acres of old-growth forests on federal lands as critical habitat in Oregon, Washington and northern California for the Owl. The Thomas Report (Thomas and others 1990, 1993) and President Clinton's Forest Plan for the Cascades and coastal forests emphasized ecosystem management. A proactive effort to protect remaining old-growth forests in California for the California Spotted Owl soon followed. The National Forests weren't just for timber harvesting anymore. These plans spared the old-growth forests from logging but protecting the old-growth forest habitats from stand replacing fire was necessary for recovery of the spotted owl (Verner and others 1992).

The traditional justifications for protecting forests from fire were based primarily on protecting timber values. If the agency could no longer log the forests, how could it justify spending millions of dollars on fire prevention and fire suppression? The answer was in recognizing and valuing the public goods and services provided by the forest but not accounted for in traditional markets, such as habitat for endangered species.

It just so happened that during the previous decade environmental economists had been refining a technique that could measure the off-site or public good economic values of protecting habitat for threatened and endangered species. While the contingent valuation method (CVM) was originally designed to value recreation (Knetsch and Davis 1966), the method emerged in the 1980s as a technique that could value what economist John Krutilla (1967) called existence values. These existence values were benefits that non-visiting people might receive from the knowledge that a unique natural environment or habitat was protected for the current and future generations.

Applications of CVM to monetize the existence value of endangered species (Brookshire and others 1983) and wilderness (Walsh and others 1984) demonstrated the techniques would work with the general public. Test-retest studies demonstrated the reliability of the CVM technique to measure use and existence values of visitors and the general public, respectively (Loomis 1989).

Can CVM quantify the public's willingness-to-pay for forest fire prevention and suppression?

The USDA Forest Service's Pacific Southwest Station's Associate Research Director and a fire economist in the Forest Fire Lab in Riverside, California in 1992 became aware of the possibility of using nonmarket valuation techniques to determine the benefits of protecting old-growth forests (as habitat for the spotted owl) from fire. While the USDA Forest Service had relied upon nonmarket valuation techniques such as the travel cost and CVM to value recreation use (Sorg and Loomis 1984; Donnelly and Nelson 1986) it had been reluctant to include existence benefits when valuing wilderness despite documentation of such values' importance in the literature (Walsh and others 1984).

So what was different in 1992? It was the convergence of several factors. One was the growing awareness that to comply with the Endangered Species Act requirements to recover species, old-growth forests were to be protected from fire (Verner and others 1992). Another might have been the recognition that if the agency and society were to forego harvesting of commercially valuable old-growth trees, it would be wasteful to just let them burn due to a lack of fire prevention and fire suppression. Still another was the movement within the agency toward ecosystem management that recognized the forests were more than a collection of multiple uses and rather, were unique natural environments that represented interconnected wildlife habitat and watersheds. Finally, the USDA Forest Service was recognizing that its stakeholders included people who never have visited a National Forest, but were vociferous in their views of how public forests should be managed. This could be addressed by expanding survey sampling from visitors to the general public; the taxpayers who funded management of the National Forests needed to be included.

Estimating the total economic value to Oregon households from reducing wildfire

In response to these factors, Armando González-Cabán (1993) at the Forest Fire Lab, Pacific Southwest Research Station outlined a program on how to obtain and incorporate such information in the Forest Service Fire Management Planning system. Later on the same year, he funded and participated in a study designed to estimate the monetary amount Oregon households would pay to reduce wildfire across 4 million acres of critical habitat units (CHU) designated for the northern spotted owl. In cooperation with Robin Gregory at Decision Data, the authors developed a contingent valuation survey of Oregon households⁴. Respondents were

⁴ This paper is not an exhaustive review of the literature available, but an effort to highlight the origins of the use of nonmarket valuation in fire economics in the Forest Service and where it may lead to.

asked if they would vote in favor of a program to reduce by half the amount of old-growth CHU that burned each year, from 7,000 acres to 3,500 acres. The program involved three elements: (a) greater fire prevention; (b) earlier fire detection; and (c) more aggressive fire response.

Using repeat mailings of the survey, the household survey achieved nearly a 50 percent response rate. Oregon households indicated they would pay an average of \$77 per household per year. This translates into a WTP of \$28 per acre protected⁵ (see Loomis and Gonzalez-Cabán 1994 for more details).

This study led to a natural extension to broaden the study to protection of spotted owl habitat in northern California and Oregon. In addition, because the Spotted Owl was a federally listed threatened species under the Endangered Species Act and the CHUs were on National Forests, it was a natural extension to investigate the geographic extent of willingness-to-pay to protect the owls' habitat from wildfire. Thus, the sample frame included households in California and six New England states of Connecticut, Massachusetts, Maine, New Hampshire, Rhode Island and Vermont. Respondents in each of the two geographic areas were asked their WTP for a program that would protect Spotted Owl critical habitat from wildfire in: (a) California; (b) Oregon; and (c) both California and Oregon.

The results shown in Table 1 are plausible given that they conform to what might be expected from economic theory. Households in California have a higher WTP to protect spotted owl critical habitat units in their own state (\$79 per household per year) than in Oregon (\$59), but California households still have a fairly high WTP to protect critical habitat units in Oregon. New England residents WTP for protection of California and Oregon critical habitat is similar at approximately \$45 in each state and only somewhat smaller than California residents' WTP for protecting Oregon owl habitat. Despite the nearly 2,500 mile distance of New England households from the spotted owl critical habitat units, annual per household WTP is substantial. This suggests that there are national benefits to preventing wildfires on National Forests for federally listed species. This helped to broaden the USDA Forest Service's perspective and to recognize national stakeholders, in addition to local constituencies. Finally, the total WTP for the combined California and Oregon program was substantially higher than just the WTP for the Oregon program indicating that respondents' WTP was sensitive to acres protected. As a result, Loomis and González-Cabán (1998) were able to estimate a willingness-to-pay function for protecting acres of spotted owl habitat from fire that

⁵ The value per acre protected is obtained by dividing the total WTP value estimated (\$84.6 million) by the total acreage of old-forest in protected critical habitat units of Northern Spotted Owl (3 million acres).

could be used by managers in Oregon and California. For more details on the California and New England study see Loomis and González-Cabán (1997).

Table 1 summarizes the annual values per household from the Oregon, California and New England studies, along with the respective values per acre of spotted owl habitat protected from wildfire. For example, the California and New England values per acre of spotted owl protected (\$772 and \$256, respectively) is more than 25 and ten times, respectively, higher than Oregon state residents' values. Because the values per household are similar in magnitude between Oregon, California and New England residents, the large difference in values per acre is due to the fact that far more people live outside of Oregon, and these people would pay for protection of a federally listed species on their National Forests.

Table 1—*Annual State and Regional Benefits per Household and Benefits Per Acre Protected*

State/Regional Residents	California Program	Oregon Program	Combined CA & OR Program	Benefits Per Acre of Habitat Protected
California \$7	8.69	\$58.56	\$94.77	\$772
New England	\$45.70	\$44.70	\$61.17	\$256
Oregon	N/A	\$77.00	N/A	\$ 28

The wildland urban interface explodes!

Not long after the spotted owl crisis, the national attention shifted to dramatic large-size fires that threatened the wildland-urban interface including the Daytona Beach, Florida in 1998 and the fire complex in the Bitterroot Valley of Montana in 2000. Specifically, it was the Florida fires occurring during 4th July weekend that shut down the Daytona Beach 500, and the Interstate Highway that garnered policy makers' attention. In response to the events in Florida the Joint Fire Science Program⁶ funded work to design a survey on the effects of these fires and whether these effects had changed public support for fuels reduction programs such as prescribed burning and mechanical fuels reduction. The success of the Florida work led to application of the same survey instrument in California and Montana.

Survey design

A survey booklet was initially developed in conjunction with forestry professionals in Florida and subsequently adapted for California and Montana to convey information

⁶ Joint Fire Science Program is a forest fire research grants program funded jointly by the USDA Forest Service and the USDI Bureau of Land Management.

on the extent of the problem, and two possible programs to reduce the problem (i.e., prescribed burning and mechanical fuels reduction).

The survey booklet described the acreage that is burned by wildfires in an average year in each state, as well as the typical number of houses lost to wildfire each year in each state. The effect of wildfire on forests, houses and air quality was illustrated with a color drawing showing the flame height and rate of fire spread⁷.

A program increasing the use of prescribed fire or controlled burning in California, Florida, or Montana was described and illustrated next. Specifically, respondents were told that the prescribed burning fuels reduction program would reduce potential wildfire fuels through periodic controlled burning. It was acknowledged that prescribed burning does create 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 prescribed burning program was described as a cost-share program between their state government and the county the individual lived in.

The wording used in the survey was identical for California, Florida and Montana, except the number of acres and numbers of houses burned were changed to correspond with particular state numbers.

For the mechanical fuel reduction program, the survey booklet stated the same wildfire acreage reduction as achieved with the prescribed burning program, and stated that only one of the two programs would be implemented.

Again, identical wording was used in all 3 states of California, Florida and Montana, except the number of acres burned and numbers of houses were changed to correspondent with particular state numbers discussed after the wording of the prescribed burning WTP question (for additional information see Loomis and González-Cabán 1998).

While conducting the CVM in California, Florida and Montana we realized that a segment of the population was not accounted for, Native Americans. To estimate Native Americans willingness-to-pay for the same fuels reduction programs we revised the survey instrument to represent their lands and experiences. Because Native Americans represent an important demographic of Montana we conducted a CVM study comparing Montana general population and Native Americans. The survey instrument used was the same as that used in the California, Florida and Montana study, except that it was revised to account for Native Americans lands and characteristics.

⁷ A copy of the survey can be obtained by contacting Armando González-Cabán.

Data collection and survey mode

The surveys were conducted in Florida in 1999 and in 2001 in California and Montana through a phone-mail-phone process in all three states. To obtain a representative sample of households, we used random digit dialing. An additional sample from Montana's general population and of the Blackfeet and Salish-Kootenai Tribes members was collected. The counties were selected to include a mix of counties with a range of wildfire experience and exposure. This variation had two useful features. First, it ensured variation in responses to questions like whether the respondent "had seen a wildfire". Second, targeting this sample aided in generalizing the results to all areas of the state.

Once initial contact was established, elicitation of initial attitude and knowledge of wild and prescribed fire occurred, 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 to assist with interviews. These interviews were conducted with the aid of this color booklet. The booklet was sent in English to Caucasians and in Spanish to Hispanic households in California and Florida. 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

Descriptive statistics by fuel reduction program and samples

The percentage of respondents answering yes to the dichotomous choice CVM question for each state and each program are instructive. The prescribed burning program consistently received 60 percent or higher positive responses, ranging from a high of 84 percent among Hispanics in California to 60 percent among Caucasians in Montana. The same is true for Native Americans with almost a 93 percent Yes responses. The mechanical fuel reduction program support was much lower among Caucasians, being only 34 percent to 50 percent, but 50 percent to 68 percent among Hispanics. However, Native Americans positive response rate, although lower than for the prescribed burning program, is high at 78 percent.

Willingness-to-pay results

Mean WTP was estimated for Caucasians and Hispanics using a logistic regression model. Mean WTP of Caucasians for prescribed burning was \$460 in California, \$392 in Florida, and \$323 in Montana. For the mechanical fuels reduction program the mean WTP of Caucasians in California was \$510, while it was much lower in Florida at \$239 and Montana at \$186. These results are consistent with the lower

percent positive values, and suggest far less support for the mechanical fuels reduction program than prescribed burning in these three states.

Hispanics in Florida mean WTP is \$473 for the prescribed burning program, about half what Hispanics in California would pay, \$838. Hispanic's in Florida WTP for the mechanical fuel reduction program is \$373.

The ranking of mean WTP per household follows the magnitude of acres protected from fire and houses saved. While all the state programs represented an equivalent proportional reduction (25 percent reduction) in acres and houses burned, the absolute magnitude or amount of fewer acres that burned and number of houses saved did vary across states. In terms of the three states program, California would protect 90,000 acres and 18 houses; Florida would protect 50,000 acres and 18 houses; and Montana would protect 35,000 acres and 12 houses. The ranking of mean WTP per household is in the same order as the number of acres prevented from burning and houses saved. In particular, mean WTP by California households is noticeably higher than for Florida households, which is noticeably higher than Montana households.

When comparing Montana's general population households with Native American households we find that the general population WTP for the prescribed burning program is larger than that of Native Americans, \$174 vs. \$135 (González-Cabán and others 2007). For the mechanical fuels reduction program the opposite is true and Native Americans WTP is \$305 vs. \$286 for the general population. However, statistical analysis shows that there are no statistical significant differences between the two populations for the prescribed burning or the mechanical fuels reduction programs.

Table 2—Mean WTP for Prescribed Burning and Mechanical Fuels reduction programs in California, Florida and Montana.

State	Prescribed Burning		Mechanical Fuel	
	Caucasians	Hispanics	Caucasians	Hispanics
California (89,500 acre reduction)				
Mean WTP	\$460	\$838	\$510	n/a
Florida (50,000 acre reduction)				
Mean WTP	\$392	\$473	\$239	\$373
Montana (35,000 acre reduction)				
Mean WTP	\$323		\$186	

With mean willingness to pay of more than \$400 per household, and more than 13 million households in California, the willingness to pay for either of these fuel reduction programs is about \$5 billion. In Florida, with 7.6 million households this translates to about \$3 billion for the prescribed burning program and \$2 billion for the mechanical fuels reduction program. In Montana, with only 366,000 households, state level benefits would be close to \$118 million for prescribed burning and \$68 million for mechanical fuels reduction. 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 fuels reduction programs together. However, these state level values reflect only what state residents would pay for the program, and Loomis and González-Cabán (1997) found that non-resident households often have a willingness-to-pay to prevent wildfires in ecologically important forests in other states.

What's next in the future of fire economics?

Visual representations in fire surveys

Given the dynamic nature of fire and fuel treatment programs such as prescribed burning, diagrams used in previous work are rather static, two dimensional representations. With the advent of videotape, DVDs and the Internet the potential exists to more realistically represent the “with” fire treatment program and the wildfire consequences of the without program. Furthermore, DVDs and the Internet give rise to the opportunity to provide context-sensitive information to respondents at critical points in the survey where some respondents might want it. In addition, DVDs, videotape or Internet provides the opportunity for an onscreen interviewer to conduct a mock in-person interview.

We have recently experimented with using videotape as a survey delivery mechanism with some success. This small pilot demonstrated it was feasible to conduct wildland urban interface surveys identical to the California WUI survey described above. There was no statistical difference between the annual WTP obtained using videotape and that of the original phone-mail-phone interview approach. See Loomis and others (2006) for more details.

In an exciting application of virtual reality to economic valuation of fire, Fiore and others (2007) use the FARSITE⁸ simulation model and virtual reality headsets to expose the survey respondents to the dynamic progression of a wildfire. Risk information is then communicated and respondents are asked a valuation question to reduce the likelihood of the wildfire they “observed” in the virtual setting. As noted

⁸ A fire growth simulation model developed by the Forest Service.

by the authors this is truly the cutting edge of virtual reality in attempting to create a simulated field experiment in a safe lab experiment environment.

Multi-attribute stated preference surveys

Many times fire management programs such as creating defensible space or using mechanical fuel reduction such as thinning involves tradeoffs between competing desirable attributes. Homeowners move to the forest to be surrounded by vegetation. Thinning and removal does reduce the fire danger, but at the expense of reducing the very amenities they sought. Understanding tradeoffs such as these is the strength of attribute-based valuation methods (Holmes and Adamowicz 2002). Recently, Holmes and others (study in progress) have applied a multi-attribute choice experiment to value homeowner and community fire risk reduction programs. Often, the resulting WTP functions from a multi-attribute approach lend themselves to benefit transfer to other settings even better than CVM. This is because the choice experiment allows unbundling of the attributes of a fuel reduction program. Thus, with a choice experiment, WTP can be calculated for the type and levels of attributes of interest in the new application, as long as those attributes were included in the original choice experiment.

Benefit transfer

The values in *Table 1* allow managers to perform an average point estimate benefit transfer per acre. But a more suitable benefit transfer to provide a marginal or incremental benefit per additional acre of reduced wildfire can be calculated using the respective study's WTP functions.

Following the procedure of Cameron (1988) the logit equations used to estimate mean and median WTP based on CVM responses can be reparameterized into WTP equations for reductions in acreage burned. This will yield a straightforward WTP function for reducing acres burned. For example, dividing the constant and acres by the absolute value of the bid coefficient we therefore obtain WTP per household as a function of acres burned for Caucasian households in California, Florida and Montana for the prescribed burning program:

$$\text{WTP per household} = \$174.06 + 0.002578 (\text{Acre Reduction})$$

WTP equations such as these can be calculated from Loomis and others (2008) and applied by managers to estimate the economic value per household for reducing acres of wildfires due to the prescribed burning program.

Conclusion

As our understanding of fire ecology and appropriate fire management responses evolves, there will be a continuing need to quantify the benefits and costs of the new fire management responses. The strength of stated preference methods such CVM and choice experiments is that they are limited only by natural scientists' abilities to predict the effects of the fuels treatments, and social scientists' abilities to communicate those effects to the public. Stated preference methods also have the ability to value broader forest management programs inter-relating fire, invasive species and watershed protection. Thus, stated preference methods may hold the key to integrated fire management planning. Finally, as public land management agencies continue their move to ecosystem management and begin to value ecosystem services, stated preference methods may move into the forefront of forest economics as they are the primary technique to value many of the nonmarket ecosystem services provided from public lands.

Acknowledgments

We want to thank Juan Marcos González Sepúlveda, Jonathan Yoder and Hayley Hesseln for reviewing an earlier version of this paper.

References

- Brookshire, D.; Eubanks, L.; Randall, A. 1983. **Estimating Option Prices and Existence Values of Wildlife Resources.** Land Economics 59(1): 1-15.
- Cameron, Trudy. 1988. **A new paradigm for valuing market goods using referendum data: Maximum Likelihood estimation by censored logistic regression.** Journal of Environmental Economics and Management 15: 355-379.
- Donnelly, D.; Nelson, L. 1986. **Net Economic Value of Deer Hunting in Idaho.** Resource Bulletin RM-13. Fort Collins, CO: Rocky Mountain Forest and Range Experiment Station, USDA Forest Service; 27 p.
- González-Cabán, Armando. 1993. **The Economic Impact of Fire: Improving the Forest Service's Fire Management Planning System Capabilities to use Non-Market Values.** Wildfire 2(4): 16-21.
- González-Cabán, Armando; Loomis, John B.; Rodriguez, Andrea; Hesseln, Hayley. 2007. **A Comparison of CVM Survey Response Rates, Protests, and Willingness-to-Pay of Native Americans and General Population for Fuels Reduction Policies.** Journal of Forest Economics 13: 49-71.

- Holmes, T.; Adamowicz, V. 2003. **Attribute Based Methods**. In: Champ, P.; Boyle, K.; Brown, T., editors. *A Primer on Nonmarket Valuation*. Boston MA: Kluwer Academic Publishers: 171-220.
- Krutilla, John. 1967. **Conservation Reconsidered**. *American Economic Review* 57: 777-786.
- Knetsch, Jack; Davis, Robert. 1966. **Comparison of Methods for Recreation Evaluation**. In: Kneese, A.; Smith, S., editors. *Water Research*. Baltimore, MD: Johns Hopkins University Press: 125-142.
- Loomis, J. 1989. **Test Re-test Reliability of the Contingent Valuation Method: A Comparison of General Population and Visitor Responses**. *American Journal of Agricultural Economics* 71(1): 76-84.
- Loomis, John; González-Cabán, Armando. 1994. **Estimating the Value of Reducing Fire Hazard to Old Growth Forests in the Pacific Northwest: A Contingent Valuation Approach**. *International Journal of Wildland Fire* 4(4): 209-216.
- Loomis, John; González-Cabán, Armando. 1998. **A Willingness-to-pay function for protecting acres of spotted owl habitat from fire**. *Ecological Economics*, 25: 315-322.
- Loomis, John; González-Cabán, Armando. 1997. **Comparing the Economic Value of Reducing Fire Risk to Spotted Owl Habitat in California and Oregon**. *Forest Science* 43(4):473-482.
- Loomis, John; Miller, Julie; González-Cabán, Armando; Champ, Joseph. 2006. **Testing the Convergent Validity of Videotape Survey Administration and Phone Interviews in Contingent Valuation**. *Society & Natural Resources* 19: 367-375.
- Loomis, John; Huang, Le Truong; González-Cabán, Armando. 2008. **Willingness to Pay Function For Two Fuel Treatments to Reduce Wildfire Acreage Burned: A Scope Test and Comparison of White and Hispanic Households**. In: González-Cabán, Armando, technical coordinator, *Proceedings of III International Symposium on Fire Economics, Planning, and Policy: Common Problems and Approaches*, April 29 to May 2, 2008, Carolina, Puerto Rico. Albany, CA: Pacific Southwest Station, USDA Forest Service.
- Sorg, C.; Loomis, J. 1984. **Empirical Estimates of Amenity Forest Values: A Comparative Review**. General Technical Report RM-107. Fort Collins, CO: Rocky Mountain Forest and Range Experiment Station, USDA Forest Service. 23p.
- Thomas, J.W.; Forsman, E.D.; Lint, J.B.; Meslow, E.C.; Noon, B.R.; Verner, J. 1990. **A conservation strategy for the Northern Spotted Owl: a report of the Interagency Scientific Committee to address the conservation of the northern spotted owl**. U. S. Department of Agriculture Forest Service, Portland, Oregon.
- Thomas, J.W., Raphael, M.G.; Anthony, M.G.; Forsman, E.D.; Gunderson, A.G.; Holthausen, R.S.; Marcot, B.G.; Reeves, G.H.; Sedell, J.R.; Solis, D.M. 1993. **Viability assessments and management considerations for species associated with late-succession and old-growth forests of the Pacific Northwest—the report of the Scientific Analysis**

Team. U.S. Department of Agriculture Forest Service, National Forest System, Washington, D.C.

Verner, J.; McKelvey, K.S.; Noon, B.R.; Gutiérrez, R.J.; Gould Jr., G.L.; Beck, T.W. 1992.

The California Spotted Owl: A technical assessment of its current status. General Technical Report PS W-GTR-133. Albany, CA: Pacific Southwest Research Station, USDA Forest Service 285 p.

Walsh, R.; Loomis, J.; Gillman, R. 1984. **Valuing Option, Existence and Bequest Demands for Wilderness.** Land Economics 60(1): 14-29.

The Helitransport Brigade Technician: Toward Professionalization of the Sector¹

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Abstract

Over the past twenty years in Spain, helitransport brigades have become an essential and highly effective force in attacking forest fires due to the numerous advantages they offer, such as rapid response, enhanced vision, and greater capacity for extinguishing fires. On the other hand, they also require heavy investments in order to be operative. The human resources allocated for such brigades are basically made up of administrative personnel with training in fire fighting, as well as personnel subcontracted from government agencies, the latter being hired on a temporary basis. Their principal functions include coordinating air transport, commanding brigades, and directing the initial extinguishing of the fire prior to the arrival of the appropriate administrative personnel. When the helitransport technician arrives at a fire, he establishes a plan of attack the efficiency of which will depend, in large part, on his experience and knowledge of the affected region. This would include, among other factors, knowledge of regional orography, vegetation, meteorology and fire systems, as well as factors relating to the organization itself, such as personnel, communications, fire fighting equipment, procedures, cartography, etc. If properly and successfully planned, aside from minimizing the burn area and any contingent losses, this would also reduce costs related to extinguishing the fire. The helitransport technician would also be responsible for enhancing another fundamental aspect, namely the safety of all personnel and any others intervening in the event. However, a large part of this organizational know-how, and its pertinent advantages, is being lost due to the precarious and seasonal hiring practices of such technicians, since many of them wind up choosing other more stable sources of employment in other specializations within the forestry sector. This is evidenced in an annual rotation rate that presently exceeds 40 percent, and which also translated into teams of very young technicians who have little

¹ An abbreviated version of this work was presented at the Third International Symposium on Fire Economics, Planning and Policy: Common Problems and Approaches, April 29 to May 2, 2008, Carolina, Puerto Rico.

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experience and are constantly on a basic learning curve. Investing in this situation would require greater and more thorough technical professionalization, with greater outlays in longer-term and higher-paid employment contracts. The costs related to such a measure, when compared with those being spent on the aircraft/pilot/mechanics trinomial, is insignificant, and the benefits are very clear: capitalization of experience, an increase in safety and efficiency, and in the long run, a reduction in burn areas with a subsequent decrease in public expenditures.

Keywords: Capitalization of experience, helitransport brigades, helitransport combat, fire extinguishing cost, efficient extinguishing costs, formation, helitransport technicians, personnel safety, professionalization.

Introduction

The human resources allocated for preventing and attacking forest fires are basically made up of forest service personnel, mostly technicians and environmentalists who sign up during forest fighting season, as well as personnel subcontracted from government agencies, the latter being on a permanent or temporary basis, as well as the agencies' own personnel.

As a general rule, a technician is under contract for three to five months, and is dedicated exclusively to fighting forest fires during the peak months of the fire season. During the rest of the year, if they are lucky, such technicians carry out fire prevention work in the sylvan ecosystems. The majority of the security measures opt for a first automatic rapid response by helitransport brigades, made up of various specialists, between four and eight, headed by a technician and/or foreman (Figure 1).

Present Situation

The end of the decade has been marked by huge forest fires that have caused repercussions way beyond the fires in question, alerting the authorities to the risks as well as to the serious damages caused to buildings and infrastructures.

The organization against forest fires in Spain.

During this last decade (1997-2007), the Autonomous Regions (territorial and administrative divisions within Spain) have consolidated forest fire-fighting organizations by acquiring specialized services that do not respond to a common pattern. In heavily developed Autonomous Regions such as Catalonia, Madrid and Navarra, fire extinguishing has been turned over to the Fire Department and the prevention of forest fires to the Forest Service. In others, such as Valencia and

Asturias, those responsible for extinguishing fires belong to the Emergency Department, complementing Fire Departments with Forest Brigades (Forest Firefighters), similar in structure to that of the Forest Service. A third group, made up of the rest of the Autonomous Regions, has kept fire prevention and extinguishing as part of the forestry system, coordinating with the General Directorate of Civil Defense and Emergencies when assets other than forests are in danger.



Figure 1—When the helitransport team arrives on the ground it must verify the actual viability of forest fire strategies and attack tactics that were planned by their Technician during the flight. Photo: Dídac Díaz, 2005.

Another characteristic of this decade is regionalization, based on reducing the time of rapid response, introduced during the 1990's in places such as Andalusia, with its Center for Forestry Defense, or Galicia, with its Forestry Districts.

Coordination of services has become an inevitable necessity when faced with the complexity of administrative structures and the multiple resources that are employed. Coordination Centers have been created under different names (Emergency Coordination Center in Valencia, Regional Operational Center in Andalusia, etc.), with the common goal of facilitating and coordinating the mobility of resources within the Autonomous Regions and channeling requests for help to the Central Administration and to other Regions.

Experience has shown that no territory is free from the danger of big forest fires and/or simultaneous forest fires. In order to combat this, most of the Autonomous Regions have developed an Emergency Management System in order to tackle simple situations with local resources, as well as complicated ones that rely on distant resources, their own or others, and which include various agencies. Likewise, Autonomous Regions have signed agreements with each other that facilitate the operation of the fire extinguishing resources regardless of their place of origin, when the fires are close to the demarcation lines of their respective territories.

During this decade, a degree of professionalization among fire fighters has begun to develop with collective agreements that attempt to regulate working conditions, as well as extend the duration of contracts. The Autonomous Regions

have increased the number of helitransport bases and the figure of the brigade technician has been established. The equipment used by the fire extinguishing personnel has been improved outfitting the brigades with EPI, Individual Protective Equipment, (according to the recommendations made by the Fight Against Forest Fires Committee) as well as compensation for accidents occurred during fire extinguishing.

For more information on the organization against forest fires in Spain, please see texts (Vélez 2000, Junta de Andalucía 2003, MMA 2004, Rabade and Aragoneses 2004, WWF/Adena 2004 and WWF/Adena 2006).

The figure of the technician, the one in command

The principle behind there being only one technician in command is defined by the fact that the chain of command needs to be not only perfectly defined, with no duplication of departments that would result in obstacles or a lack of coordination, but that at the highest point within that chain there exist an authority figure recognized by the rest of the chain. Only in this way can the necessary coordination and capacity for response in unforeseen circumstances or abrupt changes in the fire's behavior be ensured.

It must be kept in mind that in a fire, resources of a very different nature can and do intervene, that they must integrate into a unique system with established protocol. The situation becomes complicated if the agencies are not used to working together as a team. This circumstance is what makes the existence of a pre-established hierarchical structure so crucial, one that includes an agile decision-making mechanism.

One of the responsibilities of each command is the safety of those in subordinate positions. The brigade technician directs and supervises the extinguishing of fires, on occasion assuming the direction of other units that might be incorporated into the assigned sector. When the brigade technician arrives at a fire (Figure 2) he or she must evaluate it, submitting to the orders of the Director of Fire Fighters if there is one, and if not, he or she will act as such, deciding on the place and kind of attack, escape and safety routes, coordinating the unloading of the helicopter since, many times, the technician is the first to arrive. Technicians also provide complementary assistance in planning.

This experience should eventually lead him or her to aspire to the job of forest fire analyst (Molina et al. 2007).

The helitransport brigade technician with experience in forest fires is of vital importance, given the fact of being airborne in a rapid response, more so than with land-based resources, and the global overview of the forest fire, allow him to provide the coordination center with precise information on the present and future behavior of

the fire so that the director in charge of extinguishing the fire can correctly mobilize the necessary resources, information which is of great importance during simultaneous forest fires.



Figure 2—Partial view observed from the cabin of the helicopter by the Technician of the brigade when arriving at a fire by air. This view helps to plan strategies and attack tactics that may be followed. Photo: Julio de Miguel, 2006.

The selection of a good strategies and tactics for extinguishing the fire is also important, since the time it takes to control a fire is directly related (the less time, the more availability of the air resource and the lower cost), as well as the final perimeter of the forest fire (less surface, less damage).

Once on the ground, it is important that the technician know the affected region and the history of fires in the area, since this will help in the decision-making process and in the safety of all personnel when it comes time to choose a safe zone and an escape route. The technician is also in charge of the effectiveness of the airborne resources and makes sure that the release of extinguishing materials is synchronized with the ground personnel since the release on its own does not usually control and put out the fire.



Figure 3—Technician carrying out the task of Director of Forest Fire Extinguisher (left) and supervising the maneuver by his brigade of boarding the helicopter safely once their work is done (right). Photos: Juan Camaño, 2005 (left) and Clara Quesada, 2004 (right).

The technician is responsible for avoiding future repetitions and new mobilization of resources to places which have already been taken care of, and which would increase the cost. And, finally, the technician can act as Director of Fire Fighters (Figure 3).

Extinguishing costs

In terms of monetary outlays, we could say that in Spain the cost of extinguishing and fire prevention, as understood in terms of support infrastructures (firebreaks, water rafts, etc.), divided between the Ministry for the Environment (MMA) and the autonomous regions in Spain, adds up to 450 million euros per year (2005 figures). We could also say that in Spain the average surface burned per year, without distinguishing between kinds of vegetation, adds up to 150,000 hectares. The budgets for extinguishing and active preventive measures such as the maintenance of firebreaks, construction of water supplies, educational campaigns, etc., are included in the annual costs in the fight against forest fires. According to these values we can say that, from the point of view of extinguishing costs, each burned hectare involves an outlay of 3,000 euros. But this is a preliminary value and may not be the best estimate since the costs produced by forest fires are not always proportional to the burn surface since the difficulty in extinguishing the fire and the consecutive incorporation of the resources have to be factored in. The job of the rapid response brigade technician can be crucial in this kind of situation in order to evaluate the fire's potential and to assign resources appropriately.

It is estimated that the damage caused by forest fires produces a loss of no less than 1.125 billion euros, to which is added the 650 million euros spent on extinguishing fires, active prevention and the restoration of the burn areas, for a total of 1.8 billion euros. Obviously, these numbers do not include other values such as the loss of human life or personal property, or the existential value of the lost landscape and its influence on tourism, leisure, etc.

Everything seems to indicate that within the next few years there will continue to be a trend toward stabilizing and even reducing the number of fires and that the majority of forest fires will be controlled more quickly. Yet, there will still be a reduced number of fires that will escape the initial attack, thus reaching great proportions and causing a significant degree of damage.

Investing in this situation would require greater and more thorough technical

professionalization. The costs related to such a measure, when compared with those being spent on the aircraft/pilot/mechanic trinomial, is insignificant and the benefits are very clear: capitalization of experience, an increase in safety and efficiency, and in the long run, a reduction in burn areas with a subsequent decrease in public expenditures.

Improvement and discussion proposals

The problem

As in other facets of the forestry sector, the extinguishing of forest fires is framed by the precariousness of the labor pool due to the seasonal nature of hiring practices. This is particularly troublesome to technical teams that do not belong to Agencies with contracted personnel. As a result, this generates the non-existence of a defined and recognized profession.

Faced with such a lack of definition, we decided to carry out a survey that would reflect the reality of the teams of engineers who work and/or have worked as Helitransport Brigade Technicians, which would allow first-hand knowledge on past and present aspirations, as well as the inherent problems and concerns of this professional sector.

In this case, we limited the research to contracted personnel and not civil servants, since we believe it is appropriate to pay more attention to the group we consider to be more vulnerable at the present time.

We therefore formulated a series of questions, in a closed and structured questionnaire, in which we have tried to include all the members of the technical groups in Spain with a representative sample of the whole. This was not an easy task, given the geographical difficulties in locating technicians, the lack of contact among professionals themselves, and the logical lack of official and trustworthy databases on the same. The characteristics of the survey are found in Table 1.

Characteristics of the survey of Helitransport Brigade Technicians
Personal survey of a sample of 76 individuals selected among the population of technical forestry engineers and forestry engineers who have worked during the 2007 campaign or who have worked as technicians at any given time. The sample we used corresponds to approximately 40 % of the total population and includes 25% of the implicated companies.
The geographic field of research has been within the national territory of Spain.
The tool used to gather information was a structured questionnaire.
The method used to gather information has been a survey through personal interview or by telephone when the first option was not possible.
The dates encompassing this field work extend from April to October 2007.

Table 1—*Principle characteristics of the survey carried out on Helitransport Brigade Technicians between April and October 2007.*

A total of 76 individuals were finally located throughout the national territory, a more than representative sampling of the whole. These professionals graciously collaborated in the survey, which included those who worked during 2007 and those who worked in previous years, even if they are presently engaged in other tasks (Table 2). The special distribution of the sample is independent of the total number of professionals within each Autonomous Region. In this way we were able to learn how the profession has evolved in recent years, and, at the same time, what experience has been gained during this period.

The first limiting factor that appears when we approach the study is the scant attention given to this kind of analysis by the forestry administration, at least from an official standpoint. An experimental phase has been carried out in which first-hand information has been gathered for the group under study. Nevertheless, we hope that the research continues so that the number of interviewees can be increased significantly and thus approach the total of that population as closely as possible.

Spatial distribution of the sample	Number of Technicians interviewed
North and West (Galicia, Asturias, Cantabria, Basque Country and Navarra)	8
Along the Mediterranean (Andalucia, Murcia, Community of Valencia, Catalonia and the Balearic Islands)	48
Canary Islands	10
Interior regions (Extremadura, Castile La Mancha, Castile León, Madrid, La Rioja and Aragón)	10
TOTAL	76

Table 2—*Spatial distribution of a sample of the population of engineers that presently work or have worked as Helitransport Brigade Technicians. Drawn up from information gathered during field work carried out between the months of April and October 2007.*

This study enabled us to establish that this group is truly concerned about its profession. The results obtained, generally not at all surprising, are summarized in the following section.

This profession does not seem to fall within the scope of research on fire extinguishing techniques, since, in many cases there is limited and generally rote theoretical knowledge. The training is unfinished business framed between non-existent suitable training models and the precariousness of many of the existing ones.

From objective and self-critical observations (admittedly, with room for improvement) it was determined that:

- A great number of those in charge of fire extinguishing are civil servants who belong to the forestry service and are devoted to selviculture, public works and improvements, and others who during the summer season are also in charge of extinguishing forest fires, and who thus have little or no training in personnel management, teamwork, emergency management, fire behavior, physical education, etc. With very few noteworthy exceptions, no plans exist at universities or other educational institutions to incorporate courses on extinguishing forest fires that might be suitable to the present requirements, in tandem with ongoing developments in science and technology. It is enough to see how much of the information generated during the International Forest Fire Congresses actually reaches the fire fighting group members.
- There is no defined or officially endorsed master plan to regulate training that would integrate the little research that exists, nationally or internationally, or extensive curricula that would permit the design of integral training plans and thus build on the accumulated experiences and the advances of other interrelated fields. The evidence of this can be seen in the fatal accidents that occur time and again, following similar patterns.

- Investments in prevention are still extremely limited. Fires have become more and more powerful because of fuel accumulation and the arsenal of fire-fighting tools can now only deal with a few meters of flames; all reasons why there must be more investment in this area. Prescribed burning seems to be a tool that is being accepted more each time, but it requires very well trained fire management technicians.
- Approaching fires exhibiting G.I.F. behavior due to biomass accumulation require control techniques such as firebreaks, which are very complicated if there is no adequate training or experience.
- In many areas this seems to be a marginal sector because of the temporary nature of the job and its remuneration, translating into a high percentage of non-qualified personnel, in many cases without hope of training, but, at the same time, working in such a delicate and dangerous area as that of forest fires. Perhaps the worst part is the high turnover rate among experienced technicians due to the lack of a professional future and their replacement by young technicians with little experience.

A greater and more thorough technical professionalization would result in the possibility of an increase in safety and a reduction in burn areas through better techniques, adequate physical fitness and the development of teamwork on all levels. It is incorrect to believe that this is a job only for the physically fit young man or woman.

The lack of permanent structures for extinguishing forest fires is another reason for not achieving optimum success, since each fire fighting campaign needs to be set up and later dismantled, with negative repercussions at all levels. A clear example of this is the breaking up of teams who, in many cases, never work together in other campaigns due to constant relocation. This is of great inconvenience to the technician since each new brigade requires time for adaptation in which the personnel learns to trust the technician and vice-versa.

At this point, it should be reiterated that approximately half of those interviewed believe that the Administration should be in charge of fire fighting, as it has been until now, as a vote of confidence and hope for improvement, whereas the other half believes that the service should be privatized because of the Administration's incompetence.

Other factors compounding the problem include:

- The division between Autonomous Regions with different working styles, in many cases without any fluid coordination between them.
- The lack of integral and unified training among the fire fighters at different territorial levels.
- The need for resources and budgets that reflect real professionalization. There is

improvement but it is slow, and of course, insufficient.

- The considerable problems generated by self-criticism, however positive, as reflected in this research.

Present-day Spanish society, which considers itself first-world and continues to develop regardless, does not accept when emergencies get out of control. It is sufficient to cite the numerous cases of forest fires taking place in urban developments or in the vicinity of same, in which our maximum capacity is required.



Figure 5— Efficient strategy and control tactics carried out by an experienced Technician (left) and executed by the brigade under his command (right). Photos: Mauricio Martín, 2006.

Professional technicians versus contracted technicians. The present situation and hiring practices.

Clearly, the helitransport brigade technician's situation is minor importance when compared to the big picture. But there is a very important point to keep in mind. When the helitransport brigade arrives at the fire, many times the first one on the scene because of its rapid response, depending on how it carries out the attack, the fire can be a minor or small one, or it can become a GIF, which is extremely costly.

The veteran professional technician already knows the characteristics of the territory's, the operating and technical personnel, the mechanisms and the general and particular working styles.

The transient, seasonal hiring by campaign of three to five months, many times as first jobs, implies insecurity, stress and the result that the resources will not be as efficient as they should be. Situations of indecision are generated for reasons such as not knowing how a fire behaves. It is very clear to all of us, that a basic course in forest fires is not sufficient for making decisions and this creates serious problems such as the lack of trust of the personnel under command and even setbacks in the decision-making process that puts safety at risk.



Figure 6—Situations in which the Technician plans an efficient fire-fighting airborne attack because of prior knowledge of the intervention zone. Photo: Clara Quesada, 2004 (left) and 2006 (right).

Despite the adaptability of some individuals to the ongoing challenge of starting from scratch at each new base, too much time and effort is invested, much more than is desirable.

This group suffers from initial stress in adapting existing responsibilities to each new destination. There already exists an enormous responsibility in each initial attack since the decisions made directly reflect on the intensity of the fire while guaranteeing complete safety for the personnel under the Technician's command. Therefore, there is twice as much stress added to the fact of being new at the job.

Drawbacks: fires grow because of rookies in command. How costly is this growth?

In the initial attack, available resources are mobilized which can either lead to speedy control of a fire or the opposite. Depending on the case, the potential area that can be put out by the helitransport brigade will grow or diminish, but there comes a point when, if control has not been achieved more resources need to be called in and the expense thus increases due to extinguishing costs and the degree of damages produced.

But, *how much is burned with rookies in command and how much less damage would there be if we were really expert and hardened professionals?* This is a very difficult question to answer because of the absence of facts, in other words, because it is very subjective, but the technicians who work in this field know that mistakes are made in the beginning, in most cases because of lack of experience, sometimes simply because of a lack of local experience. This generate stress, and, as a consequence, technicians may hesitate in making decisions, with little or no capacity to prioritize in the selection of tools to be used prior to landing, given such variables as the type of fuel, which might be unknown.

When we speak of inexperience we must include factors relating to the high degree of mobility to which we have become accustomed. A clear example of this occurs when a technician from the peninsula is transferred to the Canary Islands or vice-versa. In this case, the technician will be faced with very different meteorology, fuels, work style and territory than to the one he is accustomed. In this, as in other situations, he or she will need time to adapt, or, in the best of cases, there may be improvement over time. (Figure 7).



Figure 7—Helitransport brigade in an initial attack following instructions of the Technician who is experienced and with advanced training in forest fires. Photo: Federico Grillo, 2006.

Therefore, it is clear that there are strong possibilities for having medium and large fires because of technician “incompetence” during the initial phase. This has been avoided, on occasion, thanks to the help of foremen and brigadiers who are veterans of the area, who have not suffered relocation from one base to another, as well as having historical knowledge of local fires.

Solutions. Invest in more qualified technical personnel.

A good helitransport brigade technician can greatly reduce costs while making worthwhile his or her salary many times over. How?

Experience can be gained in less time if there is advanced training (Grillo and Molina 2007) since much of the available and detailed information as to how forest fires behave, from a mechanical standpoint, has not reached many Helitransport Brigade Technicians (temporary or civil servants). Some detailed studies as to how those historic forest fires behave can be found, among other sources, in UTGRAF (2000-2007) a weekly electronic journal on fires that have taken place (edited by Bomberos de Cataluña), Grillo and Molina (2007), Viegas 2007 and Vegas et al. (2007)

But let us divide the problem into logical parts:

Investment in the training of technicians, who are also specialists, so they can

do a better job. This can be achieved:

- a.- From recognized universities and colleges, with greater implications.
- b.- From the Administrations of the Autonomous Regions.
- c.- From the private sector, with investments in R+D+i.

Continuity, so that those specialists can earn a living from their work and do not have to leave it because of other obligations. Compliance with only the previous section would still result in a loss of talent over time. In order to avoid such situations, we propose the following:

- a.- Longer-term contracts, and, if possible, with prevention tasks and training out of fire fighting season.
- b.- Better salaries that would make the profession more attractive and would allow the workers to deal with the inactive winter season with dignity.

Local stability that would turn them into experts on the territory. (Figure 8)

Investigation and development (studies)

New technicians, according to the recommendation in the book by Vélez (2000), could not form part of the helitransport teams until they have had two years' experience. This requirement could be substituted if the new technician accompanies a veteran technician in fire fighting during his or her first year. This measure, used in the past in the BRIF A, would increase the new technician's efficiency in subsequent campaigns and would have better results than if they only had the week-long theory course of TBH, which we consider to be insufficient.

This is not the first time that this sector accepts the challenge of trying to integrate professionalization in forestry management, and we do not pretend to introduce new approaches or discover simple solutions to complex problems. This is only an attempt to demonstrate that professionalization is not only an obligation but a necessity. These would be small solutions but with enormous significance in improvements.



Figure 8—Our proposal for quality professionalization: a combination of worker continuity, suitable training and accumulation of experience. Drawn from the conclusions of this investigation.

Acknowledgments

We wish to acknowledge the collaboration of all the engineers who have selflessly given of their time for this research on the profession and without whose help this work would never have been possible.

References

- Grillo, F., Molina, D. (coordinators). 2007. **Curso de Especialización en Análisis del Fuego Forestal**. Universidad de Lleida y Academia Canaria de Seguridad.
- Junta de Andalusia. 2003. **Iª Valoración Económica Integral de los Ecosistemas Forestales, 2003**.
- MMA. 2006. **Informe de incendios forestales en el decenio 1996-2005**.
- Rábade, J.M. y Aragonese, C. 2004. **Políticas, Planificación y Economía en la Defensa contra Incendios Forestales** en II Simposio sobre Políticas, Planificación y Economía en la Defensa contra los Incendios Forestales. 19-22 abril 2004, Córdoba, Spain.
- Vélez, R. ed. 2000. **La defensa contra incendios forestales: Fundamentos y experiencias**. McGraw_Hill, Madrid, c. 1400 p.
- Viegas, D.X. **Analysis of Eruptive Fire Behaviour** en “Proceedings of the 5th International Conference on Forest Fire Research”. 27-30, noviembre 2006, Figueira da Foz. Portugal.
- Viegas, D.X., Rossa, C., Caballero, D., Pita, L.C.P., Palheiro, P. 2006. **Analysis of accidents in 2005 fires in Portugal and Spain** en “Proceedings of the 5th International Conference On Forest Fire Research”. 27-30, noviembre 2006, Figueira da Foz. Portugal.
- UTGRAF 2000-2007. Lo forestalillo.
- WWF/Adena. 2004. **Incendios forestales: Causas, Situación Actual y Propuestas**. WWF/Adena, Madrid. 24 pp.
- WWF/Adena. 2006. **Grandes Incendios Forestales Causas y efectos de una ineficaz gestión del territorio**. WWF/Adena, Madrid. 34 pp.

Forest Fire Compensation: A Contingent Valuation Exercise With a Fixed Bid and Varying Environmental Quality Levels¹

Dulce Armonia Borrego and Pere Riera²

Abstract

In dichotomous choice contingent valuation, the environmental change is fixed throughout the sample whereas the monetary bid changes. This paper applies this procedure to estimate the “debit” or value of natural resource damages. In a value to value framework, the equivalent “credit” in environmental improvement has to be calculated. For that, a variant of the dichotomous choice contingent valuation method is proposed, where the monetary bid is fixed to the estimated debit value and the amount of environmental compensation varies. In that way, the minimum amount of physical compensation for the damage is calculated. A case study application is preformed based on a forest fire occurred in the northeast of Spain.

Introduction

Resource equivalency approaches have been broadly used in the United States to measure environmental liability with the purpose of protecting natural resources. Recent European Union environmental laws have been enacted to ensure that environments are rehabilitated and restored by providing compensation for damage of man-kind to natural resources (European Commission, 2006). In this context, environmental liability can be defined as the responsibility of polluters to restore the environmental damage to a baseline condition and account for interim losses.

In general, two approaches can be used to calculate the amount of required compensation: the physical natural resource needed to compensate for the harm (resource to resource or habitat to habitat) and the social value of the harm (value to value). The European Directive on Environmental Liability gives priority to the former, but also contemplates the latter.

In a resource equivalency analysis, the “debit” or damage is computed in terms of lost of damaged resources. The planned compensation or “credit” is equivalent in

¹ An abbreviated version of this paper was presented at the Third International Symposium on Fire Economics, Planning, and Policy: Common Problems and Approaches, April 29 – May 2, 2008; Carolina, Puerto Rico.

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resource terms to the debit. Similarly, in a habitat equivalency analysis, the debit and credit in terms of habitat are equated. Also, in the value equivalency analysis (VEA), the value to society of the credit offsets the social value of the debit. Depending on the approach adopted, the results would be expressed in different metrics, for example the area of required remediation (e.g. ha of forest), the number of organisms or species to be replaced (e.g. trees, birds, and other wildlife), the time units of recreational use, the monetary units, etc.

This paper applies a stated preference approach –the contingent valuation method (CVM) – as a tool for estimating the appropriate remediation for a burned forest in Catalonia, Spain, in a value to value framework. The contingent valuation method is probably the most widely used method for the valuation of environmental resources (Carson, 2004). A questionnaire describes the change to be valued, explaining how it will be implemented, and the method of payment (Mitchel and Carson, 1989). In its open ended format, the elicitation question asks a sample of the population to report their maximum willingness to pay (WTP) to obtain an improvement or avoid a worse situation, or their minimum willingness to accept to forego an improvement or accept a worse situation. More often, however, a dichotomous choice approach is used. The respondent is faced with an environmental change and a payment (or a compensation), and is asked to state whether she would agree with the new situation at the given cost. The amount asked to be paid, usually called bid, varies across the sample, while the environmental change remains constant.

Most VEA approaches have employed attributed-based stated choice methods in order to identify the preferred alternatives that will provide compensation from interim losses (Bishop et al., 2000; Swait et al., 1998). The main contribution of this paper is to propose and apply a variant of the contingent valuation method in a value to value or VEA framework. While the debit is estimated with a standard CVM application, the credit uses a dichotomous choice type of question where the environmental change varies and the bid is fixed and equal to the debit. In this way, the minimum amount of environmental change that offsets the value of the environmental damage to be compensated is estimated.

Thus, the application to a forest fire and the subsequent afforestation uses two sequential CVM questionnaires. The first questionnaire estimates the economic value to citizens of the Barcelona province for a forest fire prevention program using the typical dichotomous choice format. The size of the forest area prevented from burning is defined in accordance to past events caused by power lines in the central part of Catalonia. The second questionnaire, measures the public preferences for the amount of the restoration project to provide services of equivalent value due to the incident, using the explained variant of the dichotomous choice format.

Next section presents a brief overview of the theoretical framework of CVM. Section 3 provides information about the construction of the survey design. Section 4 addresses details of the experimental design and about the application in the pilot study. Section 5 reports the results, and section 6 the conclusions. Appendices A and B reproduce the questionnaires used in the pilot study.

Foundation

Welfare economics provides the framework for assessing natural resource damages. Specifically, compensating variation (CV) is a measure of welfare change that provides a basis for the pursuit of damage valuation. It is assumed that individuals will maximize their utility based on their budget, prices of market goods (x), non-market good levels (z), and other characteristics (s). The level of non-market goods is assumed exogenous.

$$\text{Max } u(x, z, s)$$

Solving this problem one can obtain the optimal consumption combination (in particular, the optimal quantity of x^*). The utility function can also be expressed in an indirect form:

$$u(x^*, z, s) = v(p_x, y, z, s)$$

The indirect function depends on the prices of market goods (p_x), the income of the individual (y), the initial and final level of the public good change, and other characteristics of the individual (s). The utility function can include a random variable, represented by the stochastic component, ε , reflecting the limited or imperfect information that a researcher faces. Thus, the indirect utility function is represented by $v(p_x, y, z^0, z^1, s, \varepsilon)$, where the change from the original to the final level of the public good (z^0 and z^1) is what typically the researcher intends to value.

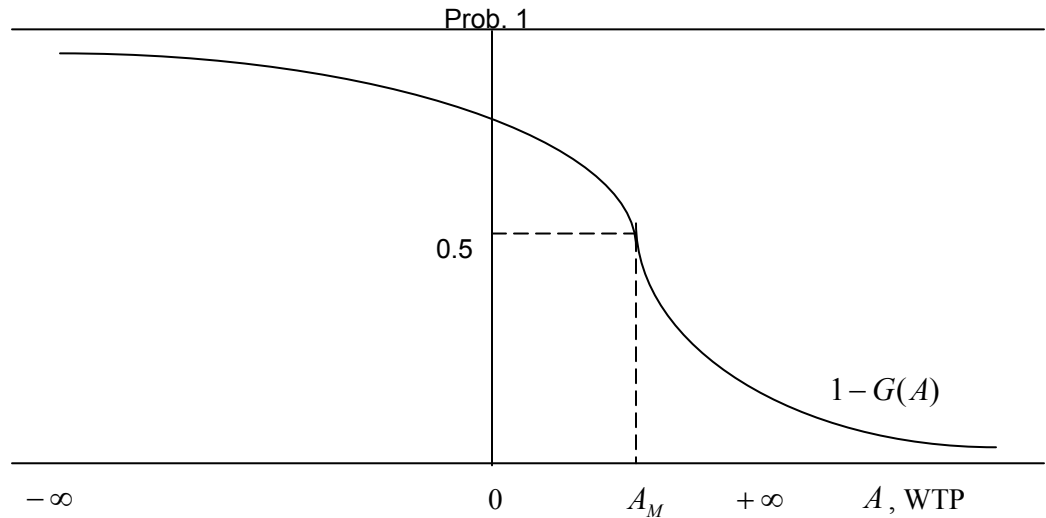
Using a dichotomous choice contingent valuation format, the probability of a respondent saying yes to a propose payment of a bid amount of A monetary units is equal to the probability of CV or maximum willingness to pay being greater or equal than A . Or, what is the same,

$$\Pr\{yes\} = \Pr\{v(p_x, y, z^0, s, \varepsilon) \leq v(p_x, y - A, z^1, s, \varepsilon)\} [1]$$

An assumption on the distribution of the stochastic term, together with varying

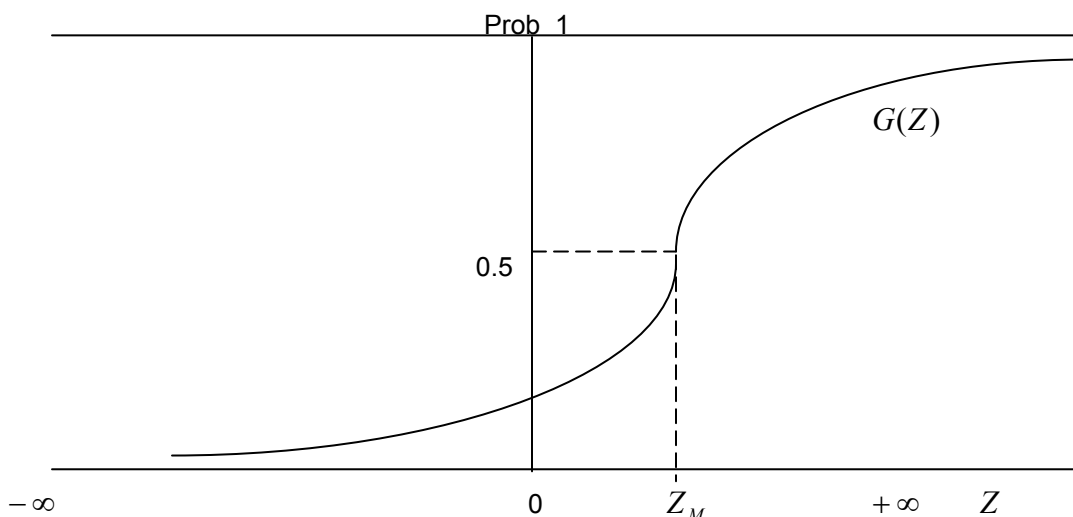
the bid amounts asked to respondents, is the basis for the econometric estimations undertaken in actual applications to elicit the mean or median CV. Graphically (figure 1), the probability of saying yes to the bid amount A is modeled through $1 - G(A)$, where $G(A)$ is the cumulative distribution function (cdf) of the compensatory variation or maximum willingness to pay.

Figure 1. Probability of saying yes to a given bid amount



Similarly, the level in the provision of the public good (z^1) can vary, keeping the bid amount constant. The probability of saying yes to the proposed change at a cost of A depends on whether the change is large enough, provided as an improvement. Therefore expression [1] applies. The difference is that now an assumption on the distribution of the stochastic term, together with a varying (z^1), elicits the mean or median minimum or public good compensation required (z^1) for the fixed payment of A . In graphical terms, the probability of saying yes to the public good compensation can be represented by the cdf of the minimum amount of public good required, $G(Z)$, as shown in figure 2.

Figure 2. Probability of saying yes to a given public good increase



Construction of the contingent valuation market

For this study two different valuation exercises are needed. Both exercises correspond to a contingent valuation pre-test survey conducted in Catalonia. The first exercise obtains values of a fire prevention program for one third of the *pinus nigra* forest area in Catalonia. A second survey presents a *pinus nigra* afforestation program in other parts of Catalonia as compensatory restoration plan and identifies the amount of size compensation required to return individuals to the pre-fire utility level.

The first stage of this study aims to assess social values for losses due to a large forest fire occurred in Catalonia in 1994 that affected approximately one third of the *pinus nigra* forest area. Even though this particular incident happened some years ago, it was presented as a future scenario in the questionnaire. The baseline and post-fire information about this event was available from the Forest Ecological Inventory of Catalonia (IEFC) and the Spanish Second National Forest Inventory (IFN2) carried out in the burned area just one year before the occurrence of the large forest fire.

The affected species is included in the EU Habitats Directive with a high priority of conservation. This species is the third most extensive pine type growing in Catalonia. The lack of regeneration of the *pinus nigra* results in changes in the landscape. In mixed forests, oaks have resprouted, as well as grasslands and open shrublands. *Pinus nigra* forests are mainly used for recreational alternatives such as mushroom picking or rural tourism.

The information presented to respondents in a survey was provided by *pinus*

nigra and forest fire specialists in Catalonia in order to ensure accurate information in the questionnaire. In particular, the expected effects for the next years until full recovery as well as consequences on the habitat for wildlife species and recreation were estimated by ecology specialists.

Two focus groups were conducted with a total of nineteen participants selected from the general public. In addition, several one-on-one interviews were undertaken before the pre-testing to ensure clarity in the information provided to respondents with respect to the consequences of large *pinus nigra* forest fires for the next 10 years, and reliable WTP responses, and the acceptance of the market institution simulated in the questionnaire.

Prevention of large forest fires

Following current practice in natural resource damage assessment (see for instance Carson et al., 2003), a future large forest fire prevention program was considered. Thus, the fire prevention program proposed in the questionnaire aims at protecting and preserving one third of the *pinus nigra* forest area distributed in the central surface of Catalonia that would otherwise burn in the next 10 years. The constructed scenario of the CV questionnaire on the first stage emphasizes the duration and extent of damage of the expected fire from the time of the incident until the forest recovers to baseline conditions. Thus, the information provided to respondents indicates that after the occurrence of the expected large forest fire it would take about 50 years to return the environmental levels to baseline conditions.

With respect to the concept of *interim losses*, focus groups and personal interviews showed that people distinguished the differences between permanent and temporary consequences or losses. Debriefing questions revealed that they understood correctly the fact that after the fire event, regeneration was almost inexistent, and that eventually the landscape would be covered with some oaks and shrublands after natural regeneration.

Compensatory program

The second step in a value equivalency approach requires the identification a compensation program that offsets the value for interim losses. The approach selected was the plantation of *pinus nigra* trees as it would provide similar habitat lost, and conceptually, the loss can be off-set through the provision of similar resources but off-site. The practical reason for choosing an off-site regeneration program is to test for WTP distance decay from the damage site, which is the object of a different paper.

As already mentioned, for purposes of this study, a modified form of the CVM was used to estimate the adequate quantity of compensatory program, by keeping

the bid amount constant to the value estimated from the previous questionnaire, and varying the amount of compensation.

Application

Design

In the autumn of 2007, the questionnaire was pre-tested on a small sample of municipalities belonging to the province of Barcelona (San Andreu, Manresa, and Sabadell). Forty one people participated in the pre-test for the prevention program, and forty four in the compensation one. The survey was designed to be conducted using face-to-face interviews with residents of at least 18 years of age. The median interview time was 14 minutes, including debriefing questions regarding the content of the questionnaire, if they understood correctly the current situation of the forest (for both versions, the pre- and post-fire situations), if they considered the information provided was simple and clear enough, understood the concept of interim losses, as well as any question about the program, and the payment vehicle.

Almost all respondents stated to be familiar with the main effects and consequences of the large forest fires in Catalonia. After the elicitation question, respondents were asked about their reasons for accepting or rejecting the WTP question, which is used to identify protest answers in the survey. Finally, the results obtained in the pre-test were useful to define the range of bid amounts and the forest compensation levels to use in the final version of the questionnaires.

Prevention questionnaire

After the introductory presentation, the first part of the questionnaire asked respondents to indicate the level of concern for some general problems such as immigration, household expenses, environmental protection, and unemployment (see appendix A). This question had the intention to start the respondent's process of thinking in a general context.

Next, the questionnaire informed about the surface covered by forests in Catalonia and some pictures introduced the four main forest types, which included the *pinus nigra* specie. From these pictures respondents were asked to indicate which of those four types, if any, they had visited in the past. The information included a map showing the distribution of the *pinus nigra* forests.

After this, the questionnaire informed about the forest to be preserved, its current density of the forest, the likelihood for a large fire and its consequences. The program to avoid large forest fires was to be promoted by a non profit organization. At this point respondents were informed that in case of the implementation of the prevention program it would have to be supported by all Catalonia residents by

annual compulsory contributions to a special fund over the next 10 years. The WTP question took a single bounded dichotomous choice form. Three different bids, 20€, 50€ and 100€, were randomly assigned to respondents.

Finally, the third part of the questionnaire included some debriefing questions and collected socioeconomic characteristics of the respondent and their household.

Compensation questionnaire

The compensation questionnaire was structured similarly to the prevention one (Appendix B). Before asking respondents how much they would pay for the remediation program, the scenario described the post-fire scenario and the expected years until full recovery. Then they were told that a non profit foundation was promoting a program with the aim of compensating the interim losses. The proposed remediation consisted of an afforestation program in suitable areas of Catalonia other than the burned area. They were told that the afforestation plan would have a cost and it would have to be covered by Catalonia residents in compulsory annual contributions over a 10 year period.

As already explained, the elicitation question stated a fixed bid for different amounts of compensation program (i.e. hectares of afforestation) due to the losses caused by the environmental damage. The afforestation surface was expressed in percentage terms of the originally burned area. Four levels were randomly assigned to respondents, 10%, 20%, 60% and 100%.

Results

Prevention

One third of the pre-test interviews for the valuation of the prevention program resulted in protest answers. The main protest reason for not willing to pay was that the program should be paid by the government. Protest answers were discarded for the WTP estimation. Consequently, 26 interviews constituted the database for the pre-test value elicitation. Table 1 shows some statistics from the respondents.

Table 1. Mean of demographic characteristics from the prevention survey

	Pilot 1
Percent males	46,15
Percent females	53,85
Education level (years)	12
Age	39,3
Visit to the forest (%)	61,00

A logit model relating the yes/no answer to the cost of the prevention program presented to the respondents was estimated to elicit the mean WTP (Hanemann, 1984). Table 2 reports the regression results. The mean WTP resulted in 68.7 euros per year, in values of 2007, during 10 years to implement a program that would prevent one third of the area of *pinus nigra* in the central part of Catalonia from burning.

Table 2. Logit regression results for prevention

	WTP for Prevention	P
Mean WTP	68.7	0.0285
(	56.65, 80.8)	

The debriefing questions at the end of the questionnaire revealed no major problems in the understanding of the good to value and of the questionnaire in general.

Compensation

The compensation questionnaire used the WTP from the previous exercise rounded to 70 euros. The protest response rate was 36%, leaving 26 elicitation answers for the analysis. Again, the main reason for protesting was that the government should take care of the program implementation without extra payments from the citizens, followed by the opinion that forest owners should pay. Table 3 shows some statistics from the surveyed population.

Table 3. Mean of demographic characteristics from the compensation survey

Pilo	t 2
Percent males	50,00
Percent females	50,00
Education level (years)	13
Age 34	,0

A logit model relating the yes/no responses to the size of restoration was estimated, as shown in table 4. The mean of the minimum compensation for the interim losses, expressed in percentage (over the originally burned area) of reforestation of *pinus nigra* resulted in 43.06%, or 10,800 ha to be planted in the county of Anoia.

Table 4. Logit regression results for compensation (%)

	Percentage of afforestation	P
Mean WTP (	43.06 49.19, 36.92)	0.0069

Again, there were no signs of major problems with the questionnaire.

Conclusions

Sometimes, like in equivalency analyses, researchers might be interested in estimating both the value of a damaged environmental resource, or debit, and the minimum amount of environmental improvement (credit) that offsets the loss value. This paper proposes a sequential approach, where a standard CVM application is used to calculate the value of the damage first, and a modified CVM variant estimates the mean or median of the minimum compensation required. The variant consists of fixing the bid amount and varying across the sample the environmental quality level. Both CVM applications are based on a random utility maximization model.

A pre-test application to some forest management in the northeast of Spain suggests that the sequential approach is feasible. The fact that in a single bounded format, the elicitation question in both CVM variants looks the same to the respondents, i.e. whether a given amount of euros would be paid for an environmental change, facilitates the implementation of the minimum compensation approach.

The debit pre-test application to a forest prevention program that would save one third of the *pinus nigra* area in central Catalonia that otherwise was expected to be burned over the next 10 years, showed a mean value of practically 70 euros (in 2007 values) to be paid annually for 10 years. The 70 euros value of the interim losses constituted then the bid amount for the credit calculation. The mean minimum compensation consisted in planting *pinus nigra*, off-site, for an extension equivalent to 43% of the stated burned area (one third of the *pinus nigra* forest in central Catalonia). These results are only preliminary, since they come from a small pilot survey.

It is left for further research a full size implementation of the case study, and the use of other than a single bounded dichotomous choice format of the elicitation question.

Acknowledgments

The research is based upon the EU *Resource Equivalency Methods for Assessing Environmental Damage* research program (REMEDE). In addition to its financial support, especial thanks are due to the partners of REMEDE consortium.

References

- Bateman, I.J., Langford I.H., Turner R.K., Willis, K.G., Garrod, G.D. 1995. Elicitation and truncation effects in contingent valuation studies. *Ecological Economics*. Vol. 12.
- Bishop, R., Breefle, W., Lazo, J., Rowe, R., Wytinck, S., 2000. "Restoration scaling based on total value equivalency: Green Bay Natural Resource Damage Assessment" Final report. Prepared by Stratus Consulting Inc. Boulder, CO.
- Carson, R. T., 2004. Contingent Valuation: A Comprehensive Bibliography and History, Cheltenham: Edward Elgar Publishing.
- Carson, R. T., Mitchell, R. C., Hanemann, M., Kopp, R., Presser, S. and Ruud, P. A. 2003. Contingent Valuation and loss passive use: Damages from the Exxon Valdez oil spill. *Environmental and Resource Economics*, 25 (3).
- European Commission, 2006. Homepage for Environmental Liability.
- Hanemann, M. 1984. Welfare Evaluations in Contingent Valuation Experiments with Discrete Responses. *American Journal of Agricultural Economics*, 66 (3).
- Mitchel, R.C. and Carson, R.T., 1989. Using Surveys to Value Public Goods: the Contingent Valuation Method. Resources for the Future, Washington, D.C.
- Swait, J., Adamowicz, W., Louviere, J., 1998. Attribute-Based Stated Choice Methods for Resource Compensation: An Application to Oil Spill Damage Assessment. Natural Resource Trustee Workshop. Washington, DC.

Review of the Existing Fire Detection Systems in Europe and North Africa¹

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Abstract

In order to minimize the damages associated to wildfire is crucial to have, primarily, a good prevention. When this fails, a fast and accurate detection should help an efficient first-attack followed, if everything fails, by a strong fire-fighting.

This paper presents the first results of a European, Morocco and Tunes inquiry regarding fire detection, sent to the forest experts group of the European Community. The present work is contextualized on the European Project FIREPARADOX (FP6-018505) which aims to inventory, classify and analyse the fire detection systems in Europe and Northern Africa, to develop proposals to improve their effectiveness.

As a result we see that the most common detection system continues to be lookout towers followed by mobile brigades. The resource to aerial detection is made by the countries that have more problems with forest fires.

Spain is the country that uses all the resources available to detect forest fires and is the country that spends more money on fire detection.

The fire detection system is based particularly on seasonal workers employed during fire season. Most of the countries give specific training to their workers and the institutions that give training are in general the forest services and the civil protection.

Keywords: Fire detection, lookout towers, mobile brigade, new technologies, Europe.

¹ An abbreviated version of this paper was presented at the Third International Symposium on Fire Economics, Planning, and Policy: Common Problems and Approaches, April 29 – May 2, 2008, Carolina, Puerto Rico.

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Introduction

The European forest area amounts to 1004 million ha including the Russian Federation (MCPFE, 2003). An important portion of these woodlands has been created through reforestation activity during the 20th century, developed under conservation and environmental protection policies (FAO, 1995).

Although fire is a common element that has always been present in the wildland, is in the South European countries and in the North African countries, where wildfires are the most important damaging factor, with 300.000 to 500.000 ha of forests and other wooded land burnt every year around the Mediterranean region (DGJRC, 2005).

In order to minimize the damages associated to wildfire is crucial to have, primarily, a good prevention. When fire prevention fails, fire-fighting steps must be initiated, but this can only happen following detection. The fire detection is based in a series of activities with the following objectives: discovery, localization and report to the communication centre (Ruiz, 2000).

The analysis of the fire detection systems in Europe and in Northern Africa is one of the objectives of the FIRE PARADOX project, “An innovative Approach of the Integrated Wildland Fire Management Regulating the Wildfire Problem by the Wise Use of Fire: Solving the FIRE PARADOX” (2006 to 2010). Funded by the European Commission within the Sixth Framework Programme, this is an Integrated Project, involving 31 partners (Universities, Research Centres, Fire Management Agencies, International Networks, SMEs and Non-Governmental Organizations) from 13 countries (Finland, France, Greece, Germany, Italy, Morocco, Poland, Portugal, Slovenia, Spain, Switzerland, Tunisia and the United Kingdom) coordinated by the School of Agronomy, Technical University Lisbon, Portugal (ISA/CEABN).

This paper has the goal to present which are the fire detection systems used in the European and North African countries, what kind of new technologies are being used as detection systems and who are the human resources working on detection and their specific training.

Methodology

The main tool to obtain the required information for the identification and classification of wildfire detection techniques was an inquiry enclosed in a questionnaire designed by the Scientific Research Group of the University Complutense of Madrid, in collaboration with FIRE PARADOX partners involved in

the assessment of policies and practices within the Project⁷.

The mentioned questionnaire was addressed by the Institute of Agronomy, through the European Commission (EC), in November 2006 to the members of the Forest Fire Prevention Expert Group (WGFFP), a working group associated with the European Forest Fire Information System (EFFIS) established by the Joint Research Centre (JRC) of the Commission. This expert group is composed by experts from the national authorities nominated by the EU Member States and the EC; as they deal with operational issues related to wildfire prevention and fighting, they have a complete and exhaustive knowledge about wildfires in their countries and account with primary access to information sources on these issues. For the North African countries (Morocco and Tunisia) and other Member States without any representative member in the WGFFP, the questionnaire was sent through the partners involved in the FIRE PARADOX project to the respective policy-maker.

The questionnaire replies received until July 2007 includes twelve countries: Austria, Bulgaria, Cyprus, France, Latvia, Lithuania, Morocco, Poland, Portugal, Spain, Sweden and Tunisia.

In order to complement the questionnaire answers and to perform a more profound analysis in the countries where wildfire are an important issue, Portugal, Morocco, Spain and Poland elaborated for each one a study case. For the different study cases elaborated by each partner, the methodology used was documental analysis and interviews with national fire detection experts.

Results and Discussion

The fire detection systems can be divided in three major groups:

Terrestrial detection systems – It includes fixed ground surveillance (lookout towers) and mobile ground surveillance (mobile brigades);

Aerial detection – helicopters, airplanes;

New technologies for fire detection – Infrared and video cameras, remote sensing, laser detection, unmanned aerial vehicles (UAV's), satellites.

The results of the questionnaire are focused on this classification. According to the questionnaire results, Austria is the only country that doesn't present any detection system. This data can be explained since wildfires are not an important problem in this country. In 2005, Austria had 1759 wildland fires with a total burnt area of 104 ha and 954 forest fires which resulted in 74 ha of burnt land. Most of the

⁷ FIRE PARADOX Module 7 "Policies and practices assessment" partners: Instituto Superior de Agronomia (ISA/CEABN), European Forest Institute (EFI), Max Planck Gesellschaft Zur Foerderung Der Wissenschaften (GFMC), Universidad de Lleida (UL-UFF), Institut National du Génie Rural, Eaux et Forêts (INRGREF) and Ministère de l'Agriculture, du développement Rural et des Pêches Maritimes (ENFI).

fires were smaller than 1 ha, the largest fire event resulted in 5 ha of burnt area (DGJRC 2005).

All the others eleven countries at least use one of the already mentioned detection systems. The most common detection systems are the lookout towers used by ten (83%) countries, followed by the mobile brigades with eight (67%) answers. Also in the field of the terrestrial detection, five countries (42%) have volunteers programs that complement the official terrestrial detection.

France, Lithuania, Poland, Portugal and Spain, together with the detection by the lookout towers use Video Surveillance. This technology continues to be somehow expensive and there's an international discussion about his advantages and disadvantages (WFDW, 2006), which could explain his use just by a few countries.

The use of airplanes and helicopters for the aerial vigilance are not very frequent. Only six countries use airplanes, and just Spain uses helicopters for this purpose.

Sweden is the only country that although doesn't utilize terrestrial detection systems, uses airplanes for surveillance actions. This situation is due to the reduction of the State contributions for fire detection, together with the civil protection act where it mentioned that the responsibility to protect forests is a task of the forest owners. In consequence, the big owners or municipalities hire airplanes to cover small areas.

Although the different detections systems complement each other, just five countries use both the terrestrial and aerial systems. As presented in table 1, we observe that Spain uses not only the lookout towers, but also mobile brigades, airplanes and helicopters. Portugal, Morocco, Poland and France utilize the same systems with the exception of the helicopters. This can be explained by the numerous forest fires and area burnt in Portugal, Spain and France, and also by the relevant extension of forest area under high and medium fire risks (DGJRC, 2005).

Whilst Poland doesn't belong to the Mediterranean countries group, the fire risk danger has been increasing in the last years, as well as the number of fires and area burnt (DGJRC, 2005).

Table 1 – *Detection systems distribution per country*

Country	Terrestrial detection			Aerial detection	
	Lookout towers	Mobile brigades	Video surveillance	Airplanes	Helicopters
Bulgaria	x	x	-	-	-
Cyprus	x	x	-	-	-
France	x	x	x	x	-
Latvia	x	-	-	-	-
Lithuania	x	-	x	-	-
Morocco	x	x	-	x	-
Poland	x	x	x	x	-
Portugal	x	x	x	x	-
Spain	x	x	x	x	x
Sweden	-	-	-	x	-
Tunisia	x	x	-	-	-

Terrestrial detection

Looking to table 2, it shows that the percentage of forest area in these eleven countries is very different between them, with a minimum of 6% in the case of Tunisia, and a maximum of 61% in Sweden. The countries with a larger forest land are Sweden, followed by Spain and France.

Taking into account the number of lookout towers and the forest land for each country (table 2), we see that Cyprus is the country who has the biggest number of lookout towers in a thousand hectares (0,161) followed by Poland, Latvia and Portugal, respectively with 0.069, 0.063 and 0.062.

In consideration of the ratio of the human resources by each lookout tower, the numbers are very variable, from a minimum of one person by lookout in Morocco, until a maximum of four persons in Portugal. All the other countries that replied to this question are surrounding two or two and a half persons per lookout.

Table 2 – *Relation between area of forest land and the number of lookout towers*

Country	Forest land (1000 ha) *	% Forest land*	Number of Lookout Towers **	Number Lookout towers / 1000 ha	Ratio Human Resources / lookout towers**
Bulgaria	3625	33	90	0,025	-
Cyprus	174	19	28	0,161	2,4
France	15554	28	645 ***	0,041	-
Latvia	2941	46	186	0,063	2
Lithuania	2099	32	102	0,049	2
Morocco	4364	10	130	0,030	1
Poland	9192	29	637 ***	0,069	-
Portugal	3783	41	234	0,062	4
Spain	17915	35	741***	0,041	2,3
Sweden	27528	61	-	-	
Tunisia	1056	6	-	-	

* Data source: FAO, Global Forest Resources Assessment 2005

** Data Source: FIREPARADOX questionnaires Module 7.

*** Case studies for FIREPARADOX

The number of mobile brigades by country is even more variable according to the questionnaire answers. The minimum belongs to Cyprus that has twenty six brigades, Morocco has sixty four, Bulgaria can vary from eighty to one hundred fifty, Portugal has three hundred and eighty nine and Spain has five hundred and fifty one brigades. Poland and France are the countries with more mobile brigades, correspondingly four thousand two hundred and thirteen brigades and one thousand and ninety four brigades. These brigades are composed by two or three elements depending on the country.

Aerial detection

As mentioned above, Spain uses not only planes but also helicopters to perform aerial detection. Portugal, Morocco, Poland and France utilize as aerial means only airplanes.

Although Morocco presents aerial detection, it is not an organized aerial surveillance system for forest fires detection. However, since the forest with an higher risk is located near the aerial navigation corridor to Europe (Rif forests) and to the Middle East (Rif Forest, the oriental and Middle Atlas), the Civil Aviation Direction sensitises the aerial companies to collaborate in the forest fires detection and alert.

New Technologies

The use of new technologies has been one of the demands of foresters and technicians working with forest fires (Colaço and others 2007). Much research has been done in the past years about this subject. However, from eleven countries, only Spain, France and Portugal utilize some new technologies to complement the traditional means as follows:

- Surveillance and first attack vehicles
- Three dimension models
- Global Position System (GPS)
- Panoramic photographs (Ubifoc System, VIGIS System)
- Thermographic camera
- Photographic and recording camera
- Video Vigilance
- Infrared Cameras
- PDA'S - communications of the alerts by sms
- Satellite images

Although only Castilla and Leon (Spain) utilizes satellite images to have meteorological prediction and hot spot detection, other countries also referred this system, but to follow-up the development of a fire and to quantify the burned areas.

Human resources

With the objective of understanding the nature of the human resources working on these systems, it was asked for each country who works on each detection systems and the nature of their employment contract (Table 3).

Table 3 – Employment contract by detection system

Country	Terrestrial detection			Aerial detection		Volunteers
	Lookout towers	Mobile brigades	Video surveillance	Airplanes	Helicopters	
Bulgaria	SW / T / NG	NG	-	-	-	X
Cyprus	SW	SW / T	-	-	-	X
France	SW / T	SW / T / NG / V	T	SW / T	-	X
Latvia	SW	-	-	-	-	-
Lithuania	SW	-	T	-	-	-
Morocco	SW	Employees	-	Commercial airlines	-	-
Poland	SW	T / NG	SW / T	T	-	-
Portugal	SW / NG	SW / NG	SW / NG	SW / T	-	X
Spain	SW / T / O	SW / T / NG / V / O	SW / T	SW / T / NG / M / O	SW / T / NG / M / O	X
Sweden	-	-	-	T	-	-
Tunisia	SW	SW / T	-	-	-	-

(SW – Seasonal worker; T – Technician; NG – Nature guards; O – others; V – Volunteers; M – Militaries)

Table 3 shows us the importance of the seasonal workers to allow the lookout towers functioning. All the countries using this system utilize this type of workers, and Portugal, Spain, Bulgaria and France complement them with the help of technicians, nature guards or forest rangers.

Concerning the mobile brigades, although several countries utilize seasonal workers, these are also complemented by nature guards, volunteers, technicians and employees. There's a small tendency for the human resources when working with video surveillance to be more specialized. For that, the work is developed predominantly by technicians, which are complemented by seasonal workers or nature guards.

The aerial surveillance, being a more expensive vigilance, is only performed by six countries that use technicians and seasonal workers or in the Spanish case, it is also complemented by the militaries, nature guards and volunteers.

Concerning the specific training each workers group receive to perform their duties, almost all countries give training with the exception of Morocco and Lithuania. In the majority of the countries the training is given by institutions related to Forest or to Civil Protection (table 4).

Table 4 – Institutions that provide the specific training for each detection system

Country	Terrestrial detection			Aerial detection	
	Lookout towers	Mobile brigades	Video surveillance	Airplanes	Helicopters
Bulgaria	State Forest Service	State Forest Service	-	-	-
Cyprus	State Forest Service	State Forest Service	-	-	-
France	Ecole d'application de la sécurité civile de Gardanne et Office national des forêt	Ecole d'application de la sécurité civile de Gardanne et Office national des forêt	-	Ecole d'application de la sécurité civile de Gardanne	-
Latvia	State Forest Service	-	-	-	-
Lithuania	No	-	no	-	-
Morocco	No	No	-	no	-
Poland	Forest Districts	Forest Districts	Forest Districts	Forest Districts	-
Portugal	State Forest Service, Republican National Guard, Nature Conservancy Institute	State Forest Service, Republican National Guard, Nature Conservancy Institute	Private equipment companies	State Forest Service	-
Spain	Yes	Yes	yes	yes	yes
Sweden	-	-	-	The organization that provides the airplanes gives a small introduction as training.	-
Tunisia	Protection civile	Protection civile	-	-	-

Detection costs

The existence of several detection systems in simultaneous can have great costs. Although we have asked to all the countries how much money they spent on each particular detection system, the answers were very sparse and for most countries, those data were not available. The countries that answered to this question were Portugal, Spain (just some autonomic regions), Latvia and Cyprus.

The costs presented for the terrestrial detection are presented in table 5. Comparing the data for the lookout towers, we see that Latvia is the country where to have a lookout tower functioning you spend less money, and in Spain, more specifically in the Valencia Region is exactly the opposite, with the more expensive lookout tower.

Table 5 – *Costs associated to the terrestrial detection.*

Country	Lookout Towers (€)	N° Lookout Towers	€ / LT (€)	Mobile Brigade (€)	N° Mobile brigades	€ / MB (€)
Cyprus	1.000.000	28	35.714	700.000	26	26.923
Latvia	635.000	186	3.414			
Portugal	2.700.000	234	11.538			
Castilla and Leon (Spain)	2.172.114	174	12.483	7.518	27	278
La Rioja (Spain)	290.000	14	20.714	1.662.000	12	138.500
Madrid (Spain)	1.045.262	43	24.308	198.156	5	39.631
Valencia (Spain)	3.438.816	71	48.434	12.061.805	104	115.979

In Spain, the region of La Rioja, the utilization of mobile brigades is the more expensive when compared with the other regions and countries. Also belongs to Spain, the less expensive mobile brigades, more precisely in the community of Castilla and Leon.

When taking into consideration the aerial detection, only Portugal and the Community of Castilla and Leon in Spain gave data for detection with airplanes. While Portugal spent around five thousand euros per airplane, Castilla and Leon spend twelve times plus, with the amount of sixty two thousand euros per airplane. This huge difference can be somehow explained by the use in Spain of infrared cameras in this aerial surveillance, and Portugal only uses GPS and a Unit of automatic localization and communication (ULRA) (Germano 2007).

Spain is the only country that refers to use helicopters for fire detection. Madrid, Navarra and Valencia gave us the numbers for the utilization of one helicopter per fire season. The more expensive one works in Navarra, with the amount of four hundred and fifty thousand euros, followed by Valencia that spends three hundred and eighty six thousand euros and by Madrid with two hundred and thirty two thousand euros.

Portugal and Valencia (Spain) also work with volunteers for fire detection, and each one spends per volunteers respectively one hundred and forty two euros and one hundred and sixty eight euros.

The use of new technologies was just quantified by the region of Castilla Leon where the use of satellite for meteorological prediction and hot spot detection costs thirty six thousand seven hundred and eighty four euros.

Table 6 – *Detection system costs by country and autonomic region from Spain*

Country	Terrestrial detection (€)	Aerial Detection (€)	Others (€)	Total (€)
Cyprus	1.700.000	-		1.700.000
Latvia	635.000	-		635.000
Portugal	2.700.000	49.837	1.500.000	4.249.837
Castilla and Leon (Spain)	2.179.632	310.725	36.784	2.527.140
La Rioja (Spain)	1.952.000		1.645.000	3.597.000
Madrid (Spain)	1.243.418	232.100		1.475.518
Navarra (Spain)	Not available	450.000		450.000
Valencia (Spain)	15.500.621	386.000	673.269	16.559.890

Trying to quantify the amount of money spent by each country for fire season to perform fire detection (table 6), we see that the Region of Valencia (Spain) is the one that spend the biggest amount of euros. This region spends almost thirty seven times more than his neighbour, the region of Navarra, although the data for this region is not complete. The country that spends less money to perform detection is Latvia. In decreasing order, Spain is the country that spends the largest amount of euros for fire detection, followed by Portugal, Cyprus and in the last place Latvia.

Final Remarks

After analysing all the questionnaires sent by the eleven countries, we see that the most common detection system continues to be the lookout towers. This system is complemented by the mobile brigades that help to cover the shadow areas not seen by the lookouts.

The resource to aerial detection is made by the countries that have more problems with forest fires.

Spain is the country that uses all the resources available to detect forest fires (terrestrial and aerial detection as well as new technologies), and it is also the country that spends more money on fire detection.

The fire detection system is based particularly on the seasonal workers, which are employed during the fire season. Most of the countries give specific training to their human resources and the institutions that give these trainings are in general the

forest services and the civil protection.

Bibliography

- Gibbs, K. 2006. Wildland Fire Detection Workshop – Discussion Notes. Net.
- Germano, A. 2007. Monitorização 2007. Direcção Geral Recursos Florestais.
- Directorate-General Joint Research Centre. 2005. Forest Fires in Europe 2005, European Communities 2006.
- FAO. 2005. Global Forest Resources Assessment. Food and Agriculture Organization of the United Nations, Rome, Italy.
- Colaço, M. C., Meira, P., Rego, F., 2007, Prevención de Incendios Forestales: Un estudio sobre la formación de los técnicos forestales in Investigaciones en Educación Ambiental. Naturaleza Y Parques Nacionales, Serie Educación Ambiental. Organismo Autónomo Parques Nacionales. Ministerio de Medio Ambiente. España.
- Ruiz, E.M. 2000. Detección. In: Vélez, R. (Coord.). La defensa contra incendios forestales. Fundamentos y experiencias. Madrid, España: McGraw-Hill/Interamericana de España, S.A.U.; pp. 17.1-17.15
- Madrid. European Commission. 2006. Forest Fires in Europe 2005, Directorate-General Joint Research Centre, European Communities, Italy.
- MCPFE Liaison Unit Vienna and UNECE/FAO. 2003. State of Europe's Forests 2003.

Assessment of the Growing Importance of Wildland-Urban Interfaces in Fire Risk Management: WUI Regional Patterns in Spain¹

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Abstract

The transition areas between wildland masses and urbanized spaces in Spain (wildland-urban interface, WUI) are subject to an increasing expansion, linked in many cases to the desire for a closer proximity to natural spaces. These interface areas create new problems that affect environmental management in said spaces, and especially forest fire risk management.

Residential developments in wildland areas introduce a higher risk element (possible loss of human lives, destruction of dwellings and other structures), which is added to fire damages in wildland masses. Consequently, WUI areas must be identified in the territory and also characterized in relation to forest fire risk in order to establish an effective and efficient forest fire risk management model, suitable for these areas.

Currently, there are various methods used to classify interfaces, based on the local analysis of mainly two variables: human presence (population and settlements) and the type of vegetation coverage. However, the expansion processes of the WUI are a product of spatial dynamics that take place at a regional level. In this context, the analysis of land use planning, spatial organization models, and forestry planning instruments are key aspects while characterizing interface areas.

The objective of this paper is to present an assessment of the current situation of the wildland-urban interface concept and the planning materials in Spain. This analysis is the first step towards the characterization of these areas in their territorial context and their foreseeable evolution. The final objective would be to identify possible spatial patterns that can influence forest fire risk management in wildland-urban interface areas.

With this goal, a multi-level and multi-sector analysis is proposed which stems from a general focus of the situation in this type of area in Spain, and an assessment at an autonomous level.

¹ An abbreviated version of this paper was presented at the Third International Symposium on Fire Economics, Planning, and Policy: Common Problems and Approaches, April 29 - May 2, 2008, Carolina, Puerto Rico. This research is developed in the frame of the FIRE PARADOX Integrated Project “An innovative approach of Integrated Wildland Fire Management Regulating the Wildfire Problem by the Wise use of Fire: solving the Fire Paradox”, financed by the VI Framework Programme, Sub-priority 6.3 Global Change and Ecosystems.

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Keywords: Forest fire, Spain, spatial planning, wildland-urban interface.

1. The Problem in Context

The wildland-urban interface concept is gaining more importance in Spain in relation to a system of settlements with a marked tendency toward dispersion and a preference for forest areas with great landscape value. The incidence and the consequences of forest fires are of catastrophic potential due to the growing use of the environment by human society; some examples of this took place over the last few summers (Catalonia, 1998; Galicia, 2006).

The confluence of urbanized areas in forest land creates spaces that are especially problematic when planning and managing forest fires. The presence of residential developments in forest areas increases the vulnerability of these territories when facing the possible loss of human lives, destruction of housing and other structures, as well as the evident damage to forest masses. In addition, there is a higher risk of fires caused by human negligence or carelessness, often because of ignorance about the inherent realities of the forest.

This situation has created a need for a normative treatment for this type of space in relation to forest fire risk, and also the establishment of preventive planning. However, Spain's regional diversity highlights the need for the development of a forest fire management system that can be adapted to each territory's specific needs and characteristics.

The analysis of the most relevant normative and planning materials from the point of view of prediction, prevention, and suppression of forest fires is presented with the objective of assessing the extent to which the territorial context of the wildland-urban spaces is considered while planning fire risk management in urbanized areas.

2. Methodology

The area of study focuses on Spain's Autonomous Communities. Spain's particular situation, as a country with a decentralized political-administrative structure, means that there is a distribution of responsibilities for forest policy and the conservation of nature, according to the Spanish Constitution. In this context, the greatest part of the responsibilities for legislative development, the administration, and the management of forest and natural spaces, falls on the Autonomous Communities; the General Administration of the State is responsible for establishing the basic legislative framework and the general objectives on forest policy, in which the Autonomous Communities develop their functions. This decentralized situation means that we must be mindful of the established State regulations during the

analysis, and especially, the particularities of forest fire management at an autonomous level. For this study, a sample of Autonomous Communities³ has been selected which, because of their historic incidence of fire as well as their normative development, make possible a relatively comprehensive comparative analysis on the situation in Spain.

Forest fires are a complex, multi-dimensional issue due to the incidence of certain ecological, socioeconomic, and political factors. In this sense, policies external to the forestry sector (those pertaining to the conservation of nature, or to agriculture and rural development, including civil protection) can influence the preventive treatment of the risk of forest fire as well as fire behavior. For the concrete study of fire risk in the wildland-urban interface areas, the following aspects of planning have been considered:

- First, forestry policy is the basic foundation on which all aspects relating to management and protection of forest areas are supported, and includes, although in a very general way, the treatment of fires;
- given the great incidence of forest fires in our country, there is a wide production of guidelines and planning materials, specifically for the management of the integrated fight against forest fires;
- emergencies and civil protection planning establish the criteria to be followed in the concrete cases in which a forest fire threatens the safety of humans and property;
- lastly, spatial and urban planning can have a determined on the planning of settlements, as well as the regulation of activities and uses that can cause fires.

The basic sources of information to be analyzed are the normative or regulatory texts and the planning materials which correspond to the four identified territorial policies (see Appendix). The specific objectives of this material analysis have been: (i) to assess the inclusion of these new interface spaces and their definition by the legal and planning instruments; (ii) to study the possible actions and measures proposed vis-à-vis forest fire risk management; and finally, (iii) to identify the existing links and the elements for integration and coordination between the different policies being considered.

3. Defining the Concept and Delimiting the Wildland-Urban Interface

The WUI concept, understood as spaces where humans and forest interact for reasons other than typical forest or agricultural use and that because of their characteristics and location can be affected by forest fires, is developed mainly

³ Andalusia, Catalonia, the Canary Islands, Extremadura, and Galicia.

through forestry legislation, specifically legislation covering forest fires, and is subsidiarily adopted in other plans.

In general, the definition is very broad and imprecise. The State Woodlands Law of 10/2006 refers to wildland-urban areas as those which include “urban developments, other structures, buildings, electric facilities, and an infrastructure for transportation, which are located in forest areas and their periphery”; and it is the Autonomous Communities’ responsibility to identify these spaces with greater precision, establish the necessary safety regulations, and control the activities that may generate fire risks.

The autonomous forestry planning guidelines and materials barely develop a definition that goes beyond what is established by the State Woodlands Law. Galicia’s case is an example in which any population nucleus or group of buildings located less than four hundred meters from the forest is subject to the application of the established preventive measures. In contrast, Catalonia has approved a fire law specifically for WUI areas where it is specified that “urban areas that are not immediately contiguous to the urban fabric and are located less than 500 meters away from forest terrain, as well as isolated structures and facilities in forest terrain, excluding structures and facilities used in agriculture and cattle farming” will be affected by special preventive measures.

In order to establish accurate planning and management of protection against forest fires in the WUI areas, it is indispensable to geographically identify these spaces. The *Forest Fire High Risk Areas* definition was introduced with the approval of the State Woodlands Law; these are defined as “areas in which the frequency or virulence of forest fires and the importance of the threatened property necessitate special measures for protection against fires.” According to this definition, the spaces classified under this category must have protection plans that, among other aspects, control the activities that might increase the risk of forest fire. However, this legal definition does not include human settlements as a factor that justifies the importance of threatened property. Thus, the Autonomous Communities must be the ones to determine which spaces will be subject to these special measures.

Forest fire high risk areas are generally delimited based on meteorological variables, the characteristics of the forest mass, the topography of the soil. In certain cases, the frequency of fire and its causes are considered important factors. In this zoning, the human variable is not usually directly taken into account. However, geographic delimitation is evolving towards an inclusion of new parameters of vulnerability which are linked to the presence of settlements and property that are potentially threatened by fires. Including settlements and human activity would make it possible to obtain an effective database to identify WUI spaces and subsequently characterize them.

4. Actions Considered in Regulatory and Planning Materials

The level of development of forest fire risk planning and management varies in the different Autonomous Communities, and to a great extent, is a reflection of recent local legislation and the historical level of incidence for forest fires in populated areas (reaction to catastrophes).

Generally, references to new WUI territories are scarce in forestry legislation and planning materials, and, in most cases, they reflect almost literally what is set forth in the State Woodlands Law. Given the high incidence of fire in Spain, all the Autonomous Communities have specific fire guidelines, and a great number of them have approved prevention and defense plans against forest fires in addition to the corresponding civil protection plans. Regulations related to fire risk management in the WUI are broadly discussed, specifically in forest fire materials. However, urban and spatial planning policy can influence population distribution and the activities in a given region. Thus, inadequate regional or urban planning can worsen the negative effects of forest fires, while correct organization of land use can minimize possible damage.

The types of action identified in the texts which correspond to the different sectors being analyzed have been grouped in three stages in the management of forest fires: prediction, prevention, and suppression.

4.1 Fire Risk Prediction Measures

While predicting situations that may cause a risk of forest fires, it is necessary to highlight the important role of urban and spatial planning. The State Land Law of 6/1998, and the subsequent Law of 8/2007, both point to a need to keep affected spaces from being urbanized because of natural risks according to what is established under sectoral legislation. Autonomous legislation incorporates this principle and have developed it, referring the responsibility for classification to territorial planning at a regional/sub-regional scale or directly to urban planning at a local scale.

Consideration of the different natural risks among the planning parties is not homogeneous. While specific risks, such as floods or erosion, are always taken into account, forest fires are not always included, even in areas with a high incidence of this kind of occurrence.

The treatment of forest fires since territorial planning stems from two action principles:

- The determination to incorporate sustainability objectives, which translate into a prudent and reasonable use of the territory with the application of the preventive protection principles established in the normative guidelines.
- The inclusion of risk cartographies defined according to sectoral planning

(waters, civil protection, forest fires, etc.) as an instrument for the regulation of uses and activities in the territory.

The development of these principles within the territorial plans can lead to a certain level of disagreement on the importance given to forest fires in the chapters on analysis and diagnosis, even in the definition of the objectives and criteria of territorial management, and the limited efficiency of the proposed plan. Overall, there is a clear predominance of merely indicative planning instruments rather than the necessary binding determinations.

In order to achieve a correct planning and organization of space (regulation of uses and activities in it) it is necessary to define and delimit cartographically the territory subject to risk. In the case of forest fires, zoning is organized by the Forest Administration, and only subsidiarily by spatial planning. For this reason, the cartography which has been drawn up has a different purpose than that of spatial planning, and can be adjusted according to prevention needs (changes made in the forest mass, the creation of infrastructure...) and fire suppression needs (allocation of resources), but not expressly to the definition of a territorial model that bears in mind the risk of forest fire.

In the majority of cases, the zoning of forest fire risk depends on the probability of ignition and propagation of fire, and it does not always include a complete analysis of the vulnerability of the space, which is usually restricted to the level of damage that a fire might cause on the forest mass. The Community of Castilla-La Mancha calculates the vulnerability index based solely on the value of the forest coverage. In the Valencian Community, their special configuration “makes it practically impossible to make a comprehensive vulnerability analysis that includes aspects such as: the life and safety of the population; protection values for infrastructure, facilities, and residential areas” to create an autonomous risk map.

An innovative approach was introduced with the Forest Fire Prevention and Defense Plan of Galicia in 2007. The zoning of the Galician territory is a result of the integration of fire risk and the different types of vulnerability in the territory. When calculating the vulnerability index, not only is the level of damage sustained by the forest system taken into account, but also, it includes the population vulnerability as well as the land vulnerability. *Population Vulnerability* is defined as the the level of defenselessness of a specific population when facing the possibility of forest fire. In order to calculate this vulnerability, indicators are used, such as: the presence of residents by km²; the presence of population nuclei; the percent of people over 65 years of age, and the distance between the urban nuclei and the forest surface.

Most regions do not always keep in mind the existence of WUI when zoning for fire risk and similarly, fire risk is not taken into account when establishing new urban developments. However, the existence of urbanized areas within *High Fire Risk*

Areas is significant when determining the necessary preventive measures in the defense plan.

4.2 Preventive Measures against Forest Fires

Fire risk management in the WUI, in the autonomous normative guidelines and planning materials, focuses mainly on the adoption of preventive measures, presented from two perspectives: (i) Interface, as vulnerable space, is sensitive to fire damage because of its special characteristics. In this sense, the autonomous materials demonstrate the need to develop strategies to protect people and property from fires. On the other hand (ii), WUI areas are also identified as territories of risk of which their existence and associated activities are potentially forest fire producers. From this standpoint, the measures to be adopted lean toward the prevention of ignition and possible propagation of fires from urbanized areas to the forest masses.

The way in which these measures are actually made effective depends on each region, and, although generally the measures follow a similar course of action, there is some variety between the Autonomous Communities when they carry them out. The main preventive measures against fires in the WUI areas can be summarized as:

- a) *Management of fuels around structures located in forest land or in its area of influence.* In general terms, a security field surrounding the housing developments is created, and all the dry vegetation must be cleared out. The width of said field varies, from 15m in Andalusia and the Canary Islands, 25m. in Catalonia, and 80m. in Extremadura. In Galicia, specific plant species which propagate fire due to their characteristics will also be avoided.
- b) *Creation and maintenance of adequate preventive infrastructure.* Urbanized areas in forest land must have enough sources of water and, in specific cases, a homologous hydration network (Catalonia). Also, access channels and gutters will be cleared of dry vegetation. Other requirements are the interconnection of channels around the population nucleus as well as adequate access to fire suppression services.
- c) In a few instances, there is a reference to special measure related to *a building's resistance to fire* given that the construction materials (stone, brick) used in Spain are not usually inflammable.
- d) *Awareness and information* for the population of the WUI areas. References to action protocols, specifically for the residents of the forest area, are not found in the planning materials or in the normative texts.
- e) The drafting of *prevention plans for Wildland-Urban Interface areas.* Extremadura proposes the approval of municipal *preventive plans for the urban periphery* in which specific prevention measures are considered in the urban areas. The scope of these measures depends on the location of the population nucleus, inside or outside of the High Fire Risk Areas.

f) In order to avoid the ignition of fires in populated areas, which might then propagate into forest spaces, there is a *control and regulation of activities* susceptible to provoking them (local celebrations: pilgrimages, fairs, the use of fireworks), especially in high risk seasons⁴.

Landowners are usually responsible for carrying out their own measures for management of fuels and maintenance of preventive infrastructure; nonetheless, the town council's subsidiary action is proposed if obligations are not met. Catalanian legislation provides assistance for the development of determined enforced preventive measures.

4.3 Planning Fire Suppression

Wildland-Urban Interface spaces play a crucial role in the suppression of forest fires. The presence of residential developments in forest areas can force the suppression services to make decisions that favor protection of population. In this sense, the protection of human lives is a priority rather than the suppression of the fire in the forest, which often grows out of the control of the suppression instruments, and becomes a fire that affects a vast amount of the forest surface area. Also, fire management in such spaces, in which people, property and forest areas are threatened at the same time, requires specific training, techniques, and instruments.

Forest fires in general are considered a risk that must be included within the Civil Protection field given the high risk situations or public catastrophes that might ensue. Moreover, the Civil Protection Basic Rule establishes the need to manage forest fires within special plans. In this sense, the *Forest Fire Emergency Plans* directly link the protection of property and people with the risk of fire.

In general terms, in civil protection legislation and planning, actions are considered at the moment of the emergency in order to ensure the protection of people and property, seeking coordinated action by the different participants in the suppression. Thus, they do not usually include preventive actions or actions subsequent to the fire.

Protection planning in the WUI when facing a fire is determined by the drafting of *Self-Protection* aimed at establishing the actions to be developed in case of emergency due to forest fire in populated areas (urban developments, isolated population nuclei, camping sites, companies) located in risk areas. Once more, having correct zoning of the territory as a function of fire risk, and the vulnerability of the space, is essential for suppression.

The Autonomous Communities have adopted provisions established by the State guidelines and every autonomous forest fire emergency plan includes the elaboration

⁴ Forest Fire Prevention Plan of Extremadura.

of self-protection plans that are integrated in the superior planning field, and must be approved by the Commission of Civil Protection of the Autonomous Community. The contents of the self-protection plans are similar in the different Spanish regions: they include surveillance and detection actions; organize the material and human means; prepare the intervention of outside assistance; establish human protection and evacuation measures. These plans can also include informative actions so that the population becomes aware of the risks and at the same time inform them about the protection measures that they must follow.

5. Integration of Fire Management in the Different Sectoral Fields

The treatment of forest fires in the WUI areas integrates the management of urban areas and the forests, the prevention of fires, and civil protection. In this new scenario, the connection and coordination between different policies and administrations is key in the management of forest fires. In this sense, spatial planning is presented as the ideal framework to integrate the factors that derive from the different normative guidelines involved in the management of forest fire risk.

The guidelines on forest fires in Galicia are thus inclined, recognizing that “the rural means defense policy against fires cannot be implemented in an isolated fashion, but rather integrating it in a broader context of territorial planning and rural development”. In Andalusia, an integrated vision of the risks at a regional level has been developed in the autonomous Andalusian Territory Organization Plan (POTA by its Spanish acronym). The *Regional System for the Protection of Territory* diagnoses the subjacent causes of the ignition and propagation of fire, and establishes territorial criteria that must be developed by the organization plans in sub-regional and municipal fields. These criteria determine:

- The identification of areas with high fire risk and the incorporation of the necessary measures derived from Civil Protection and forestry planning.
- The minimization of the fire risk through land use planning, evaluating the implementation of activities that might increase the probability of fire in particularly sensitive areas.
- Sub-regional and municipal organization plans will include the implementation of infrastructure and equipment in order to prevent fires and offer assistance to the suppression teams.

However, sub-regional plans are limited to reproducing the rules derived from forestry and fire legislation, without establishing connecting determinations.

In the rest of the analyzed regions, the forestry and fire guidelines only highlight that urban planning needs to adapt to the requirements indicated from the fire specific

sectoral policy in order to reduce the danger of fire in the WUI areas. The Autonomous Community of Catalonia must be acknowledged for its Forest Plan (2007) which connects the risk of forest fire with urban planning, forcing isolated urban areas in forest land to develop the fire prevention measures discussed in fire legislation. Also, partial plans approved for forest land must include adequate forest fire prevention and suppression measures for the future urbanized area.

6. Conclusion

- The wildland-urban interface concept is included in the normative and autonomous planning materials. However, the lack of a clear and concise definition of the spaces which will be considered as “wildland-urban interface” represents a significant deficiency in the management of forest fire risk connected to urbanized areas. This situation results in a generic treatment of the spaces which, given the regional differences in Spain, require plans that adapt to the characteristics specific to the territory. In this sense, an urgent need to correctly characterize these spaces and apply preventive and firefighting measure adapted to the ecologic and socioeconomic context of each region is identified.

- In general terms, legislation identifies the WUI as spaces vulnerable to the effects of forest fires. For this reason, the majority of the contemplated measures are directed towards prevention and the protection of property and people. However, the role they play as territories susceptible to generating forest fires must be stressed, and thus, the need to establish a regulation of activities and uses.

- Forest, fire, and civil protection guidelines regulate the necessary measures in order to prevent risk situations in urbanized areas in contact with a forest mass. However, future urban developments must also be given special attention. Spatial planning and urban planning are responsible for predicting and preventing dangerous situations by declaring the areas subject to forest fire risk as territories that are not suitable for urbanization, or integrating the necessary prevention measures in future developments.

- The objectives for zoning the territory facing forest fire risk do not usually include WUI areas, and are based on protecting the forest from fires. Since there are new spaces where the forest and the urban areas integrate, it is necessary to rethink the variables included in the risk analysis and to create a useful zoning of the territory in order to adopt adequate preventive measures and urban planning.

- The management of fires in the WUI is given very similar treatment in the different analyzed regions. However, those regions that have suffered significant fire-related catastrophes in populated areas (Galicia and Catalonia) have guidelines that incorporate these new territories and establish effective measures for their protection.

References

- Antrop, M. 2004. **Landscape change and the urbanization process in Europe**. Landscape and urban planning 67: 9-26.
- García, A.; Carrascal, J. 2007. **Planes periurbanos de prevención de incendios forestales en la interfaz urbano forestal en la Comunidad Autónoma de Extremadura**. Libro de Resúmenes de la IV Conferencia Internacional sobre incendios forestales, Seville, Spain, 13-18 May 2007.
- Radeloff, V. C.; Hammer, R.B.; Stewart, S.I.; Fried, J.F.; Holcomb, S.S.; McKeefry, J.F. 2005. **The wildland-urban interface in the United States**. Ecological Applications 15 (3): 799-805.
- Vince, S.W.; Duryea, M.L.; Macie, E.A.; Hermansen, L.A. (ed.). 2005. **Forests at the wildland-urban interface: conservation and management**. Boca Raton: CRC Press; 293 p.

Appendix: Normative and Planning Materials

State	• Law 43/2003 on Woodlands and its amendments of 2006. • Basic guidelines for planning Emergency Civil Protection against forest fires.
Andalusia	• Law 5/1999 on prevention and firefighting. • Decree 247/2001 which approves the Forest Fire Prevention and Protection Regulations. • Adapting the Andalusian Forest Plan (2003). • Andalusian Forest Fire Plan. • Andalusian Territory Organization Plan.
Canary Islands	• Decree 146/2001 on Prevention and Suppression of Forest Fires. • Canarian Civil Protection and Emergency Response Plan due to Forest Fires. • Law 9/1999, of 13 May, on Canarian Territory Organization.
Catalonia	• Law 5/2003 and Decree 123/2005 on preventive measures against forest fires in urban areas without immediate continuity with the urban fabric. • The Forest Plan of Catalonia (2007-2016). • Special plan for forest fires in Catalonia.
Galicia	• Law 3/2007 on prevention and protection against forest fires. • Prevention and Protection Plan against forest fires in Galicia. • Basic protection plan against forest fires.
Extremadura	• Law 5/2004 on Prevention and Protection against forest fires. • Decree 86/2006 on the approval of the Forest Fire Prevention Plan of the Autonomous Community of Extremadura. • Decree 123/2005 by which the Forest Fire Protection Plan of the Autonomous Community of Extremadura is approved. • Law 15/2001, of 14 December, on Land and Spatial Planning of Extremadura.

Wise Fire Use Practices in Wildland Fire Management: An Overview of the European Situation¹

A. Lázaro²

Abstract

In the history of land-use in Europe, fire has been an important element in forestry, agriculture and pastoralism, and an important process in shaping landscape patterns of high ecological and cultural diversity. However, crisis taken part over rural areas during the second half of the 20th century caused the loss of the notion of fire as a useful tool and changed its perception from tool to threat, resulting in the complete elimination of traditional burning practices in some areas. At present new opportunities and challenges are underway for the development of the use of fire for management purposes in Europe. The aim of this document is to present a first approximation for the development of prescribed burning (PB) and suppression fire (SF) in Europe.

Keywords: Europe, fire management, practices, prescribed burning, suppression fire.

1. Introduction

Fire can be a destructive force and, conversely, be a natural and vital component in ecology as well as a useful tool for improving people live. It can also be both at the same time. These are the two faces of fire, an issue which is receiving recent and growing interest due to changing paradigms in ecology and nature conservation. Its international dimension has become evident in forums such as the 4th International Wildland Fire Conference (Seville, May 2007), through the recognition of the critical role of fire within the overreaching framework of the Strategy to Enhance International Cooperation in Fire Management and its Fire Management Voluntary Guidelines³.

Nonetheless, the fire paradox has not achieved the same development in all parts of the world, neither has the same characteristics. Long term changes in

¹ An abbreviated version of this paper was presented at the Third International Symposium on Fire Economics, Planning, and Policy: Common Problems and Approaches, April 29 - May 2, 2008, Carolina, Puerto Rico. This research is developed in the frame of the FIRE PARADOX Integrated Project “An innovative approach of Integrated Wildland Fire Management Regulating the Wildfire Problem by the Wise Use of Fire: Solving the Fire Paradox”, financed by the VI Framework Programme, Sub-priority 6.3 Global Change and Ecosystems.

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³ Fire Management Strategy <http://www.fao.org/forestry/site/firemanagementstrategy/en/>

vegetation caused by successful fire exclusion as well as escalating suppression costs launched the use of PF for fuel management and ecological purposes in USA, Australia and Canada, which have recognized the need to focus on the core issue of fire in land management rather than the suppression of wildfire⁴. Thus the introduction of PB practices is largely derived from the functional role that natural fire has played in ecosystems through historical and contemporary fire regimes.

In Europe, this *fire paradox* is presented as a substitution tool for traditional land-use and management systems, and hence is to be applied in cultural landscapes rather than natural fire ecosystems. Twenty five years after its introduction the operational implementation of fire as a management tool remains very limited due to different types of constraints (i.e. fire bans, land structure, lack of professional experience and negative public perception) (Xanthopoulos et al, 2006). However new opportunities and challenges are underway for the development of the use of fire for management purposes in Europe. On the one hand, regarding wildland fire management, particularly in Mediterranean countries, the increasing risk of high-severity wildfires and the impossibility to continue increasing suppression efforts at high economic costs, is requiring new approaches to improve their prevention and suppression strategies⁵. On the other hand rapid socioeconomic changes taken place during last decades have resulted in the abandonment of traditional practices which have shaped many valuable landscapes and ecosystems; a situation which is now leading to reconsideration of fire-exclusion policies in certain sectors of nature conservation, forestry and landscape management (Goldammer et al, 2007).

The aim of this paper is to present a first approximation of the development of prescribed burning (PB) and suppression fire (SF) in Europe, in order to show the existing diversity of fire use practice within the continent as well as to infer possible temporal and spatial patterns for their development in space and time. For this purpose, a review of fire use practices at the national and regional for different EU member-states was developed taking into an original approach, based not only in the objectives for the use of fire, but adding the importance of the degree of standardization. Results obtained have been developed within FIRE PARADOX⁶, a European Integrated Project which is part of the 6th Framework Programme (2006-2010).

⁴ Self Assessment, conclusions and recommendations of the *Regional Session: Australasia and North America*, held in 4th International Wildland Fire Conference (Sevilla, Spain. 2007)

⁵ Self Assessment, conclusions and recommendations of the *Regional Session: Europe, Southeast Europe, Mediterranean North Africa and Caucasus*, held in 4th International Wildland Fire Conference (Sevilla, Spain. 2007)

⁶ For more information, see webpage: www.fireparadox.org

2. Methods

The main source of information for the approximation of the diversity of PB and SF in Europe was a questionnaire designed within the FIRE PARADOX project where qualitative data information regarding fire use practices, referred to each country and georeferenced at the regional scale⁷, was compiled through an excel sheet structured in three categories of fire use practices:

- i) Traditional burning practices: present uses and historic references
- ii) Prescribe Burning: management purposes, personnel involved in this tasks, the role of PB for wildfire prevention, pros and cons for using prescribed burning as a management tool in their country or region.
- iii) Suppression fire: techniques, the role of SF in fire suppression, pros and cons for using suppression fire as a wildfire fighting tool in their country or region.

In order to achieve these objectives, the questionnaire was addressed to EU member states, through the European Commission, to the members of the Working Group of Forest Fire Prevention Experts⁸ (WGFFP), an informal working group composed by experts from the national authorities nominated by the EU Member States and the European Commission, which deals mainly with operational issues related to wildfire prevention and fighting in their countries⁹.

Moreover, information compiled through the questionnaire was complemented through an extensive search in literature databases, scientific journals of high impact based on a systematic alarm-search, expert networks, governmental and non-governmental agencies, international and European scientific research projects as well as EU and national/regional legislation and policy instruments.

Once the information was obtained, the existing PB and SF practices related to the EU member-states were classified through their incorporation in a matrix where two main classification criteria were considered (See Fig 1). The first classification criteria, refers to the **objectives for the use of fire (C1)**, which includes the following: (i) reduction of wildfire incidence and severity, (ii) silviculture, (iii) nature conservation, (iv) rural activities (i.e. agriculture, grazing improvement) and (v) others (i.e. landscape maintenance, improving access, improving habitats for hunting)

The second classification criteria, **degree of standardization (C2)**, requires considering three levels:

- *Traditional practices*: developed by rural population, without any technical and

⁷ For this purpose the territorial units established by the European Community (NUTS) were used at the NUTS3 scale (NUTS 2 in the case of Holland, Belgium and Germany)

⁸ For more information, see webpage <http://ec.europa.eu/environment/forests/wgffp.htm>

⁹ Responses to the questionnaire received till the date, correspond to the following countries: Austria, Bulgaria, Cyprus, France, Latvia, Lithuania, Poland, Portugal, Spain and Sweden. For the German case, although not having received the complete questionnaire a partial response was obtained which has allowed to include relevant information for this country in the assessment.

administrative regulation or intervention

- *Renovated or innovative practices*: regulated and developed by forest/civil protection services, with the possible intervention or assistance of professionals. They might be executed either to incorporate new objectives and/or techniques of PB in forest management or as an instrument to deal with clandestine burnings.
- *Experimental practices*: tests carried out by national or regional Administrations or scientific institutions.

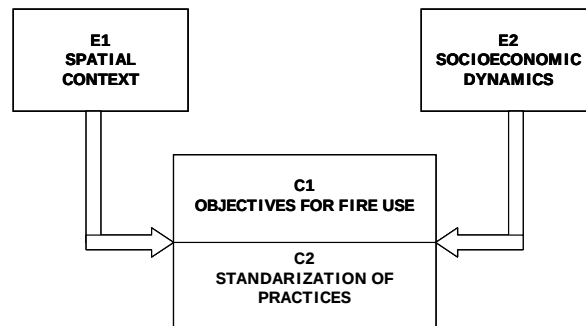


Figure 1—Core elements and influencing factors in fire use practices.
Author: A. LÁZARO (UCM, 2007)

Finally, in order to illustrate the different patterns followed in the development of PB and SF practices in Europe, the mapping of fire use practices at the regional level for the UE 27 (+ Switzerland) was developed taking as a reference scale the Nomenclature of Territorial Units for Statistics (NUTS) established by the European Union¹⁰. The cartographic base used was the vector layer for the NUTS 3 administrative limits for Europe (shapefile format), joining the corresponding NUTS 3 units for those cases where NUTS2 levels need to be used (Belgium, Netherlands and Germany). The mentioned layer corresponds to 1:3.000.000 scale, and was kindly supplied by the European Commission—Statistical Office of the European Communities (EUROSTAT).

3. Results

3.1. Comparative analysis of fire use practices in European countries

Information compiled through the questionnaire and the complementary literature review, is synthesized below in a comparative assessment on fire use practices for the

¹⁰ The Nomenclature of Territorial Units for Statistics (NUTS) provides a single uniform breakdown of territorial units for the production of regional statistics in the European Union. See http://ec.europa.eu/eurostat/ramon/nuts/home_regions_en.html

European countries analyzed throughout the document. In particular the analysis is focused on the current situation of fire use in traditional rural activities and the development of prescribed burning and suppression fire techniques in each country, with emphasis in: (i) the objectives for its use, (ii) the extent of development within the country, and (iii) the degree of standardization.

Austria

Regarding PB, the use of fire for management purposes is not a technique used in this country. However, several Austrian agencies and science institutes have expressed interest in the use of prescribed fire but have not yet practiced active burning. In the case of SF, fire is not used as technique for wildfire suppression.

Bulgaria

Fire use for agricultural purposes and grazing improvement has a long tradition in this country. Although forbidden at present, people continue to use it as most cheap and traditional way to clean his lands. However, the use of PB for different management purposes is not practiced. In wildfire suppression, SF, both backfiring and burning out are techniques used.

Cyprus

Farmers have traditionally used fire for burning of grass-gorse or stubble for clearing and preparing their land for agricultural purposes. However the structure of forested areas and agricultural lands does not favour the use of PB as a management tool. In exceptional cases, the Department of Forests applies prescribed fire in areas adjacent to the State Forests only for the purpose of reducing fire hazard. Since 1960 fire is used in suppression in backfiring and burning out techniques.

France

Fire is an ancient tool in mountain areas and the Mediterranean region of France used for grazing improvement, management of wetlands and improvement of habitats for hunting. The use of fire in suppression is also a long-standing tradition in some areas of the Mediterranean region, where local communities use backfires to protect their assets from a wildfire event.

PB is used as a tool for various management purposes: fuel management, habitat improvement, to facilitate grazing, landscape maintenance and wetland management. Several groups are involved in its development: Forest and Fire Services, pastoral technicians, civil protection intervention units and nature agents of protected areas. From 1989, the different teams constitute a Prescribed Burning network in the Mediterranean region coordinated by the INRA. At present, experimental research on PB is being developed for land management, conservation and wetland management. Fire-fighting services have adopted SF techniques since 2005. Both, backfiring and burning out are techniques used for wildland fire suppression in many Mediterranean départements (e.g. Gard, Corse, l'Ardèche, les Alpes-Maritimes).

Germany

Slash and burn cultivation was maintained into 20th century in some places. The burning of heath and grasslands was widespread, but since the 1970s there is a complete burn ban for these traditional practices. Some museum-type initiatives have been realized showing traditional slash-and-burn cultivation in SW Germany.

PB is used for various management purposes: landscape maintenance, habitat management, vegetation management, fuel reduction. Although most burns are operational measures they are still under the umbrella of experimental research burns that require special permits due to the general ban of using fire in vegetation management (in all States). In the case of SF, fire is not used as technique for wildland fire suppression.

Latvia

Slash and burn cultivation was maintained till 19th century. Today, fire is still used for burning of agricultural residues and grass lands during spring season. The use of PB as a management tool is not practiced in Latvia. However there have been experimental tests to apply PB within some nature conservation projects (Vidzeme and Zemgale). In fire suppression, direct attack is the major method used in fire fighting while backfire is applied in rare cases only.

Lithuania

Grazing improvement is a widespread traditional practice maintained in the country. Burning of old grasses is also a very old tradition which is a big problem for forest fires. PB and SF are techniques which are not practiced in this country.

Poland

At present, there is no traditional fire use practices maintained in this country. Regarding PB, fire is considered a factor which negatively impacts the environment under Polish circumstances. However, State Forest's employees use PB (broadcast burning) in order to reduce fuel loads on clear-cut areas. Suppression fire is seldom applied.

Portugal

The use of fire is a widespread practice for the elimination of agricultural residues, pasture renewal and grazing improvement in most Portuguese provinces.

PB was introduced in North Western Portugal during the 1970s for fire hazard reduction. Nowadays, PB is used for various purposes: fuel management, facilitate regeneration of certain vegetable species, plant succession control, habitat improvement and to facilitate grazing. The regions where this technique is more consolidated are Northern and Central Portugal. Several organisms are involved in its development: Forest services agents, Conservation Institute agents responsible in the protected areas, several municipalities and specialized groups with wildfire prevention duties *Sapadors Florestais*. Experimental prescribed burning programs

are being developed by the Forest Services in collaboration with the University Trás-os-Montes e Alto Douro (UTAD). Since the mid 20th century fire is used in suppression in backfiring and burning out techniques.

Spain

The use of fire by rural population is a long-standing tradition in Spain which remains an important tool for grazing improvement and for elimination of forest and agricultural residues. The use of fire in suppression is also a long-standing tradition which lasts in some northern regions, where local communities use fire to protect their assets from a wildfire event (e.g. Galicia and Cataluña).

Since every region has the responsibility for forest and fire management, the development of PB differs quite a lot from one another. When used, PB is applied mainly for wildfire prevention: either fuel management (to difficult propagation) or to deal with pastoral uncontrolled burnings (to avoid wildfire initiation). The northern regions are the area where this technique is more consolidated (i.e.: Galicia, Asturias, Castilla y León and Cataluña). Several groups are involved in its execution: forest and civil protection services, forest guards and specialists groups trained in fire use (i.e. developed by the State (EPRIF) as well as by the Autonomous regions (GRAF, Cataluña)). Experimental burning is being carried out by scientific institutions (e.g. INIA, Centro Forestal Lourizan) as well as universities (e.g. University of Lleida and University of Córdoba) and Forest Services. The use of suppression fire is widely included as an available technique for indirect attack by most regions since the 60s-80s. Its use in practice is quite heterogeneous, being in most regions not a common practice due to lack of experienced personnel while others have developed considerable experience such as Castilla y León (León and Zamora), Asturias and Cataluña.

Sweden

Traditionally Sweden used burning for forest and agricultural purposes. However since 1970s these practices began to disappear and nowadays no areas are burned for these purposes. Present fire use is merely the burning of old grasses in spring by farmers and families with summer houses.

In a quite small proportion PB is being developed for conservation purposes: i) In protected areas, developed by Environmental Managers. Promising signs of this work are Jämtgaveln and Strommyran-Lommyran natural areas in Västernorrland county (Goldammer et al, 2007) ii) PB developed by major private forest companies to comply with conservation requirements established by the Forestry Stewardship Council (FSC) to meet certification standards (achieve 5 percent of the annual clear-cut area). Fire research is mainly concentrated in the north (Umea) with studies on succession, fire behaviour (pilot-studies) and fire history (Niklasson & Granström, 2004). Both backfiring and burning out are techniques contemplated in wildfire

suppression. However they are not very extended due to the fear that firemen have to accidents and consequences.

3.2. Classification and Mapping of fire use practices in EU member-states

A classification of the existing PB and SF practices for the analyzed countries is proposed based on the consideration of two main criteria: the objectives for the use of fire and the degree of standardization. For this purpose, both aspects have been incorporated into a matrix to give fifteen categories. The interpretation of the information contained in the matrix, requires taking into consideration the premises followed during the filling in process:

- A country is included in as many categories as types of practices are present within the country.
- A country's incorporation into one category does not imply the national representativity of a practice, but its existence at least in one region. This issue is especially relevant for those federal or decentralized countries which show greater diversity in this sense.
- In particular for PB, it is frequent to find situations where the application of this technique pursues simultaneous objectives. For these situations the main objective considered was the one provided by countries.

Table 1—Classification of fire use practices in European countries. Source: Replies to the Fire Paradox questionnaire. Author: A. LÁZARO (UCM, 2007)

	Traditional Fire Use	Renovated or Innovative Use of Fire	Experimental Fire Use
A. Rural activities	Bulgaria Lithuania Cyprus Portugal France Latvia Spain	France Germany Spain Portugal	Germany Spain
B. Wildfire Prevention		France Spain Germany Portugal	Germany Portugal Spain
C. Wildfire Suppression	France Spain Portugal	Bulgaria Poland Cyprus Portugal France Spain Latvia Sweden	

D. Silviculture		Poland Portugal	Spain Sweden	Sweden
E. Nature conservation		France Germany Portugal	Spain Sweden	France Spain Germany Sweden Latvia
F. Others	France Germany	France Germany Spain	France Germany	

Finally, in order to infer the possible temporal and spatial pattern in space and time for the development of PB and SF practices, four different maps have been obtained as a result of georeferenced information compiled through the questionnaire at the NUTS3/2 level for the different countries analyzed throughout the paper. These are the following:

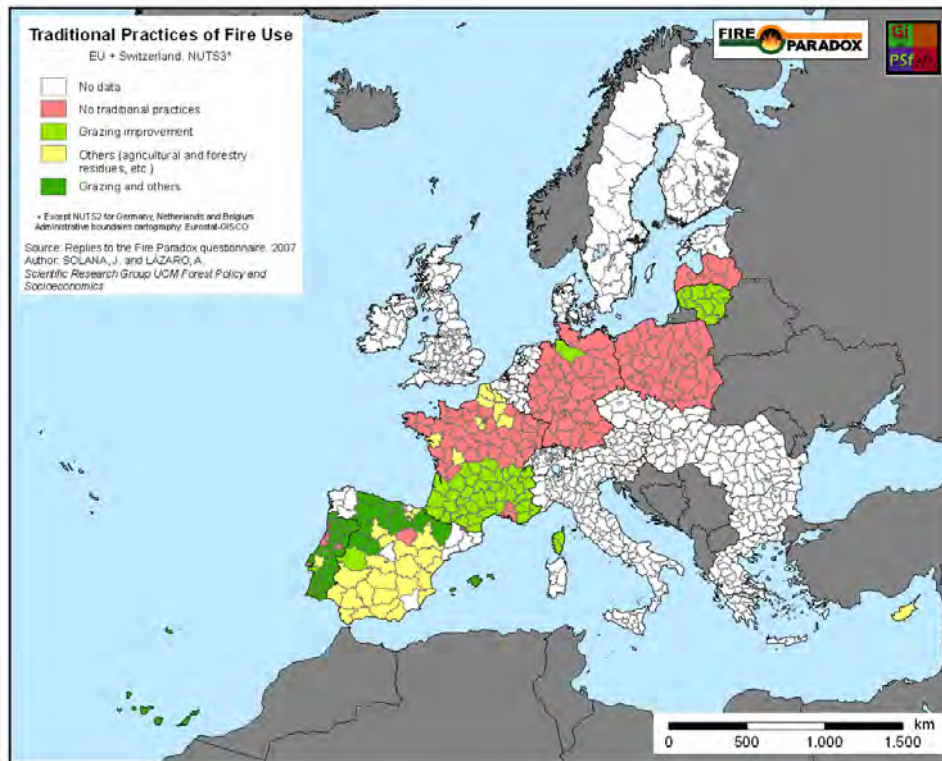


Figure 2— Map of traditional fire use practices in European countries.

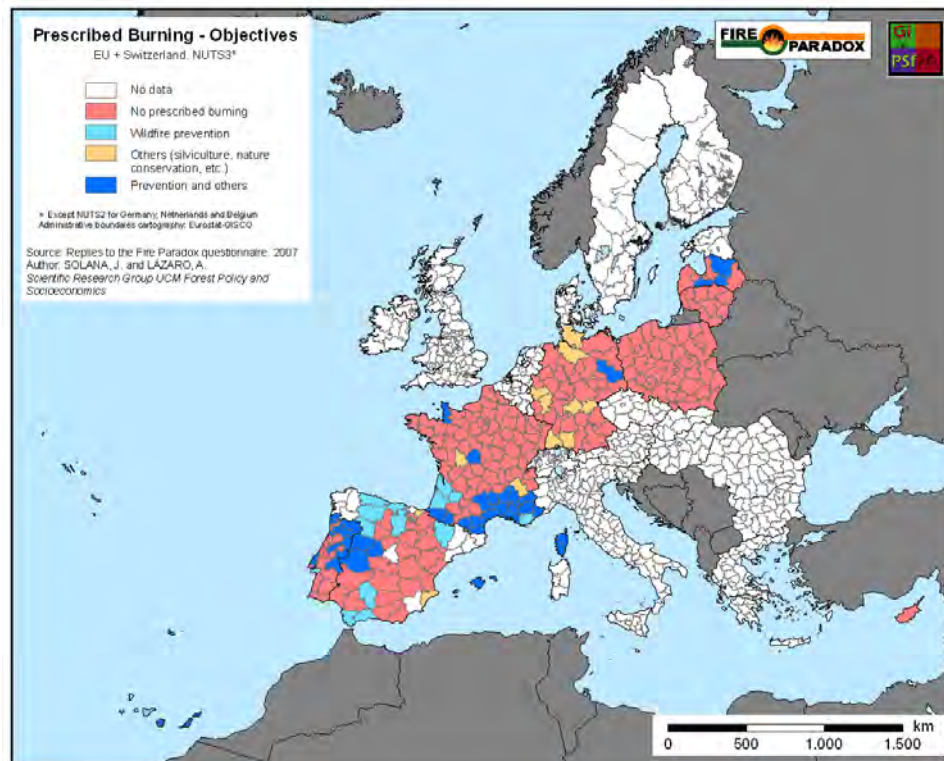


Figure 3— Map of prescribed burning objectives in European countries. Different objectives: wildfire prevention, vegetation management, others or none.

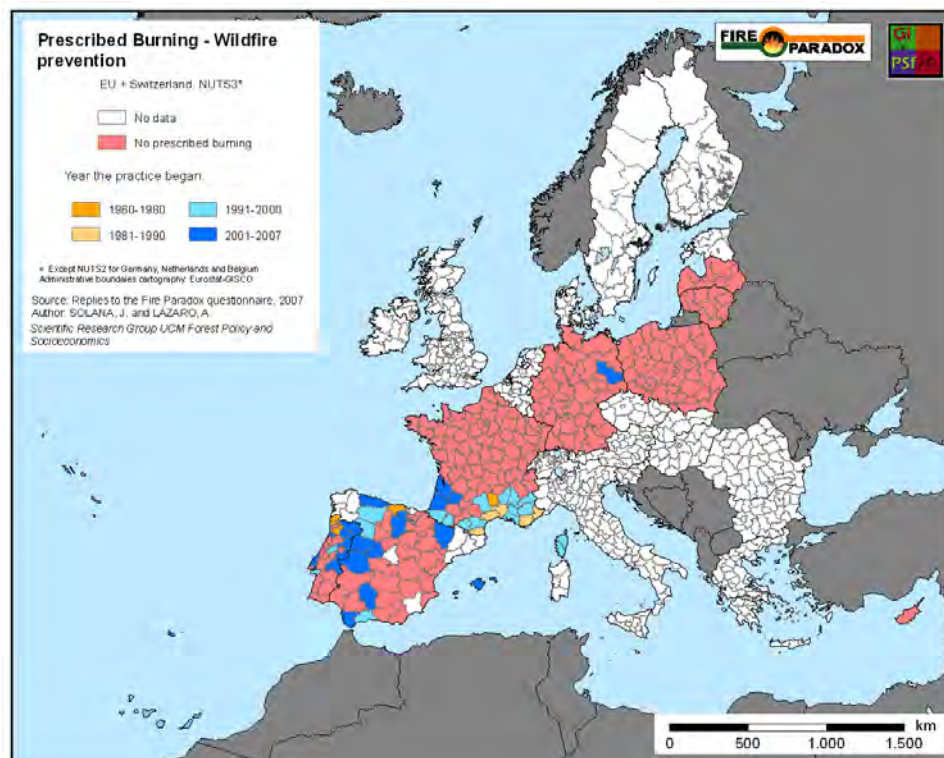


Figure 4— Map of prescribed burning for wildland fire prevention in European countries. Incorporates years of initiation.

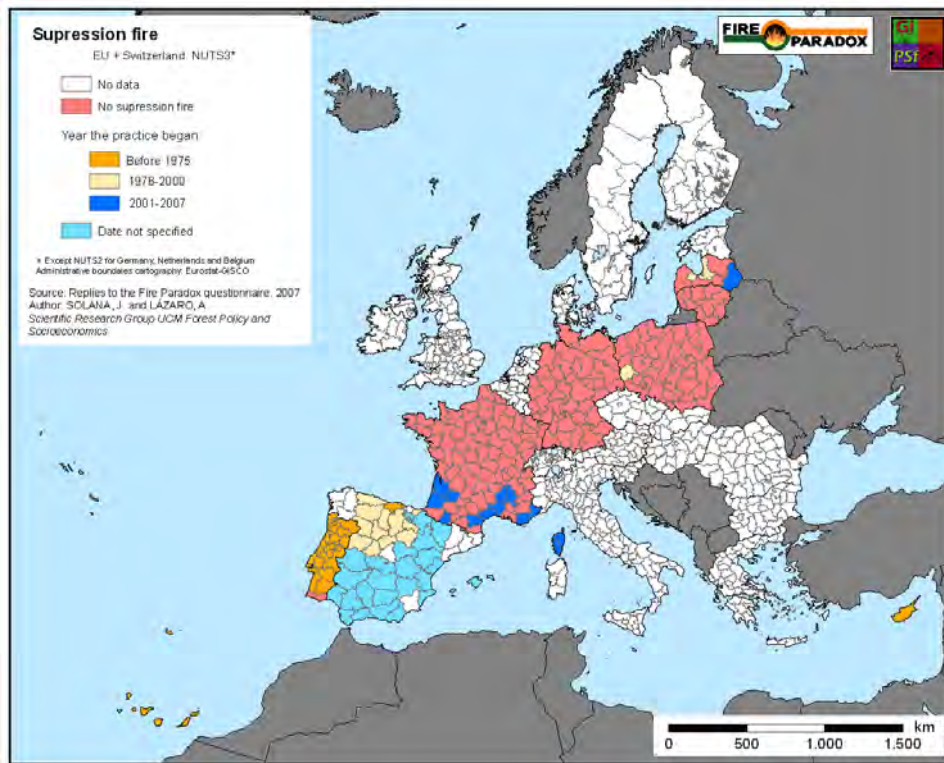


Figure 5— Map of suppression fire for wildland fire suppression in European countries. Incorporates years of initiation.

Discussion

Results presented in this paper provide a first approximation of the diversity of fire use practices in Europe and a starting point for the future assessment of the potential development of PB and SF as tools for wildfire management, as well as for other management purposes in the case of PB. Some of the common findings obtained in this direction are the following:

- There is a general abandonment of rural fire practices in Central Europe and Baltic countries vs a deeply rooted use of fire as a tool for rural activities in Mediterranean Basin and other European member-states of recent incorporation.
- The incipient development of PB practices in Europe has taken place in different areas and with different objectives: in Mediterranean countries its introduction refers mainly for wildfire prevention purposes, while in Northern Europe silviculture and nature conservation are the main objectives. However these tendencies have shown to evolve with time since some southern countries (e.g. France and Portugal) have started to widen its objectives to forest and biodiversity management, while the increase of wildfire risk in North and Central European countries might entail the development of PB initiatives for wildfire

prevention in a near future (i.e. Germany).

- The application of prescribed burning for wildfire prevention is concentrated in the southern European countries, having acquired relevant progress in its development towards the end of the 90s and the beginning of 21st century.
- The development of suppression fire practices is mainly concentrated in the southern European countries, having an earlier development between the 70s and the 80s in Portugal and Spain and more recently in southern France and other European countries.
- Spatial contexts and on-going socioeconomic dynamics have been identified as determinant influencing factors for the existence and nature of fire use practices in the different countries and regions. Their identification is fundamental since only an appropriate application of the fire use techniques according to regional specificities will have the possibility to achieve a necessary social and political agreement allowing the use of fire for management purposes.
- Among these influencing factors, the existence of traditional fire use and knowledge has been identified as one of the main factors, which is going to determine and guide the strategies and recommendations to be applied over a given context.

References

- Botelho, H. S.; Rego, F.C. and J.M. Silva 1987. Prescribed fire behaviour in *Pinus pinaster* forests of Northern Portugal. In Com. International Symposium for the formulation of an effective common strategy for the prevention and combat of forest fires in the Mediterranean Region. Athens, Greece.
- FAO/GFMC 2003. Wildland Fire Terminology. On-line update of the first edition of 1986 <http://www.fire.uni-freiburg.de/literature/glossary.htm>
- Goldammer, J. G.; Hoffmann G.; Bruce, M.; Konrashov L.; Verkhovets S.; Kisilyakhov Y. K.; Rydkvist T.; Page H.; Brunn E.; Lovén L.; Eerikäinen, K; Nikolov, N. and Chuluunbaatar T-O 2007. The Eurasian Fire in Nature Conservation Network (EFNCN): Advances in the use of prescribed fire in nature conservation, landscape management in temperate-boreal Europe and adjoining countries in Southeast Europe, Caucasus, Central Asia and Northeast Asia. In 4th International Wildland Fire Conference, Seville, Spain, 13-17 Mayo 2007
- Pyne, S. J. 1997. Vestal Fire. An environmental history told through fire, of Europe and Europe's encounter with the world. University of Washington Press
- Rigolot, E. 2000. Le brûlage dirigé en France: outil de gestion et recherches asocies. In Vega, J. A. & Vélez, R (Coord.): Actas de la Reunión sobre quemas prescritas, Cuadernos de la Sociedad Española de Ciencias Forestales, n°9-2000, 165-178 p.
- Xanthopoulos G; Caballero, D.; Galante M.; Alexandrian D.; Rigolot, E. & Marzano R. 2006. Forest Fuels Management in Europe, in Andrews, P. L. & Butler, Bret W. (2006): Fuels Management-How to Measure Success: Conference Proceedings (Portland, 28-30 March 2006), USDA Forest Service, 807 p.

Analysis of Wildfire Risk Management From a Territorial Policies Perspective: Strengths and Weaknesses in the European Framework¹

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Abstract

The wildfire problem, especially the growing importance of large fires, responds to complex structural causes. Risk management cannot be only dealt from a sectoral perspective of conventional wildfire policies (forest and civil protection). On the contrary, requires a global approach made from different policies with effect in territory, which may contribute in a conclusive way in wildfire prevention. The aim of this study is to analyse public policies with effect on wildfire management at the European scale, in order to identify and establish the possible influence and/or impacts that these policies may have in wildfire management. An assessment of the main regulatory and planning instruments is developed, out of a selection of policies with greater incidence in wildland fire management: *spatial planning, agricultural and rural development policies, energy policy and environmental policy*.

Keywords: Europe, fire management, public policies, territory, wildland fire.

1. Introduction

Wildfires represent a serious threat for European forest, in relation to the ecologic, economic and social point of view. This situation has been worsening in the second half of the 20th to become one of the major hazards for forests in Europe together with pollution, plagues and erosion.

¹ An abbreviated version of this paper was presented at the Third International Symposium on Fire Economics, Planning, and Policy: Common Problems and Approaches, April 29 - May 2, 2008, Carolina, Puerto Rico. his research is developed in the frame of the FIRE PARADOX Integrated Project “An innovative approach of Integrated Wildland Fire Management Regulating the Wildfire Problem by the Wise use of Fire: solving the Fire Paradox”, financed by the VI Framework Programme, Sub-priority 6.3 Global Change and Ecosystems.

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However, the wildfire problem presents different territorial incidence in the European Continent since it is determined by different ecologic, socio-economic and political factors. The northern countries of the Mediterranean basin are the most affected, having the highest number of fires and the most extensive burned area reported with 300,000 to 500,000 ha burnt every year (DG JRC, 2005). In this region, land use change dynamics have aggravated fire hazards and disaster potential due to increasing flammability of the ecosystems and a settlement model with a sharp trend to dispersion, which dangerously increases ignition risk. Changes with greatest incidence are: the abandonment of rural areas, change in forest policy priorities and the growth of extensive wildland-urban interface areas (Xanthopoulos and others, 2006).

To counter this situation, most part of European countries has adopted suppression-oriented policies greatly improving their fire suppression resources at high economic costs. Moreover, national governments usually develop their wildland fire policies as an ad-hoc reaction to specific a situation which already has been created (FAO, 1999). Hence, structural factors basic in wildland fire initiation and propagation, which may not necessarily be within the forest sector, are left behind. However, wildland fire management is not exclusively affected by sectoral policies, but also by policies in other areas, such as: environment, natural resources and economy. Often these “external” policies have impacts which may lead to unintended consequences outside the sectors where they have been implemented. Taking into account a cross-sectoral approach of policies with incidence in the territory, provides the opportunity to address the long term social, legal and economic factors with incidence in the way land is managed, which are out of the scope of forest policies: the structural causes of wildfires.

The aim of the present paper is to identify and analyse policy measures external to the forest sector with potential influence in wildland fire prevention and propagation in the European framework. In order to do that, out of a selection of policies with greater incidence in wildland fire management, an assessment is developed focused in: i) identifying cross-sectoral policy impacts influencing wildfire prevention and propagation ii) main strengths and weaknesses for Integrated Wildland Fire Management.

2. Material and Methods

This paper is focused in a selection of policies identified as relevant regarding wildland fires due to its incidence in sustainable land use and natural resource management. These type of policies have been referred in this paper as *Territorial Policies*: (def) Development policies undertaken by public authorities - the central

state as well as regional and local governments - with the aim of promoting a more efficient use of resources within specific geographical areas (OECD, 2003).

The territorial policies to be analysed through out the document are: i) **spatial planning policies**, ii) **agricultural and rural development policies** and iii) **environmental policies**. In addition to the selected public policies, it has been considered necessary to incorporate **energy policies** into the assessment since currently the European energetic model is an important issue for debate, and the use of forest biomass have acquired renovated relevance as a renewable source of energy.

The main scale for the assessment is focused in the EU level, where a cross-sectoral approach is especially relevant since no EU Treaty provides a comprehensive common forest policy to all EU countries. However, is at the national level, where lays the responsibility to develop forest and civil protection policies and where takes place the most important interdependencies between these policies with other public policies. Hence, although not the aim of this paper, relevant considerations upon wildland fires at the national level are incorporated.

The analysis of territorial policies' impact on wildfires has been mainly focused in the analysis of relevant regulation texts and planning documents corresponding to the different public policies.

3. Results

3.1. Spatial planning policies in wildland fire risk management: strengths and weaknesses

Spatial planning, as a public policy focused in influencing the distribution of people and activities in spaces, includes all level of land use planning (urban planning, regional planning, national spatial plans and the EU level). Although Europe does not have a common spatial planning policy on its own, in recent years European orientations for spatial planning have been developed⁵. However, the development of spatial planning policies differs quite a lot in the different member-states, thus the opinion about the real effects upon wildland fire management is very different from one country to another. Nonetheless, it is possible to find some commonalities: the important role spatial planning has for the development of prevention measures and in particular for those related with the management of wild-urban interface areas (WUIs).

Forest's plans are nominally integrated in the spatial planning system (Montiel and Galiana, 2005). However, the need to connect forest policy, especially

⁵ These orientations have been specified through the European Spatial Development Perspective (ESDP) of 1999, which is, at the present moment, in its operative development stage.

intervention on wildland fires, to spatial planning is one of the most common topics among any bibliographic contribution which tries to go into depth in the structural factors affecting wildland fires. This approximation is done usually from the forestry perspective, and particularly in relation with large fires, in which origin converge complex structural causes (Badia et al, 2002) which are not feasible to be approached under an exclusive sectoral optic. These structural causes are basically two of them (Plana, 2004): (i) A settlement model with a sharp trend to dispersion, which dangerously increases ignition risk and (ii) the evolution of forest vegetation towards fuels accumulation favouring wildfire propagation. Spatial planning provides the possibility to take part in the urban's settlement organization, in the one hand, putting under restrictions occupation in risk areas and in the other hand favouring a territorial matrix which difficult propagation. This should be developed in coordination with forest planning; however the absence of a coherent frame between these two policies limits spatial planning's potential for intervention.

Spatial planning does not just translate principles coming from forest administrations, but introduces particular and differentiated principles for this type of areas. In spatial planning instruments, forest areas are highly valued, with growing recognition for the territorial model. This entails a *conservational approach* for forest stands through the establishment of protected areas, which, as well as incorporating criteria considered by other types of planning (i.e. environmental, forestry), widens conservation objectives by incorporating criteria closely related with the functioning of territorial systems. This approach may entail negative effects, since the prohibition for forest area reduction does not take into consideration fuel reduction measures, which are absolutely necessary from a wildland fire management perspective within a context of rural abandonment and uncontrolled vegetation succession (Badia et al, 2002). Thus, a clearly *regulatory approach* is posed over forest areas, through the establishment of a *zoning*, which basically entails the setting of restriction for uses and activities depending on the carrying capacity's limit, resource use and natural hazards. This approach, established through land use planning instruments (also recognised by forest planning), has been put into question by other recent approaches which insist on the need for a more strategic spatial planning approach (Davoudi, 2004).

Spatial planning's performance over wildland fire management is framed in the wider approach undertaken by this public policy upon natural hazards. This policy provides the potential to favour a more sensible use for the territory within a sustainable territorial model, which incorporates the biophysics matrix and the dynamics knowledge unto the territorial analysis and diagnosis.

There is a generic treatment for land use occupation in relation with natural hazardousness, which usually tends to limit uses and activities in areas affected by

this kind of events to minimize harms caused by them. The need to establish limits precisely in this type of areas acquires a growing relevance in spatial planning legislation. The regulatory capacity for spatial planning instruments allows its incorporation to the *protected areas* category (either as differentiated lands or as a restraint imposed to other planning categories).

Nonetheless, this regulatory approach does not seem to be effective for wildland fires. There is a need for a change towards a more *strategic* approach based upon the regulation of more relevant transformation processes under a global perspective (territorial model) and according to the socially acceptable capacity for transformation (e.g. loss of biodiversity, landscape modification, increase in vulnerability).

Therefore, an analytic and diagnostic frame different from conventional spatial planning ones (zoning and regulatory) is needed, with new approaches posed from Landscape Ecology principles: patch, pathway, pattern (territory as a system) (Marull and Mallarach, 2002). Identification of territorial functionality and its incorporation to the model would allow the definition of tools to measure wildland fires impact, areas sensible to ecologic damage, potential for urban development with less impact etc. Hence, an essentially dynamic frame for spatial planning would be set opposite to the static one to land use planning.

3.2 Agricultural and rural development policies in wildland fire risk management: strengths and weaknesses

From the beginning, agriculture has been one of the major priorities for the UE. The Common Agricultural Policy (CAP) is regarded as one of its main policies areas, if we consider its extent, its share of the EU budget and the controversies it has aroused. More than forty years after its conception, the CAP has undergone through various reforms and has progressively has incorporated new elements of growing importance in the political agenda such as the environment, sustainability and rural development. In particular, the growing importance of rural development measures within the CAP corresponds to a reality where according to the European Commission (1997) approximately 80% of the territory of the European Union can be called 'rural', where due to major transformations in last decades agriculture is no longer the obvious pillar of the countryside.

From the policy point of view, forestry is increasingly recognised as one of the activities to be considered in such development. The growing importance of the role that forests play in the rural development has been reflected in the evolution of the rural development policy: forestry measures undertaken by CAP have evolved from

mainly afforestation measures⁶, to the constitution of a specific group of measures on forestry covered by the Rural Development Regulations (RDR)⁷. The present RDR for the programming period 2007-2013 includes a set of measures targeting the sustainable use of forestry land through: first afforestation of agricultural and non-agricultural lands, first establishment of agro forestry systems, restoring forest potential and introduction of prevention actions, Natura 2000 and forest-environment payments, and support for non productive investments. Regarding forest protection, the RDR makes explicit mention to forest fires regarding the funding of prevention measures as well as restoration activities in forests damaged by natural disasters and for the maintenance of fire breaks through agricultural measures. Moreover, all measures proposed upon forestry in medium or high forest fire risk areas within the framework of the Community action on protection against fire, must conform to the forest protection plans established by the member states for these areas⁸.

As forests acquire an increasing role in the development of local communities in forest areas, Agricultural and Rural Development Policies have greater potential to influence structural causes affecting wildland fire initiation and propagation.

As mentioned above, some of these measures are in close relation with forest protection and wildland fire prevention. Thus, the RDR, together with Forest Focus, the two main instruments for the support of prevention and restoration activities to be carried out by the Member States, co-financed by the recently created European Agricultural Fund for Rural development (EAFRD) for the present programming period 2007-2013.

However the potential of rural development policies in solving the wildland fire problem is most important in those measures aimed at guaranteeing the maintenance of viable local communities in both the social and economic sense. RDR pursues this aim not only by improving the competitiveness of the traditional rural sectors (agriculture and forestry) but also by promoting the diversification of the rural economies (i.e. tourism and micro-enterprises) and improving the quality of life in these areas. In this context, the promotion of the multifunctional role of forest contributes to the development of rural communities depending on forest areas and in the long term constitutes a guarantee for forest conservation, especially in the European context where forest ecosystems are subject of growing anthropogenic pressure. This is especially relevant in areas with conflict in clandestine burnings,

⁶ Council Regulation (EEC) n° 2082/92 Reformulation of a system of aids for afforestation

⁷ Council Regulation (EEC) n° 1257/99 of 17 May 1999 on support for rural development from the European Agriculture Guidance and Guarantee Fund (EAGGF) and amending and repealing certain regulations. Council Regulation (EEC) n° 1698/2005 of 20 September 2005 on support for rural development by the European Agricultural Fund for Rural Development (EAFRD)

⁸ Council Regulation (EEC) n° 1783/2003 amending regulation (EC) No 1257/1999 on support for rural development from the European agricultural Guidance and Guarantee Fund (EAGGF)

such as in the Mediterranean areas where fire remains an important tool in rural activities as a mean for making wildlands profitable and constitute the main cause for the initiation of wildland fires.

Moreover, the maintenance of rural activities in forested areas such as use of forest fuel, establishment of agro-forestry systems or the harvesting of non-wood forest products such as mushrooms or hunting activities, favours discontinuities in forest vegetation, which in the long term sets up the best defence against increasingly frequent large fires events.

However, although RDRs establish the need to assure compliance of all co-funded forestry measures developed in high or medium forest fire risk areas with forest protection plans established by Member states, in practice we find measures which on the contrary may worsen the wildland fire problem (i.e.: excessive use of afforestation' use of fast growing species). Moreover, the need to assure compliance with forest fire dynamics should be considered for other measures undertaken by CAP which may indirectly affect forest areas such as the effect of decoupling payments from production, which although beneficial for the extensification of less land use may also induce disappearance of livestock and thus the threat of land abandonment and a decrease in the area of extensive pasture (Zdanowic et al, 2005). On the other hand, funding for livestock without the necessary increase in pasture areas might as well have a negative effect in wildland fires incidence due to the use of clandestine burnings by rural population to create them.

From the member-states perspective, rural development policies are considered an opportunity for funding their national wildfire prevention policies (e.g. development of awareness campaigns, silvicultural treatments, maintenance of defensive infrastructures or agro-environmental measures). However, as important as these preventive measures might be from the technical point of view, there is a need to link these actions with sustainable economic activities in order to guarantee their maintenance in the long term (e.g. agro-alimentary activities or rural tourism).

3.3 Energy policies in wildland fire risk management: Strengths and weaknesses

Energy policy, unlike environmental policy, is not an EU legally-binding policy on the whole. Energy-related decisions have been considered as affecting member states' crucial interests and are therefore still subject to unanimous rule in the European Council. Due to this fact energy policy has been Europeanized only to a very limited extent.

In spite of that, the EU clearly acknowledges the relevance of energy issues, as it is exemplified both in its international leading role regarding the promotion of the Kyoto Protocol and in its support of renewable energies (RE) at the European level.

The recurrence of wildland fires, being aggravated by global warming and subsequently compounding the greenhouse effect itself, should obviously be targeted as an objective of EU energy decisions. In this respect, the Kyoto protocol, as mentioned before, not only envisages tradable emission permits but also promotes forests as sink recipients of CO₂. Regarding RE a proof of its importance is the EU's recent commitment to increase its presence in the European energy market up to 20% by the year 2010⁹. Since the EU is severely dependent upon energy imports¹⁰, the promotion of endogenous sustainable sources, such as biomass (following the Danish and Finnish successful examples), has been envisaged.

Concerning the Kyoto Protocol the necessary time span to assess its impact is missing as it entered into force in the EU as late as the 16 February 2005. Further, the subsidiarity principle, that has entailed a bigger role for member states vs the EU Commission, alongside the sustainable development (SD) European programme, that allows for many different -and sometimes contradictory- ways to attain sustainability, compound the problems surrounding the assessment of the influence of EU energy policy on wildland fires. Both factors, subsidiarity and SD, might aggravate the very unequal performance of the different member states as far as Kyoto is concerned. The absence of EU enforcement powers to reduce the gap between "law-abiders" and "law-breachers" is in this respect striking. To sum up, lack of sanctions and voluntarism might aggravate poor performance of an international treaty that contains important potential for tackling fire forests.

As regards RE, although certain sectors and specific countries have clearly deviated from a rather uninspiring norm, little progress can be detected between 1997 and 2000. The problem lies again in the overall absence of clear mandates and compulsory goals, as most EU decisions in this field adopt the shape of communications (or strategies and white papers). The case of biomass clearly exemplifies this point: in an area that is considered crucial for energy supply and CO₂ reductions, the Commission has merely confined itself to supporting voluntary measures. A Communication has established that "it is necessary to disseminate knowledge and information more widely within the European Union and to launch promotion campaigns stressing the energy, environmental and economic aspects of this technology". Further, lack of policy coordination and insufficient funding is impairing the process leading to biomass production while support for forestry

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This commitment has superseded the COM (97) 599 Energy for the future: renewable energy sources - White Paper laying down a Community strategy and action plan. This paper provided a strategy for renewables, its main objective being to double the proportion of RE in the EU's gross domestic energy consumption from 6% in 1997 to 12% in 2010.

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At present, the EU depends on imports to meet 50% of its energy needs. This percentage is expected to increase up to 70% in 2030 with a growing reliance on oil and gas.

biomass is still insufficient in half of the European countries (Directive 2001/77/EC). This situation is discouraging since biomass could provide a solution for the overgrowth of forests masses, thus reducing the risk for wildland fire initiation and propagation. Moreover, the use of forest biomass is considered as one of the factors with potential to enhance forest-value, an issue which is contemplated within national rural development policies developed by member-states.

Not every aspect concerning renewables is of course left to the member states' free judgement. A number of directives, establishing binding goals and discretionary means for their attainment, have also been approved, as the case of Directive 2003/30/EC on the promotion of the use of biofuels or other renewable fuels for transport shows¹¹. As previous experience has shown, implementation deficit is likely to affect the enforcement of this and other energy-related directives.

3.4 Environmental policies in wildland fire risk management: Strengths and weaknesses

Since its inception at the end of the 60s-early 70s, environmental policy in the EU has been gradually moving towards sustainability. During this process, environmental protection achieved formal recognition (in the 1986 Single European Act) and increased its "assertiveness", as shown by the fact that subsequent EAP ceased to consider the environment as something that should be regulated because of its spill-overs on the internal market but rather because it was an important asset in itself. Connected with growing assertiveness was the enlargement of environmental powers assumed by the Commission.

Yet, the initial environmental legislative impetus of the Commission started to be subject to criticism since the mid 80s as a result of the increasing popularity of the subsidiarity principle. As a consequence of this, fewer directives have been passed recently while proposals for new frame directives (e.g. the 2000 water framework directive, 60/2000) have been made. This will entail that the directive, as the main legal instrument in environmental policy hitherto, will lose its initial specific focus and become more lax and vague as a policy tool. A new approach on better implementation (rather than simple legislative elaboration) as well as a new consensus on the need to combine command-and-control instruments with market-based, voluntary and self-regulatory and educational measures, are at the base of this

¹¹ This legal instrument sets a minimum percentage of biofuels to replace diesel or petrol for transport purposes in each member state: the minimum share of biofuels sold on their markets should be 2% by 31 December 2005 at the latest, and 5.75% by December 2010.

new policy paradigm¹². Another element of the “new” EU environmental policy is related to “conditionality”: the distribution of funds -LIFE, cohesion fund, structural funds- will increasingly come to depend on the fulfillment of environmental objectives. The Cardiff Process has also entailed that environmental concerns be incorporated into all other policy areas by means of the application of the environmental integration principle; that is, environmental policy will gradually be less of a traditional sectoral policy but rather an objective incorporated into all environmentally-related policies. Finally, the role of the EU as a signatory party to international environmental agreements is on the rise.

Of all the areas that environmental policies might embrace, those that could impinge more directly upon forest fires are: water policies that link the quality of the resource with the preservation of a minimum flow in the basin unit; air policies that combat climate change by means of forestation schemes that might contribute to decrease CO2 emissions through the promotion of the sink effect; urban waste policies that aim to eliminate illegal dump sites in semi urban/rural populations; and conservation and biodiversity policies that focus on the fight against desertification and the promotion of sustainable development schemes in forest and semi-rural areas. Leaving aside the explicit reference to fires provided by a number of regulations¹³, most environmental norms do not address this problem explicitly. At the member-state level, environmental policies’ intervention upon wildland fire management is merely limited to the prevention stage and in particular by favoring the implementation of sectoral (forest or civil protection) legislation and plans through the establishment of guiding principles for fire risk activities and as an additional source for funding prevention activities.

Unlike the energy policy, environmental protection is mainly based on directives, this entailing that environmental objectives enjoy a legally-binding force. However, implementation deficit, as well as lack of enforcement powers on the part of the EU, has been traditionally identified as the main explanatory factors of slow progress in this area. As the habitat directive 92/43, establishing the European network of protected areas Natura 2000 (as well as the previous birds directive 79/409) shows, when it comes to defining, adjusting and implementing those legal instruments the crucial actors are the member states.

¹² Alongside hard harmonization (legislation), diffusion and emulation (i.e. networking, best practice exchange -the cases of IMPEL or European Network for the Implementation and Enforcement of Environmental Law, The Community Framework for Cooperation to Promote Sustainable Urban Development-), know-how transfer and better governance are being increasingly promoted.

¹³ i.e.: EC N° 2278/1999 laying down certain detailed rules for the application of Council Regulation (EEC) N° 3528/86 on the protection of the Community’s forests against atmospheric pollution, and EC N° 1727/1999 laying down certain detailed rules for the application of Council Regulation (EEC) N° 2158/92 on protection of the Community's forests against fire)

If implementation deficit is concomitant of legally-binding instruments, what might not happen to instruments that lack this legal force (for example, the Commission proposal concerning a biodiversity action plan for the conservation of natural resources through the use of specific silvicultural techniques to better mimic natural processes, or the VI EAP that, covering the period 2002-2012, has identified nature and biodiversity as one of its four priority areas).

Another important element in current environmental policy is the growing reliance on what might be termed as “voluntarism”, as exemplified in information-exchange mechanisms, best-practice transfer, private networking and the like. A clear example in this respect is the call to set up a network for the exchange of prevention practices and tools in relation to natural accidents and disasters that the heading Nature and Biodiversity (VI EAP) contains. Important as they might be, these mechanisms reflect the new self-regulatory mood that has swept across the EU, pushing more traditional and forceful instruments to a peripheral position.

To sum up, the dilution of the EU environmental policy into the SD programme might prove negative for fire-management proposals since new possibilities for divergent national plans and outcomes open up now. The gradual loss of impetus of the Europeanization process might equally impair the attainment of harmonized and coherent measures that tackle the fire problem at the EU level. Although the subsidiarity principle contains an important element of truth when advocating that certain environmental problems (such as wild fires) are best dealt with at the local or regional level, lack of involvement of the EU might result both in unequal and unsatisfactory outcomes and the emergence of obstacles in terms of lesson-drawing experiences.

6. Conclusions

Taking into account a cross-sectoral approach on public policies with effect in land management provides an opportunity to understand the structural causes affecting wildland fires as well as to assess their potential for intervention in wildfire prevention and propagation. Direct action upon the way land is managed and the analysis of social, ecological and economic conditions which contribute to set the wildfire risk are some of the examples of this potential.

Coordination needed to achieve a cross-sectoral approach is however hindered by the different nature of territorial policies. In order to overcome these difficulties, it is necessary to assess the level of coincidence between public policies objectives, that is, to what extent there are complementary or conflictive relations among these. The territory should be placed in the centre of the sustainability debate, this entailing making some headway towards territorial governance and policy coordination.

In general, territorial policies are far from strictly considering fire-related

objectives. In those cases where these objectives are contemplated, a vague approach seems to be the norm; wildland fires are frequently included among natural hazards in general. Moreover, the neglect of wildland fire objectives in these policies may set the conditions for more devastating fires.

The adoption of a multilevel approach is also needed when assessing the impact that public policies have on wildfire management, particularly in the case of decentralized countries due to their multilevel governance structure. This entails considering: main orientations stemming from the EU, the member-state national regulatory framework and the implementation at the regional and local level. In this sense, European policies that impinge most directly upon fire management (i.e. forest-related policies) are not part of the *acquis communautaire* and lack therefore a compulsory nature. That is, forest plans will have to be drawn up by member states (e.g. Reg 2152/03) under the subsidiarity principle, thus allowing for heterogeneous results in terms of quality elaboration, comprehensiveness, targets specification and deadlines. In this respect, the absence of specific EU wildland fire management legislation plus the little Europeanization affecting those policies that most directly impinge upon wildfires, leads us to conclude that a concerned effort on this front is not likely to be anticipated in the foreseeable future. The most Europeanized policies analyzed in this document (i.e. the CAP and certain environmental policies) have only a marginally effect upon fire-related issues.

References

- Badia A; Sauri D; Cerdan R; and Llurdes J-C. 2002. Causality and management of forest fires in Mediterranean environments: an example from Catalonia. In: Global environmental change, Part B: Environmental Hazards, Vol.4 Issue.1; 23-32 p.
- DG JRC. 2005. Forest Fires in Europe 2005. Report n°6; 53 p.
- Montiel, C.; Galiana, L. 2005. Forest policy and land planning policy in Spain: a regional approach. In: Forest Policy and Economics, vol. 7/2;131-142 p.
- Plana, E.; Carlomagno, E.; De Miguel, S. 2005. Fire risk management, forest policy and territorial planning: comparative assessment and proposals for an integrated model. II International Conference on Prevention Strategies for fire in Southern Europe, Barcelona, 9-11 May 2005.
- FAO 1999. Report of meeting on public policies affecting forest fires, 14th session, Rome, Italy, 1-5 March 1999, I. Preamble 3.
- OECD, 2003. Report on innovation and effectiveness in territorial development policy. 6th Session of the Working Party on territorial indicators. Switzerland, 23-24 June 2003, page 2.
- Xanthopoulos G; Caballero, D.; Galante M.; Alexandrian D.; Rigolot, E. & Marzano R. 2006. Forest Fuels Management in Europe. In: Andrews, P. L. & Butler, Bret W.: Fuels Management-How to Measure Success: Conference Proceedings (Portland, 28-30 March 2006), USDA Forest Service; 807 p.

A Comparative Assessment of the European Forest Policies and Their Influence in Wildfire Management¹

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Abstract

Wildland fire issues are mainly considered within national forest policies as threats affecting forests. Therefore, wildfire issues are responsibility of the Member States in the European Union, developed in the frame of the National Forest Programmes and according with the different territorial contexts and needs. Besides, the European Union can influence or complete specific aspects of the forest sector, namely the forest fire issues. So, the forest policy processes and planning documents are a good opportunity to introduce new approaches in the fire management, towards a more efficient action, based on the integration of the different aspects of fire (from wildfire to prescribed or suppression fires).

The objective of this paper is to assess the contribution of forest policies and legislation to the integrated wildfire management. For this purpose, it will be developed a comparative analysis about the main strengths and weaknesses of the forest policy instruments with relation to wildfire at the European scale and in the frame of national forest policies. Besides, it will be presented how the different European forest policies consider the wildfire problem with the aim of identifying common patterns at the regional scale.

Keywords: European Union, forest policy, national forest programme, planning documents, wildfire management.

1. Introduction

Wildfires are one of the main risks affecting European forests, particularly in the Mediterranean countries. The socioeconomic changes, some forest management actions (i.e. forest plantations) and other policy measures outside

¹ An abbreviated version of this paper was presented at the Third International Symposium on Fire Economics, Planning, and Policy: Common Problems and Approaches, April 29 - May 2, 2009, Carolina, Puerto Rico. This research is developed in the frame of the FIRE PARADOX Integrated Project “An innovative approach of Integrated Wildland Fire Management Regulating the Wildfire Problem by the Wise use of Fire: solving the Fire Paradox”, financed by the VI Framework Programme, Sub-priorit 6.3 Global Change and Ecosystems.

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the forest sector (i.e. environmental and nature protection policies) have influenced the flammability of ecosystems and increased the risk of large wildfires. Thus, the forest sector must come to new realities that are bringing about fundamental change in Europe⁴.

Over the last century, the wildfire policies adopted by most part of European countries have been based on the total fire exclusion. Nonetheless, there is a recent failure in recognizing the role of fire in the ecosystems and in understanding the underlying socioeconomic and cultural aspects in which many fires occur. Fire has been widely used as a tool for the agricultural and forest practices in past and present times (FAO, 2006). Moreover, the fire use is being reintroduced in some areas as a mechanism to reduce hazardous fuels and risk of damage and loss (Hesseln, 2006).

On the other hand, the recent trends in wildfire policy have evolved into take long-term preventive actions, not simply emergency suppression measures when a fire disaster strikes. Until now, the process to induce changes in wildfire policies or the adoption of new political measures has been a fast *ad hoc* reaction to a catastrophic situation that has already happened, rather than a proactive mitigation before the emergency arises (FAO, 1999).

Policy measures are influenced for the perceived level of threat that varies with the intensity and scale of fire-related problems in each country. Thus, new approaches for wildfire defence are required to improve the strategies of prevention and suppression. A further step is given by the concept of *integrated management of wildland fires*. It involves the consideration of the various aspects of fire in suppression and prevention, but also the use of fire as a tool for management practices.

The aim of this paper is to assess the main strengths and weaknesses of the forest legislation and policies in the EU countries to promote new management practices and to achieve an integrated wildland fire management system, adapted to the specific territorial contexts. It has been developed in the frame of the European Integrated Project FIRE PARADOX (2006–2010)⁵, whose one of its final objectives is to provide recommendations for long-term policy measures and to encourage a shift in the current wildfire situation.

2. Material and Methodology

The assessment of wildfire legislation and policy instruments is developed covering two scopes: (i) the European scale and (ii) the national frame of several EU

⁴ IV International Wildland fire Conference, (Seville, Spain. 2007).

⁵ www.fireparadox.org

Member States⁶.

The research has been mainly based on legal and policy documents obtained through the following information sources:

- A questionnaire formulated in the frame of the FIRE PARADOX project, which has been the main source to compile official information. It was addressed, through the European Commission, to the members of the *Working Group of Forest Fire Prevention Experts (WGFFP)*. This expert group is composed by experts from the national authorities nominated by the EU Member States and the EC; as they deal with operational issues related to wildfire prevention and fighting, they have a complete and exhaustive knowledge about wildfires in their countries.
- National expert contacts including Fire Paradox partners, *Eurasian Fire in Nature Conservation Network (EFNCN)*, national representatives of the WGFFP, regional government representatives and scientific researchers from European universities.
- National regulation texts regarding the use of fire, wildland fire and forest legislation; national forest plans and specific planning documents concerning defence and protection against wildfires.
- Bibliographical and literature references completing the official documents were obtained from official web pages and from the data bases of official organisations and non-governmental agencies⁷, European research project's databases (i.e.: EUFIRELAB and FIRE TORCH) and other online databases (i.e.: Web of Science, Science Direct and Universities, FAO NFP Update⁸).

The methodology for the assessment of the collected data is based on (i) the review of the official documents and other literature references, (ii) a comparative assessment of the data at the national level and (iii) the identification of common patterns among the countries at the regional scale. A final SWOT analysis is developed, based on the regions obtained from the comparative analysis, which identify the strengths and weakness of the legislation and policy instruments concerning the Integrated Fire Management systems and the responsible use of fire at the regional scale.

3. Results

Wildland fire issues are mainly dealt inside the forest policy as threats affecting forests. The development of forest policies, and therefore wildfire issues, are responsibility of the Member States in the European Union. Although there is no common forest policy for the EU-Countries, the EU can exert certain influence over

⁶ Austria, Bulgaria, Cyprus, France, Latvia, Lithuania, Poland, Portugal, Spain and Sweden.

⁷ FAO, European Council, United Nations Forum on Forests, Global Fire Monitoring Centre, Joint Research Centre, The Nature Conservancy, the International Forest Fire News (IFFN).

⁸ <http://www.fao.org/forestry/site/nfp-update/en/>

its Member States and complete their national policies.

Other sectoral policies (civil protection, spatial planning, rural development and agricultural policies) can have certain influence, directly or indirectly, in the wildland fire management due to the wide perspective of the wildfire problem. However, as the wildfire issues are broadly developed within the forest sector, the analysis will focus on forest legislation and policy frameworks from the European and national approaches.

3.1. Analysis of the European Union legal and policy instruments related to wildfires

European Union policy takes concern over the negative impact of forest fires on people's lives, local economies and the forest ecosystem. European Union forest fire policy developed, early in the 1980s, with the provisions of the 'fire regulations' with the main emphasis on national forest fire prevention measures and to establish a pan-EU forest fire information system. The latest major European Union document that outlines the EU forest policy, the Forest Action Plan (2006), recognises the sizeable influence of forest fires on the ecological condition and productive capacity of forests in the EU. The main key objectives regarding fires are:

- Work towards the further development of the European Forest Fire Information System (EFFIS).
- Analyse the main factors influencing the evolution of forest condition in Europe (including forest fires).
- Encourage Member States to form groups in order to study particular regional problems on forests,
- Support research on protection of forests.

The European Environment Agency in its latest State of Environment report (2005) stated that adoption of an integrated approach to forest fire management is crucial. The EU has recognised the problem of forest fires in a wide range of policies such as in biodiversity, climate change, desertification and renewable energy policies. Through the agricultural (EAGGF⁹) and environmental (LIFE+) instruments, the European Commission supports EU Member States with a variety of measures in the fight (pre, ad-hoc and post) forest fires.

3.2. Comparative assessment of the national legislation and policy instruments

Wildfires affect millions of people worldwide and cause major economic impacts at all levels. However, fire occurrence and its incidence are different in the European regions. The highest number of fires and the most extensive areas are

⁹ European Agricultural Guidance and Guarantee Fund.

reported in the Mediterranean countries in the North of the Basin. This tendency appears to be extending from the Northwest to the East. The western European countries bordering the Atlantic Ocean, the English Channel and the North Sea have less wildfire problems; they occasionally experience large wildfires. Regarding Baltic countries, the number of fires and the annually burned area vary depending mainly on weather conditions. In the Nordic countries (boreal zone), fire is not considered as a problem and the area burned annually is rather small. In fact, fire has been an important element in forestry, agriculture and sheepherding in these countries.

These regional differences justify the assessment of the wildfire problem and its consideration in the different national legal and policy frameworks in the European countries considered in this report.

3.2.1. Legal frameworks for wildland fire management

The legal frameworks of the countries where wildfires have had historically environmental and public security impacts (Mediterranean countries) have a broad development, as they have been progressively approving very complete legal tools in order to fight fires. However, in the Northern, Central and Eastern European countries, where wildfires are a relatively recent problem, their legal treatment is still quite incomplete and usually limited to extinction.

The assessment of the contents within the national regulations of each country has focused on:

(a) Wildland fire prevention regulation:

The most significant regulation in terms of volume and implementation is that of the Mediterranean countries; in the rest of Europe (especially in Scandinavia), there are many instances of forestry provisions, but their express aim (although tacitly, where possible) is not actually the avoidance of forest fires. In these countries, productive aims continue to prevail over all others. However, in recent years, the countries of northeastern and eastern Europe have started to develop a not-insignificant normative production that seeks to curb an upward trend in the forest fires suffered in the recent years. In this regard, Sweden, Lithuania, Latvia, Bulgaria, and Poland are good examples.

The different preventive measures regulated may be systematized as follows: Forestry treatment in order to avoid forest fires; division into zones of areas at risk; declaration of high-risk seasons; hazardous activities, preventive measures with regard to infrastructures or housing developments; controlled burns; and measures aimed at encouraging prevention (social participation, education and research).

b) Wildland fire suppression regulation:

In general, there is certain balance between all European countries and those of the Mediterranean area. In almost all countries, there exists a relatively complete

legal framework for the resources with which to fight fires, for the organization of the relevant Authorities or for the training of the people in charge. The resources, to which the norms refer, tend to be of the traditional sort. In fact, suppression fire techniques are provided for in an almost anecdotal manner.

c) Prescribed Burning Regulation:

Except for France and Portugal, references in other countries are very sketchy (such as Sweden or Poland). In other countries such as Spain, this legal framework has not been provided for in the basic nationwide legislation, but in some Autonomous Regions such as Catalonia.

The two countries that have made the biggest effort towards the regulation of this matter have been France and Portugal. In general, the regulation mentions the conditions for the performance of burns; the approval of the relevant body; also provision is made for the compulsory notice of the performance of the burn to the affected owners and extensive regulation of the know-how and technical requirements needed in order to carry out controlled burns.

Finally, attention should be drawn to various concurrent aspects in other countries. Firstly, in Bulgaria this practice is not envisaged because any kind of controlled burn is prohibited. Secondly, in Sweden there seem to be some initiatives in this matter but rather they are aimed towards scenery and the environment.

d) Suppression Fire Regulations:

Except in the Spanish case, and with regulations that are absolutely limited, and in France, where fire breaks have recently been introduced into the national legal framework, this practice has not been the subject of regulation in any other country. When this matter has been regulated, it has been considered that the execution of fire breaks is a power that rests with the operational director, and the intervention of the Authorities is meaningless.

3.2.2. National wildfire policies

The political efforts have recently evolved in some countries from a fire policy focused in emergency suppression measures, with high costs, towards the promotion of long-term preventive actions. However, this objective should be linked with the development of fire prevention plans accompanied with financial support. The budget allocated for suppression and prevention could allow us to guess the political concern about wildland fires; however, there are not reliable databases charting the national investments and the official information available is quite partial and insufficient. In general terms, EU-countries realize the importance of prevent fires better than fight them but the economic resources allocated in prevention are still less than the budget spent in suppression, specially in Mediterranean countries.

Countries have very different institutional arrangements for organizing wildfire

management. Nonetheless, two trends have been reported from the questionnaire analysis: (i) countries in which the forest service is responsible for forest fire prevention and control (e.g. Lithuania, most Spanish regions) and (ii) countries with a mixed system, where responsibilities in preventive and suppression actions are allocated at different administrative organisms (e.g. France, Portugal).

Apart from the allocation of prevention and suppression roles, there are several agents participating in fire management actions, especially in extinction. In countries like Portugal, Cyprus and Sweden there are three or more organisms participating. In this context, cooperation among all these agents is essential for an effective fire management and control. Although in all the countries an organism responsible of the coordination within their action field has been fixed, the lack of coordination among all the agents is still perceived as a constraint and an important point to work on.

At the moment of facing a fire a correct planning of the actions and have complete information of the situation in the field is very important in order to direct the necessary suppression actions. All the countries, excluding Lithuania, have developed or are developing Geographical Information Systems for decision making.

Regarding the scarce official information about participation and cooperation, a preliminary conclusion could affirm that all the countries have tried to establish cooperation mechanisms with local population, mainly with land owners and through local societies. In those countries with a decentralized political system, all the efforts to include stakeholders in wildland fire management are made from the regional and local levels (e.g. Spain and Sweden). The exception is Cyprus where there is not almost any community participation; but voluntary groups are being promoted.

A key issue in the national documents is the planning of preventive and defensive infrastructures. Two different spatial models are distinguished: a net of fuel breaks where the vegetation is totally reduced and the creation of a heterogeneous landscape mosaic of low fuel volume and low flammability resistant to fire spread. The combination of firebreak areas with the traditional lineal firebreaks is the option that is being adopted by most countries (i.e. Spain, Portugal, France, Cyprus, Poland and Bulgaria). Regarding fuel treatments in the wildland-urban interface in order to protect settlements and housing areas are considered in France, Portugal, Poland and Spain. However, there is not information about its regulation in planning documents.

The need for reducing fire hazard through active fuel management is indeed becoming more and more obvious. Preventive silviculture is one of the cornerstones for successful fire management and could help to understand until what extent preventive measures are empowered by the countries. The choice of which methods are used varies depending on factors such as vegetation type and characteristics, seriousness of the fire problem, available funds, available experience and expertise, tradition, social concerns, etc.

Within the countries considered, there is a general tendency to use mechanical brush out to reduce fuel accumulation and in a second place manual brush out. The use of phytocides is almost not used in none country. Regarding controlled grazing, it is starting to be promoted although by the moment, it is not a technique for fuel management very extended. It takes place in some regions of Spain, Portugal and more frequently in Bulgaria and France (Mediterranean countries).

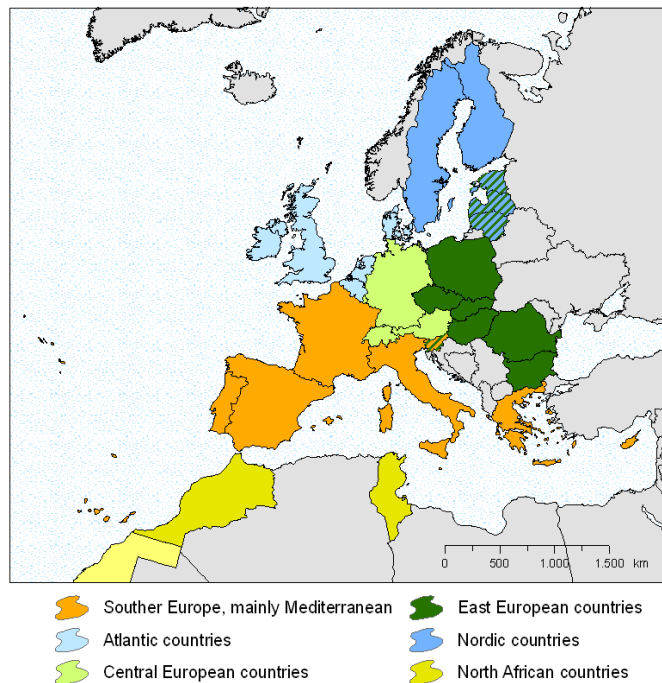
The use of prescribed fire for fuel management is almost not used in Europe. Countries like Austria, Cyprus, Latvia, Lithuania, Poland and Sweden do not consider these practices for fuel management in their policy documents. France, Portugal and Spain apply these fire techniques through regional fire prevention plans.

Besides, specialized professional teams and training programmes have been created. In fact, Portugal recently puts an emphasis in the reintroduction of prescribed fire and for this purpose has started a broad training program of foresters and support crews. On the other hand, Spain has developed “Equipos de Prevención Integral de Incendios Forestales” that collaborates in prevention actions with the Autonomous Regions. Also France has official training centres for professionals of the fire use.

4. Discussion: SWOT assessment of the wildfire legal frameworks and policy instruments

The results obtained from the comparative assessment of the national wildfire legal frameworks and policy instruments allow identifying spatial patterns (fig. 1) that are useful to base the analysis of the strong and weak points of fire-management activities in Europe.

Figure 1— Wildfire legislation and policy zonation.



Source: Proposal of J. Goldammer & C. Montiel. Elaborated by J. Solana (UCM, 2007).

Table 1—Results from the SWOT analysis.

Zones	Strengths & opportunities	Weaknesses & Threats
Southern Europe	- Preventive actions undertaken in wildfire management with a proactive approach (i.e. Spain). - Political will on coordination among the different administrative bodies with responsibilities in fire management.	Institutional limitations on forest sector development. Top-down bureaucratic approach in policy style. - In general, there is a lack of participatory processes to enable those people who have a direct stake in forest resources to be part of decision-making. Traditional burning practices were made illegal without prior educational programmes.
Nordic countries	- Prevalence of the consensual tradition in policy processes, formulation and implementation Stakeholder's participation. Transparency of the political processes:	Difficulties in political leadership. The decentralization process has entailed that forest protection has ceased to be a state responsibility, this is leading to a decrease in state budgets. Effective inter-sectoral and multilevel coordination:
Atlantic countries	Clear and coherent political processes. A wide-ranging consultation process that has involved public discussion, expert opinion and the input of sectoral interests.	Any specific weakness for this region has been identified.

Central European countries	▪ Forest policies are understood as iterative, open and dynamic processes.	▪ It is not evident the existence of a real political will to achieve integrated wildland fire management, since the wildfire risk is not perceived as a social demand neither a political priority. ▪ Coherence of the political processes (specific timeframes, issues and actors for the NFP). ▪ Coordination. In decentralized countries between the central government and the regional powers (i.e. Germany) but also, when different agencies participate in fire management (i.e. Austria). There is a need of coordination mechanisms or techniques to sort out jurisdictional disputes.
East European countries	▪ Growing transparency in the political processes: The new Forest Law was passed by the Parliament in Lithuania.	▪ Weak stakeholders' participation. ▪ Lack of negotiating tradition. ▪ Effective coordination: For instance, in Latvia, the responsibility for fire control is in different public administrations.
European Union	▪ The EU has no common forest policy as it has no legal responsibility for forest policy, but it has an important influential role and it can complement national policy and as such fulfill a unifying and harmonising role in the Union. ▪ Forestry measures are influenced mainly from the agricultural, regional development and environmental policies. It is guarded however that thematically the different policies do not overlap and that they certainly do not contradict. ▪ EU forest fire legislation has developed during the past two decades. The forest fire problem is recognized as a threat to sustainable forest management, but also it is considered in relation to, e.g. biodiversity, biomass and climate change policy. ▪ Willingness at EU level to fund integrated projects openness to consider 'new' approaches. ▪ The EU has transparent, open and flexible institutional bodies where experts, commission, country and other stakeholder representatives have opportunities to establish dialogue. There exist several policy coordination levels: within the Commission, within the Council, between the Commission and the Member States.	▪ The EU has no overruling powers over the Member States. This can be considered as a weakness in cases where implementation by national/regional authorities would seem lacking. ▪ EU policy only refers to 'forest fires' and 'prevention' and 'monitoring' measures. There is no stance towards integrated wildland fire management. ▪ The EU recognises the importance of prevention, extinction and post-fire activities. However, the rehabilitation of fire-affected forest lands reportedly suffers from underinvestment. ▪ There exists an EU Forest Fire Expert Group, integrated by representatives from EU Member State competent national authorities, but the group could be more transparent and open towards other stakeholders in the forest fire issues. ▪ Besides of the influence of wildfires in rural development and in forest management, support of integrated wildfire policy might need further cross-sectoral dialogue (i.e., resource management, biodiversity and climate change aspects).

5. Conclusions

- Legislation and policies are key instruments for the introduction of innovative approaches and recommendations towards an integrated wildland fire management.
- Wildfire issues deserve a different consideration inside national legislation depending on: the different rhythm and evolving stages of the national forest policies and the risk severity of wildfires in national contexts. However, some common aspects, with the nuances derived from the territorial contexts of each country, have been found within the different countries studied. It has resulted in the identification of common patterns in fire management policies at the regional scale.
- In spite of the coincidences, there is a need of harmonization of the wildfire regulations at the European level. It would contribute to achieve a reunification of the very disperse existing regulations. However, there must be variations according to the countries.
- In all the countries, the evolution process of the legal framework starts in the regulation of the extinction. While the legal frameworks evolve and the wildfires become a serious problem, the preventive field gains attention.
- Although fire prevention is slowly gaining importance within national wildfire legislation and policies, it is still undervalued compared with extinction in the national budgets. Prevention is a constant task over the year, covering various action fields that sometimes do not have public recognition; however, is the way to avoid emergency situations and costly suppression actions.
- Wildfire policies adopted by most European countries have been based on fire exclusion; only some countries (Portugal, France, Spain) consider the use of fire with forest management, fire prevention and suppression objectives within their legislation frameworks.
- Regarding fire use techniques, there is a need of a basic legal framework on backfiring practices and more detailed description of the conditions to develop prescribed burnings.

References

- Dimitrakopoulos, A. & Mitsopoulos I. (2006): **Global Forest Resources Assessment 2005-Report on fires in the Mediterranean Region**. Fire Management Working Papers FM/8/E. FAO Forestry Department. 38 p.
- FAO (1999): **Report of meeting on public policies affecting forest fires**, 14th session, Rome, Italy, 28-30 October 1998, I. Part 1.
- FAO (2006): **Fire management: Voluntary guidelines — Principles & strategic actions**. Fire management Working Paper FM17E. Rome. 71p.
- FAO (2007): **Fire management — global assessment 2006**. FAO Forestry Paper 151. Rome, 2007. 156p.
- FAO (2001b): **Legal Frameworks for Forest Fire Management: International Agreements and National Legislation**. Follow-up Report to FAO/ITTO International Expert Meeting on Forest Fire Management, March 2001. Working Paper FFM/3/E. FAO, Rome, Italy.
- Goldammer, J.G. (2000): **Fire Policies: Shaping the institutional Frameworks**. International Forest Fire News No. 23, 3-8.
- Hesseln, H. (2006): **An assessment of domestic and foreign wildfire policy** (Unpublished).
- Simorangkir, D., Moore, P., Haase, N., Moore, P. (Editors) (2003): **Fires, laws and regulations – Towards best practices for legal aspects of fire**. Project Fire Fight South East Asia (IUCN and WWF). 68p.
- Vélez, R. (2002): **Causes of forest fires in the Mediterranean Basin**. In: Risk management and sustainable forestry. Eds: Arbez, M.; Birot, Y.; Carnus, JM. EFI Proceedings N° 42. September 2001, Bordeaux (France). 35-42
- Working Group from the Regional Session (2007): Self-assessment of the fire situation and fire management capabilities. Conclusions from the Regional Session C: Europe, Southeast Europe, Mediterranean North Africa and Caucasus. 4th International Wildland Fire Conference, Sevilla, Spain, 15 May 2007.

Implementing a Code of Practice for Fire Management on Public Land in Victoria, Australia¹

Aimee Haywood² and Rachaele May²

Abstract

In 1995 a Code of Practice for Fire Management on Public Land was developed for Victoria, Australia. The challenge for Victorian fire managers has been to balance the safety of humans living nearby to parks and forests with the needs of flora and fauna. The Code was one of the first strategies to set an overall framework for integrated management of wildfire and fire-related activities on Victorian parks and forests. Significant public scrutiny and key learnings from the 2002–2003 fire-season provided a solid basis to begin the scheduled 10-year review of the 1995 Code.

Over an eighteen month period, a thorough review of the Code was undertaken. Essential to the review was collaboration with the Victorian community, stakeholders and wildfire specialists. The approved 2006 Code is now being implemented across the seven million hectares of parks and forests in Victoria and interest has been shown in a broader application of the Code by international wildfire experts. The Code establishes a framework for the public administration of fire management, with community engagement providing the foundation for successful wildfire prevention, suppression and recovery. It links wildfire management with the active use of fire for ecological purposes and contributes to global wildfire management strategies.

Keywords : Code of practice, community engagement, fire management, suppression, wildfire prevention.

Introduction

The State of Victoria is located in the bottom south-eastern area of mainland Australia. While Australia is a typically dry, fire-prone continent, the geography, climate and vegetation of southeastern Australia makes it one of the most severe fire

¹ An abbreviated version of this paper was presented at the Third International Symposium on Fire Economics, Planning, and Policy: Common Problems and Approaches, 29 April – 2 May, 2008, Carolina, Puerto Rico.

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regions in the world along with southern France and southern California. Fire, both as a natural event and its use by Australian Indigenous people, has been significant in shaping much of Australia's ecosystems.

Many Australian flora and fauna species depend on wildfire as part of their life cycle. Typically, Victorian indigenous ecosystems consist of sclerophyllous vegetation that often requires wildfire to induce seed fall, flowering or germination. Many plant species have adopted vegetative regeneration through epicormic shoots and lignotubers so that even severe fires will not kill some species. The specific interaction of ecosystems with wildfire depends upon the frequency, seasonality and intensity of the wildfire, coupled with the life stage of key species in that ecosystem.

The Victorian public land estate of national parks, state forests and other reserves plays host to nationally and internationally recognised rare and threatened species. Managing both naturally occurring and human-induced wildfire over these seven million hectares is the responsibility of the Victorian Department of Sustainability and Environment. Victorian legislation is clear in allocating the responsibility of wildfire prevention and suppression on public land to the Department, with similar responsibility for rural private land resting with the Country Fire Authority.

As public land managers the Department must primarily reduce the incidence and severity of wildfire on the public land estate whilst balancing the need to protect human life and property and use or exclude fire to maintain ecosystem health. With people increasingly choosing to inhabit areas abutting parks and forests, there is a growing expectation that the public land manager will bear part of the responsibility for wildfire risks associated with the natural environment.

Accordingly, an overarching set of standards and principles is required to ensure that sound fire management practices are carried out on Victoria's public land estate. The Victorian 'Code of Practice for Fire Management on Public Land' was established to provide the strong framework for integrated fire management. It assists with the recognition and balancing of often competing objectives for fire management: the role of fire in the maintenance of biological diversity, the responses of different ecosystems to fire, natural patterns of succession and the risk of wildfire to human life and property.

The Code of Practice ensures the Department meets obligations enshrined in legislation whilst providing a basis to respond to critics and support implementers. It sets the standards on which to base fire plans and outlines instructions for operational requirements.

A Code of Practice is Developed

Following a number of significant fires and increasing community interest in the way fire was managed, the development of a Code of Practice for Fire Management on Public Land commenced in 1995. The basis of the initial Code of Practice was to:

- Establish a coherent and consistent policy;
- Clearly define and fully integrate planning processes for all planned uses of fire;
- Ensure consideration of the appropriateness of fire regimes to the maintenance and vigor of indigenous flora and fauna; and
- Promote a high and consistent standard of fire, based on practices which are openly documented.

After an extensive development and consultation process, the original Code of Practice was published in December 1995 with the primary purpose to:

“...promote efficient, effective and integrated management of fire and fire related activities on public land for the purpose of protecting human life, property, assets, and environmental values from the deleterious effects of wildfire or inappropriate fire regimes...” (CNR, 1995)

The Code of Practice was the umbrella document under which all Fire Plans were to be developed, and compliance was a requirement for all fire-related activities in Victoria’s parks and forests.

Undertaking a Review

The Code of Practice was a robust, enduring document, and widely respected over its first ten years of inception both within Australia and internationally. In a 2003 Audit Report into Fire Prevention & Preparedness, the Victorian Auditor General acknowledged that the Victorian State Government was “...regarded as demonstrating industry best practice through the Code...” (Auditor General, 2003)

The 1995 Code of Practice gave a commitment that it should be reviewed within ten years of its approval. In accordance with that obligation, a review of the Code of Practice began in January 2005. This followed a significant fire season which saw over one million hectares of land burnt by wildfire over a period of fifty-nine days. The subsequent Inquiry into the 2002-2003 Victorian Bushfires conducted by the Victorian Emergency Services Commissioner made a number of recommendations relating both directly and indirectly to the Code of Practice.

From the outset it was recognised that community participation in the review of the Code of Practice was essential. Without community partnership, the Code of Practice would not endure for the next ten years nor meet the expectations held by stakeholders and landowners. Collaboration with the Victorian community throughout the review would eventually set the standard of ongoing consultation with the wider Victorian community in relation to fire management issues.

Coupled with a desire to work with the community was a series of legislative obligations that needed to be undertaken as part of the review process. The requirement to seek public submissions on a Draft Reviewed Code of Practice was easily accommodated in the overall consultation strategy.

Advisory Groups

A number of advisory groups were established at the beginning of the project to actively contribute to the review of the Code of Practice. Members included partner fire agencies, national parks managers, specialists in meteorology, fire behaviour, fire ecology, statutory planning, water, forest management, fire operations, recovery as well as members of advocate groups. All of these representatives directly contributed at each stage of the project.

A project plan for the review process was designed in collaboration with these advisory groups. In order to ensure formal and informal input at all stages of the review, two key steps in the project were identified at the beginning. An initial scoping Discussion Paper was to be followed by a Draft Reviewed Code of Practice.

Discussion Paper

A Discussion Paper was developed early in the review process seeking comment from the wider Victorian community, partner fire agencies and stakeholder groups. It focused on a number of key issues that, since implementing the Code of Practice in 1995, had significantly changed or were identified as in need of consideration. Discussion topics were briefly described and then followed by a short list of questions of which the community was invited to answer.

Approximately seventy submissions were received on the Discussion Paper, from adjoining landholders, universities, advocate groups, partner fire agencies and other industry bodies. Overall, most submissions acknowledged that while some parts of the Code of Practice required updating, most issues stemmed from inconsistent or lack of, implementation. Areas of particular focus in the feedback included the need for improved community education and engagement, relationship management with partners, particularly locals and monitoring and reporting, especially back to the community.

Draft Reviewed Code of Practice

Analysis of the Discussion Paper submissions, coupled with the feedback from the advisory groups and community meetings led to a Draft Reviewed Code of Practice. This document was widely distributed to stakeholders, advocate groups and the wider Victorian community for comment.

Over 100 formal submissions on the Draft were received. While a range of opinions and ideas were presented, common topics raised for amendments included:

- More involvement of the community at all stages of fire management;
- Increased emphasis on seeking and using local knowledge in fire management planning and incident management;
- Better defined fire management planning processes;
- Demonstrated links with private land fire management;
- Stronger audit requirements to ensure implementation of and compliance with the Revised Fire Code; and
- Amendments to the Fire Management Zones.

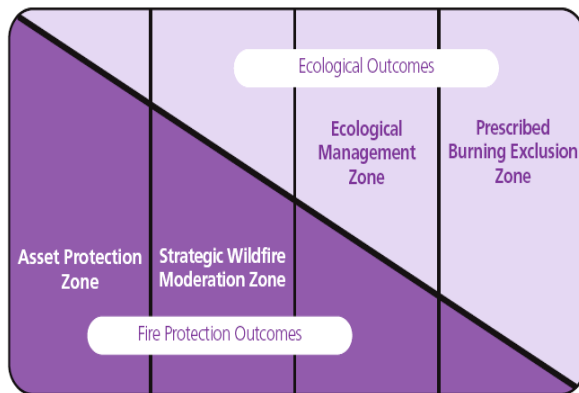


Figure 1— Fire Management Zones (DSE, 2006)

An updated Code of Practice

Community input was a vital component of the review process. Partner fire agencies, key stakeholder groups and the wider Victorian community were all encouraged to participate at a number of stages throughout the review. Information gathered from individuals, organisations, public meetings, the Discussion Paper and Draft submissions as well as comments from scientists and technical experts, were analysed and considered in the development of a final document. The reviewed Code of Practice was approved by Victorian Parliament in February 2006, and then gazetted in September 2006 revoking the 1995 Code of Practice. It lays down minimum statewide standards for fire management on public land (DSE, 2006).

The review of the Code of Practice incorporated up to date fire management science, including the effects of fire on biodiversity. It ensured integration with fire protection on private land and addressed some of the recommendations from the Inquiry into the 2002-2003 Victorian Bushfires conducted by the Victorian Emergency Services Commissioner.

A number of significant changes present themselves in the reviewed Code of Practice for Fire Management on Public Land. Importantly, the dual roles of the State

Government as both a public land manager and a fire suppression service are more clearly distinguished and a foundation of community engagement is established.

Key to the integrity of the reviewed Code of Practice is the maintenance of both a quality management framework (typically ‘goals-plan-implement-review’ see figure 2) and the fire protection framework of Prevention, Preparedness, Response and Recovery. Research is a requirement across all sections of the Code of Practice.

Using the quality management framework as a basis, the reviewed Code of Practice is broken into five key sections: Overarching Principles, Planning, Land Management Burning, Wildfire and Compliance. Each of these five sections contains foundation principles, a planning component, an implementation section and a review requirement. This quality management framework applies throughout the document, enabling constant feedback and review to ensure effective implementation.

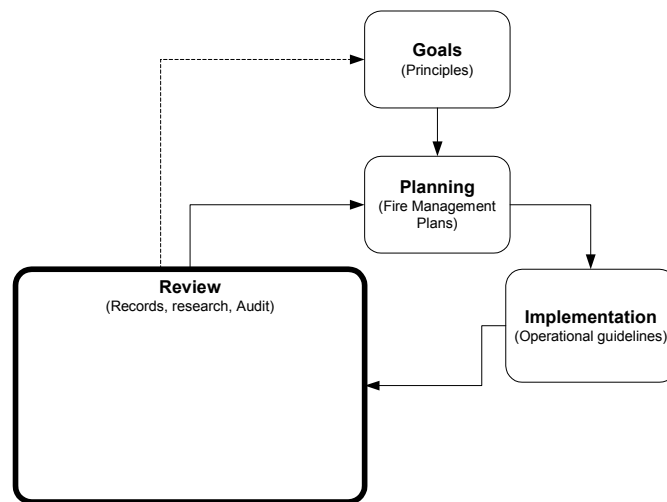


Figure 2 — “Goals-Plan-Implement-Review” cycle illustrated at the start of each chapter, underpins the entire Code. The bold-box indicates the context for each section.

Overarching principles

The broad principles for fire management on public land are established at the beginning of the document to address the threat of wildfire, guide the use of prescribed burning, and provide for the achievement of integrated land management objectives. Specifically, they establish the minimum requirements in relation to risk management; prescribed burning (operations), fire protection (prevention, preparedness, response and recovery), environmental management and community partnerships. Community partnership and engagement principles were added to the overarching principles to reflect the Department’s commitment to improving its relationship with the community. In addition to these added principles there is a

specific recognition that local knowledge is to be included in all incident management teams and targeted during planning operations throughout the year.

Planning

The Planning section outlines the structure under which fire protection and other land management objectives are delivered in a planned and integrated manner. It recognises the concept of genuine fire management that encompasses both fire protection strategies and fire ecology strategies.

Strategic Fire Management Plans are described for each management area of Victoria. These ten-year plans must contain specific goals, objectives and standards for the integrated use and exclusion of fire to meet asset protection, fuel management, ecological and cultural objectives. Importantly it is set that the Fire Management Plans must demonstrate clear links to fire protection strategies on private property (land tenures beyond the jurisdiction of the Code of Practice) and contain a monitoring and evaluation component to assess if fire management outcomes are being achieved.

On a rolling annual basis, Fire Operations Plans must also be annually prepared in accordance with the strategic Fire Management Plan for a given area. Fire Operations Plans contain a three-year forward program for prescribed burning and a schedule for other preparedness works. The rolling, annual nature of these plans provides increased flexibility to access works planned over a three-year period if, for example, first year works cannot be undertaken due to weather restrictions.

The key to fire planning in the reviewed Code of Practice is the concept of zoning all public land according to the fire protection and ecological priorities for an area. In response to the Emergency Services Commissioner's recommendation to review zones in the original Code of Practice, fire management zones were reduced in quantity from five to four. As described in the reviewed Code of Practice the four zones have clear fire management objectives for asset protection, strategic wildfire moderation, ecological management or the exclusion of prescribed burning.

Land management burning

The first of the two 'implementation' chapters outlines requirements relating to prescribed burning on public land. In Victoria prescribed burning is used to achieve one of three objectives: to reduce fuel levels for fire protection, to stimulate regeneration of tree species following timber harvesting and to maintain or enhance indigenous ecosystems. Operational standards and guidelines for the conduct of prescribed burning are described in this part of the Code of Practice. This includes

the authorisation, ignition, patrol, rehabilitation and ongoing monitoring of a prescribed burn area.

Wildfire

The second of the two ‘implementation’ chapters sets the minimum standards and guidelines for addressing the threat of wildfire in Victoria’s parks and forests. The fire protection framework of Prevention, Preparedness, Response (Suppression) and Recovery is applied here.

Prevention

All activities concerned with minimising the incidence of wildfire, particularly those of human origin, are described in this section. This includes education, enforcement and prevention operations.

Preparedness

This section of the Code of Practice describes all activities associated with the preparation for wildfires, such as fuel management (including the application of Fire Management Zones), readiness, aircraft, roading, personnel training, communications, equipment standards and detection of wildfire.

Response (suppression)

The wildfire suppression chapter of the Code of Practice refers to all activities associated with restricting the spread of wildfire following its detection, and making the wildfire safe. This includes health and safety of personnel and the community, dispatch of resources, incident planning, interagency coordination, operational guidelines (including environmental standards) and fire investigation.

Recovery

This section of the Code of Practice describes all activities associated with recovery from the impact of wildfires, including the rehabilitation of fire suppression disturbance, community recovery and debriefing of personnel.

Compliance

The concluding chapter of the reviewed Code of Practice for Fire Management on Public Land complements the final component of the quality management framework – the review stage. Compliance with the Code of Practice is undertaken through records, research, on-going monitoring as well as a comprehensive, external audit requirement. The reviewed Code of Practice details a more frequent and stringent

audit process, with yearly internal audits and five yearly external audits. This extends and links with the improvements made to the community engagement aspects of the Code of Practice, as results of the audits will be made available to the community to ensure an open and transparent process is followed and that the Code of Practice is being adequately and consistently implemented around the State.

Implementing the new direction

Implementation of the reviewed Code of Practice initially focused on the education of fire management staff with regards to changed practices and business principles. All members of advisory groups, and those individuals or groups who participated at any stage of the review process were provided with a copy of the reviewed Code of Practice and a summary of the key changes. To complete the engagement process commenced during the review, implementation of the reviewed Code of Practice will include public information sessions to provide details of amendments and to inform that there will be changes in the way DSE (and partner agencies) conduct fire management operations and the opportunity to raise questions.

Many changes in the reviewed Code of Practice reflect improvements in operational practice that have occurred in the ten years since the original document was approved and released. Others reflect where the Department wishes to head into the future. The Code of Practice can also be used to help implement the Food and Agriculture Organization of the United Nations “Fire management Voluntary guidelines: Principles and strategic actions”. The comprehensive and integrated nature of the Code of Practice keeps Victoria amongst the leaders in public land management in Australia, if not the world.

Meeting Challenges and the way forward

The reviewed Code of Practice was approved over twelve months ago, but has only been implemented for approximately eight months. These first eight months have been some of the most significant eight months that Victorian public land managers and fire agencies have faced in recent history.

Over the summer period of November 2006 - February 2007 more than 1.2 million hectares of land was burnt in a series of large, intense wildfires continuing for sixty-nine days. The majority of these wildfires were started by lightning, and burnt in extremely dry vegetation that had been effected by a continuing ten year drought in many areas. It was the second time in four years that Victoria experienced more than one million hectares burnt in a single summer season. This poses a significant

challenge for public land managers, fire services, and the community who choose to live in these environs.

One challenge for the implementation of the Code of Practice includes the education of the community in order to minimise confusion over the new concepts for fire planning. The reviewed Code of Practice describes Fire Management Plans that incorporate both fire protection and ecological strategies. This is broader than the Fire Protection Plans described under the original Code of Practice. There is also the consideration of management of naturally caused wildfires being used to meet fire management objectives in accordance with the relevant Fire Management Plan.

In addition it is becoming clear that increasingly engaging with communities about fire management on public land is, in some cases, dividing communities. By initiating discussion about fuel management works, wildfire suppression techniques and ecological requirements, the community has become more educated and has an increased desire for information (at an increased speed). In some cases this has brought forward divisions of thinking within a community to the forefront, which is actively contributing to the emerging 'blame culture' associated with natural disasters.

Prolonged periods of below-average rainfall, which narrows the window for the safe conduct of prescribed burning programs, coupled with an increasing migration of communities to the peri-urban boundary have meant that the adverse risk of wildfire to human life and property has increased. In the case of the recent Victorian fires, there is much discussion in the community and media as to the most effective way to manage fire in parks and forests. Polarised discussions surrounding fuel reduction practices and ecological requirements are being raised openly and loudly in the public arena. Public land managers recognise that severe wildfire events, in a naturally fire prone region, are likely to increase as the effects of climate change become more pronounced.

Summary

Full implementation of the Code of Practice will continue with framework development for Fire Management Plans to assist in the change over from Fire Protection Plans and further policy definition to set out a Victorian version of 'Wildfire Use Policy'. This is expected to be completed by the middle of 2008 before the 2008-2009 wildfire season. It is imperative that the wider Victorian community plays an active role in the implementation of the new Code of Practice, which recognises a shared responsibility for wildfire risk, and seeks open community scrutiny to monitor fire management practices.

Over the next few years it is expected that more information will be accumulated about the likely impact on wildfire management and ecological changes as a result of climate change. Consideration must therefore be given to bring forward the next review of the Code of Practice to reflect any new information and the need for significant shifts in strategic thinking around fire management. Successful implementation of the reviewed Code will be dependent upon the willingness to learn from recent large, prolonged fire events, past practices, future thinking and to listen to community expectations.

Acknowledgments

We thank the staff, stakeholders and members of the community whom contributed and made comment on the Draft Code and to all involved in the Advisory Groups during the revision of the 1995 Code in 2005.

References

- Auditor General Victoria. 2003. **Fire Prevention and Preparedness**. Melbourne, Victoria: Crown (State of Victoria).
- Department of Conservation and Natural Resources (CNR). 1995. **Code of Practice for Fire Management on Public Land**. East Melbourne, Victoria: Crown (State of Victoria).
- Department of Sustainability and Environment (DSE). 2006. **Code of Practice for Fire Management on Public Land (Revision No 1)**. East Melbourne, Victoria: Crown (State of Victoria).

Decision Modeling for Fire Incident Analysis¹

Donald G. MacGregor² and Armando González-Cabán³

Abstract

This paper reports on methods for representing and modeling fire incidents based on concepts and models from the decision and risk sciences. A set of modeling techniques are used to characterize key fire management decision processes and provide a basis for incident analysis. The results of these methods can be used to provide insights into the structure of fire management decision making, including key decision drivers and influences. The methods are applied to two fire incidents to illustrate the various phases of fire management decision making. Both applications identify critical decision points that influenced incident outcomes, including (a) the importance of “worst-case” analysis and scenario generation, (b) accessibility and usability of local fire management knowledge, (c) effects of individual differences in IA/EA decision making, and (d) discontinuities in fire management decision processes.

Keywords: Decision modeling, incident analysis, risk analysis.

Introduction

Although 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 of the incident is required in terms of decisions and decision factors that influenced the outcome.

The focus of this research is a method for analyzing fire incidents in terms of decision-making principles, using the language of decision and risk analysis as basis for representing the relationship between fire management decision making and incident outcomes. The basic approach is embodied in one of the central concepts from decision analysis, that of decomposition by which large, complex problems can

¹ An abbreviated version of this paper was presented at the Third International symposium on Fire Economics, Planning, and Policy: Common Problems and Approaches, 2008 April 29 - May 2; Carolina, Puerto Rico.

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be understood better by breaking them down or “decomposing” them into smaller, more tractable problems that can be solved or characterized in some detail.

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 (Armstrong 2001, MacGregor 2001).

Large-fire decision making is a multi-layered phenomenon and has properties of organizational decision making as well as individual decision making. We first develop the general concept of an incident decomposition and identify a tiered layering of social, organizational and incident factors that influence incident-specific decisions and decision outcomes. A set of relevant theories and models relating to dynamic decision making serves as a basis for identifying concepts and principles that have value in explaining or characterizing incident decision. We then apply this theoretical development to the decomposition of an incident in terms of an event-frame model, by which key events relating to the incident are set out in a temporal sequence and represented according to a set of concepts and principles identified in the overview of models. The structure of an incident is populated with two general sources of information: the documentation generated as part of the incident, and a protocol approach for key incident personnel. The overall approach is illustrated in the context of case studies to illustrate how the language and models of decision theory can be transferred and applied to key decisions on actual fire incidents.

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*).

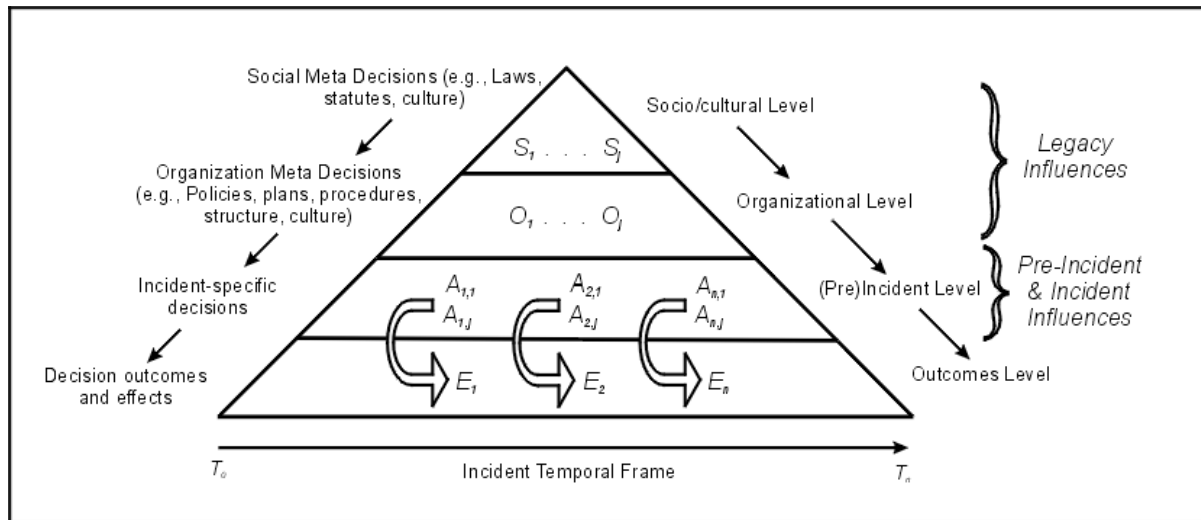


Figure 1 – General model of incident decomposition. Adapted from Paté-Cornell (1993)

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. 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. 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.

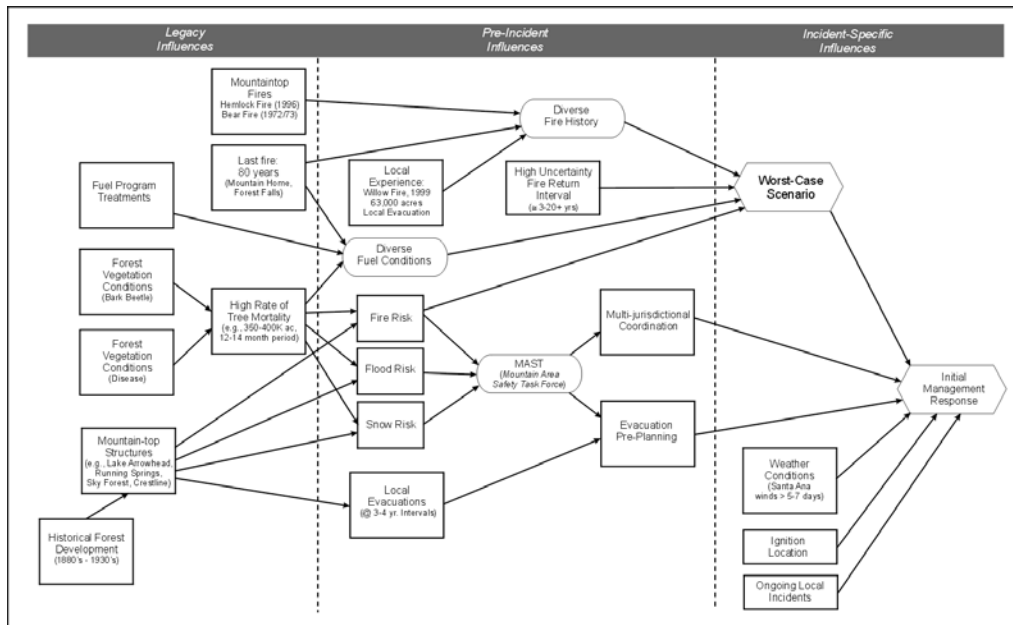


Figure 2 – Influence diagram representation of an initial management response decision based on the Old Fire, San Bernardino National Forest, October, 2003.

Dynamic Decision Making Influences on Decision Outcomes

Cue-based Models

A general model of judgment based on multiple cues is the lens model (Cooksey and Freebody 1985, Cooksey 1996). The lens model draws a distinction between an information environment that is represented by a collection of cues, and the psychological representation of that object in terms of a decision or judgment based on those cues.

The importance of cue-based approaches to decision modeling is their emphasis on discrete information elements in the decision environment and on the recognitional processes that the decision maker uses to select and weight information in forming a decision response. These processes rely heavily on attention resources and on the ability to focus on the most relevant information in dynamically changing environment, as well as reject or filter out irrelevant, redundant or unreliable information. An important aspect of cue-based decision making is the ability of the decision maker to recognize information that is not present in the environment but that should be. Other related theories also conceptualize decision making in terms of the relationship between the decision maker and the decision environment, sometimes accounting for decision performance in terms of critical cues that

stimulate the recognition of decision situations that call for specific behaviors or actions (e.g., Klein and others 1989).

Control Theory Models

A class of decision models that are important in dynamic environments are control theory models (Weiner 1948, Sheridan and Ferrell 1981, Wickens and Hollands 2000). Control theory models conceptualize the human decision maker as an element of a closed-loop system that exercises control through a set of output processes that impact the environment (*fig. 3*). The environmental effects of the output processes are returned to the human decision maker through a negative feedback loop where they are compared with one or more reference points. The results of the comparison yields an error signal that is interpreted by the human decision maker in terms of available control or decision options to effect an environmental change in the appropriate direction.

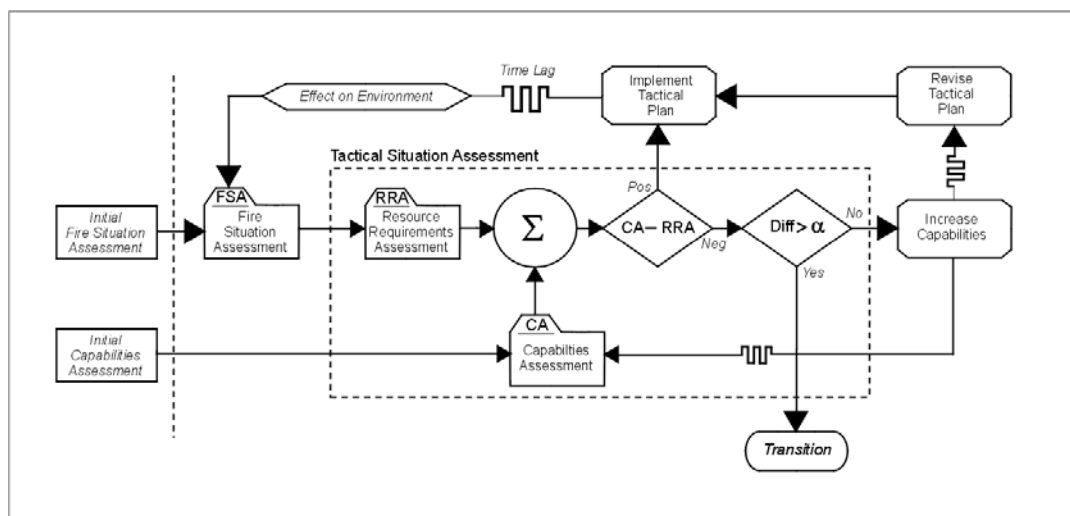


Figure 3 – Control theory representation of IA/EA decision making based on the Fork Fire, Mendocino National Forest, August, 1996.

Reference points are conditions that serve as a gauge by which system effects on the environment are compared. Reference points can be established by a number of means, including directives, policies, elements from training scenarios, cues in the environment (e.g., fire behavior), and affective or emotional conditions of the decision maker.

A second key concept is that of *comparator mechanism* by which the human decision maker evaluates the effect of system outputs under their control in terms of the magnitude and meaning of departures or differences from a reference point. How departures from reference points are evaluated in the comparator process with respect

to *gains versus losses* can have dramatic impacts on decision behavior.

Production Models

An important class of models that relate to control theory are *production models*. Production models represent the human decision maker in the context of a process or product environment that is goal or objective oriented. Fire management organizations can be thought of as acting according to a production model. The various system processes (e.g., procedures, plans, internal communications) result in *products* that are outputs of the production system. These outputs include decisions, actions and communications that are intended to have an effect on the environment within which the system operates (e.g., a fire incident). The impact of the production system on the environment acts as a closed-loop feedback to the input of the system, thereby controlling its actions (Powers, 2005). Essentially, production systems are a form of *cybernetic control system* for which output from the system serves as a basis for the evaluation of how well system processes (e.g., fire management decisions) are meeting the goals and objectives of the system (e.g., perimeter control).

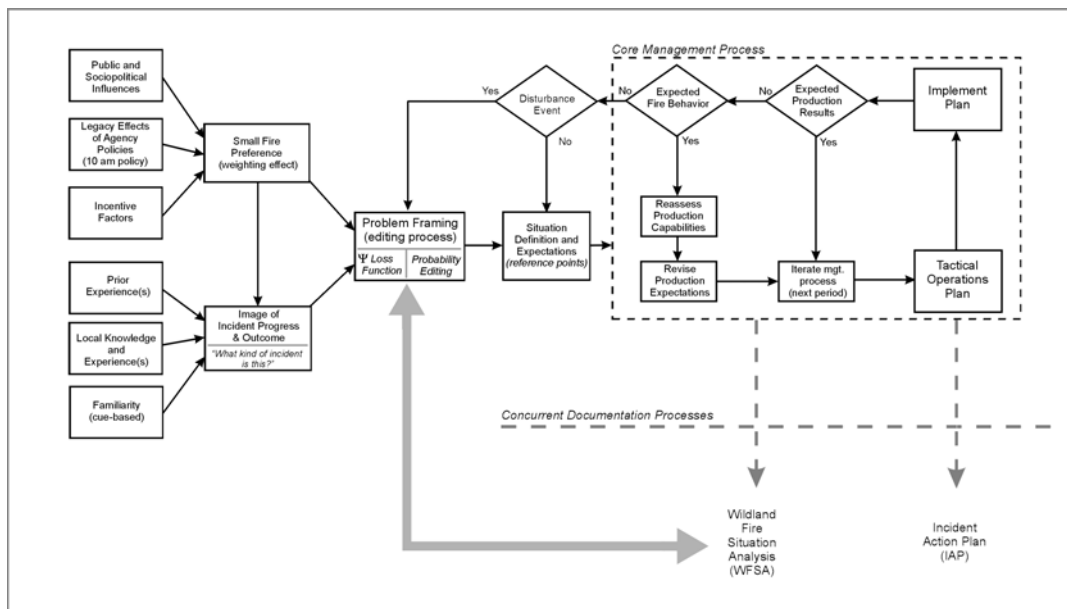


Figure 4 – Production system model of ongoing incident management team operations based on the Fork Fire, Mendocino National Forest, August, 1996.

Summary

The objective of this line of research is to use the concepts, models and language of decision making to characterize the decision processes on large fires. In pursuit of this objective, we have described a range of decision concepts and models and

applied their associated modeling languages to decisions made on two case studies that serve as examples for how we can better represent the basis on which fire management personnel make the decisions that they do.

Decision processes vary according across incidents and according to the events that comprise the incident. As our modeling shows, some incident decisions are actually legacy decisions and the incident itself is an event for which decision making has already occurred but the actions not yet executed. These types of incidents are anticipated incidents—ones for which even extreme occurrences have been envisioned and action contingencies pre-established. Although no large fire can be thought of as a normal occurrence, it is within reason to think of large fires as “normal catastrophes”, to paraphrase Perrow’s description of major technological failures as “normal accidents” (Perrow 1984). Given the precursor combination of forest conditions, weather & climate, and private inholdings, the trigger conditions necessary to produce high impact events may be just a matter of time. And, like technological failures, decision making about their management is part of a larger cycle that involves preparation and analysis well in advance of their occurrence.

Even within ongoing incidents, decision processes can vary considerably depending upon the stage of the incident and upon how management processes are structured and executed. Analysis revealed that local knowledge plays a key role in early management stages as well as in management decision making several days into an incident. We note as well that fundamental and important discontinuities may exist in these different management decision making stages. While fire is a continuous, exponential process that changes seamlessly although abruptly at times, management is a discrete process that changes linearly and in relatively discontinuous stages. This fundamental relationship between fire as a non-linear, continuous process and management as a linear and discontinuous one means that discontinuities in management processes may have the effect of retarding management performance. One definition and operationalization of these concepts may be found in the notion of *decision process discontinuities*. A better understanding how mismatches occur between decision processes at different management stages of fire incidents may help identify how decision processes and fire management training can be improved.

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.

References

- Armstrong, J.S. (ed.). (2001). *Principles of forecasting: A handbook for researchers and practitioners*. Norwell, MA: Kluwer Academic Publishers.
- Cooksey, R.W.; Freebody, P. (1985). Generalized multivariate lens model analysis for complex human inference tasks. *Organizational Behavior and Human Decision Processes*, 35: 46–72.
- Cooksey, R.W. (1996). *Judgment analysis: Theory, method, and applications*. San Diego, CA: Academic Press.
- Frohwein, H.I.; Lambert, J.H. (2000). Risk of extreme events in multiobjective decision trees Part 1. Severe events. *Risk Analysis*, 20: 113–123.
- Haimes, Y.Y. (1998). *Risk modeling, assessment, and management*. New York: Wiley.
- Keeney, R.L.; Raiffa, H. (1976). *Decisions with multiple objectives: Preferences and value tradeoffs*. New York: John Wiley & Sons.
- Klein, G.A.; Calderwood, R.; MacGregor, D. (1989). Critical decision method for eliciting knowledge. *IEEE Transactions on Systems, Man, and Cybernetics*, 19: 462–472.
- 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.
- Oliver, R.M.; Smith, J.Q. (eds.). (1990). *Influence diagrams, belief nets, and decision analysis*. New York: Wiley.
- 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.
- Powers, W.T. (2005). *Behavior: The control of perception*. New Canaan, CT: Benchmark Publications.
- Raiffa, H. (1968). *Decision analysis*. Reading, MA: Addison-Wesley.
- Sheridan, T.B.; Ferrell, W.R. (1981). *Man-machine systems: Information, control and decision models of human performance*. Cambridge, MA: The MIT Press.
- Weiner, N. (1948). *Cybernetics*. New York: John Wiley.
- Wickens, C.D.; Hollands, J.G. (2000). *Engineering psychology and human performance*. Old Tappan, NJ: Prentice Hall.

A GIS-Based Framework for Evaluating Investments in Fire Management: Spatial Allocation of Recreation Value¹

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Abstract

The U.S. Forest Service is responsible for developing tools to facilitate effective and efficient fire management on wildlands and urban-wildland interfaces. Existing GIS-based fire modeling software only permits estimation of the costs of fire prevention and mitigation efforts as well as the effects of those efforts on fire behavior. This research demonstrates how the economic benefits of fire management strategies also can be incorporated into a GIS-based planning structure. In this paper, spatially delineated wilderness recreation values are derived by allocating per-trip values for hiking from a travel cost analysis to the landscape using the viewshed tool in ArcGIS. Future work will incorporate water supply and real estate values, and develop a cost-benefit analysis framework. This research expands the economic capabilities of the Stewardship and Fireshed Assessment process by enabling decision makers to weigh the benefits of management activities against the costs.

Keywords: Fire management benefits, GIS, nonmarket valuation, recreation, San Jacinto Wilderness, viewshed analysis.

Introduction

The USDA Stewardship and Fireshed Assessment process utilizes fire modeling software that generates estimates of the costs of fire prevention and mitigation efforts and the effects of those efforts on fire behavior. However, this tool currently cannot estimate the benefits of those efforts making it difficult to evaluate investments in and trade-offs associated with fire management strategies. In cases where fire poses an imminent threat to life, crucial public infrastructure, or valuable private property,

¹ An abbreviated version of this paper was presented at the Third International Symposium on Fire Economics, Planning, and Policy: Common Problems and Approaches; April 29 – May 2, 2008 ;Carolina, Puerto Rico.

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it is unlikely that decision-makers would undertake a formal cost-benefit analysis before taking action. But consider, for example, a fire in a remote location used exclusively for back-country recreation. Should resources be allocated to this fire at all? If so, which resources and where should they be located? Or consider the option to undertake fire prevention activities in a mixed use landscape. Where should brush be cleared? Where trees should be thinned? Which areas should be protected given limited fire prevention resources? Without the capability to assess the benefits of fire prevention and suppression activities in a spatial context, efficient resource utilization is difficult to achieve.

Assessing the benefits of fire management strategies in general requires information about market and non-market values of landscape features and how those values are impacted by fire. Resource economists traditionally have utilized a typology that classifies values as either use or non-use values (Freeman 2003). Use values include extractive use of a resource such as timber harvesting or water supply, or in-situ use such as recreation or tourism; while non-use values include the desire to preserve a resource for the intrinsic value of its existence or for the option to use the resource in the future. Use values also may derive from service flows that exhibit the properties of either public or private goods: public use values would include ecosystem service flows such as nutrient cycling or carbon sequestration from which many people benefit freely and equally; private use values would include recreation activities or home ownership that provide benefits exclusively for the individual engaging in the activity, even though the value received may depend on public goods such as the quality of the natural environment.

The focus of this research is on private use values in a forested landscape, specifically: water supply, land development (real estate), and recreation. The value of public infrastructure such as reservoirs and power lines typically is assessed at its replacement value: how much would it cost to find an alternative water or electricity supply for some period of time? How much would it cost to replace damaged infrastructure? The value of private property can be based on market prices or assessed values. Both types of values are relatively easily represented in a spatial context because they are derived directly from landscape features with specific locations themselves (e.g., a watershed or a building).

Recreation value can be determined from a statistical analysis of users, their frequency of use, and the time and money spent to reach the recreation site; this is commonly called a travel cost analysis. Assessing recreation value typically is more difficult than assessing infrastructure or property values because it is not possible to directly observe the price of recreation; instead the price must be estimated through a travel cost or similar analysis. Furthermore, traditional models of recreation demand have focused on a “trip” as the unit of analysis (Freeman 2003) without addressing

the question of how the value of a trip is derived from the landscape in which the recreation activity takes place. That is to say, a recreation trip is valuable presumably because the user experiences an appealing landscape; but how can we use available data to determine which areas are more valuable than others? Spatially allocating the recreation value of a wilderness to the landscape is an essential part of any GIS-based benefits assessment, but the literature has yet to address this topic; this paper proposes a methodology for doing so.

This study ultimately will provide an analysis of water supply, real estate, and recreation values and demonstrate how they can be incorporated into a GIS-based planning structure and cost-benefit analysis framework. Such a framework is useful for public stewards who must allocate limited management resources across a landscape, ideally to create the greatest benefit for the public. This paper focuses on the spatial allocation of backcountry recreation value as this is one of the more novel and broadly applicable contributions of the research. In the sections that follow we present our data, methodology, and preliminary results. We conclude with a discussion of issues raised by this research and plans for future work.

Methods

This study examines backcountry recreation in the San Jacinto Wilderness in the San Bernardino National Forest in Southern California. The wilderness is located within a 2.5 hour drive of most of the greater Los Angeles, San Diego, and Palm Springs metropolitan areas and attracts roughly 60,000 backcountry visitors each year. Another 350,000 ride the Palm Springs Aerial Tramway into the Mt. San Jacinto State Park but do not enter the backcountry. The Pacific Crest Trail traverses the wilderness from north to south, and elevations range from 1,800 to 3,300 meters. The current drought has left the wilderness very dry and vulnerable to fire. In 2006 the Esperanza Fire severely burned a large area just to the northwest of the wilderness; currently campfires are not allowed even in designated campsites within the wilderness.

Backcountry access is regulated by two U.S. Forest Service Ranger Stations and one State Park office. Horses are allowed but bikes and motorized vehicles are prohibited. Day hiking is by far the most popular activity in the backcountry. All users entering the backcountry are required to obtain a permit, but the Forest Service estimates the compliance level is around 75% (Lyon 2007). Data needed to perform a standard travel cost analysis is available from permit receipts maintained by the Forest Service and State Park offices. Each permit lists the date of the trip, the number of people in the group, the entry and exit points, and the home address of the group leader. Most wilderness areas maintain similar records which helps explain the

popularity and usefulness of travel cost models for estimating recreation value.

Using conventional methods as in Weber and Berrens (2003), we combine the permit data for 2005 with the most recent census data (U.S. Department of Commerce 2000) to construct a dataset containing the number of backcountry trips taken from each ZIP code within a 2.5 hour drive of the wilderness and certain population characteristics of each ZIP code that are likely to help explain variation in recreation demand across ZIP codes (e.g., race, gender, age distribution, education level, income). The price of a trip from each ZIP code is estimated to be the sum of driving costs (a function of distance) and time costs (evaluated at one-third of the wage rate). We also augment our dataset with voting records on environmental initiatives from the 2000 election (California Secretary of State 2000) to help control for variation in environmental attitudes across ZIP codes. This approach is commonly known as a Zonal Travel Cost model (Haab and McConnell 2002).

Space limitations prevent a thorough discussion of the model estimation, but our standard Poisson regression indicates that the average value for Southern California residents of a backcountry day trip in the San Jacinto Wilderness is around \$76. Approximately \$48 of this value is consumed by trip costs leaving an average individual consumer surplus of \$28 per trip. With an estimated 60,000 backcountry users each year, the annual value of backcountry wilderness access is around \$4.5 million. This is likely an underestimate of the actual value because day users living further than 2.5 hours from the wilderness who tend to have higher travel costs and thus higher values were not included in our regression sample.

A spatial representation of this value requires it to be allocated to the wilderness landscape according to some rational methodology. Ideally one would collect information, perhaps stated preference data, eliciting the welfare effects of severe fires or trail closures in different areas of the wilderness to determine the values of landscape features. Such data is costly and time consuming to collect; often analysts must work only with the type of data we have for this study (Moeltner 2003). From the permit data we can infer not only the value of a backcountry trip, but also how many people enter the wilderness at each trailhead and, with some information and assumptions about destinations and hiking speeds, we can infer the likelihoods of various paths taken through the wilderness. Thus we can allocate the wilderness value to various trail segments, but the problem of allocating it to the surrounding landscape still remains.

To proceed, we make the reasonable assumption that landscape values for backcountry hikers are closely related to scenic quality. Obviously certain unique landscape features may have particularly high values, but in a relatively homogenous wilderness such as the San Jacinto, we posit the value of any specific location in the landscape may be well approximated by its visibility to backcountry users. For

example, land traversed by a popular trail is viewed up-close by many users; therefore it would have higher value than land which is viewed only at a distance and by a few users. Land which cannot be seen from any trails would have no recreational value.

A normalized weighting function can be calculated for each point in the landscape that indicates its relative scenic value for wilderness users. Consider a wilderness consisting of J points and with K trail segments, each traversed by n_k users during a recreation season. Each segment can be represented by a path in three-dimensional space from its starting point t_k^s to its end point t_k^e . At any point t on trail segment k , let $S_k(t)$ be the set of visible landscape points, and let $I_j(t) = 1$ if $j \in S_k(t)$ and 0 otherwise. Let $x_j(t)$ be the distance between points j and t , and let $w(x)$ be a weighting function such that $w > 0$ and $dw/dx < 0$. For each trail segment k , we can then define the “absolute visual weight” of point j as: $v_{jk} = \int_{t_k^s}^{t_k^e} I_j(t) w(x_j(t)) dt$, and the “normalized visual weight” of point j as: $V_{jk} = v_{jk} / \sum_j v_{jk}$, such that $\sum_j V_{jk} = 1$. If the value of a trip on trail segment k is p_k , then $\sum_K n_k p_k V_{jk}$ gives an estimate of the scenic value of point j .

To implement this valuation framework, we utilize standard tools available in ArcGIS (ESRI 2006). Our study area is divided into 30-by-30 meter grid cells within a Digital Elevation Model (DEM). Trails are divided into 42 unique trail segments, each connecting two trail junctions or a junction and a dead end. Each trail segment is divided into observation points that are located at intervals of 60 m along the trail. The visual experience of an individual hiker at each point is then simulated with the Viewshed Analysis tool. This tool identifies and calculates the number of times each parcel in the DEM is visible from the set of observation points by scanning the area surrounding each point. We set the scan angles to obtain a 180 degree vertical and a 360 degree horizontal scan. The offset value is set at 1.7 m, which corresponds to the average height of adult Americans. We limit the maximum search radius to 30 km as this is the maximum distance between any point along any of our trail segments and the boundary of our study area. As in previous viewshed studies (e.g., Llobera 2003), our analysis does not account for effects of varying atmospheric conditions or the presence of vegetation that could render the landscape less visible than implied by the viewshed results.

To define the weighting function, we rely on previous empirical work by Higuchi (1983) that establishes a method for measuring the quality of visual landscape characteristics based on their appearance from a given observation point. Using trees as the standard object of analysis, Higuchi creates distance indices that help identify at what point qualitative differences are discernible. He divides the landscape into the foreground, middle-ground, and background. Trees are discernible as separate units at short-distance, but are only visible as outlines and more

recognizable as a forest unit at middle-distance. At long-distance, one can only observe major topographical features, such as mountains and valleys and colors differ only by shade contrasts.

In our study we modify the indices suggested by Higuchi and increase the short and middle distances to account for bigger trees in our study area (i.e., Yellow and Ponderosa Pines). In addition, we divide the far-distance band into two separate bands where the “far background” begins at 15 km, instead of having one far-distance band that extends past 5 km as described by Higuchi. This gives us four distance bands around each observation point: 0 – 0.2 km, 0.2 – 5 km, 5 – 15 km, and 15 – 30 km. To reduce our computational burden, each point in each band is assigned the average radius of the band from the observation point. We then calculate the weight of each parcel as: $w(x_j) = e^{-\bar{x}_j/10}$, where $\bar{x}_j$ is the average band radius in km. This gives us band weights of 0.99, 0.72, 0.34, and 0.10, from nearest to farthest.

Finally we must specify the number of people hiking each trail segment and the value of a trip on each segment. As is often the case with permit data, we do not have complete information about the specific routes taken through the wilderness by each hiker; but we do know entry and exit points for each trip and we know all trips are day trips. To proceed, we assume an average hiking speed of 3.3 km/h and a maximum round-trip hiking time of 8 hours, and we assume that when a trail junction is encountered there is an equal probability of taking each trail segment from that junction. This produces a relative trip frequency for each trail segment which, when combined with the number of entries at each trailhead, gives an estimate of the number of hikers on each segment, n_k . To calculate the value of a trip on each segment, p_k , we allocate the value of a trip taken at each entry point to the associated trail segments based on the relative magnitude of $\sum_j v_{jk}$ for each segment. This is because; all else equal, longer trail segments and segments with more expansive viewsheds tend to have larger $\sum_j v_{jk}$, and thus by our reasoning should contribute relatively more to the value of a trip.

Results

We obtain values ranging from \$3 to \$819 per 900 m² parcel, corresponding to \$36 to \$9104 per hectare, with a mean of about \$340/ha. Seventy-five percent of these values range from approximately \$33 to \$644/ha. As shown in figure 1, the highest values are concentrated in areas with the highest elevations, in particular around the high peaks in the northeast. These include San Jacinto and Jean Peaks with elevations of 3,302 m and 3,252 m. Because the high mountain peaks have the best visibility from most points along the trails, these parcels receive higher visibility weights and thus contribute more to the value of a trip. However, these values can only partially

be explained by the visibility and elevation of these parcels as the final parcel value also depends on viewing distance and trail use frequency. In contrast, parcels located in relatively remote areas and on steep slopes descending away from trails generally have lower and sometimes zero values because of their limited visibility.

Discussion

Given the concentration of high values in a relatively small area in figure 1, and the broad expanse of low values across most of the landscape, it appears that the benefit of preserving recreation opportunities is significant only in a limited area of this wilderness. However, figure 1 should be interpreted carefully. If a fire in a low value area is expected to spread to a high value area, then resource allocation decisions clearly should incorporate this risk. Similarly, if a small fire is expected to spread to a large area of even low value landscape, this risk also should be incorporated. In both cases, prevention and suppression activities could be justified in any area regardless of its value to preserve nearby recreation opportunities. Therefore a spatial dynamic cost-benefit analysis framework is needed to properly evaluate management decisions. Figure 1 is most appropriately interpreted as an input to this framework.

Furthermore, the value surface in figure 1 is determined in part by our assumptions about how values are derived from the landscape. Therefore one of our immediate next steps is to collect additional data on actual routes traversed and times/distances traveled, as well as on the effects of hypothetical fire damage and trail closures on recreation behavior, in order to verify and calibrate our methodology. We also plan to augment this data layer with information about water supply and real estate values to provide a more complete picture of the spatial allocation of benefits derived from the landscape. Finally, a formal GIS-based cost-benefit framework will be developed that accounts for the impact of fire on benefits flows and thus can be incorporated directly into the Stewardship and Fireshed Assessment process.

Summary

This research demonstrates how the economic benefits of fire management strategies also can be incorporated into a GIS-based planning structure. Spatially delineated wilderness recreation values are derived by allocating per-trip values for hiking from a travel cost analysis to the landscape using the viewshed tool in ArcGIS. Values are found to range from \$36 to \$9104/ha, with a mean of \$340/ha and with most values between \$33 and \$644/ha. Future work will incorporate water supply and real estate values and develop a cost-benefit analysis framework. This research expands the

capabilities of the Stewardship and Fireshed Assessment process by enabling decision makers to weigh the benefits of management activities against the costs.

Acknowledgments

This research is funded by Cooperative Agreement No. 05-JV-11272165-094 between the United States Forest Service and the University of California at Riverside. Able research assistance was provided by Yeneochia Nsor, Sunil Patel, and Victoria Voss. The authors also thank Melinda Lyon, Jerry Frates, and Roman Rodriguez of the U.S. Forest Service's Idyllwild and Long Valley Ranger Stations, and Eddie Guaracha of the Mt. San Jacinto State Park Office in Idyllwild for their assistance.

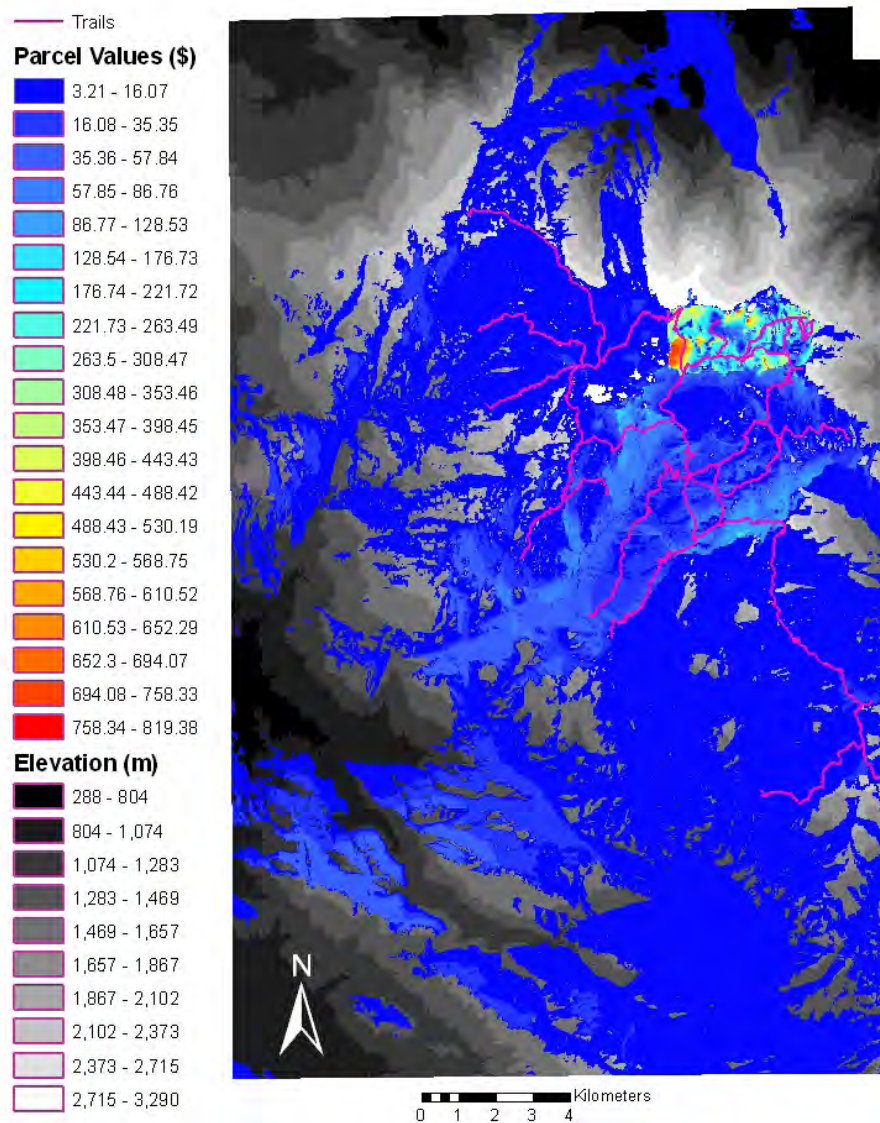


Figure 1 – Derived recreation value surface for the San Jacinto Wilderness. Values correspond to 900 m² parcels and are based on backcountry day trips only.

References

- California Secretary of State. 2000. **Statement of Vote 2000 Primary Election**. Available at: http://www.sos.ca.gov/elections/sov/2000_primary/contents.htm. Accessed March 2007.
- ESRI. 2006. ArcMap 9.2. **Using Arc GIS Spatial Analyst**. Environmental Systems Research Institute. Redlands, CA.
- Freeman, A.M., III. 2003. **The Measurement of Environmental and Resource Values**. Washington, DC: Resources for the Future Press.
- Haab, T.C., and K.E. McConnell. 2002. **Valuing Environmental and Natural Resources**. Cheltenham, UK: Edward Elgar.
- Higuchi, T. 1983. **The Visual and Spatial Structure of Landscapes**. Cambridge: MIT Press.
- Llobera, M. 2003. **Extending GIS-based Visual Analysis: The Concept of Visualscapes**. International Journal of Geographical Information Science 17(1): 25-48.
- Lyon, M. 2007. Wilderness/Trails Manager, San Jacinto Ranger District, San Bernardino National Forest. Personal Communication. October 12, 2007.
- Moeltner, K. 2003. **Addressing Aggregation Bias in Zonal Recreation Models**. Journal of Environmental Economics and Management 45(1): 128-144.
- United States Department of Commerce. 2000. **United States Census 2000**. Available at: <http://www.census.gov/main/www/cen2000.html>. Accessed March 2007.
- Weber, M., and R. Berrens. 2006. **Value of Instream Recreation in the Sonoran Desert**. Journal of Water Resource Planning and Management 132(1): 53-60.

A Study of the Socioeconomic Factors Influencing Wildfire Occurrence in Mediterranean Basin Countries¹

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Abstract

Forest fires in Mediterranean basin are a complex phenomenon due to the existing socioeconomic factors. The objective of this study was to examine the effects of socioeconomic factors (population density, Gross Domestic Product (GDP) and livestock density) on the number of forest fires and burnt areas during the decade 1995–2004, in most of the Mediterranean basin countries. The analysis was carried out by the method of stepwise multiple linear regression. The variables found significant, for the number of forest fires, were: the Gross Domestic Product (Spain), the livestock density (Greece and Italy) and the population density (Portugal, Israel, Cyprus, France and Turkey) for the period 1995–2004. The variables found significant, for the burnt areas, were: the Gross Domestic Product (Turkey, Spain and Greece), the livestock density (Italy, Cyprus, France and Portugal) and the population density (Israel and Cyprus) for the period 1995–2004. The results of the research show that the socioeconomic factors in Mediterranean basin have a moderate effect in forest fires with different degrees of correlation per country. The national planning of prevention of forest fires should take into account socioeconomic factors as well.

Keywords: Forest fires, socioeconomic factors, burnt areas, stepwise multiple linear regression, Mediterranean Basin.

Introduction

In the Mediterranean Basin, many countries with severe human pressure resulting in burning, cutting and grazing on non-arable lands and clearing, terracing, cultivating, and later abandoning arable portions, have created a strongly human-influenced landscape. The cultivation of marginal areas under increasing population pressure has been common in Southern Europe since the 16th century. It is not possible to understand current vegetation patterns in the

¹ An abbreviated version of this paper was presented at the Third International Symposium on Fire Economics, Planning, and Policy: Common Problems and Approaches, April 29 – May 2, 2008; Carolina, Puerto Rico.

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Mediterranean Basin without taking into account past anthropogenic activities and land uses. Human intervention has been so strong that it is still making a significant impact on current and future vegetation patterns (Alexandrian et al. 1992)

The changes in fire occurrence during the last decades closely reflect the recent socio-economic changes underway in the European Mediterranean countries. With industrial development, European Mediterranean countries have experienced: depopulation of rural areas, increases in agricultural mechanization, decreases in grazing pressure and wood gathering and increases in the urbanization of rural areas. These changes in traditional land use and lifestyles have implied the abandonment of large areas of farm land, which has led to the recovery of vegetation and an increase in accumulated fuel (Moreno and Oechel 1994). In Southern Europe, human activity has dramatically increased fire frequency as a consequence of land abandonment and tourist pressure. Land-use changes produced during the present century in Southern Europe are parallel to the changes in the fire regime, from being few in number and affecting small areas, to becoming very numerous and affecting large extensions every year. This trend is not observed in the Southern Mediterranean Basin where traditional land uses remain the major socio-economic system. (Velez 1993).

Jennings (1999) presented an extensive literature review on the socioeconomic characteristics and their influence on forest fire incidence. He suggests that fire frequency is affected by community characteristics, while the correlation between fire loss and invested resources is weak.

Cardille et al. (2001) examined the influence of environmental and social factors on fire occurrence using spatial data of natural areas in the USA. They reported that spatial distribution of forest fires are both related to a combination of abiotic, biotic and social factors. Sturtevant and Cleland (2007) claimed that while human factors dominate the probability of fire ignition, ecological factors constrain the fire spread ability. Vadrevu et al. (2006) pointed out that population density is one of the main factors that explain the variation of fire occurrence in India.

The aim of this study was to investigate the effects of socioeconomic factors (population density, gross domestic product (GDP) and livestock density) on the number of forest fires and burnt areas during the decade 1995–2004, in most of the Mediterranean basin countries.

Methods

The data set used in this study concerning the number of fires and burnt area that

occurred in eight Mediterranean countries (Spain, Portugal, France, Italy, Greece, Turkey, Cyprus and Israel) during the period 1995-2004, was obtained from the 'Fire Records' of the Food Agriculture Organization (F.A.O.) (Dimitrakopoulos and Mitsopoulos 2005). The socioeconomic factors (population density, Gross Domestic Product (GDP) and livestock density) values of each country were taken from the F.A.O. statistics division (2004) and the United Nations statistics division (2004)

Stepwise multiple linear regression was applied in order to investigate the statistically significant socioeconomic factors that influence the number of fires and burnt area in the studied Mediterranean countries. Stepwise multiple linear regression has proved to be an extremely useful computational technique in data analysis problems. This procedure overcomes the acute problem that often exists with the classical computational methods of multiple linear regression. In stepwise linear regression the variable with the largest probability of F is removed and the equation is recomputed without the variable and the process is repeated until no more independent variables can be removed (Draper and Smith 1981).

The statistical analysis was carried out by the SPSS ver.14 statistical package (Norusis 1997).

Results and Discussion

Table 1 presents the statistically significant ($p=0.05$) factors according to Pearson correlation coefficient, the coefficient of determination (R^2) and the regression equation parameters for the number of fires in each studied country, during the period 1995-2004.

Population density was the variable that statistically significant correlated with the numbers of fire in Portugal, France, Turkey, Israel and Cyprus. The Pearson correlation coefficient varied from 0.33 to 0.77. Population density, explained the fire occurrence variation in these countries, ranged from 11% in Turkey to 60% in Cyprus.

Livestock density was the variable that statistically significant correlated with the numbers of fire in Italy and Greece. The Pearson correlation coefficient varied from 0.38 to 0.85. Livestock density, explained the fire occurrence variation in these countries, ranged from 15% in Italy to 71% in Greece.

GDP was the variable that statistically significant correlated with the numbers of fire in Spain. The Pearson correlation coefficient was 0.57. GDP explained the fire occurrence variation in Spain with a value of 33%.

Table 1 — *Stepwise multiple linear regression results for the number of fires and the socioeconomic factors in each studied Mediterranean country during the period 1995–2004¹*

Country	Portugal	Spain	France	Italy	Greece	Turkey	Israel	Cyprus
Socioeconomic factor	Population density	GDP	Population density	Livestock density	Livestock density	Population density	Population density	Population density
Pearson correlation coefficient	0.65	0.57	0.64	0.38	0.84	0.33	0.49	0.77
Coefficient of determination (R²)	0.42	0.33	0.41	0.15	0.71	0.11	0.24	0.60
Model parameters	a) 284162 b) 2.5	a) 28309 b) 1.15	a) 102909 b) 1.61	a) -9236 b) 470.7	a) -40083 b) 2088.8	a) -817.7 b) 4.04	a) 2358.3 b) 2.25	a) -2882.7 b) 4.40

¹ Equation form: $Y=a+bX$

Table 2 presents the statistically significant ($p=0.05$) factors according to Pearson correlation coefficient, the coefficient of determination (R^2) and the regression equation parameters for the burnt area in each studied country, during the period 1995-2004.

Population was the variable that statistically significant correlated with the burnt area in Israel and Cyprus. The Pearson correlation coefficient varied from 0.35 to 0.70. Population density, explained the burnt area variation in these countries, ranged from 12% in Cyprus to 49% in Israel.

Livestock density was the variable that statistically significant correlated with the burnt area in France, Italy and Portugal. The Pearson correlation coefficient varied from 0.30 to 0.46. Livestock density, explained the burnt area variation in these countries, ranged from 8% in Italy to 22% in Portugal.

GDP was the variable that statistically significant correlated with the numbers of fire in Spain, Greece and Turkey. The Pearson correlation coefficient varied from 0.13 to 0.55. Livestock density, explained the burnt area variation in these countries, ranged from 1.6% in Turkey to 31% in Greece.

Table 2 — *Stepwise multiple linear regression results for the burnt area and the socioeconomic factors in each studied Mediterranean country during the period 1995-2004¹*

Country	Portugal	Spain	France	Italy	Greece	Turkey	Israel	Cyprus
Socioeconomic factor	Livestock density	GDP	Livestock density	Livestock density	GDP	GDP	Population density	Population density
Pearson correlation coefficient	0.46	0.20	0.43	0.30	0.55	0.13	0.70	0.35
Coefficient of determination (R²)	0.22	0.04	0.18	0.08	0.31	0.016	0.49	0.12
Model parameters	a) 3104699 b) 90329.6	a) 146979 b) 5.5	a) 413622 b) 8224,2	a) -140309 b) 5761.2	a) 103755.3 b) 5.12	a) 13177.8 b) 1.98	a) 30395,9 b) 4.337	a) -74802 b) 0.20

¹ Equation form: $Y=a+bX$

From the statistical analysis revealed that most of the studied countries gave as more important factor that it relates with the phenomenon, the population density. A possible explanation is that despite that statistics on the causes of forest fire in the Mediterranean region are far from complete; it is evident that people set more fires. Natural agents such as lighting also cause fires, but the number of naturally occurring fires is small in comparison with those caused by people.

In Italy and Greece, livestock density it is presented as the most important factor that explains the number of fires. An important source of fires is shepherds in these countries, who ignite the grasslands to promote new flushes of growth for grazing animals. Farmers also use fire to eliminate crop stubble and invasive thorn plants and to push back the forest to make room for agricultural expansion. The central Government likely should give particular importance and focus their efforts limiting the above actions. Spain is the unique country which presents as main variable of correlation of number of fires and of burnt area the GDP. A likely explanation can be given, relating GDP that constitutes a very good economic indicator of growth, with growth of tourism, with changes in the use of land and with internal immigration to the big urban areas. An increasingly important cause of fires is the burning of large quantities of waste by tourists and other recreational users of forest areas. Another important role motivation for destructive fires is an attempt to change land-use classification. It's also important to relate GDP with the migration of population from rural areas to cities. However, this migration increases the forest fuels. The population shift does not imply the total elimination of activities in the forest area. The remaining, often elderly, rural population continues to use fire to eliminate

stubble and renew pastures and fields. Moreover, the sparse rural population makes fire suppression more difficult. The other countries that correlate the burnt area with GDP are Greece and Turkey. Portugal's and Italy's burnt area correlated with livestock density, fact that indicates the important and fast measures that should be taken for the shepherds. Finally Israel's and Cyprus's burnt area correlated with population density strong evidence that people set more fires also.

Summary

Overall, a moderate correlation between forest fires and socioeconomic factors was observed in the studied Mediterranean countries, as indicated by the stepwise multiple linear regression. The results of research show that the socioeconomic factors in Mediterranean countries have a moderate effect in forest fires with different degree of correlation in each country. Further study including the influence of other factors (environmental, etc.) it would probably contribute to the variability explanation on fire occurrence and burnt area in the Mediterranean countries. The rational planning of prevention of forest fires in each country should take into account socioeconomic factors as well.

References

- Alexandrian D., Esnault F., Calabri G., 1992. **Forest fires in the Mediterranean are a**. Unasylva 197, Vol.50.
- Cardille, J.; Ventura, S.; Turner, M.; 2001. **Environmental and Social Factors Influencing Wildfires in the Upper Midwest, United States**. Ecological Applications 11: 111-127.
- Dimitrakopoulos A.P., Mitsopoulos I.D. 2005 **Global Forest Resources Assessment 2005 – Report on fires in the Mediterranean Region**. Fire Management Working Paper 8. F.A.O. 43p.
- Draper, N.; Smith, H. 1998. **Applied Regression Analysis**. 3rd Edition. Wiley & Sons New York 706p.
- F.A.O. 2004. **Food and Agriculture Organization, Statistics Division**, Available at: <http://faostat.fao.org>
- Jennings C. 1999. **Socioeconomic Characteristics and Their Relationship to Fire Incidence: A Review of the Literature**. Fire Technology 35: 7-35.
- Moreno J. M., Oechel W.C. 1994. **The role of fire in Mediterranean-type ecosystems**. Springer-Verlag. New York.
- Norusis M. J. 1997. **SPSS professional statistics**. Chicago: SPSS, Inc.
- Sturtevant, B.; Cleland, D. 2007. **Human and biophysical factors influencing modern fire disturbance in northern Wisconsin**. International Journal of Wildland Fire 16: 398-413.
- United Nations. 2004. **United Nations, Statistics Division**, Available at: <http://unstats.un.org/unsd/databases.htm>
- Vardaru, K.; Eaturu, A.; Badarinath, K. 2006. **Spatial Distribution of Forest Fires and Controlling Factors in Andhra Pradesh, India Using Spot Satellite Datasets**. Environmental Monitoring and Assessment 123: 75-96.
- Velez R. 1993. **High intensity forest fires in the Mediterranean Basin: Natural and socioeconomic causes**. Disaster Management 5: 16-20

Modeling Fire Behavior on Tropical Islands With High-Resolution Weather Data¹

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Abstract

In this study, we consider fire behavior simulation in tropical island scenarios such as Hawaii and Puerto Rico. The development of a system to provide real-time fire behavior prediction in Hawaii is discussed. This involves obtaining fuels and topography information at a fine scale, as well as supplying daily high-resolution weather forecast data for the area of interest. FARSITE, the fire simulation program we use, works with the fuel models commonly found in the contiguous United States, so vegetation found on an island needs to be mapped to fuel models accordingly. We examine a specific fire incident in detail, looking at how well it can be modeled given output from the system under development. Analysis of such examples can help in fire behavior prediction system calibration for real-time use. There are several potential causes of error between simulated and actual fire perimeter. Different methods of eliminating this error and improving accuracy of the simulation are considered. Finally, we discuss further work and challenges once a developing fire behavior prediction system becomes operational.

Introduction

Fire behavior in much of the world's larger land areas has been studied and modeled for some time. However, less is known of wildfires occurring in tropical island scenarios, such as Puerto Rico and the Hawaiian islands. More attention is now being focused on such fires for several reasons. Land use change, such as the movement of wildland urban interface boundaries, is resulting in the need for greater fire prevention and suppression. Areas inhabited by plants or animals that are now threatened or endangered may need special protection from fire. In some island locations, fire-fighting resources may not be readily available, stressing the importance of longer lead-times on fire activity. Wildfires on tropical islands may appear to be minor threats compared to those that occur on larger landmasses, but damages can be very costly.

¹ An abbreviated version of this paper was presented at the Third International Symposium on Fire Economics, Planning, and Policy: Common Problems and Approaches, 29 April – 2 May, 2008, Carolina, Puerto Rico.

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The U.S. Forest Service and other agencies have begun adapting existing fire behavior analyses and technology to better suit conditions found in Hawaii and similar environments. There has been recent work on mapping and modeling Hawaiian fuels (Weise and others 2005, Wright and others 2002, Clark and others 2004). A version of the U.S. National Fire Danger Rating System, originally designed for use in the contiguous United States, has been modified for use in the Hawaiian Islands. In this paper, we discuss a process for running a fire behavior simulation program in Hawaii, which had been designed for use on the U.S. mainland. These are tools that fire-fighting crews on the ground can use.

Cooperators in the Meteorology department at the University of Hawaii (UH), Manoa, are producing daily high-resolution weather forecasts for the state. Each daily forecast run is generated on a cluster computer running the MM5 weather model, and consists of 48 consecutive hourly forecasts at points spatially aligned on square grids over the Hawaiian Islands (see <http://www.soest.hawaii.edu/MET/Faculty/mm5/>). There are five grids, or domains, with varying spacings (*table 1*). At each grid point, forecast values are computed for temperature, relative humidity, precipitation, wind speed and direction, and cloud cover.

Table 1—*Domains for the UH MM5 daily forecast.*

Domain	Grid spacing (km)	East-west points	North-south points
State 9		75	87
Kauai County	1.5	45	51
Oahu County	1.5	51	63
Maui County	3	48	72
Hawaii County	3	69	90

We worked with UH and a cooperator from the Institute of Computational Earth System Science (ICESS) at the University of California, Santa Barbara (UCSB) to make the output from the weather forecast model available as input into a computer program that predicts fire behavior called FARSITE (Finney 1998). FARSITE has been in use for some time in the contiguous U.S., but has seen little application in Hawaii. To simulate fire spread and other characteristics, FARSITE requires several input sources, namely topography, fuels information, and weather conditions. Topography and fuels information for fire-prone areas is often readily available to fire managers well in advance of a fire event. These data layers can be imported into FARSITE to create maps of wildland areas of concern. Accurate weather information, however, is harder to obtain. Weather data is dynamic in a FARSITE run – a different collection of variable values may be used for each hour of simulation run. In the case of real-time fire simulation, forecasted weather data is

needed to predict future fire behavior. The daily production of FARSITE-ready weather forecast data from UH and UCSB fulfills this need for the Hawaiian Islands.

A Specific Case: The Waiohuli Fire

A recent fire incident gave us opportunity to test simulation runs in an island scenario. The Waiohuli fire was spotted on January 23rd, 2007 in a remote area on Mount Haleakala's western slope in Maui, Hawaii. Cause was attributed to a cigarette left close to a nearby hiking trail. The fire burned over 930 ha in seven days and cost more than \$340,000 to contain. No structures were damaged, but many sandalwood trees and rare plants were destroyed. The state's Department of Land and Natural Resources' Division of Forestry and Wildlife (DOFAW) and others on the scene captured valuable information during the event, which helped greatly with our analysis. With this, along with available GIS data and weather data supplied by UH and UCSB, we assembled some fire simulations to compare with the actual behavior.

Because FARSITE is typically used with fuel models that occur commonly on the U.S. mainland, we had to adjust these fuel models to better match Hawaiian fuel characteristics. As mentioned earlier, some work has been done on statewide classification of vegetation into fuel models. However, we used information from a recent fire assessment study by the Pacific Disaster Center (PDC), located on Maui. The PDC study had a detailed analysis of fuels specifically for Maui, relating them to fuel models commonly used on the U.S. mainland (*table 2*). PDC had also assembled fuels and topographic maps at 30-m resolution for Maui. We imported both of these maps into FARSITE.

Table 2—Maui fuels from PDC study. Vegetation was mapped to the fuel models defined by Anderson 1982. FARSITE uses these fuel models, but allows custom fuel models to be defined. Equivalent NFDRS fuel models are also shown (Deeming and others 1972).

Description NFDRS	fuel model	Anderson fuel model
Grass, kiawe trees, shrubs	L	1
Discontinuous pukiawe / 'a'ali'i	T	2
Fountain / guinea grass	N	3
Gorse shrub	B	4
Continuous pukiawe / 'a'ali'i	F	5
Fire-proof forest / shrub / scrub	R	8
Ironwood trees	H	8
Eucalyptus trees	G	10
Missing data, developed / cultivated land, deciduous forest, non-fuel, water	n/a	0, 94, 95, 97, 98, 99 ^a

^atreated as unburnable area.

PDC had collected satellite imagery of the area and overlaid it with the observed

fire perimeter (*fig. 1*). We used this to help verify that the landscape loaded into FARSITE was aligned with actual geography and fuels.

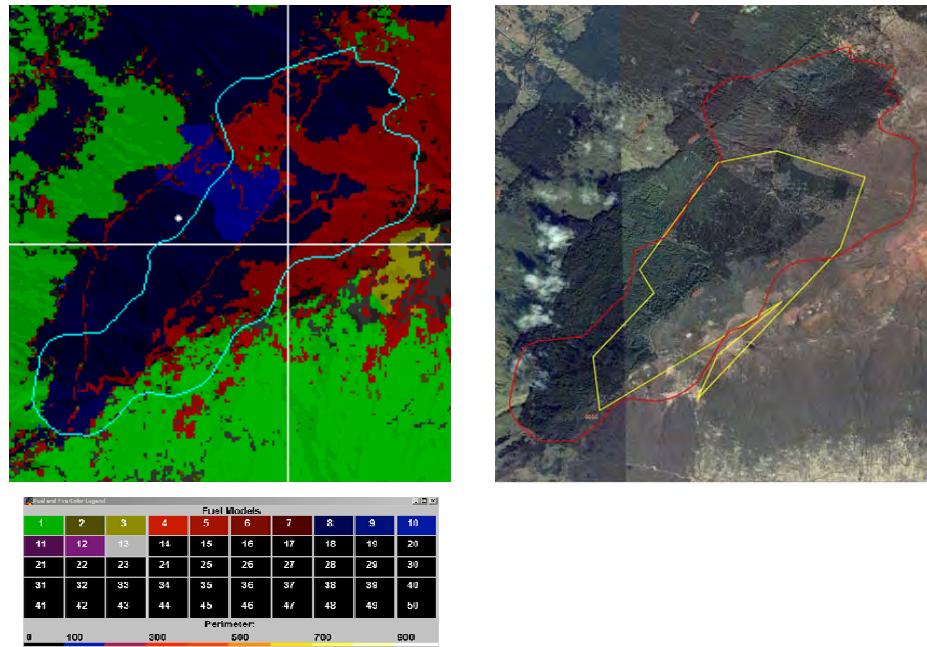


Figure 1—Comparison of digital landscape in FARSITE (topographic and fuels data) and actual satellite imagery. The yellow perimeter in the satellite image was observed on January 27th, 2007. The similarly shaped perimeters in the FARSITE landscape (cyan) and satellite image (red) represent the observed perimeter on January 28th, 2007. This perimeter data was available from PDC in a format that could be imported into FARSITE and overlaid on the displayed landscape. The displayed Fuel Models legend shows the fuel models associated with the colors in the FARSITE landscape.

Our UH and UCSB cooperators supplied daily weather forecast information for the days of the fire. Because the fire had already occurred and was not presently active, the needed forecast runs were retrieved from archive. Separate forecast runs for each day the fire burned had been made – January 24th through 29th of 2007. Each daily forecast run contained 48 consecutive 1-hour sets of forecasted weather variables. This meant that the latter portion of each forecast run overlapped the next day's run. Therefore, we used only the first 24 hours of each run and joined these together into a single progression of hourly forecast data. Another scheme may have been to use all 48 1-hour sets of data from every other daily forecast (in other words, January 24th, 26th, and 28th), but forecast accuracy is believed to decrease in the latter portion of each run, so it seemed desirable to use the latest model output for each hour being forecasted.

Our UCSB cooperator made the weather forecast data ready for direct import into FARSITE. Forecasted values of temperature, relative humidity, precipitation, wind speed, wind direction, and cloud cover over a square grid for every hour the fire

burned were used. The spacing between grid points for Maui, where the Waiohuli fire occurred, was about 3 km (*table 1*).

In this study, we used version 3 of FARSITE, though a more recent version is now available (see <http://www.farsite.org>). Version 3 allows the import of temperature and relative humidity fields over a regular grid, and adjusts fire behavior calculations accordingly. This feature was taken out of later versions because it competed for computing resources with a newer feature. In version 4, only single hourly values for temperature and relative humidity represent the entire landscape. Gridded wind information, however, is accepted by all FARSITE versions.

In our initial fire simulation run, we used the terrain, fuels, and forecasted weather for the entire island of Maui. The simulated fire ignition point was taken as the starting location and time of the actual fire as determined by DOFAW (*fig. 2*).

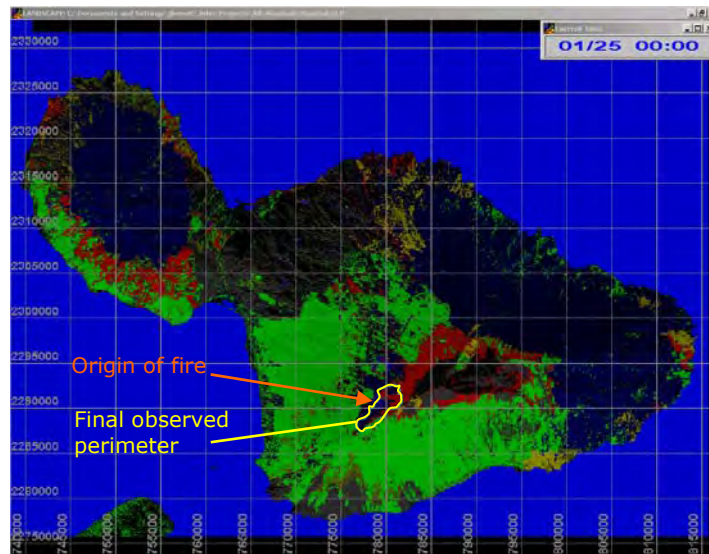


Figure 2—Waiohuli fire simulation using entire island domain. The simulated fire was started at the location given as the origin of the actual fire (pointed to by orange arrow). Also shown is the final perimeter of the Waiohuli fire (yellow).

Incorporating all of Maui in the simulation allowed us to view larger-scale features such as fuel and wind patterns over the entire island. However, small details were difficult to see, and only coarse features of the simulated fire perimeter growth could be seen. There was also a strain on computer resources. The simulation was computationally slow, and the FARSITE program frequently crashed during the run.

We ran a second simulation, cropping the input maps to a close-up rectangle around the fire area, enabling us to see finer details of the simulated perimeter (*fig. 3*). The smaller amount of landscape data loaded into FARSITE also meant that less computer memory was needed, and the simulation run completed without crashing.

The perimeter grew nearly circular for the first 3 days during which it burned in

fuel model 8. When the fire reached an area dominated by fuel model 10 (eucalyptus trees), the symmetry broke and spread rate increased in that part of the perimeter.

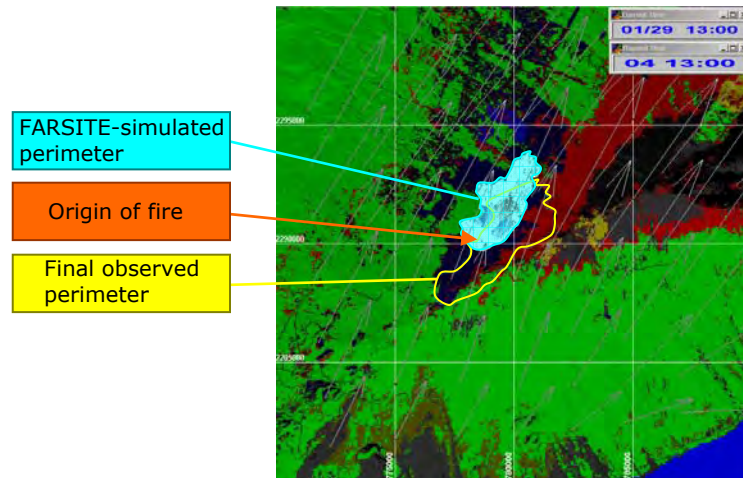


Figure 3—Close-up simulation run of Waiohuli fire area. Finer detail can be seen than in the island-wide run. The displayed predicted perimeter (cyan) is about a day before the actual final perimeter (yellow). However, perimeter size and shape varied little during the rest of the run. Forecasted wind vectors (white arrows) are also displayed, showing upslope winds during this point in the run.

At one point the fire grew near an area marked as fuel model 1 (grass, kiawe trees, shrubs), but surprisingly burned *around* this area, staying within denser woods (fuel model 8). This peculiar behavior may need to be investigated further. The simulated fire moved upslope, to the northwest, which matched the predominant direction of the forecasted winds. The actual Waiohuli perimeter, however, appears to have covered a more downslope (southwesterly) area than the simulation. This discrepancy may signify possible inaccuracy in the setup or running of the simulation, in the recording of the observed fire behavior, or both.

The Waiohuli fire's reported starting location was only an approximation determined by on-scene fire investigators, so next we considered the simulated fire behavior if the starting location were changed by a small amount. We tried simulation runs by specifying starting locations a short distance from the reported actual location, keeping all other initial conditions the same (weather, fuels, topography, and start time). The perimeters simulated from different starting locations varied greatly. For example, by 'igniting' the simulation at a point about 441 m from the reported observed starting location, we found a simulated perimeter that matched the observed perimeter much closer at times as it grew (*fig. 4*). The simulated perimeter then continued growing, however, until it was much beyond the observed one. This difference in perimeter size may be due to fire suppression efforts hindering the actual fire growth that were unaccounted for in the simulation. FARSITE is capable simulating suppression activity, but there was not enough

information about what actions were taken on the Waiohuli fire to use in our runs.

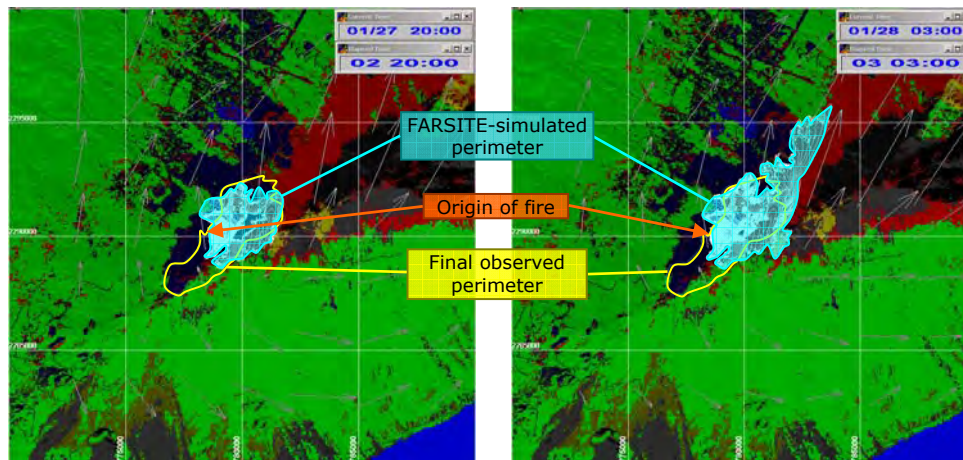


Figure 4—Simulation run with ignition started 441 m southeast of the reported starting location. Simulated perimeters (cyan) are shown at two different times. On the left (January 27th, 8pm), the simulated perimeter matches closer to the actual perimeter than the run that was started at the reported starting location. The right-hand image shows a later time (January 28th, 3am), where the simulation ran beyond the observed perimeter, though the Waiohuli fire burned longer (to January 29th).

The difference in perimeter size and shape, with only small changes in location, was surprising. In *figure 5*, the ignition point was specified only 40 m east of that specified in *figure 3*; no other initial conditions were changed. Note that FARSITE generates fire perimeters deterministically based on initial conditions. If all conditions remain the same in two runs, output should be identical³. Likewise, discrepancy in the perimeters from a pair of runs must solely be due to changes in initial conditions or imported weather, and not random behavior at run-time.

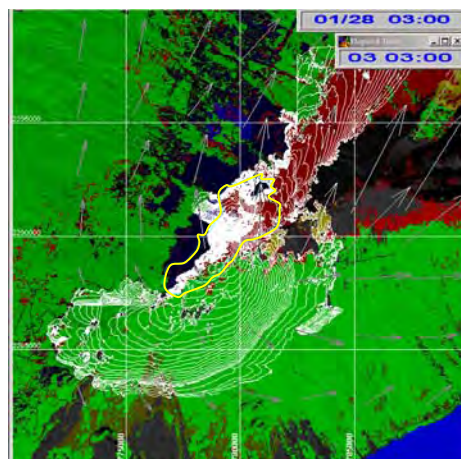


Figure 5—Run with ignition point set 40 m to the east of the reported starting location. The perimeter (white) was much larger than that produced when the

³ FARSITE can simulate randomly generated spot fires, but we chose not to use this feature.

simulation started at the reported location (*fig. 3*). Note that the time of the image in *figure 3* occurred over a day *after* the time of the image in this figure.

We also tried altering the starting *time*. Like the reported starting location, the starting time was approximated based on investigation. By testing ignitions at different times during the day, we got an idea of its sensitivity. *Figure 6* shows a frame from a run started six hours later than the previous simulations. Similar to the left image in *figure 4*, for some time during the run, the perimeter matched the observed fire line closer than in *figure 1* (where the simulation was started at the reported starting time and location).

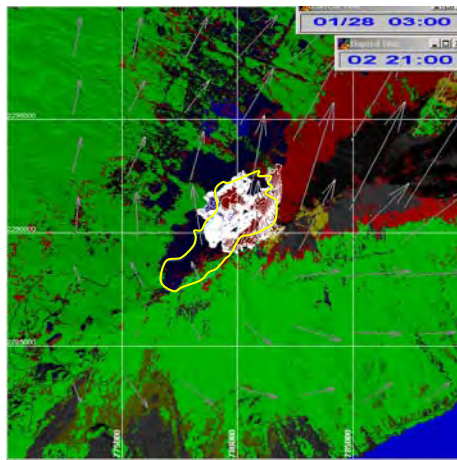


Figure 6—Run with ignition starting 6 hours later than the actual reported time.

We did not try simulations with changes made to any other initial conditions (weather, fuels, or topography data). Nor had we tested altering more than one variable simultaneously, such as both ignition location *and* time. A great deal of further work can be done on simulations run with these combinations of changes.

Conclusions

In this study, we were interested in the effectiveness of real-time fire behavior prediction in a tropical island environment. We wanted to know what technical difficulties must be overcome, how well the weather and fire predictions perform, and how we can improve the overall process. The specific case discussed here – the Waiohuli fire – was *not* a real-time test of the process. However, it gave insight into the challenges that must be met in the workings of a fire behavior prediction system. We also believe that the gained experience from looking at such an example can be extended to similar island environments other than Hawaii.

The fire behavior simulation program we used – FARSITE – is flexible and has several features, many of which we did not employ here. If fuels, topographic, and

weather information can be accurately specified within FARSITE, it is likely to be suitable for use in a tropical island scenario. We encountered some technical problems during simulation runs, mostly relating to computer memory issues. These were resolved by clipping out landscape data distant from the area of interest before importing it into FARSITE. We also employed version 3 of FARSITE, which accepted gridded values of forecasted temperature and relative humidity. It is not known if the gridded data does actually improve fire behavior prediction over single values. We would expect improved accuracy to depend on the size and complexity of the landscape in the simulation.

The simulation of fire behavior within FARSITE was quite sensitive to small changes in initial conditions, such as ignition location and time. We believe the variability in predicted behavior extends to small perturbations in other factors as well, such as fuel parameters and forecasted weather patterns. There are several other possible causes for discrepancy between simulated and actual perimeters, such as not accounting for relevant environmental factors, errors in the simulation setup, lack of precision in the fire behavior model, and inaccuracy in recording the observed fire. We did not account for suppression activity that took place on the Waiohuli fire, which probably had a large influence on the resulting fire line. Capturing such activity is often difficult in real-time scenarios when fire-fighting crews have other priorities. However, if the location of actual fire line could be captured at time intervals and fed into a simulation program, this information could reinitialize the simulation to match reality closer.

Observing the simulated fire growth over time, we noticed how different fuel types considerably altered the speed of fire spread. The slope and wind also had a strong affect on the direction and speed of the growing perimeter. We will probably need to investigate further why the predicted perimeter burned around a grass fuel model area rather than through it – an unexpected behavior given that the fire instead stayed within a denser wood fuel model. This may indicate incorrectly specified fuel model parameters in the simulation program.

In further work, we may examine better ways to quantify error between predicted and actual fire perimeters (for example, Fujioka 2002). Quantitative measurements can be used to iteratively test simulation runs with different initial conditions to search for optimal sets of parameter values. This may help calibrate the simulation model or determine the likely time or location of a fire ignition.

Once an efficient fire behavior prediction system is ready for use in a real-time fire scenario, fire managers would need to know how to use it. This would probably involve a cycle of interaction between those involved and the model itself – a feedback loop for calibration. Thus, a small amount of additional work may be required on the part of those on the actual fire line, but the return is a more accurate

forecast of future fire behavior.

References

- Anderson, Hal E. 1982. **Aids to determining fuel models for estimating fire behavior**. Gen. Tech. Rep. INT-122. Ogden, UT: Intermountain Forest and Range Experiment Station, USDA Forest Service; 22 p.
- Burgan, Robert E.; Fujioka, Francis M.; Hirata, George M. 1974. **A fire danger rating system for Hawaii**. Fire Technology 10(4): 275-281.
- Clark, Matthew L.; Roberts, Darin A.; Gardner, Margaret E.; Weise, David R. 2004. **Estimation of Hawaiian Islands fire fuel parameters from AVIRIS imagery**. In: Proceedings of the 2004 AVIRIS Workshop; 2004 March 31-April 2; Pasadena, CA. 10 p.
- Deeming, John E.; Lancaster, James W.; Fosberg, Michael A.; Furman, R. W.; Schroeder, Mark J. 1972. **The national fire-danger rating system**. Res. Paper RM-84. Fort Collins, CO: Rocky Mountain Forest and Range Experiment Station, USDA Forest Service; 165 p.
- Finney, Mark A. 1998. **FARSITE: Fire Area Simulator – model development and evaluation**. Res. Paper RMRS-RP-4. Ogden, UT: Rocky Mountain Research Station, USDA Forest Service; 47 p.
- Fujioka, Francis M. 2002. **A new method for the analysis of fire spread modeling errors**. International Journal of Wildland Fire 11: 193-203.
- Jones, Charles; Dennison, Phil E.; Fujioka, Francis M.; Weise, David R.; Benoit, John W. 2003. **Analysis of space/time characteristics of errors in an integrated weather/fire spread simulation**. In: Proceedings of the Second International Wildland Fire Ecology and Fire Management Congress and Fifth Symposium on Fire and Forest Meteorology; 2003 November 16-20; Orlando, FL. Washington DC: American Meteorological Society; 7 p.
- Roe, Kevin P.; Stevens, Duane; McCord, Carol. 2001. **High resolution weather modeling for improved fire management**. In: Proceedings of the 2001 ACM/IEEE Conference on Supercomputing; 2001 November 10-16; Denver, CO. New York: Association for Computing Machinery; 5p.
- Scott, John E.; Burgan, Robert E. 2005. **Standard fire behavior fuel models: a comprehensive set for use with Rothermel's surface fire spread model**. Gen. Tech. Rep. RMRS-GTR-153. Fort Collins, CO: Rocky Mountain Research Station, USDA Forest Service; 72 p.
- Weise, David R.; Fujioka, Francis M.; Nelson, Ralph M., Jr. 2005. **A comparison of three models of 1-h time lag fuel moisture in Hawaii**. Agricultural and Forest Meteorology 133: 28-39.
- Wright, Clinton S.; Ottmar, Roger D.; Vihnanek, Robert E.; Weise, David R. 2002. **Stereo photo series for quantifying natural fuels: grassland, shrubland, woodland, and forest types in Hawaii**. Gen. Tech. Rep. PNW-GTR-545. Portland, OR: Pacific Northwest Research Station, USDA Forest Service; 91 p.

Wildfire Regimes and Ecosystem Variability¹

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Abstract

Wildfire regime characterization is one of the main issues for wildfire managers, especially for the areas where the fire is a frequent threat for communities and property. The capability to partition a region articulating differences in timing, frequency and intensity of the phenomena, among different zones, can assist decision makers in defining proper wildland fire policies and resource management planning. Several works published in recent years, showed how wildfire frequency-area distributions follow a so-called power-law distribution. However, a power-law distribution, or in general a heavy-tailed distribution, of a set of wildfires over a certain region may also arise from the aggregation of zones characterized by different features related to wildfire occurrences within the region. On this basis, starting from the assumption that a power-law distribution can represent the frequency-area distribution of a given geographical area, in the paper a procedure for the selection of homogeneous zones for wildfire characterization is presented and discussed with reference to a real case study. Results show that the estimation of the power-law parameters, along with the characterization of the wildfire regime of a given area, provides a set of results significantly different, depending on the way the area is partitioned into its various components. In addition, it has been shown that it is actually possible to discriminate, within a given region, different wildfire regimes characterizing different zones.

Keywords: Forest fires, frequency-area statistics, power-law distribution, risk assessment.

Introduction

Fire in many ecosystems is fundamental for the survival and continued cohabitation of the existing species. In these areas the forest ecosystem and the wildfire regime are often in equilibrium (Weber and Flannigan, 1997). In ecosystems dominated by humans it is especially difficult to identify the relationship, which maintains the equilibrium between the forest ecosystem and the frequency-area distribution of wildfires. In some areas the presence of

¹ An abbreviated version of this paper was presented at the Third International Symposium on Fire Economics, Planning, and Policy: Common Problems and approaches, April 29 – May 2, 2008; Carolina, Puerto Rico.

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humans has radically modified the forest ecosystem, reducing or eliminating native species and substituting them with species that can guarantee new resources for a continuously growing population. In these areas naturally caused fires are negligible. In Italy, for example, humans start almost 99% of wildfires. Many of these wildfires threaten urban areas requiring complex and costly intervention. Humans, by both causing and extinguishing wildfires, influence both their frequency and their burnt area. In this case, if wildfire regime identification makes sense, the understanding of that regime could be very useful for wildfire managers. Wildfire management protection programs require the design of infrastructure elements (e.g., fire-breaks, hydraulic networks, rural roads, etc.) and the coordinated use of different mobile resources (e.g., trucks, engines, water-bombers, humans, etc.). The effectiveness of these resources in emergencies is related to the seasonal nature of fires, since their dynamics are mainly governed by the meteorological conditions and the state of the vegetation.

The high costs of the acquisition, management, and maintenance of these resources can be justified only after a careful analysis of a suitable trade-off between the costs and the actual attainable benefits. Such an analysis can be conducted with the objective of articulating differences in timing, frequency and intensity of the phenomena among the various zones of a given region. Thus, the objective of the present work is to develop an approach suitable for characterizing the average wildfire risk distribution over a given region.

The evaluation of the average wildland fire risk distribution over a given area has been considered by various publications in recent years. Some authors considered the risk as the potential intensity that a fire could assume in connection with topography, vegetation cover, climate, and, overall, average fuel conditions (Núñez-Regueira and others, 1999; Filippidis and Mitsopoulos, 2004). Another approach is to statistically analyze large populations of data referring to forest fire occurrences (Forestry Canada Fire Danger Group, 1992; McKenzie and others, 2000; Riera and Mogas, 2004; Iliadis, 2005).

The approaches based on the identification of the “frequency of events” are popular and provide robust results. However, it is worth remarking that wildfires, like other natural events (i.e. landslides, earthquakes, floods) are characterized by a large number of low-intensity events and a small number of extreme events. Such behaviour can be suitably represented by a power-law distribution. The power-law distribution is one of the most frequently used for the statistical characterization of wildfire regimes (Malamud and Turcotte, 1998; Ricotta and others, 1999; Song and others, 2001; Turcotte and Malamud, 2004; Telesca and others, 2005; Malamud and others, 2005). However, a power-law

distribution of a set of wildfires over a certain region may also arise from the aggregation of zones characterized by different features related to wildfire occurrences within the region.

The aim of the present paper is to define a practically applicable and conceptually sound procedure, which, starting from the data available from historical wildfire databases is able to discriminate, in space and time, different wildfire regimes, i.e. the combination of the timing, frequency and magnitude of all wildfires occurring in a given region.

A case study relevant to Liguria, an Administrative Region located on the northwestern coast of Italy and frequently affected by severe wildland fires, is selected to evaluate the effectiveness of the proposed approach.

Methods

A power-law distribution is such that the expected number of events of a certain magnitude, within a given time interval and a given geographical area, is proportional to a power of that value of magnitude (*Newman, 2005*). Particularly, for wildfires, one measure of the magnitude of an event is the burnt area (*Malamud and others, 1998*). This choice may be justified on the basis of the consideration that burnt areas are measurable data and can be obtained from the data records relevant to wildfire occurrences within a given region.

Following the formalization by *Malamud and others (2005)*, we define n as the number of fires with burnt areas A_F that belong to the interval $[A_F - \varepsilon, A_F]$, where ε is the bin width. Then the frequency densities $f(A_F)$ of wildfires occurring in ‘unit’ bins, is given by $f(A_F) = n/\varepsilon$. *Malamud and others (2005)* further formalize that in a given region and period of time there will be a power-law dependence of the frequency density $f(A_F)$ on the burned area A_F :

$$f(A_F) = \alpha A_F^{-\beta} \quad (1)$$

where α and β are suitable (real) constants. On log-log axes (1) corresponds to a linear relationship

$$\log[f(A_F)] = -\beta \log[A_F] + \log \alpha \quad (2)$$

When dealing with data coming from experimental observation or from historical data bases, assuming that a significant data set is available, the values of $f(A_F)$ for each bin can be reported on a log-log plot and linearly interpolated, using ordinary least squares, according to the structure of the power law in (2). The “best” (in the least squares sense) values of $\log \alpha$ and β are obtained for a given region and for a given time interval.

It then follows that the expected number of events with a burnt area belonging to interval $[A_F - \varepsilon, A_F]$ in a time interval of length τ , and over a region of area A_R , is given by $\tau A_R \alpha A_F^{-\beta}$ provided that time and space homogeneity is ensured. Besides, still referring to Malamud *and others* (2005), the expected number $N_F(A_F, A_R, \tau)$ of wildfires with a burnt area greater than or equal to a given area A_F , within a region of area A_R , and a time interval of length τ , is given by

$$N_F(A_F, A_R, \tau) = \tau A_R \int_{A_F}^{\infty} f(x) dx = \tau A_R \frac{\alpha}{\beta - 1} A_F^{1-\beta} \quad (3)$$

Finally, the recurrence time interval $T(\geq A_F)$ of wildfires occurring in a region of area A_R , within a time horizon of length τ , characterized by burnt areas greater than or equal to a given area A_F , is given by

$$T(\geq A_F) = \frac{\tau + 1}{N_F(A_F, A_R, \tau)} = \frac{\tau + 1}{\tau} \frac{\beta - 1}{\alpha} \frac{A_F^{\beta-1}}{A_R} \quad (4)$$

However, the aggregation of the available information over a given region in a unique power-law may be misleading, since the considered region may consist of various sub-regions characterized by significantly different wildfire regimes. The problem of partitioning a given region needs to be examined as there may be reasons leading to different characterizations for various sub-regions. These reasons may correspond to differences in vegetation cover, in topography and in climate conditions, as well as in land use, and socio-economic characteristics.

The partition of a region is simply the subdivision of the region into non-overlapping zones. Note that the subdivision of a given region into ecoregions may be a correct way to generate a meaningful partition (Bailey, 1996; Cleland *and others*, 2004; Malamud *and others*, 2005). However, clear-cut identification of ecoregions is not easy, especially on a small scale and in the presence of complex topography and vegetation patterns.

The region to be analyzed is assumed to be composed of a set of elementary area units (e.g., they may correspond to the administrative areas of the municipalities, but they could be defined in any arbitrary way). Let $u_1, \dots, u_n$ be the elementary area units, and thus the considered region may be viewed as the set $U = \{u_1, \dots, u_n\}$.

Assume a set $\{Z_i, i=1, \dots, K\}$ of sub-sets of U . A partition of the considered region, i.e., of set U , is defined as a choice of a set of sub-sets, namely $\mathcal{P} = \{Z_i, i \in S\}$, with $S \subseteq \{1, \dots, K\}$, such that the following two conditions are fulfilled:

$$\text{a) } Z_i \cap Z_j = \emptyset \text{ for every pair } (i, j), \text{ such that } i, j \in S, \text{ and } i \neq j \quad (5)$$

$$\text{b) } \bigcup_{j \in S} Z_j = U \quad (6)$$

Condition (5) implies that the sub-sets $\{Z_j, j \in S\}$ in the partition are non-overlapping, which means that no area unit can belong to two (or more) sub-sets in a partition. Condition (6) means that the union of all sub-sets in a partition covers all the area units in the set U . In the following, the term zone will be used interchangeably with the term sub-set.

There are many possible ways to generate a partition of a given region (i.e. of set U). The main objective of this paper is to provide a criterion to evaluate the quality of a partition based on the general goal of discriminating between areas characterized by different wildfire regimes.

In order to evaluate the quality of a partition, it is first necessary to define a quality index for a zone Z_i . Let $A_{F,h}$, $h = 1, \dots, H$ be the right extreme of the discretization intervals (bins) defined *a-priori* for the power-law representation, and let $n_{i,h}$ be the number of wildfires occurring in zone Z_i (normalized with respect to the area of the zone and the length of observation time) whose burnt areas fall within bin $[A_{F,h-1}, A_{F,h}]$ $h = 1, \dots, H$. Then, define m_i as the number of bins $[A_{F,h-1}, A_{F,h}]$ for which $n_{i,h} \neq 0$, and let $B_i = \{h: n_{i,h} \neq 0\}$. That is, B_i is the set of indexes corresponding to bins for which at least one wildfire is recorded, and m_i is the number of its elements. In addition, let $N_i = \sum_{h \in B_i} n_{i,h}$ be the total number of fires that occurred in zone Z_i . Then, one possible quality index for a sub-set Z_i is the following

$$\Phi_i = \frac{1}{m_i - 2} \sum_{h \in B_i} [n_{i,h} + \beta_i \log(A_{F,h}) - \log \alpha_i]^2 \quad (7)$$

In the case that the parameters of (2) are determined through a simple linear regression, and assuming that equation (2) is perturbed by a sequence of independent errors with zero mean and with normal distribution, then Φ_i , defined by (7), is an unbiased estimator of the residual variance.

The value of Φ_i can be used as a quality index of the sub-set Z_i (the higher the value of Φ_i , the poorer the quality of Z_i , so Φ_i can be said to be the cost of Z_i). A quality index for the entire partition can be obtained by summing the quality indexes Φ_i of the elements of the partition. However, defining the quality index of a partition simply as the sum of the indexes provided by (7) for the various sub-sets in the partition may incorrectly favor those partitions with a greater number of sub-sets, each of them being characterized by a very small number of bins. This would not provide very significant results from the statistical viewpoint. One way to overcome such a drawback would be to impose a minimum threshold on the number of bins corresponding to a feasible sub-set. However, the difficulty of selecting a suitable value for such a threshold implies that an alternative method would be more appropriate.

We utilize the sum of the estimated variances of the estimates of the parameters for sub-set Z_i , i.e.,

$$\Theta_i = \sigma_{\beta_i}^2 + \sigma_{\log \alpha_i}^2 \quad (8)$$

where

$$\sigma_{\beta_i}^2 = \frac{\Phi_i}{\sum_{h \in B_i} \left(A_{F,h} - \sum_{h \in B_i} \frac{A_{F,h}}{m_i} \right)^2} \quad (9)$$

$$\sigma_{\log \alpha_i}^2 = \Phi_i \left(\frac{1}{m_i} + \frac{\left(\sum_{h \in B_i} \frac{A_{F,h}}{m_i} \right)^2}{\sum_{h \in B_i} \left(A_{F,h} - \sum_{h \in B_i} \frac{A_{F,h}}{m_i} \right)^2} \right) \quad (10)$$

The higher the value of sum of the estimated variances Θ_i (8), the worse is the choice of set Z_i , since it is associated with a set for which the estimated power-law is characterized by a linear regression with a higher parameter variance. Θ_i can be used as a quality measure (the cost) for sub-set Z_i , and consequently, the cost of a partition $\mathcal{P} = \{Z_i, i \in S\}$ can be defined as

$$\Psi = \frac{1}{|S|} \sum_{j \in S} \Theta_j \quad (11)$$

where $|S|$ is the cardinality of set S , i.e. the number of elements of the partition.

Having so defined the quality index (cost) of a partition it is possible to select a partition, among the set of possible partitions, able to better represent the wildfire regime of the considered area.

Results

The administrative Region of Liguria (Italy) has been selected for this case study. Liguria is a region of 5400 km² lying between the Cote d'Azur (France) and Tuscany (Italy) on the northwestern coast of the Tyrrhenian Sea (Figure 1). For this Mediterranean region with complex topography and dense vegetation, wildfires are recurrent phenomena both in summer and winter because, on average, about 365 wildfires of size ≥ 0.01 km² burn an area of 55 km² per year. Such a high fire density is mainly due to the extensive vegetation cover (about 90% of the administrative area), the recurrence of weather conditions suitable for rapid propagation of fire

fronts and, eventually, the presence of a widespread and almost continuous wildland-urban interface, which traverses the region along the entire coastline. Despite its compact dimensions, Liguria represents an interesting study area for the proposed procedure. In fact, the region encompasses heterogeneous vegetation cover, spanning from the Mediterranean *maquis* (shrubs) along the seafront, to broadleaved woodlands of inland areas, and eventually, Alpine fir and pine woodlands.



Figure 1— Location map for the study area chosen, Liguria (Italy), shown in red. This region of 5400 km² lies between 43.7° to 44.7° N and 7.5° to 10.1° W.

Our analysis made use of two different datasets. The first refers to the number of fires in each municipality (i.e., area unit), and the burnt area of each fire occurred in the period 1987 - 2004. This database reports 6201 wildland fires that overall burnt 1077 km² of forests and shrublands. The second refers to the geographically referred boundary of the burnt areas in the period 1996 - 2006.

Basing on the first dataset, the power-law parameters were evaluated for the whole of Liguria. In Table 1 the values of parameters β , $\log \alpha$, and the correlation coefficient r^2 are reported as well as the cost value Θ computed as in (8), the number m of bins $[A_{F,h-1}, A_{F,h}]$ for which $n_h \neq 0$, and the recurrence time interval T given by (4) for $A_F \geq 0.01$ km² and for $A_F \geq 1$ km².

Table 1— The Parameter Values Using the Partition Corresponding to the whole Liguria Region.

β	$\log \alpha$	r^2	Cost function Θ	N	A_R [km ²]	m	$T(\geq 0.01 \text{ km}^2)$ [days]	$T(\geq 1 \text{ km}^2)$ [days]
-1.86	-2.92	-0.960	0.0051	6201	5408.6	29	5.2	274.8

As this partition contains only one sub-set, the cost of the partition, Ψ , defined by (11) represents the cost of the single sub-set, Θ , defined by (8).

A second analysis was carried out using 10000 randomly generated partitions of Liguria, where each partition was composed of two sub-sets. No connectivity constraint on the sub-sets has been considered for such partitions. The average value of Ψ over the 10000 partitions was $\Psi = 0.0050$, with a minimum value of $\Psi = 0.0028$ and a maximum $\Psi = 0.0073$. To better understand the variability of cost function Ψ in relation to the 10000 different partitions, in Figure 2 the histogram of the results obtained from the application of the procedure is reported.

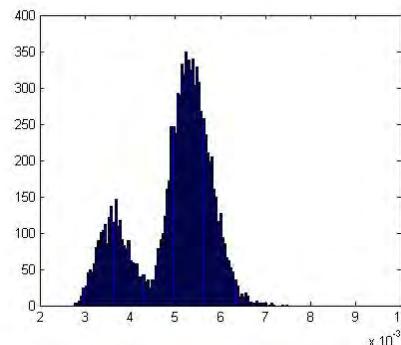


Figure 2 — Histogram of the cost function Ψ obtained for the 10000 randomly generated partitions of Liguria, where each partition was composed of two sub-sets. The range represents the values of Ψ .

It is apparent from the histogram reported in Figure 2 that the values of cost function Ψ are distributed in bimodal fashion. This may suggest the existence of, at least, two different wildfire regimes existent within the considered area.

The data belonging to the second dataset were used to perform a careful analysis on the kind of vegetation mainly involved in the ignition and subsequent wildfire propagation process. The analysis showed that in the considered dataset wildfires spread mainly through shrub vegetation. On these bases, the whole set of Liguria Municipalities was partitioned in two sub-sets; i.e., the 67 municipalities whose territory is covered by more than 2 km² of shrubland were defined as belonging to a first sub-set, named Z_1 , (represented in dark green in Figure 4), whereas the remaining others were assigned to the second sub-set, named Z_2 . Therefore, 10000 random partitions were generated both for Z_1 and for Z_2 . Histograms in Fig. 3 show the variability of the cost function Ψ in relation to the 10000 different partitions randomly generated with reference to the first (left) and the second sub-set (right), respectively.

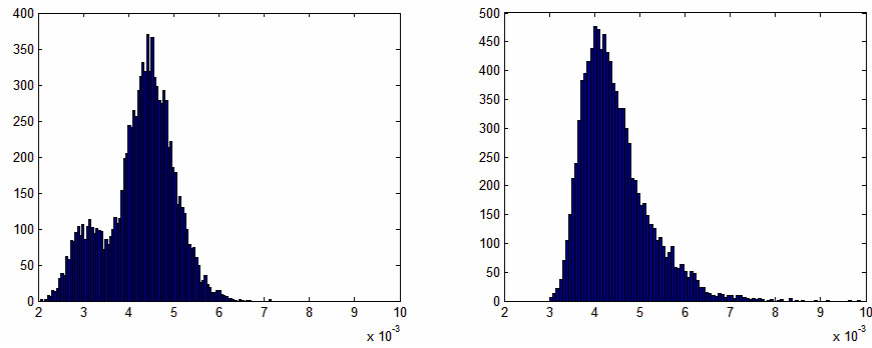


Figure 3 — Histograms of the cost function Ψ obtained for the 10000 randomly generated partitions with reference to the first subset (left) and the second subset (right), respectively.

It is worth observing from Figure 3, and from the numerical results in Tab. 2, the apparent difference in terms of distribution of the cost function Ψ for the two subsets. Subset Z_2 is characterized by a unimodal distribution with reduced variance. On the contrary, subset Z_1 still shows a bimodal distribution denoted by minimum and the maximum values lower than those obtained for the subset Z_2 .

Table 2— *The Cost Function Distribution Parameters with reference to the whole Liguria Region, subset Z_1 and subset Z_2 , respectively.*

Cost function Θ	min	max	mean	stdev
Liguria	0.0028	0.0075	0.005	0.00084
Z_1	0.0021	0.0077	0.0043	0.001
Z_2	0.0029	0.0103	0.0044	0.00072

In Fig. 4, a graphical representation of the two different subsets is presented, along with the burnt areas of wildfires occurred in the considered period of time. Notice that the majority of wildfire (> 1 hectares) was ignited within municipalities belonging to subset (zone) Z_1 , whose vegetation is significantly composed by shrublands.

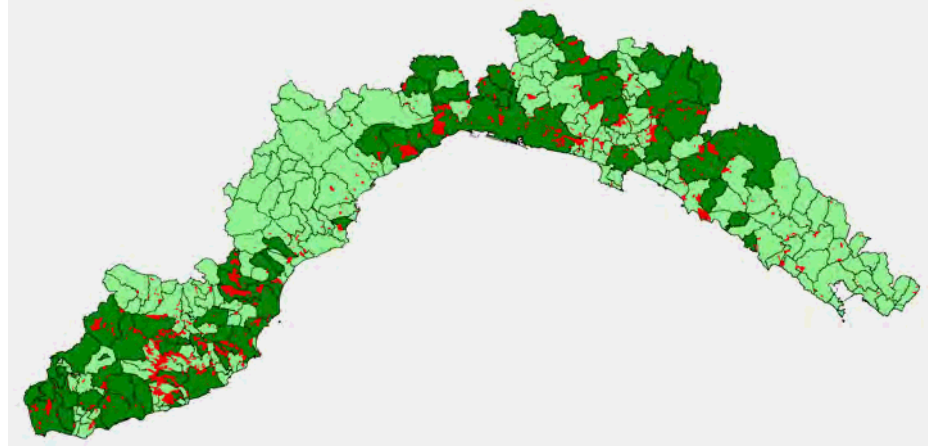


Figure 4— the graphical representation of the two different subsets along with the burnt areas of the wildfires occurred in the considered period. The municipalities in dark green belong to the zone Z_1 , whose vegetation composition presents more than 2 km^2 of shrub vegetation cover. The ones in light green belong to zone Z_2 . The red regions are the burnt areas during the period 1996 - 2006.

In Table 3 the values of parameters β , $\log \alpha$, and the correlation coefficient r^2 relevant to the different zones are reported. The table also shows the cost value Θ computed as in (8), the number m of bins $[A_{F,h-1}, A_{F,h}]$ for which $n_h \neq 0$, and the recurrence time interval T given by (4), for $A_F \geq 0.01 \text{ km}^2$ and for $A_F \geq 1 \text{ km}^2$, respectively.

Table 3— The Parameter Values Using the Partition Corresponding to the zones Z_1 and Z_2 .

zone	β	$\log \alpha$	r^2	Cost functio n Θ	N	A_R [km^2]	m	$T(\geq 0.01 \text{ km}^2)$ [days]	$T(\geq 1 \text{ km}^2)$ [days]
Z_1	-1.79	-2.75	-0.991	0.0483	3244	2294.3	29	4.5	168.7
Z_2	-1.81	-2.98	-0.990	0.0445	2957	3114.3	25	7.0	294.9

Table 3 put into evidence the behavioural differences of the two zones with reference to the recurrence time interval of fires greater than 1 km^2 . In fact, although the two zones are characterized by similar recurrence time interval for wildfires smaller than 0.01 km^2 , the zone Z_1 shows a recurrence time interval that is almost an half of that in zone Z_2 .

Conclusion

In the paper a mathematical tool useful for the identification of different zones characterized by different fire regimes is presented. The application to a real case study shows how different fire regimes may be identified only on the basis of the cost

function variability. Further research will be aimed at the comparative analysis of the results provided by the application of the proposed mathematical tool with a priori information concerning land use, population density, social issues, and the features of the wildfire response system. The aim of this analysis will be to clearly identify the major risk factors.

References

- Bailey, R.G. 1996. **Ecosystem Geography**. Springer-Verlag.
- Cleland, D.T., Crow T. R.; Saunders S. C., Dickmann D. I., Maclean A. L., Jordan J. K., Watson R. L., Sloan A. M., Broszofsky K. D. 2004. **Characterizing historical and modern fire regimes in Michigan (USA): a landscape ecosystem approach**. *Landscape Ecol.* 19, 311-325.
- Filippidis, E.J., and I. D. Mitsopoulos 2004. **Mapping forest fire risk zones based on historical fire data in Mount Olympus, Greece, using Geographical Information Systems**. *Management Information Systems*, 9, 613-625.
- Forestry Canada Fire Danger Group 1992. **Development and structure of the Canadian Forest Fire Behavior Prediction System**. Information Report ST-X-3 Forestry CA, Ottawa, ON.
- Iliadis, L.S. 2005. **A decision support system applying an integrated fuzzy model for long-term forest fire risk estimation**. *Environmental Modelling & Software*, 20, 613-621.
- Malamud, B. D., G. Morei, and D. Turcotte 1998. **Forest fires : An example of self-organized critical behaviour**. *Science*, 281, 5384, 1840-1842.
- Malamud, B. D., and D. Turcotte 1998. **Self-organized criticality applied to natural hazards**. *Natural Hazard*, 20, 93-116.
- Malamud B. D., J. D. A. Millington, and G. L. W. Perry 2005. **Characterizing wildfire regimes in the United States**. *PNAS*, vol. 102, 13, 4694-4699.
- McKenzie, D., D. L. Peterson, and J. K. Agee 2000. **Fire frequency in the Columbia River Basin: building regional models from history data**. *Ecological Applications*, 10, 1497-1516.
- Newman, M.E.J. 2005. **Power laws, Pareto distributions and Zipf's law**. *Contemporary Physics*. 46, 5, 323-351.
- Núñez-Regueira L., J. Rodriguez, J. Proupin, and B. Mourino 1999. **Design of forest biomass energetic maps as a tool to fight forest wildfires**. *Termochimica Acta*, 328, 111-120.
- Ricotta, C., G. Avena, and M. Marchetti 1999. **The flaming sandpile: self-organized criticality and wildfires**. *Ecological Modelling*, 119, 73-77.
- Riera P., J. Mogas 2004. **Evaluation of a risk reduction in forest fires in a Mediterranean region** *Forest Policy and Economics*, 6, 6, 521-528
- Song, W.G., W.C. Fan, B. H. Wang, and J. J. Zhou 2001. **Self-organized criticality of forest fire in China**. *Ecological Modelling*, 145(1), 61-68.
- Telesca, L., G. Amatulli, R. Lasaponara, and M. Santulli 2005. **Time-scaling properties in forest-fire sequences observed in Gargano area (southern Italy)**. *Ecological Modelling*, 185, 531-544.
- Turcotte, D. L., and B. D. Malamud 2004. **Landslides, forest fires, and earthquakes: examples of self-organized critical behavior**. *Physica A*, 340 (4), 580-589.
- Weber M. G., and M. D. Flannigan 1997. **Canadian boreal forest ecosystem structure and functioning in changing climate: Impact on fire regimes**. *Environmental Reviews*, 5, 3-4, 145-166.

Assessing Fire and Biodiversity Conservation for the Conterminous United States¹

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Abstract

Fire regime alteration is a known threat to the conservation of biological diversity. Specifically, altered fire regimes often result in changes in plant and animal species composition and ecosystem structure. The LANDFIRE Rapid Assessment (LFRA) project recently produced a series of maps including Fire Regime Condition Class (a measure of the departure of current vegetation from vegetation reference conditions), Fire Regime Groups and Potential Natural Vegetation Groups for the conterminous U.S. that can assist in assessing the threat to natural fire regimes and can help in establishing conservation priorities. We present the findings of an assessment of the ecological role and integrity of fire regimes across the conterminous U.S. based on LFRA data. In addition, we present examples of potential applications of the LFRA reference condition models and spatial data which could be applied outside of the U.S. Our analyses of the data reinforce that frequent fire return intervals dominate reference fire regimes across the assessment area and that approximately 80% of ecosystems and major habitat types are moderately-to-highly departed from their ecological reference conditions. Additionally, the results indicate that fire regime conditions do not differ substantially inside conservation areas or federally-administered lands compared to outside these areas.

Keywords: Biodiversity conservation, fire regime, fire regime condition class, LANDFIRE, reference conditions.

¹ An abbreviated version of this paper was presented at the Third International Symposium on Fire Economics, Planning, and Policy: Common Problems and Approaches, April 29 – May 2, 2008; Carolina, Puerto Rico.

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Introduction to Fire and Conservation

Fire is a key process in many ecosystems around the world (Agee 1993; Hardesty et al. 2005; Myers 2006; Pyne et al. 1996). Fire can also be ecologically destructive, for example, where fire exclusion has caused a build-up of fuel and altered fire behavior, or where fire frequency has increased in ecosystems with species that have not evolved in the presence of fire. Too much, too little or the wrong kind of fire can threaten biodiversity health, often with negative consequences for ecological, social and economic sustainability (Brown & Smith 2000; Smith 2000; Hardesty et al. 2005; UN FAO 2006). Because fire influences processes such as nutrient cycling, vegetation dynamics and species composition altered fire regimes can eliminate native species, accelerate soil erosion, degrade water quality and fish habitat, catalyze desertification, and alter ecosystem structure and wildlife habitat (Brown & Smith 2000; Smith 2000, Hassan et al. 2005). Changes in land use patterns and policies, such as rural development into wildlands, fire exclusion, tree plantations and agricultural conversion have contributed to changes in fire regimes in many areas of the U.S. (Weaver 1943; Cooper 1960; Covington & Moore 1994; Keane et al. 2002; Dellasala et al. 2004; Stephens & Ruth 2005). Changes in fire dynamics can also interact with other threats to ecosystems, such as climate change, invasive species, grazing, land clearing, inappropriate logging and landscape fragmentation (Keane et al. 1999; Dale et al. 2001; Brooks et al. 2004; Hardesty et al. 2005; Myers 2006), confounding efforts toward effective biodiversity conservation.

Because most ecosystems in the U.S. are fire-dependant (Shlisky et al. 2007), fire is necessarily a key process to consider in land management and conservation planning. Conservation organizations and land management agencies alike use fire as a tool to manage fire-adapted and fire-dependant ecosystems and try to abate the threat of fire in fire-sensitive ecosystems and to protect human health and livelihoods. Between July 2005 and June 2006 The Nature Conservancy, the largest U.S. conservation organization, burned over 90,000 acres for biodiversity benefit on its own lands (Blankenship et al. 2007). During calendar years 2005 and 2006 federal and state land management agencies burned approximately 2.8 million acres per year through prescribed fire or wildland fire use (<http://www.nifc.gov/nicc>). However, even with these and other efforts by The Nature Conservancy and other land management agencies, it is not clear if significant progress has been made in restoring fire-adapted and fire-dependant ecosystems in areas either deemed critical for conservation of biodiversity or managed by federal agencies.

This paper represents a partial synopsis of a larger technical report entitled “An Ecological Assessment of Fire and Biodiversity Conservation Across the Lower 48 States of the U.S.” (Blankenship et al. 2007). The goal of this report was to

improve our scientific understanding of the ecological roles of fire and the integrity of fire regimes in the conterminous U.S. Our report was primarily based on results from the Rapid Assessment phase of the Landscape Fire and Resource Management Planning Tools Project (LANDFIRE). LANDFIRE is a five-year, multi-partner project producing consistent and comprehensive maps and data describing vegetation and fire regimes across the U.S. which can be used for national level strategic planning and assessment (for more information visit www.landfire.gov). The Rapid Assessment (LFRA) phase of the LANDFIRE project, completed in 2006, quickly produced a national level assessment using maps and models of potential natural vegetation groups, reference fire regimes and fire regime departure from reference conditions (or fire regime condition class) for the conterminous U.S. We used the LFRA data to assess the ecological roles of fire and the integrity of fire regimes across the conterminous U.S. and for each of the major habitat types (Dinerstein et al. 1995) in the conterminous U.S. We also analyzed the integrity of fire regimes inside versus outside of The Nature Conservancy's portfolio of conservation areas of biodiversity significance⁴ (conservation areas) and federally-administered lands.

Data and Methods

Three metrics — reference conditions, fire regime groups and fire regime condition class — can be used to describe the ecological roles of fire and determine current ecological status across landscapes, regions and major habitat types.

Reference conditions are estimates of the range of variability in vegetation composition, structure (i.e. vegetation height and cover) and process against which current conditions can be compared, and from which ecological departure can be calculated. For the LFRA, reference conditions were based on estimated vegetation conditions prior to European settlement, and include the influence of aboriginal burning. Reference conditions for potential natural vegetation groups in the conterminous U.S. were described and quantitatively modeled by over 250 regional fire and vegetation experts. These models quantified the frequency and severity of fire and other disturbances and the rates of vegetation growth. LFRA reference condition models were used to determine fire regime groups and to calculate fire regime condition class.

Fire regime groups (FRG) are a classification of recurring fire characteristics — including average fire frequency and severity — for a given ecosystem and can be used to describe the historical or ecological role of fire (Agee 1993; Brown 1995;

⁴ The Nature Conservancy's conservation areas of biodiversity significance (conservation areas) are areas identified through an ecoregional planning process that collectively represent viable examples of all native species and plant communities within an ecoregion. The Nature Conservancy has taken direct conservation action in some, but not all, conservation areas.

Myers 2006). For LFRA, FRGs were defined as follows: Fire Regime I: 0–35 year frequency, low and mixed severity; Fire Regime II: 0–35 year frequency, replacement severity; Fire Regime III: 35–200 year frequency, low and mixed severity; Fire Regime IV: 35–200 year frequency, replacement severity; and Fire Regime V: 200+ year frequency, replacement severity.

Fire regime condition class (FRCC) is a relative measure of the departure of current vegetation and (where data are available) fire regime conditions, from ecological reference conditions (Hann et al. 2004). While FRCC may indicate the ecological status of fire regimes, it can be used more broadly as a measure of ecological departure since it includes vegetation conditions. For the LFRA, current vegetation conditions were mapped from Landsat imagery circa 1998 to 2001 and from the 1992 National Land Cover Database data, while reference conditions were defined by the LFRA reference condition models. FRCC classes are defined as follows: FRCC 1: 0–33% departed or within the natural range of variability; FRCC 2: 34–66% departed or moderate departure from the natural range of variability; and FRCC 3: 67–100% departed or high departure from the natural range of variability.

We performed the following spatial analysis steps to generate the results presented in this paper:

1. To calculate FRG and FRCC for the conterminous U.S. we summarized the raw LFRA FRG (USFS 2006a) and FRCC (USFS 2006b) grids.
2. To calculate FRG and FRCC with in major habitat types (Figure 1) in the conterminous U.S. we combined the LFRA FRG and FRCC grids with a grid of major habitat types that we created from a terrestrial ecoregions shapefile obtained from The Nature Conservancy.
3. To calculate FRCC inside and outside of federally-administered lands (Figure 2) we performed a spatial combine of the LFRA FRCC grid with a grid of federally-administered lands of unknown origin.
4. To calculate FRCC inside and outside of conservation areas we performed a spatial combine of the LFRA FRCC grid with a grid of conservation areas that we created from a 2005 conservation area shapefile and updated for 12 ecoregions. This grid was then combined with the major habitat grid to calculate FRCC inside and outside of conservation areas with in major habitat types (see Blankenship et al. 2007 for a full description of the data and methods).



Figure 1—a Major habitat types in the conterminous U.S.

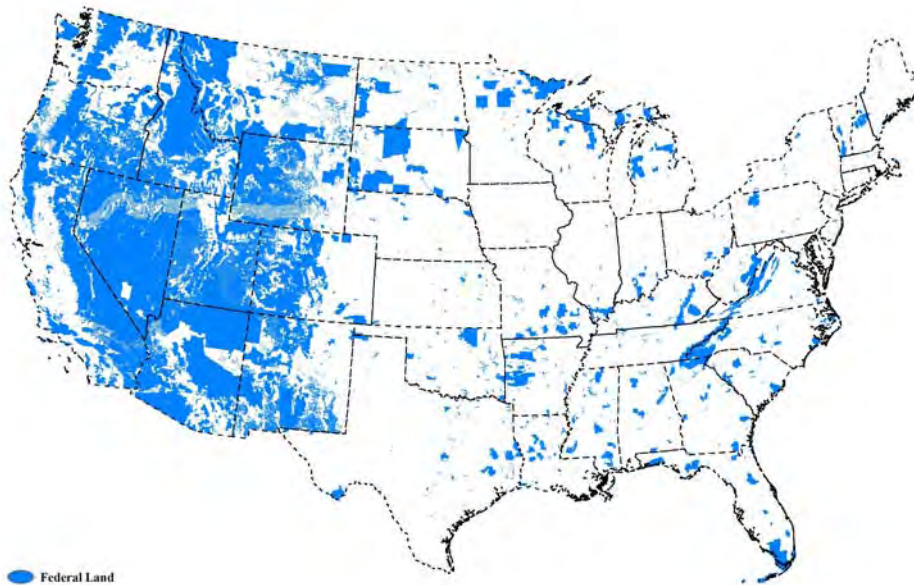


Figure 2—Federally-administered lands in the conterminous U.S.

Data Considerations

The LFRA data provide a moderate resolution, rapid, nation-wide assessment. Interpretation of the LFRA data should be based on the understanding that the data were designed for national to regional-scale strategic planning, broad ecological assessments and resource allocation. Therefore, we have restricted our presentation of the data to national and regional levels and focused on percentages and relative comparisons among regions rather than presenting and interpreting

absolute values.

Because consistent spatial data on current fire regime characteristics (fire frequency and severity) are not available for the entire U.S., LFRA FRCC results only measure the departure of current vegetation structure and composition from the reference condition. This measure can be more broadly interpreted as an indicator of ecological departure or as an imperfect, but best available proxy, for the departure of fire regimes across broad geographical extents. While altered fire regimes certainly influence vegetation composition and structure, other factors can cause similar changes in vegetation. For instance, certain forest management and domestic animal grazing practices, climate change and invasive species can alter vegetation characteristics and influence the LFRA FRCC calculation. Given that current fire regime information (including the distribution, frequency and severity of fires) is not available nationally, vegetation departure is the best approximation of fire regime conditions that currently exists nation-wide in the U.S.

FRCC in the LFRA was only calculated for areas that have natural or semi-natural vegetation. It was not calculated for areas classified as agriculture, urban, water, snow, ice, barren, transportation, mines or quarries. It was also not calculated for wetlands because they could not be reliably mapped using LFRA methods or alpine areas due to their small extent. In this assessment, we discuss results for only those areas that are classified as FRCC 1, 2 or 3.

In some cases the reference condition is based on historical information that may not reflect current climatic or biophysical conditions, and may not be synonymous with the desired future condition for a particular area due to social constraints. In these cases, FRCC may need to be supplemented to be useful for developing conservation goals or measuring conservation status or results.

Two major habitat types (Flooded Grasslands and Savannas and Tropical and Subtropical Grasslands, Savannas and Shrublands) that intersect the conterminous U.S. were excluded from this assessment because their main distribution is outside of the conterminous U.S. and they do not represent sufficient area to provide meaningful results given the resolution of the LFRA data. The spatial layer representing The Nature Conservancy's conservation areas used in this analysis did not include conservation areas for three ecoregions (Aspen Parkland, Dakota Mixed-Grass Prairie and Fescue-Mixed Grass Prairie).

Results

Conterminous U.S.

Analyses of the ecology and status of fire regime conditions across the conterminous U.S. reveal several results important to biodiversity conservation:

1. Frequent fire regimes dominate approximately 65% of the conterminous U.S. (Table 1), although regional variations exist.
2. Approximately 80% of the conterminous U.S. is moderately to highly departed from reference conditions, leaving only 20% within the range of variability described by the reference condition (Figure 3).
3. There is very little difference between FRCC conditions within conservation areas (Figure 4) or federally-administered lands (Figure 5) versus outside these areas. However, because the LFRA FRCC data were calculated for large geographic areas, they may mask local variation. Within conservation areas and federally-administered lands where actions have been taken to restore and maintain fire regimes, we expect that conditions are better than indicated by LFRA data.

Table 1—*Fire regime groups in the conterminous U.S.*

<i>Fire Regime Group</i>	<i>%</i>
1	33
2	32
3	11
4	9
5	15

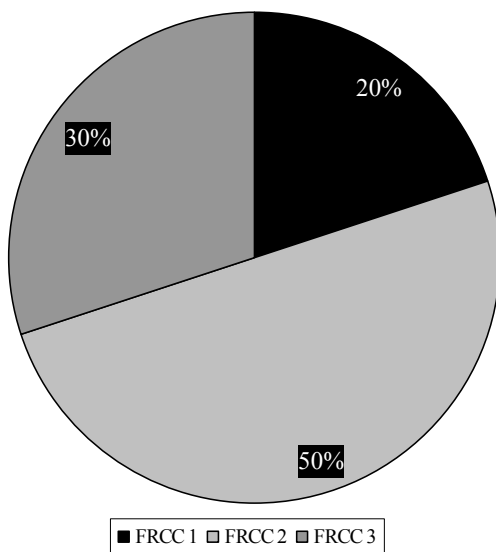


Figure 3—*Fire regime condition class in the conterminous U.S.*

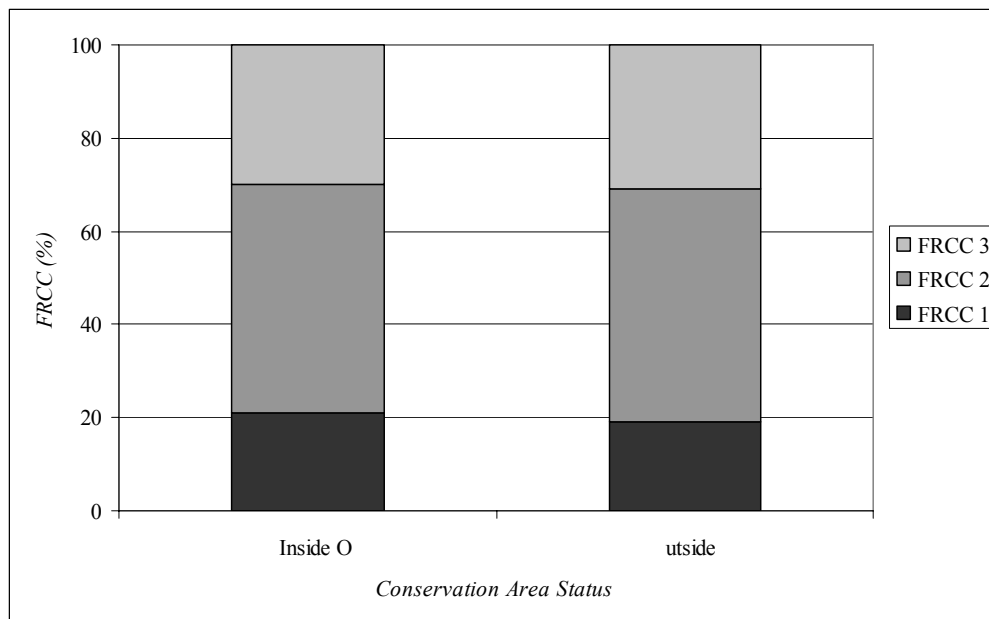


Figure 4—Fire regime condition class inside and outside of The Nature Conservancy's conservation areas in the conterminous U.S.

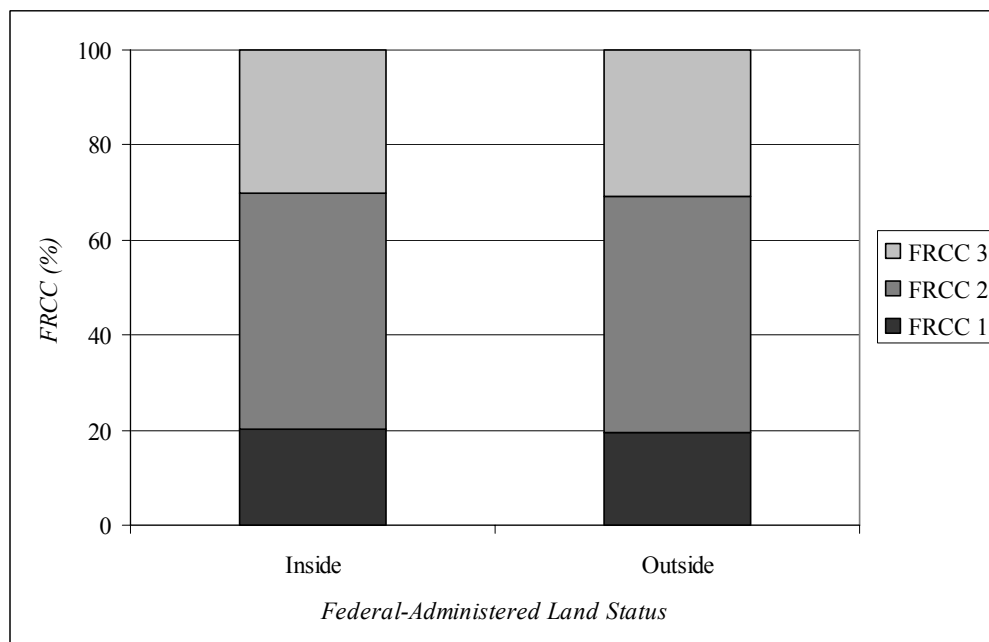


Figure 5—Fire regime condition class inside and outside of federally-administered lands in the conterminous U.S.

Major Habitat Types

Analyses of the ecology and status of fire regime conditions across major habitat types of the conterminous U.S. reveal several results important to biodiversity conservation:

1. Although a range of fire regime groups are present within each major habitat

type, frequent fire regimes dominate in three of the five types. Deserts and Xeric Shrublands and Mediterranean Forests, Woodlands and Scrub habitat types have a greater proportion of low frequency, high severity fire regimes than other types (Table 2).

2. FRCC departure is moderate to high (i.e. FRCC 2 and 3) across all major habitat types (Figure 6).
3. There is very little difference between FRCC conditions inside versus outside conservation areas within major habitat types (Figure 7).

Table 2—Fire regime groups in major habitat types in the conterminous U.S.

<i>Major Habitat Type</i>	<i>Fire Regime Group (%)</i>				
	1	2	3	4	5
Deserts & Xeric Shrublands	11	24	11	25	29
Mediterranean Forests, Woodlands & Scrub	29	21	4	42	5
Temperate Broadleaf & Mixed Forests	57	7	12	1	23
Temperate Conifer Forests	48	9	19	13	11
Temperate Grasslands, Savannas & Shrublands	15	79	3	2	1

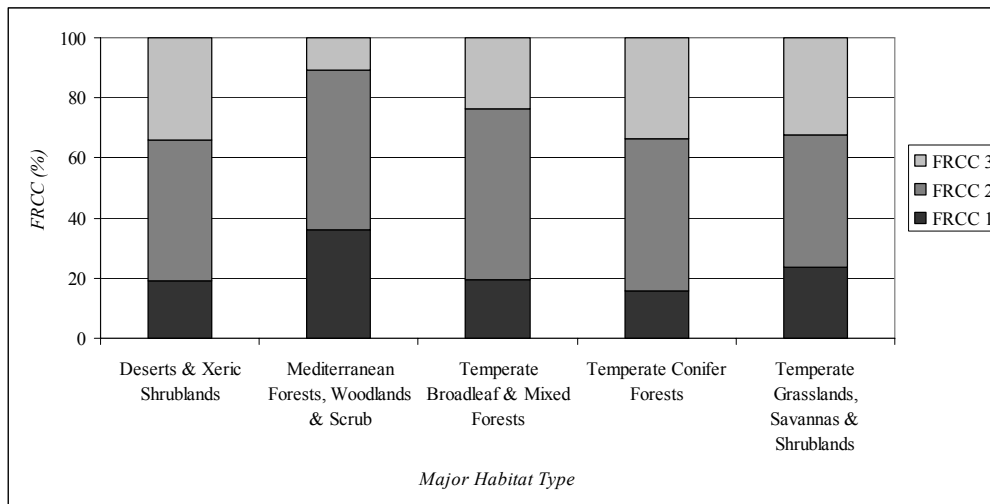


Figure 6—Fire regime condition class in major habitat types in the conterminous U.S.

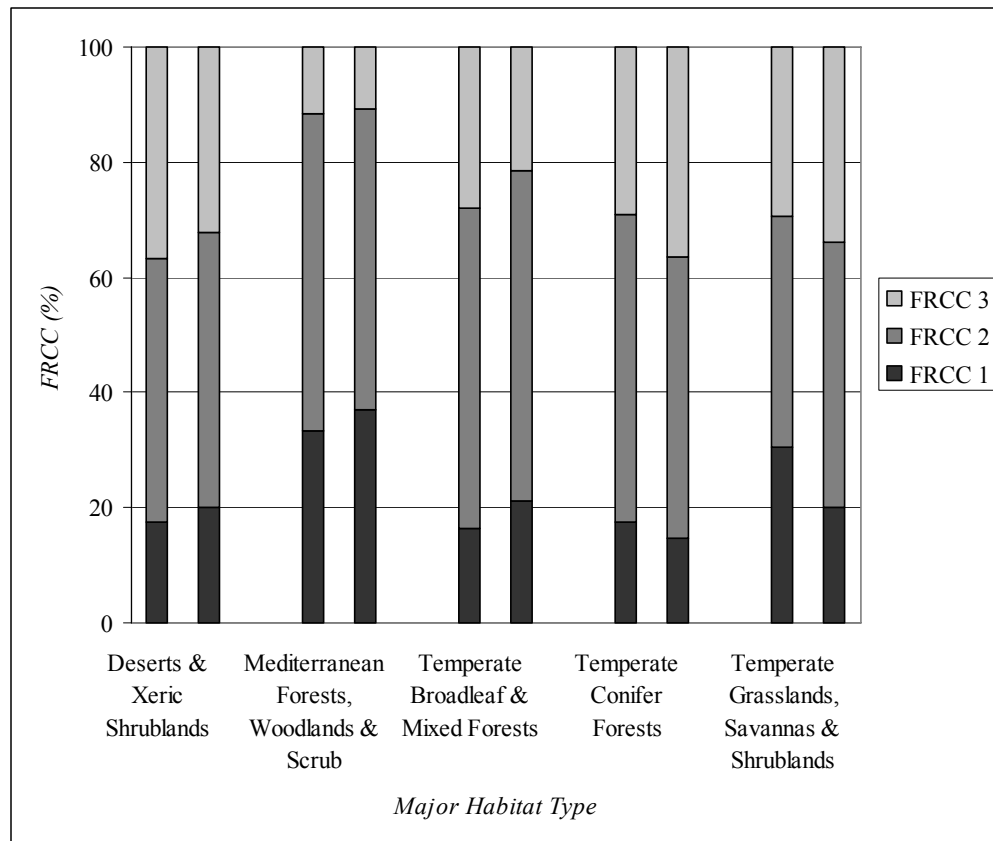


Figure 7 -- Fire regime condition class inside versus outside The Nature Conservancy's conservation areas within major habitat types in the conterminous U.S. For each pair, bars on the left represent FRCC distribution inside conservation areas; bars on the right represent FRCC distribution outside these areas.

Potential Applications

The assessment we present here clearly demonstrates several uses of the LFRA data for analysis within the U.S.; however, there are a variety of potential uses of these data outside of the U.S.:

1. The non-spatially explicit reference condition models can be adapted to similar ecological systems outside of the U.S. For example, the Great Lakes Spruce Fir reference condition model (LFRA 2005), although developed for the Great Lakes regions, represents an extensive vegetation type that spreads northward into the boreal regions of Canada and Alaska. Considerable variability can be expected across the entire range of spruce fir systems in the northern hemisphere, but the Great Lakes model could provide a starting point for adapting the model to other regions. Likewise, the similarity of some of the southwestern U.S. grasslands and conifer ecosystems to systems in adjacent Mexico and the similarity of some pine ecosystems in Florida to pine systems in the Caribbean make U.S. models reasonable starting points for modeling these

systems beyond the U.S. border. Models may also be adapted for similar ecosystems that are not geographically contiguous. For example, grassland models from the central U.S. may provide a reasonable starting point for creating models for African savannas or Mongolian grasslands.

2. Reference condition models can be used to predict vegetation conditions under different management or climate scenarios. For example, Forbis and others (2006) used vegetation dynamics models, similar to those produced by the LANDFIRE project, to test multiple restoration scenarios including full fire suppression, wildfire use in designated areas, wildfire use in designated vegetation types, no livestock grazing and restoration with an increased budget in the Great Basin. The model allowed them to analyze the impact each scenario would have over time on the distribution of vegetation in the study area. Forbis and others concluded that although the models were limited by the current knowledge of vegetation dynamics, they provided a useful tool for assessing the potential impact of different land use planning scenarios. In an analysis performed by Shlisky and others (2005) to compare the results of a coarse LFRA model to a similar local model based on local fire history data the authors concluded that “validated reference conditions such as those described here provide greater scientific certainty for local land management and conservation decision-making, and contribute to the justifications for using or refining coarser models elsewhere (Shlisky et al. 2005).”
3. The LANDFIRE methods for developing reference condition models are not geographically specific and could therefore be used to develop reference conditions for other geographies. LFRA reference condition models were developed during expert workshops held around the country and refined through a model review process that took place during workshops, via email and in small meetings. The quantitative models were built using the Vegetation Dynamics Development Tool (Beukema et al. 2003), a public domain software. The accompanying model description documents were created using the ModelTraker database a publicly available tool developed by the LANDFIRE project. This process requires engaged participants, quantitative user input on the rates and pathways for succession and disturbance, free software and a computer with Microsoft Windows 2000 or later and 512 megabytes of memory.
4. LANDFIRE mapping methods including remote sensing, ecosystem simulation and predictive landscape modeling can be used to map vegetation and fire information in other geographies. Technological know-how, sufficient computer hardware and software resources and the availability of plot data and remotely sensed imagery would be required to use the LANDFIRE’s open source mapping methods elsewhere.

Conclusion

These analyses reinforce that fire is a dominant ecological factor in ecosystems across the conterminous U.S., and that fire regimes have been altered for the majority of the conterminous U.S. and in all major habitat types. Furthermore, our analyses indicate that the level of fire regime departure does not differ within The Nature Conservancy's conservation areas or federally-administered lands compared to outside these areas. These results suggest that even within areas that may be considered conserved or protected, more work needs to be done to improve fire regime conditions. In addition, although conservation areas identified by The Nature Conservancy may have important biodiversity significance, many of them may be in a poor ecological condition as measured by their level of FRCC departure. Conservation work within areas that are moderately to highly departed from their reference condition may require increased restoration efforts to conserve the biodiversity targets they contain. Despite efforts by The Nature Conservancy and the federal land management agencies, as well as others, to restore and maintain reference fire regimes there is a gap between the scale of altered fire regimes and the scale of restoration efforts in the conterminous U.S.

National level datasets, such as the LFRA data used in this assessment, provide a useful tool for performing strategic analyses and high-level planning that can inform policy decisions and resource allocation. Users should remember that the resolution of the LFRA spatial data is likely insufficient for project level work, however, LFRA data may be used to target places where finer resolution, on-the-ground landscape assessments are needed, to identify where fire regimes may be degraded and where they might be feasibly restored. Although LFRA data were specifically designed for the conterminous U.S., the non-spatially explicit reference condition models and LANDFIRE modeling and mapping methods could be adapted for use in areas outside the U.S.

References

- Agee, J.K. 1993. *Fire Ecology of Pacific Northwest Forests*. Island Press, Washington D.C., USA.
- Beukema, S.J., W.A. Kurz, C.B. Pinckham, K. Milosheva & L. Fried. 2003. *Vegetation Dynamics Development Tool User's Guide, Version 4.4c*. Prepared by ESSA Technologies, Ltd., Vancouver, BC. 239 pp. Available at: www.essa.com.
- Blankenship, K., A. Shlisky, W. Fulks, E. Contreras, D. Johnson, J. Patton, J. Smith and R. Swaty. 2007. *An Ecological Assessment of Fire and Biodiversity Conservation Across the Lower 48 States of the U.S. Global Fire Initiative Technical Report 2007-1*. The Nature Conservancy, Arlington, VA.
- Brooks, M.L., C. M. D'Antonio, D. M. Richardson, J. B. Grace, J. E. Keeley, J. M. DiTomaso, R. J. Hobbs, M. Pellant & D. Pyke. 2004. Effects of invasive alien plants on fire regimes. *BioScience* 54(7): 677-688.
- Brown, J. K. 1995. Fire regimes and their relevance to ecosystem management. Pp. 171-178 in *Proceedings of Society of American Foresters National Convention*; 1994 Sept. 18-22; Anchorage, Alaska. Society of American Foresters, Bethesda, Maryland, USA.
- Brown, J.K. & J. Smith (eds.). 2000. *Wildland Fire in Ecosystems: Effects of Fire on Flora*. General USDA Forest Service Technical Report RMRS-GTR-24, Ogden, Utah, USA.
- Cooper, C.F. 1960. Changes in vegetation, structure, and growth of southwestern pine forests since white settlement. *Ecological Monographs* 30:129-164.
- Covington, W.W. & M.M. Moore. 1994. Postsettlement changes in natural fire regimes and forest structure: ecological restoration of old-growth ponderosa pine forests. *Journal of Sustainable Forestry* 2:153-181.
- Dale, V.H., L.A. Joyce, S. McNulty, R.P. Neilson, M.P. Ayres, M.D. Flannigan, P.J. Hanson, L.C. Irland, A.E. Lugo, C.J. Peterson, D. Simberloff, F.J. Swanson, B.J. Stocks & B.M. Wotton. 2001. Climate change and forest disturbances. *BioScience* 51(9): 723-734.
- Dellasala, D.A., J.E. Williams, C.D. Williams & J.F. Franklin. 2004. Beyond smoke and mirrors: a synthesis of fire policy and science. *Conservation Biology* 18(4):976-986.
- Dinerstein, E., D.M. Olson, D.H. Graham, A.L. Webster, S.A. Primm, M.P. Bookbinder & G. Ledec. 1995. *A conservation assessment of the terrestrial ecoregions of Latin America and the Caribbean*. World Wildlife Fund and the World Bank, Washington D. C.
- Forbis, T.A., L. Provencher, L. Fried & G. Medlyn. 2006. Great Basin land management planning using ecological modeling. *Environmental Management* 38(1):62-83.
- Hann, W., A. Shlisky, D. Havlina, K. Schon, S. Barrett, T. DeMeo, K. Pohl, J. Menakis, D. Hamilton, J. Jones & M. Levesque. 2004. *Interagency Fire Regime Condition Class Guidebook*. Interagency and The Nature Conservancy fire regime condition class web site. USDA Forest Service, US Department of the Interior, The Nature Conservancy, and Systems for Environmental Management. www.frcc.gov.
- Hardesty, J., R.L. Myers & W. Fulks. 2005. Fire, ecosystems, and people: a preliminary assessment of fire as a global conservation issue. *The George Wright Forum* 22:78-87.
- Hassan, R., R. Scholes & N. Ash (eds). 2005. *Findings of the Condition and Trends Working Group of the Millennium Ecosystem Assessment*. Ecosystems and Human Well-being: Current State and Trends, Volume 1. University of Pretoria Council for Science and Industrial Research UNEP World Conservation South Africa, South Africa Monitoring Centre, United Kingdom. Island Press Washington, D.C.
- Keane, R.E., K.C. Ryan & M. A. Finney. 1999. Simulating the consequences of fire and climate regimes on a complex landscape in Glacier National Park, Montana. *Fire in*

- Ecosystem Management: Shifting the Paradigm from Suppression to Prescription. 20th Tall Timbers Fire Ecology Conference Proceedings, No. 20.
- Keane, R.E., K.C. Ryan, T.T. Veblen, C.D. Allen, J. Logan & B. Hawkes. 2002. Cascading Effects of Fire Exclusion in Rocky Mountain Ecosystems: A Literature Review. General Technical Report RMRS-GTR-91.
- LANDFIRE Rapid Assessment (LFRA). 2005. Potential Natural Vegetation Group R6GLSF - Northern Mixed Grass Prairie: Description, [Online]. In: Rapid assessment reference condition models. In: LANDFIRE. Washington, DC: U. S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Lab; U.S Geological Survey; The Nature Conservancy (Producers). Available: <http://www.landfire.gov/ModelsPage2.html>. [2007, January 9].
- Myers, R.L. 2006. Living with Fire: Sustaining Ecosystems and Livelihoods through Integrated Fire Management. The Nature Conservancy. Tallahassee, FL.
- Pyne, S. J., P.L. Andrews & R.D. Laven. 1996. Introduction to Wildland Fire. 2nd ed. John Wiley and Sons, New York, New York, USA.
- Shlisky, A.J., R.P. Guyette, & K.C. Ryan. 2005. Modeling reference conditions to restore altered fire regimes in oak-hickory-pine forests: validating coarse models with local fire history data. EastFire conference Proceedings. George Mason University, Fairfax, VA. May 12-13, 2005.
- Shlisky, A., J. Waugh, P. Gonzalez, M. Gonzalez, M. Manta, H. Santoso, E. Alvarado, A. Ainuddin Nuruddin, D.A. Rodríguez-Trejo, R. Swaty, D. Schmidt, M. Kaufmann, R. Myers, A. Alencar, F. Kearns, D. Johnson, J. Smith, D. Zollner and W. Fulks. 2007. Fire, Ecosystems and People: Threats and Strategies for Global Biodiversity Conservation. GFI Technical Report 2007-2. The Nature Conservancy. Arlington, VA.
- Smith, J.K. 2000. Wildland Fire in Ecosystems: Effects of Fire on Fauna. General USDA Forest Service Technical Report RMRS-GTR-42-vol. 1, Ogden, Utah, USA.
- Stephens, S.L. & L.W. Ruth. 2005. Federal forest-fire policy in the United States. Ecological Applications 15: 532-542.
- UN Food and Agriculture Organization (UN FAO). 2006. Global Forest Resource Assessment: Progress Toward Sustainable Forest Management. FAO Forestry Paper 147, Rome Italy. ISBN 92-5-105481-9.
- United States Forest Service. 2006a. LANDFIRE Rapid Assessment Reference Fire Regimes (rarfrg): USDA Forest Service/Fire Science Laboratory, Rocky Mountain Research Station, Missoula MT.
- United States Forest Service. 2006b. LANDFIRE Rapid Assessment Fire Regime Condition Classes (raf rcc): USDA Forest Service/Fire Science Laboratory, Rocky Mountain Research Station, Missoula MT.
- Weaver, H. 1943. Fire as an ecological and silvicultural factor in the ponderosa pine region of the Pacific slope. Journal of Forestry 41:7-14.

Reflections on Fuel Treatment Effectiveness¹

Philip N. Omi²

Abstract:

Fuel treatments can be categorized by objective (e.g., hazard reduction vs. ecological restoration), treatment type (mechanical vs. prescribed fire or other fire use activities), and scale (project vs. landscape), among other criteria. Tradeoffs with fire suppression activities depend in part on historic fire regime and treatment intensity. In some ecosystems, for example ponderosa pine (*Pinus ponderosa*) forests that historically burned frequently with low severity, treatments that reduce fuel hazards may accomplish restoration goals while reducing future wildfire severity. In these systems the potential exists for reductions in wildfire suppression costs and losses provided intensive treatments are applied strategically across the landscape. In other ecosystems, e.g., chaparral or high elevation forests, which typically burn with high severity, fuel hazard reduction treatments may be inconsistent with restoration objectives, and in turn may have little impact on reducing fire suppression costs and losses. Similarly, wildland fire use and appropriate management responses may not reduce hazards or restore ecosystems, for example if low intensity burning or herding strategies are inconsistent with historic fire regimes. Our understanding of the effectiveness of fuel treatments may need to be reconsidered in light of changing climates. Tradeoffs that appear positive in present environments may not remain so in the future. Adaptive management strategies would seem to make sense in evaluating tradeoffs with fire suppression activities, especially in light of increasing uncertainty.

Keywords: Fuel management, fuel treatment, fuel treatment effectiveness.

Introduction

Public land managers in the US have engaged in fuel treatment activities for decades, primarily for hazard reduction aimed at facilitating eventual fire suppression efforts. The rationale commonly associated with early efforts focused on reduction of fuel loads that had accumulated in forested wildlands due to 20th century fire exclusionary practices. As ecological awareness increased from the 1970s forward, the reasons for

¹ An abbreviated version of this paper was presented at the Third International Symposium on Fire Economics, Policy, and Planning: Common Problems and Approaches, April 29–May 2, 2008, Carolina, Puerto Rico.

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treating fuels became more expansive to include restoration and/or maintenance of ecosystem health. Additional concerns include the wildland urban interface, non-timbered wildlands such as grass- and shrub-lands, and firefighter safety. Fire even has a role in managing riparian zones and intermittent, vernal pools. The point is that fuel treatment motivations have expanded considerably along with ecological understanding of fire's role in ecosystem dynamics.

Fuel treatment methods haven't changed very much despite the expanding motivations for manipulating fuel beds. Basically treatments comprise fire and non-fire (including mechanical, biological, and chemical) applications, at stand and landscape scales. However, as motivation for treating fuels has broadened, so have the needs for analytical tools to assess economic and policy impacts of fuel management alternatives.

My purpose is to overview some basic principles of fuel treatments for hazard reduction and ecological restoration, as a lead-in to broader questions related to economic and policy assessments. In keeping with the theme for this session, I'll also address in closing whether the effects of fuel treatment for hazard abatement are illusory or not.

Historical perspective on fuel management planning in the USA

In the past federal, state, and local organizations in the US have followed their own procedures for planning fuel treatments. During much of the 20th century, national forests were managed primarily for timber management and fire management was viewed as a service activity to timber and the other natural resources (range, water, wildlife, etc.). Fears of timber famine early in the century gave way to a concern for the environmental impacts of logging and other management activities subsequent to Earth Day 1970. Depending on regional silvics, until recently forest planning was heavily weighted toward providing wood supplies in perpetuity with secondary emphasis on multiple-uses and human community development. Cutting trees from the forest, including liquidation of "old-growth" drastically altered fuel beds and associated micro-environments.

Thus in forested areas, fuels management was required to reduce hazards for regeneration (brush disposal) or to dispose of slash from logging activities. In places like southern California, with relatively little timber harvest, fuel treatments were carried out under the aegis of watershed protection and management. Further, national parks increasingly focused on restoration of ecosystems in which fire had been excluded, along with hazard reduction near developed areas. More recently, other federal agencies have recognized this dual land stewardship mandate. By

contrast, state and local jurisdictions have tended to carry out fuel treatments mostly for hazard reduction to facilitate suppression objectives.

One of the first documented federal experiments with prescribed fire occurred in the saw grass prairies of Everglades National Park, in order to control tropical hardwoods which were replacing native pines in the absence of fire. Ancillary objectives included fuel hazard reduction and exotic plant control (Kilgore 1975). Prior to this time, fuels had been manipulated on the Angeles National Forest, primarily through the establishment and maintenance of fuel breaks and fire breaks since the 1930s, using available labor pools like Civilian Conservation Corps for installation.

Fuel treatment expanded greatly during the 1970s with the US Forest Service undertaking massive fire re-planning efforts involving hazard reduction on the national forests (Omi 1977). Also in the 1970s managers began distinguishing between different fuel treatment strategies in activity (i.e., harvested or thinned) vs. natural fuel beds (Hirsch and others 1981).

In 1978 the US Forest Service revised its fire policy, including among other mandates cost-effective fire management and increased use of prescribed fire as part of fire management plans. This policy revision led to development of the National Fire Management Analysis System (NFMAS), providing a tool for justifying pre-suppression budget expenditures. The Fire Economics Evaluation System (FEES) was developed by Forest Service researchers in the Riverside Fire Laboratory partially in response to perceived deficiencies in the NFMAS (Omi and others 1986).

Recognizing the importance of pre-suppression budgeting, in the early 1980s the National Park Service developed its own fire programming process (FIREPRO), an analysis system developed to allocate funds for both hazard reduction and resource management projects. Hazard reduction projects apply to areas at risk to fire within a national park (e.g., developed areas) while resource management projects are concerned with ecological restoration using fire in park wildland areas.

Other federal agencies with fire management responsibilities have borrowed from NFMAS or FIREPRO as needed to suit analytical needs. For example, the Bureaus of Land Management and Indian Affairs adopted portions of the preparedness analysis portion of NFMAS while the Fish and Wildlife Service modified FIREPRO. As a consequence federal preparedness planning was disjointed. Further, no system considered all aspects of the systematic fire management program being implemented by any single agency (Fire Program Analysis website 2005).

With the new millennium, federal initiatives like the Cohesive Strategy, National Fire Plan, and Joint Fire Science Program expanded emphases on fuel management substantially. Policy reviews during this time period also expressed the need for improvements and integration in fire program planning, including

capabilities for evaluating the cost-effectiveness of fuel treatment expenditures.

Fire Program Analysis (FPA) represents an attempt to link together the various program analyses (and resources) of federal agencies to address voids in agency-specific budgeting processes, including fuels management. Other analytical tools developed have been developed to examine the economic and policy aspects of fuels management, including several that are covered in papers presented at this Symposium.

Doubtless positive fuel management analytical developments will continue for the foreseeable future and should add considerably to our knowledge base about fuel treatments. Even so, it is timely at this symposium to raise questions about how far these new developments can take us. Further, as we continue down the road of expanded emphasis on fuel treatments, it is logical to question whether the science will ever match all the requisites for making important management decisions. Example questions include the following: How much of a reduction in fire suppression costs is achievable by implementing a unit of fuel treatment (however defined)? Can any processor ever fully evaluate the economic and policy implications of fuel treatments? How relevant and reliable are available processors for evaluating fuel treatment planning (i.e., subject to climate change, carbon sequestration, and other concerns)? Doubtless, there are other salient questions that persist, but these at least suggest significant issues to be resolved.

Current Understanding of Fuel Treatment Effectiveness

Although fuels have been treated for decades, the literature base on treatment effectiveness is surprisingly sparse. Omi and Martinson (2002) outline some of the significant voids in understanding, based on fuel treatment literature published during 1955-1999. Fifteen studies examined a variety of treatments (prescribed burning, thinning, harvest, and combinations thereof), in pine/mixed conifer stands. Comparisons were made against a variety of areas not receiving treatments, although only one study included a statistical control group. Response variables included crown damage, area burned, char height, tree mortality/survival, and soil damage. Six of the 15 studies used statistical tests, although all spoke to positive effects (one mixed). So the voids were methodological as well as ecological. Thus much of extant knowledge was anecdotal at best.

Our understanding of fuel treatment effectiveness has expanded recently with publication of several compendia (e.g., Graham and others 2004; Peterson and others 2005; Agee and Skinner 2005). These summaries provide insights into silvicultural options, focusing primarily on thinning, prescribed burning, and thin + burn alternatives. Thinning is a cultural treatment for reducing stand density primarily to

improve growth or enhance forest health (Helms 1998). Prescribed burning is the intentional application of fire to achieve management objectives (Omi 2005), subject to pre-determine environmental and ignition conditions.

While useful for considering fuel treatment effectiveness in western dry forests historically subjected to frequent, low intensity surface fires, the extrapolations need to be made with caution. In fact, attempted inferences to other ecosystems or fire regimes (e.g., southern California chaparral, high-elevation spruce-fir forests, or higher latitude boreal forests) may contradict observations in western dry forests. Thus, significant voids exist with respect to a comprehensive evaluation of fuel treatment effectiveness across all ecosystems of interest.

Further, analyses of fuel management effectiveness have failed to consider the various objectives and nuances of treatment alternatives. Most treatments studied above were not necessarily conducted for fuel hazard reduction. Also, we now recognize that the necessity and effectiveness of fuel treatments may vary by historical fire regime. Thus treatment effectiveness may vary depending on frequency, severity, seasonality, patch size and other descriptors by which fire regimes are classified (Omi 2005). Further, effectiveness may depend on fire regime condition class, an indicator of ecosystem health that depends in part on the extent to which historic fire activity has been maintained and/or restored. In other words, like any manipulation to the forest, results vary depending on a variety of circumstances, including the weather and topographic conditions under which eventual fires might occur. It turns out that this eventuality is important because fuel treatments may be installed and possibly never “tested” by a subsequent ignition.

Evaluation at the Stand or Project Scale

Even in the most widely studied systems, variability must be reckoned with. To illustrate this point, I will go into examples from a system that I have studied widely during the past 15 years, i.e., fuel treatment effectiveness in dry forests of the western US. In particular I will summarize findings from an extended study since 1994 of wildfire effects in long-needled pine forests, primarily ponderosa pine (*Pinus ponderosa*), historically subjected to frequent, low severity fires (Martinson 2006). Table 1 summarizes this extended study, spanning three separate research projects.

Table 1. Summary description of fuel treatment effectiveness studies during 1994-2006 (Pollet and Omi 2002; Omi and Martinson 2002; Omi and others 2006).

Study descriptor	Explanation
Number of wildfires studied	13
Time-span	11 years
Geographic location	8 states
Vegetation and topographic similarity between treatment vs. controls	Based on GIS data layers obtained prior to field visits
Plot layout	Untreated plots placed ahead of treated, based on spread geometry
Treatment boundaries	Buffered to allow for mapping error
Variable radius plot: Independent variables	Tree diameter (cm), tree height (m), crown base height (m), crown position, tree density (stems/ha)
Variable radius plot: Response variables	Bole char height (m), needle scorch height (m), crown volume scorch (%), crown volume consumption (%)
Fixed area (Modified Whittaker) plot: Independent variables	% slope, aspect, small tree density
Fixed area (Modified Whittaker) plot: Response variables	Stand damage, depth of char

Eight of the wildfires were studied using replicated paired treated vs. untreated comparisons. Five of the early studies prior to 2000 used a less robust methodology.

We were able to evaluate treated vs. untreated differences in stands burned by wildfire for the following fuel treatments: thin, prescribed burn, and thin + prescribed burn. Differences were analyzed retrospectively, so not all treatment combinations were present and analyzed on all fires. Results were mixed. For example, crown scorch plus consumption was less in thinned (vs. unthinned) areas on two of five fires. By contrast, differences due to prescribed burn treatments were evident on four of five wildfires. Differences due to thin plus burn were found on four of the four wildfires where this treatment combination was implemented.

Fire severity differences between various treatment combinations vs. untreated controls were also examined in terms of possible explanatory variables. Explanatory variables examined included height to canopy, canopy bulk density, residual tree diameter, weather conditions, and treatment age.

Our analyses confirmed both conventional wisdom and the variability of treatment effects. We also recognized the danger in extrapolating to other ecosystems/fire regimes. Also questions remain regarding duration of effectiveness, maintenance interval, and definitions of success. Other information voids include effects of climate change, plant successional status, and other disturbances on treatment effectiveness.

Evaluation at the Landscape Scale

While useful information for evaluating individual projects the study summarized above was conducted primarily to examine changes in fire severity between treated and untreated stands and left unanswered concerns about fuel treatments conducted at a landscape scale. For example, even though fuel treatments may reduce the severity of eventual wildfires, studies at the stand-scale provide incomplete insight into the optimal placement of treatments across a landscape.

Finney (2006) summarizes some of the considerations for evaluating the effectiveness of fuel treatments at the landscape scale. Using computer simulations, he examines probabilities for an area burning given a known perimeter or point subjected to fuel, topographic, and threshold historic fire weather distributions. His program FSPRO calculates probabilities of fire spread by simulating thousands of fire with different weather scenarios using a minimum-travel-time fire spread algorithm. He notes that the probability of burning is higher than ignition unless fuels are treated strategically across the landscape. Significant reductions in fire size and severity are possible treating as little as 20% of the landscape, if treatments are aligned strategically to retard fire spread and severity. Strategic placement takes advantage of reduced spread and severity at the stands collectively across the landscape, including shadow effects behind treated areas.

While promising, we need to recognize that insights from modeling rely generally on assumptions of fire spread algorithms that were developed for uniformly contiguous fuel beds that later were linked to crown fire equations developed from meager data sets collected elsewhere. In fact the spread model has been subjected to limited testing in a small number of fuel types and never thoroughly validated based on actual wildfires. Further, questions remain regarding the economic consequences of treatments implemented across a landscape.

Status of Knowledge

Our basic understanding of fuel treatment effectiveness has improved significantly in recent years due to shifts in priorities within the fire research community and incentives provided by programs such as the Joint Fire Science Program and National Fire Plan. At the same time, many gaps remain in our understanding of the biophysical, socio-economic, and policy implications of fuel treatment programs. Thus the status of our ignorance may be larger than our knowledge about fuel treatment effectiveness, except in the well-studied ecosystems that burn with low severity-high frequency, such as ponderosa pine.

The best test of fuel treatment effectiveness at the stand level is provided by wildfires that burn through comparable untreated then treated areas, in that order,

especially when information is available on pre- versus post-treatment structure and on-site burning conditions, i.e., fire weather. A fire integrates the influences of fuel, weather, and topography better than any model. Fires burning under more severe conditions provide better tests of effectiveness than relatively benign fires since treated vs. untreated differences provide insights to the stand's capability to withstand fire impacts. Even so, a single fire provides insights that are limited by the environmental conditions under which the burning occurs. More insights are gained when information is available on fuel treatment performance over multiple fires, spanning a range of environmental gradients.

A complex set of treatments (and effects) may follow in the many ecosystems that have missed fire cycles due to exclusionary practices. For example, mechanical thinning followed by mastication of surface fuels may be required to reduce fuel loads before fire can be restored safely as a management tool. Mechanical thinning and mastication involve numerous cost options, depending on machinery and pattern choices. Peterson and others (2005) describe six different thinning methods, each with different effects on canopy, soil disturbance (depending on machinery type), costs, and overall effectiveness, compared to the untreated condition.

Mastication or chipping of tree residues may have advantages in terms of retaining nutrients that can be cycled on-site, reducing fire potential and soil impacts, while removing host materials for insect pests (Fettig and others 2007). Crushing or mastication of shrubs may precede desiccation and burning of shrublands. On the other hand, the high levels of monoterpenes produced by chipping may attract bark beetle species and cause unintended tree mortality in forested areas.

Prescribed fire costs will vary depending on the ignition technique, firing pattern, season, and fire regime, among other variants. Risks of escape or unintended fire characteristics may affect treatment cost structure. Generally fire program analyses have difficulty analyzing more complicated or detailed treatment sequences.

In fact, fire program analysis may be largely disconnected from ecosystem restoration (and other concerns related to the wildland-urban interface, non-timbered resources, and firefighter safety) because of inattention to details. Further, we may not know how to measure the important metrics. Although much progress has been made possible through computer simulations, essentially unresolved is the payback or opportunities forgone as a result of treating the fuels in a stand or landscape. Thus, comprehensive assessment of important tradeoffs is difficult, if not impossible.

The evaluation of tradeoffs between fuel treatments and fire suppression is difficult due to problems in specifying the production function. The fundamental relationship between fuel treatment and fire suppression has defied specification because it is difficult to quantify the improvements in fire suppression (e.g., reductions in cost plus loss) made possible by treating fuels in advance. Davis (1965)

was among the first to point out this difficulty, but all the subsequent fuel treatment planning efforts alluded to earlier have struggled with this problem.

Computer modeling will no doubt continue to play an important role in future fuel management planning efforts. Unfortunately, all models are constructed with assumptions that limit their predictive or analytical capabilities. Simulation through models can provide a low-cost alternative to actual fires burning through treated vs. untreated areas, but simulated differences are mostly hypothetical guesses which may, or may not, be affirmed by future events.

Simulation and synthetic modeling can provide useful hypotheses that await testing, but also may leave unanswered the severity and impacts of the next wildfire, as well as questions related to cost-effectiveness or benefit-cost streams of a fuel management program. From a policy standpoint, analysts are also interested in relationships that link investments in fuel treatment with reductions in the cost plus loss (and net value change) of fire management.

Other important issues remain unresolved regarding the evaluation of fuel treatment effectiveness, but I'll mention just a couple more here. The first area of concern is the need for metrics in evaluating the evolving theory and practice of wildland fire use, especially as related to fuel hazard reduction but also with respect to ecosystem restoration. The second area of concern deals with the backlog of areas in need of treatment. There are certainly other areas of interest, but these three come to mind as requiring resolution if we are ever to estimate tradeoffs between hazardous fuel treatment, wildland fire use and fire suppression activities (the theme for this session).

Wildland Fire Use

Federal agencies are adopting appropriate management response (AMR) to contend with the expense of larger fires and longer fire seasons. Within AMR, wildland fire use is receiving greater consideration for managing incidents, especially where resource benefits may be associated with herding strategies for some lightning fires that meet pre-determined guidelines. From 1998-2006, an average 321 fires per year have been managed under WFU guidelines covering 160,000 ac (65,000 ha) (NIFC 2007). Over the long-term, increased reliance on WFU could increasingly be used for to fulfill fuel treatment objectives.

Recently, concerns have been aired that low intensity fires allowed to burn may produce fire behaviors (and subsequent fire effects) that are inconsistent with historical fire activity. In this context, questions are being raised about potentially negative consequences on structure and function of affected ecosystems, including invasive plants that will reduce the biodiversity of native flora and fauna. Contemporary prescribed fires would be expected to differ from historical fires with

respect to intensity and severity, but also in size and shape due to fire control lines and firing strategies.

As wildland fire use expands to areas outside remote wildernesses, similar concerns will likely arise regarding variances from historical norms of fire behaviour and effects. Fire managed under WFU guidelines tend to be applied at the same time of year and often with sole objective of reducing fuel loads (Cohen 2006). For creating defensible space around or adjacent to urban interface areas there may be no conflict. However conflicts will arise where the goal is restoration of natural processes and ecosystem health, especially where prescribed fires may not replicate historic natural fires. Examples where disparities may occur include chaparral shrublands and high elevation conifer forests. Chaparral shrub species, as in southern California, are uniquely adapted to survive and prosper in the presence of high severity fires that recur after several decades. Regenerative mechanisms, such as sprouting from root crown and soil seed banks insulated from but stimulated by high heat, tend to favor these fire-dependent native species over less successful competitors, such as exotic annual plants. By contrast, the recurrence interval in high elevation conifer forests may extend for hundreds of years between high severity fires, although every ignition may not result in a large fire, and hold-over fire activity may result in sporadic fire outbursts or runs covering thousands of hectares. In either case (chaparral or high elevation forests), low intensity fire prescriptions may not fulfil restoration objectives.

Fuel treatment backlog

Nationwide, an enormous backlog of areas in need of fuel treatment remains as a partial legacy of 20th century fire exclusionary practices. Bosworth (2003) projected a backlog of 30 million ha of national forest land at risk from wildland fires. For the continental US, an area 2-3 times this estimate may be in need of treatment to restore sustainability (e.g., after Schmidt and others 2002).

Other reasons contributing to the backlog include high handling costs and low incentives for the use, disposal, and processing of small-diameter trees (Abt and others 2006). Fear of prescribed fire escapes and aversion to smoke also figure prominently in slow progress toward reducing the backlog. Meanwhile, wildfires sweep through areas in need of treatment with a vengeance as evidenced by recent mega-fires and sieges. And even though wildfires may burn through large areas annually, the fuel profiles left behind may support recurrent fires of even greater severity in the future, thus adding to the backlog.

Conclusions

When timber production dominated US Forest Service management activities, analysts spoke of the need to consider the transition from the current situation (which at one time included substantial stands of old-growth) to the fully regulated forest. We find ourselves in a similar situation today, now that fuel treatments have replaced timber harvest as an agency focus, as fire expenditures may challenge nearly 50% of the annual budget. Instead of old-growth stands and mills suited to processing large-diameter trees, we are confronted with an enormous backlog of areas in need of treatment, supporting mostly small-diameter material. Wildland areas in need of treatment, whether for hazard reduction, ecological restoration, or both, stand little chance of withstanding a wildfire that occurs during peak burning conditions. Eventually the hope is to eliminate the fuel treatment backlog and regulate stands and landscapes on a periodic basis, depending on fire regime, values-at-risk, and safety considerations, among others. Analytical tools are needed for making wise economic decisions as the backlog is being reduced as well as for that future time period when the forest is fully regulated.

Budgetary analyses that rely on financial analysis of fire management alternatives have not so far produced satisfactory outcomes in terms of fuel management planning. There is a need to expand the current array of tools used to plan fuel treatments, but new approaches also may be necessary. Rather than attempting to optimize fuel management expenditures, agencies might consider admitting the difficulties and adopting different approaches, such as adaptive management.

The theme of this session begs the question whether or not hazardous fuels treatment and wildland fire use reduce suppression costs. Although available information is increasing, existing analytical tools still are unable to provide a definitive answer. This situation will likely persist for some time to come, especially so long as the production function for fuels treatment remains unspecified. Ultimately, understanding the human dimensions of fuel treatments may prove more important than solving the issue of tradeoffs.

Acknowledgements

I wish to thank the Joint Fire Science Program for supporting the research projects summarized here. Erik Martinson provided invaluable assistance as well.

References

- Abt, K.L., J. P. Prestemon, K. Ince., J. Barbour, R. Fight, and R. Rummer. 2003. The market economics of mechanical fuel treatments. Pre-prints for the 5th Symp. On Fire and Forest Meteorology and 2nd International Wildland Fire Ecology and Fire Management Congress, Orlando FL, 16-20 Nov. 2003. American Meteorology Society
- Agee, J.K. and Skinner, N.C. 2005. Basic principles of forest fuel reduction treatment. *Forest Ecology and Management* 211: 83-96.
- Bosworth, D. 2003. Fires and forest health: our future is at stake. *Fire Management Today* 63(2): 4-11.
- Cohen, D. 2006. Wildland fire use as a prescribed fire primer. *Fire Management Today* 66(4): 47-49.
- Davis, L.S. 1965. The economics of wildfire protection with emphasis on fuel break systems. Sacramento, CA: State of California, Dept. of Cons., Div. of For. 166 p.
- Finney, M.A. 2006. Spatial strategies for landscape fuel treatments. Presentation to Fuels and Fuel Management module, Technical Fire Management, March 14, 2006, Bothell, WA. Washington Institute.
- Fire Program Analysis website. 2005. Fire Program Analysis-Planning for the Future. History of the Legacy Systems: approx. 4:39 minutes. Pdf text of a video presentation available at <http://www.fpa.nifc.gov/Information/Presentations/index.html> (accessed September 28, 2007).
- Graham, R.T., McCaffrey, S., Jain, T.B. (tech. eds.). 2004. Science basis for changing forest structure to modify wildfire behavior and severity. Gen. Tech. Rep. RMRS-GTR-120. Ft. Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 43 p.
- Helms, J.A. 1998. The dictionary of forestry. Bethesda, MD: Society of American Foresters, 210 p.
- Hirsch, S.N., Radloff, D.L., Schopfer, W.C., Wolfe, M.L., Yancik, R.F. 1981. The activity fuel appraisal process: instructions and examples. Gen. Tech. Rep. RM-83. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 46 p.
- Kilgore, B.M. 1975. Restoring fire to national park wilderness. *American Forests* 81(3): 16-19, 57-59.
- Martinson, E.J. 2006. Assessing mitigation of wildfire severity by fuel treatments. Lesson plan. Forestry 423, Fuels Management, Humboldt State University.
- NIFC, 2007. Wildland Fire Use Fires (1998-2006). National Interagency Fire Center website, Wildland Fire Statistics. http://www.nifc.gov/fire_info/wfu_fires.htm. (Accessed Oct. 2, 2007).
- Omi, P. N. 1977. Long-term planning for wildland fuel management programs. Ph.D. Diss., Univ. of California, Berkeley. 133 p. Univ. Micro. No. 78-12720.
- Omi, P.N. 2005. Forest fires: a reference handbook. Santa Barbara: ABC-CLIO Publishing Co. 347 p.
- Omi, P.N., Martinson, E.J. 2002. Effect of fuels treatment on wildfire severity. Final report to the Joint Fire Science Governing Board. Colorado State University, Fort Collins.
- Omi, P.N., Martinson, E.J., and Chong, G.W. 2006. Effectiveness of pre-fire fuel treatments. Final report: Joint Fire Science Program project 03-2-1-07.

- Omi, P.N., Teeter, L.A., Dyer, A.A. 1986. The national fire management analysis system and fire economics evaluation system: a comparative analysis. In: Proc. of the Symp. "Fire Management: the challenge of protection and use." (J.N. Long, ed.), Logan, UT (April 17-19, 1985). Cosponsored by Dept. of For. Res., Utah State University, Intermtn. Soc. of Amer. For., USDA For. Serv., and Nat. Wildlife Coordinating Group.
- Peterson, D.L.; Johnson, M.C.; Agee, J.K.; Jain, T.B.; McKenzie, D., Reinhardt, E.D. 2005. Forest structure and fire hazard in dry forest of Western United States. Gen. Tech. Rep. PNW-GTR-628. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 30 p.
- Pollet, J. and Omi, P.N. 2002. Effect of thinning on wildfire severity. *Int. J. Wildland Fire* 11:1-10.
- Schmidt, K. M., Menakis, J.P., Hardy, C.C., Hann, W.J., and Bunnell, D. L. 2002. Development of coarse-scale data for wildland fire and fuel treatment. Gen. Tech. Rep. RMRS-87. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 41 p.

Prescribed Fire Use for Cost-Effective Fuel Management in Spain¹

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Abstract

Prescribed fire use for cost effective fuel management (and other objectives as well) is rising in some regions of Spain. At a lower scale, wildland fire is used for the same purposes. This study details fire use in both Catalonia and in Canary Islands. Wildland fire regimes are changing in Catalonia (NE Spain) and (Canary Islands, SW Spain) and large wildland fires (LWFs) are more likely to occur while most fires are suppressed very soon. This is a major change in the disturbance regime and it is a real threat for biodiversity and for total cost of fire management (fire losses, post-fire restoration, fire suppression and fire prevention expenditures). This paper studies cost effectiveness of prescribed burning as a mean to create fire resistant stands to allow wildland fire control. It is based in the current (2000-2008) prescribed burning program in both regions. We explicitly bear in mind the benefits that prescribed burning provides to instruct firefighters and to help them with the necessary skills to later use fire as a forest fire suppression tool. Prescribed fires seem to be very efficient in maintaining those shaded fuel breaks accomplished firstly with both mechanical removal (mastication) and prescribed fire itself. We are involved not only in setting fuel-breaks but in providing strategic locations for those (after Farsite and FlamMap simulations). In this paper, we also show several case studies.

Keywords: Prescribed fire, wildland fire use, cost effectiveness simulation, Farsite, FlamMap.

¹ An abbreviated version of the paper was presented at the Third International Symposium on Fire Economics, Planning, and Policy: Common Problems and Solutions, 29 April – 2 May, 2008; Carolina, Puerto Rico

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Assessment of prescribed fire use in two regions of Spain

Prescribed fire is a widely use tool in forestry and fire protection in many countries (Molina 2000a and b) and its use is increasing. Our first study case is in NE Spain, Catalonia. Since 1999 firefighters of “Generalitat de Catalunya” are using prescribed burning in different types of forest structures, and under different management goals which are within the scopes of pre-suppression planning and forest management (Castellnou and others 2002, Larrañaga and others 2006). There have been 490 ha (table 1) treated by firefighters with prescribed fire as a management tool since 1999. Additionally, we presume that this technique will continue to be used in the future.

Pre-suppression assembles all treatment aimed to transform or maintain a forest structure that can be used safely and efficiently to anchor fire suppression actions. Forest management gathers different objectives: tree thinning, range improvement, habitat restoration for wildlife and the fuel management (fuel breaks) to protect wildland / urban interface areas.

Prescribed burning as a forestry tool has required a high effort in communication and training to overcome the initial distrust and weirdness. In order to reach acceptance, a detailed assessment of costs and efficiency of both traditional tools and fire should be carry out. The study is analyzing costs and productivity for different objectives and structures treated. The final assessment will be defined by the restrictions established (by the owner or the Forest Service) which in turn depends on the management objective. This allows us to start a technical discussion about productivity and profitability of prescribed burning to compare with other treatments.

Table 1-- number and area of prescribed burns by type that involved firefighters in Catalonia (NE Spain) from 1999 to 2006.

<i>Prescribed burn type</i>	<i>number</i>	<i>number (%)</i>	<i>Area (ha)</i>	<i>Area (%)</i>
Strategic sites for fire suppression	32	43	66	135
Fuel breaks	13	18	76	15.5
Industry Empty Lots / Urban Interface	5	7	6	1.3
Wildland Urban Interface	4	5	16	3.3
Research sites	2	3	2	0.4
Range improvement	16	22	324	66.2
Total	74		490	

Mean burn size is 6.6 ha, ranging from research sites (< 1 ha) to range enhancement sites where mean size is 20 ha.

To assess both resources and safety needs, there was necessary to classify how difficult a given prescribed burn is. We consider that there are two major factors to

this: a) fuel continuity (horizontal and vertical or fuel ladder) and b) objective of the burn.

In Catalonia, prescribed burning mean cost is 1200 €/ha for major types (Strategic sites for fire suppression, Fuel breaks and Range enhancement that amount for 70% of all surface treated). Individual costs and number of person per day and hectare are displayed in Table 2. We can observed that range enhancement objective reflect the best performance.

Table 2-- cost and persons involved in each prescribed burn type that involved firefighters in Catalonia (NE Spain) from 1999 to 2006.

<i>Prescribed burn type</i>	<i>Cost (€/ha)</i>	<i>Person-day/ha</i>
Strategic sites for fire suppression	1247	8
Fuel breaks	1379	10
Industry Empty Lots / Urban Interface	1148	9
Wildland Urban Interface	566	3
Research sites	2727	19
Range improvement	242	2

Since 2002, Gran Canaria Forest Service is implementing a fuel management program that includes prescribed burning operations either alone or in combination with mechanical treatments (i.e., mastication). Additional details can be read in Molina et al (2006). In Gran Canaria, prescribed burning is aimed not only to mitigate wildland fire hazard but also to enhance rangelands and to favor forest restoration programs. A total of 103 burn units so far that means 166.5 ha of wildlands (Table 3) from 2002 to 2006. This is an equivalent to 0,27% of the total wildland area in the island. It is important to mention that additional objectives of these prescribed burns were research and the protection of special infrastructures (telecommunication towers).

Table 3-- number and area of prescribed burns by type that involved firefighters in Gran Canaria (Insular SW Spain) from 2002 to 2006.

<i>Prescribed burn type</i>	<i>number</i>	<i>number (%)</i>	<i>Area (ha)</i>	<i>Area (%)</i>
Site preparation before reforestation	7	6,8	24	14,4
Young forest stands	9	8,8	13,5	8,1
Range enhancement	3	2,9	20,8	12,5
Savannas	6	5,8	32,7	19,6
Fuel breaks	34	33	30,5	18,3
Infrastructure protection	38	36,9	39,4	23,7
Wildland Fire Research	6	5,8	5,6	3,4
Total	103		166,5	

Some costs and number of person per day and hectare are displayed in Table 4. These are estimates that are not as precise as those shown in table 2 for Catalonia. We can observed that range management objective reflect the best performance.

Table 4-- cost and persons involved in each prescribed burn type that involved forest Service personnel in Gran Canaria (Insular SW Spain) from 2002 to 2006.

<i>Prescribed burn type</i>	<i>mean ha/day</i>	<i>Cost (€/day)</i>	<i>Cost (€/ha)</i>
Site preparation before reforestation	3,4	1500	441
Young forest stands	1,5	1500	1000
Range enhancement	6,9	1500	218
Savannas	5,5	1500	273
Fuel breaks	0,9	2800	3111
Infrastructure protection	1,0	2800	2800
Wildland Fire Research	0,9	2800	3111

If we compare the two territories, there is a yearly mean of 36.3 ha burned (0.27%) by Gran Canaria Forest Service while there is a mean of 81.6 ha burned (0.025%) by Catalonia Fire Fighting Department. This is more than ten times larger in relative terms in Gran Canaria, although in absolute terms it is larger in Catalonia. In El Hierro Island (Canary Islands as well), local Forest Service is willing to start a prescribed burning program. There are three main reasons for this move:

- some profitable technical visits to Gran Canaria prescribed burning experiences.
- mechanical (mastication) fuel treatments are more expensive in El Hierro ranging from 2000 to 4000 €/ha in El Hierro.
- prescribed burning operations are excellent training opportunities to personnel that will be involved latter in fire control operations.

Concluding remarks

The last reason is going to be the topic for our conclusive remark. We strongly believe that in order to provide the best training to fire suppression workers prescribed burning is only second to real wildland fires. Some workers ready to be dispatched to a wildland fire that might have attended to a last fire weeks or months earlier. This means that they do not have much real experience in fire. Most likely they do not have the necessary competency to work towards a effective and safe control of the fire perimeter. With prescribed burning operations, we can provide the extra hours that those employees need to better understand fire behavior changes (due to subtle changes in fuel model, fuel moisture content, exposure to the sun, etc), we

can train them actively in fire suppression actions, in fire-fighters' safety issues (Beaver 2001, Pous & Molina 2005, Pous & Molina 2006), communication efficiency, and also in fire effects in vegetation. Therefore, as we can profit so much from training options, the net cost of prescribed burning per hectare may be easily assess as lower than reported earlier. This is specially true in Canary Islands where some years there are very few wildland fires to keep fire-fighters well trained in real fire suppression actions.

References

- Beaver A.K. 2001. Evaluating risk and reward relationships in wildland firefighter safety. Proceedings of the 5th International Fire Safety Summit. International Association of Wildland Fire. Missoula, MT.
- Castellnou, C, Molina, D., Messagué, S., Dalmau, E. & Galán, M. 2002. Fuel Management Philosophy and programme in Catalonia. In *Stratégies de prévention des incendies dans les forêts d'Europe du Sud*. Bordeaux France 31-01-2002: 02-02 2002; Collection Actes, Editions Préventique, pp. 95-102.
- Larrañaga A., Galán M., & Pellisa O. 2006. Discussion about the analysis of costs of the prescribed burns in the fields of pre-extinction and forest management. Evaluation of 6 years of experience in Catalonia.. V International Conference on Forest Fire Research, Figueira da Foz, Portugal.
- Molina, DM; Grillo, F; Garcia, D, 2006. Uso del fuego prescrito para la creación de rodales cortafuegos: estudio del caso "Las Mesas de Ana López", Vega de San Mateo, Gran Canaria, España. *Invest Agrar: Sist Recur For* (2006) 15(3), 271-276, Madrid [http://www.inia.es/gcontrec/pub/271-276-\(15\)-Uso_del_fuego_1166008640062.pdf](http://www.inia.es/gcontrec/pub/271-276-(15)-Uso_del_fuego_1166008640062.pdf)
- Molina, DM. 2000a. El fuego prescrito. En Vélez, R. (Ed): *La Defensa Contra Incendios Forestales Fundamentos y experiencias*; McGraw-Hill, pp. 14.36-14.41.
- Molina, DM. 2000b. Planes de quemas. Prescripciones. En Vélez, R. (Ed): *La Defensa Contra Incendios Forestales Fundamentos y experiencias*; McGraw-Hill, p. 14.42-14.61.
- Pous, E. & Molina, DM. 2005. Methodological proposal hazard abatement actions in prescribed forest fires operations. In: "II International conference on prevention strategies of fires in Southern Europe" Barcelona (Spain) 9-11 Mayo 2005.
- Pous, E. & Molina, DM. 2006. Job Hazard Abatement Actions In Both Prescribed Fire And Backfire Operations In Gran Canaria (Insular SW Spain), 15p. V International Conference on Forest Fire Research, D. X. Viegas (Ed.), 2006.

Mapping Tradeoffs in Values at Risk at the Interface Between Wilderness and Nonwilderness Lands¹

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Abstract

On the Flathead Indian Reservation in Montana, U.S., the Mission Mountains Tribal Wilderness is bordered by a buffer zone. To successfully improve forest health within that buffer zone and restore fire in the wilderness, the managing agency and the public need to work together to find solutions to increasingly threatening fuel buildups. A combination of qualitative, culturally sensitive research and a web-based mapping exercise have been used to develop understanding of the tradeoffs Reservation residents describe in relation to potential buffer zone actions. The primary meanings Tribal members associate with the Buffer Zone are protection of the wilderness, wildlife and water quality, access and functional attachments, recreation and scenic values, and personal and cultural meanings. To build trust among both tribal and non-tribal residents, fire planners must understand how proposed actions interact with values at risk assigned by the local community and describe a prioritization process that addresses publicly perceived threats

Keywords: Buffer zone, cultural landscapes, fuel treatment, geographic information systems.

Introduction

The urgency to restore fire across the landscape is growing annually, due to uncontrollable wildfires becoming more common across the western U.S., and climate change and encroachment of human settlement on fire-based ecosystems (Miller 2006). Years of active

¹ An abbreviated version of this paper was presented at the Third International Symposium on Fire Economics, Planning, and Policy: Common Problems and Approaches, 29 April – 2 May, 2008, Carolina, Puerto Rico,

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fire suppression has led to the build up of hazardous fuel loads creating ideal conditions for destructive wildfires (Johnson et al. 2001). Currently, fire management is very focused on re-instating natural fire regimes through progressive fuel treatment and allowing fire, as nearly as possible, return to function in its natural ecological role (Miller 2006). Thinning and burning are being used to reduce fuel loads to near natural conditions, after which natural fire regimes can be allowed to operate. To instil trust and accomplish resource management objectives, a high degree of collaboration and participatory planning with the public is needed (Liljeblad and Borrie 2006). Among the key contributors to trust in fire and fuel management decisions is procedural justice (Liljeblad and Borrie 2006), or the perceived fairness, equity and legitimacy of decisions managers make. People want to be assured that managers understand the values they attach to forest lands and these values are at least considered in decision making.

Throughout the western U.S., rural communities and federal, state and local agencies are working cooperatively to initiate plans for reducing risks associated with the build-up of hazardous fuel on forest and grass lands. Critically important in accomplishing fuel treatment and fire management objectives is the interface between wilderness and non-wilderness lands (Gunderson 2006). In designated Wilderness, the use of wildland fire, including prescribed burns, can help restore the natural role of fire as well as create a buffer along the wilderness boundary to protect non-wilderness values associated with adjacent lands. This paper describes a participatory process and methodology that has been developed to help capture personal and community meanings (or values at risk) associated with a landscape for the planning and potential application of fuel treatment and fire management. The aims of the project are to:

- Describe meanings residents place on the landscape within the Tribal Buffer Zone on the Flathead Indian Reservation with the ultimate goal of using this local knowledge to better understand tradeoffs in values at risk in forest fuel reduction strategies implemented by the Tribal Forestry Department; and
- Map these values for the Tribal Buffer Zone to understand the intensity and spatial distribution of individual and community meanings associated with this landscape of contested meanings.

Background

On the Flathead Indian Reservation in Montana, an interface area exists between the Mission Mountains Tribal Wilderness and the non-wilderness valley floor. The area, formally protected as the Mission Mountains Tribal Buffer Zone, was established in 1987 in the foothills of the Mission Mountains with the intention of protecting the Wilderness from outside influences; primarily human civilization and development on the valley floor (Figure

1). This interface area provides opportunities for multiple uses, including cultural uses, some home sites, recreation, and other consumptive and non-consumptive resource uses.

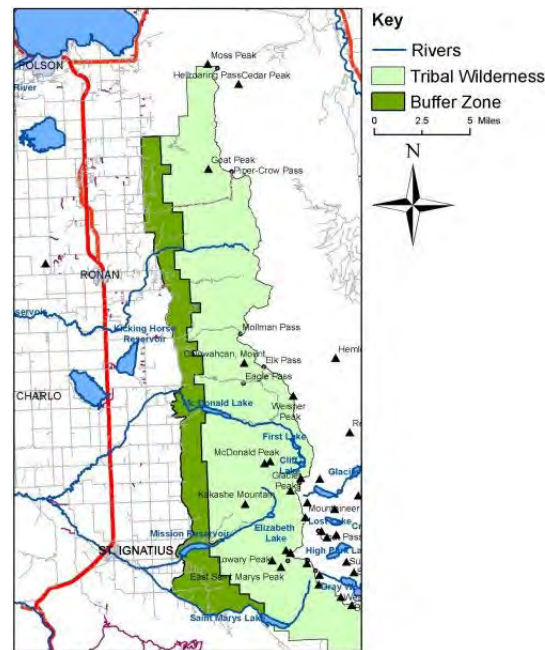


Figure 1-- The Mission Mountains Tribal Wilderness and Tribal Buffer Zone extend north to south along the eastern border of the Flathead Indian Reservation.

One of the primary concerns within the study area is the effect that fire suppression has had on the structure and general health of the forest within significant portions of the Buffer Zone. Large fires in 1910 contributed to intolerance and immediate suppression of most fires throughout the West in most of the 20th century (Aplet 2006). Both the Tribal Wilderness and the Buffer Zone exhibit heavy and hazardous accumulations of dead wood and down timber on the forest floor, a dense understory of brush and young trees, and closely spaced trees and closed forest canopy (CSKT 2005c). Such forests are increasingly regarded as “unhealthy” and highly susceptible to destructive wildfires, as well as to insects. In contrast, the traditional culture of local tribes included the use of fire as a tool to nurture and sustain the natural resources of the land. Tribal people used fire on a vast scale applying it to the land at different times of the year for various reasons. This included the thinning of dense brush in forested areas to keep them “clean” for wildlife and hunting, clearing of trails for travelling, and nurturing of food and medicinal plants for subsistence use. In the 19th Century, native use of fire began to be altered as European settlement expanded into the West, and by the early 20th Century, following these devastating fires of 1910, the traditional use of fire by tribal people was largely eliminated. Tribal resource managers now employ modern fire management

techniques, though with consideration of the cultural values ascribed to the land (CSKT 2005a).

The current focus of resource managers is on how to reduce potentially hazardous fuel loads in the Buffer Zone in order to address “emerging issues of public and firefighter safety, reduce the risk of large high intensity fires, and restore the forests to a more biologically balanced condition” (CSKT 2005b, p.1). However, past proposals to change the Buffer Zone classification from unavailable to available for timber harvest have failed due to lack of support among Tribal members. The current process therefore uses participatory methods adapted from a previous project in the adjacent Bitterroot National Forest (Gunderson and Watson 2007) and expanded to use web-based mapping methods developed in the UK (Carver et al. 2001; Evans and Waters 2007) to better capture how Tribal and non-tribal Reservation residents relate to the Buffer Zone and the threats they perceive to this relationship.

Participatory approaches to understanding values at risk

One of the key problems in developing a better understanding of different responses to landscape level management actions, such as fuel treatments, is being able to confidently record and accurately spatially delineate the meanings stakeholders ascribe to the landscape. Previous methodology development work on understanding personal and community values at risk and mapping them as input to landscape-level fuels treatment (Gunderson 2006, Gunderson and Watson 2007) utilized semi-structured interviews, key informant interviews and focus groups to encourage people to talk about their local landscape, to differentiate between the meanings associated with places they commonly went and those they seldom or have never visited, explore the scale of these meanings through mapping exercises and discuss how these meanings interact with intentional fuel treatments. Maps were then digitized and imported into GIS for display during decision making on location of fuel treatment activities and techniques used.

Being able to actually map and discuss the different meanings people place on the landscape in this fashion has a number of advantages over less place-based techniques. These include the ability to link meanings to specific locations or landscape units, and perform advanced analyses on responses by looking at spatial relationships based on proximity, adjacency, containment, connectivity and visibility. “Hot spot” areas could be delineated through categorizing and displaying information such as number of people indicating a particular spot, the importance people gave to that indicated spot and the specificity of the area indicated.

Despite success in previous methodology testing, a number of shortcomings were identified in the mapped-based aspects of methodology developed. Of particular need for improvement was the need to increase the number of people engaging in this map-based activity. The cumbersome task of a researcher meeting with every person, or even focus group discussions, and leading them through a pencil and paper exercise while trying to either record or note things they say about these important areas was a very difficult task. An individual's relationship with a local landscape is essentially fuzzy and cannot be easily captured using traditional map-based features or entities such as points, lines and polygons. So, while scale is captured, it is not captured efficiently, and the intensity of meanings attached to places was not captured at all.

In order to address these issues, the current project adopts more fuzzy methods of capturing the landscape areas that people value or for which they hold a particular meaning. This is based on the application of a Java-based mapping Applet called "Tagger" that uses a spray-can tool to allow users to define areas on a base map in a manner that allows them to easily vary the density and shape of the sprayed area (Evans and Waters 2007). This tool captures fuzzy spatial concepts in defining relationships, as well as (un)certainity and importance in the relative meanings attached to these places. The system can be used both online over the internet and offline on a stand-alone laptop computer.

Methodology

An expanded rapid appraisal technique (Beebe 1995) is used to direct three phases of data collection. Each phase is guided by a specific objective as follows. In Phase 1 key knowledgeable informant interviews were used to develop an understanding of the range and types of meanings attached to the Mission Mountains Tribal Buffer Zone and for contrast, also the Wilderness, by both Tribal members and non-tribal member residents on the Flathead Indian Reservation (Watson et al. in press). In Phase 2, participatory GIS methods were used to visually illustrate the intensity and spatial distribution of the meanings differentiated in Phase 1, and record perceived threats to these meanings, within only the Buffer Zone. In Phase 3 focus group interviews are being used to better understand the interaction between mapped landscape meanings from Phase 2, perceived threats, and potential fuel treatment options.

Phase 1: key informant interviews

Semi-structured interviews were conducted with Tribal members and non-tribal Reservation residents to solicit information on the range and types of meanings associated with this landscape (Wilderness and Buffer Zone). Following the work of Lewis and Sheppard (2005), key informants were selected to meet the following criteria: 1) knowledge, understanding and appreciation of traditional Tribal and non-tribal meanings associated with the landscape; 2) roles in the community that require a wide exposure to a range of Tribal and non-tribal

perspectives and perceptions of the landscape; and 3) ability to communicate with outsiders and ability to discuss relevant research issues in detail.

Twenty-two interviewees were asked to provide information about the meanings attached to the landscape in interviews scheduled and conducted at the convenience of the interviewee. These analyses and results are described in detail by Watson et al. (2007) and Watson et al. (in press).

Phase 2: landscape mapping

The actual methods used here to capture spatially fuzzy locations draw strongly on previous work on mapping place meanings (see Gunderson and Watson 2007) and on participatory GIS (see Carver et al. 2001 and Evans and Waters 2007). These methods are brought together in developing a fuzzy GIS-based tool for collecting qualitative, but spatially referenced, local knowledge and meanings from key informants and a broad public representing both Tribal and non-tribal residents. These are analyzed by creating composite maps of the fuzzy attribute-tagged maps generated by survey respondents and linking these to comments solicited during the mapping exercise and attached to the maps generated. The result of this phase of the project is a GIS dataset that provides a visual representation of the intensity and spatial distribution of meanings associated with the Buffer Zone, as well as comments on threats to these meanings.

All but one of the twenty-two interviewees from Phase 1 of the project were also engaged in Phase II, as well as obtaining additional input from other residents within the region via an online version of the system. Whereas it is believed possible to reach saturation in regard to the range and types of landscape meanings through 15-20 key informant interviews, research by Gunderson (2006) would suggest that greater numbers of Phase 2 respondents are required to capture the richness and variation in the spatial distribution of these meanings. Initially, thirty-four subjects participated in a test of the system to determine feasibility of this computer-based substitution for the paper and pencil method used previously. Some data were collected offline with a laptop computer. Some were done online via the web. All offline exercises were assisted by one of the research team, sometimes to make it easier for high priority participants (e.g., elders or previous participants) to engage and sometimes due to deficiency in computer skills or internet access. While the web-based exercise is open for a prolonged time to allow community participation and greater confidence in generalization, this paper illustrates results from only the initial thirty-four subjects.

Data were collected in a way that generated five map layers of themed meanings. These were driven by the Phase 1 findings and represent the meanings of the Buffer Zone for Tribal members: “protection of the wilderness,” “wildlife and water quality,” “recreation and scenic values,” “access and functional attachments,” and “personal and cultural” meanings. For demonstrative purposes, this paper focuses on 154 images developed by these 34 subjects across the five themed layers. For the overall map and categorization process, these 154

images are averaged and images produced using classes based on natural groupings inherent in the data with break points identified by picking the class breaks that group similar responses and maximize the differences between classes (Jenks 1967). For analysis purposes, the five individual meaning layer images are then presented, based on the same classification scheme used to develop the “overall mean” image. Additional analysis is possible and demonstrated by single layer analysis using the Jenks classifications generated from within the responses to a single meanings layer.

Phase 3: focus group interviews

The objectives of the third phase of the project are to present the GIS output outlined above and collaboratively discuss these with Tribal members and non-tribal residents in regard to the potential effects of different fuel treatment methods in the Buffer Zone. At the time of writing, this work is still ongoing. At least two focus group interviews will be conducted, facilitated by research team members. Phase 3 also serves the very positive purpose of informing the public that their views are valued and are being incorporated into the planning process thereby helping to break down one of the main barriers in accomplishing resource management objectives, maintaining trust.

Development of the landscape mapping tool and user interface

The main user interface is based around the “Tagger” fuzzy area definition software developed by Evans and Waters (2007) as a Java applet running within a standard web browser environment. This uses a spray can tool with which a user can define fuzzy areas of varying density on a map. Variations in intensity, or importance, can be easily made by spraying more or less over an area, making it correspondingly darker or lighter. Attribute information can be attached to the fuzzy area through the use of free-format text input boxes. The basic interface consists broadly of: a spray can tool that enables the user to spray fuzzy areas on a map; radio buttons to select small or large spray sizes; an Erase button to remove any spraying from the current map; a New Area button to save the current sprayings and allow the user to spray another area; a Paint All button that opens up a dialog window asking for a number from 0-100% to uniformly spray over the whole area; a Send Everything button that sends all the saved sprayings and attached attributes to the server; and text areas where the user is asked to answer “Why are areas important?”, and “What are the threats to these areas?”

Users progress through the application in a linear fashion as follows: 1) Welcome and outlining of the tasks and any technical requirements needed; 2) Background information about the project, fire and fuel treatments and the area of the Buffer Zone; 3) Introduction to the mapping system, explaining concepts such as “The longer you hold down the mouse button the darker it gets. The darker it gets means it has more importance” showing examples, and how users can use the mapping tool to indicate intensity; 4) Practice page, which helps people become familiar with the spray can mapping tool; 5) Questionnaire, with questions

about age, gender, residence, tribal membership, zip code, and whether they were doing the exercise individually, or in a group; 6) After the questionnaire, each person is asked to “Please show on the next map those areas that are most important to you...” for each of the five layers of meanings described in Phase I. An option is given to skip a map, if desired. 7) Maps were given (in random order, to help reduce bias) for each layer: a) Wildlife & Water Quality; b) Access and Functional Attachments; c) Protection of the Wilderness, d) Personal and Cultural Meanings; and e) Recreation and Scenic Values; 8) Besides indicating on each map where the most important areas were, they also answered the questions “Why are these areas important” and “What are the threats to these areas 9) After completing all the maps, a thank you page is shown together with further details about the project.

Each sprayed area entered by the user is processed by the Tagger software into a standard image format (gif and GeoTIFF) and compressed. The image and associated attribute information are stored and can be viewed either as an individual entity or combined into an aggregate “average” map based on all the users’ responses. The Tagger system also includes a query function, where researchers can click on the composite image of everyone's responses and query this area for the text associated with that area, weighted by intensity. Additional administrative tools include the ability to examine, delete or edit individual maps and textual responses.

Results

The results from the Phase 2 mapping exercise are shown in Figure 2 as an overall average across 154 user-created maps. These data are preliminary, representing the initial effort at obtaining public participation in this process. A mixture of online (web-based) and offline (laptop-based) participants were included and results monitored to assure quality of data capture. After this preliminary data collection with the thirty-four participants, the wider public was invited to participate in this process via the local media including announcements in the local, weekly newspaper and on the tribal government intranet web site appearing on every employee’s log-in page.

It can be seen from the averaged maps in Figure 3 that there are marked differences in the spatial pattern and intensity of meanings associated with the five themes. It should be noted that in order to aid comparison, the same classification and color scheme is used for all five theme maps and the overall average map.

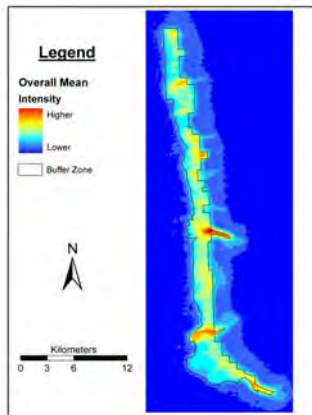


Figure 2-- Composite map for overall averaged results (Jenks method,10 categories)

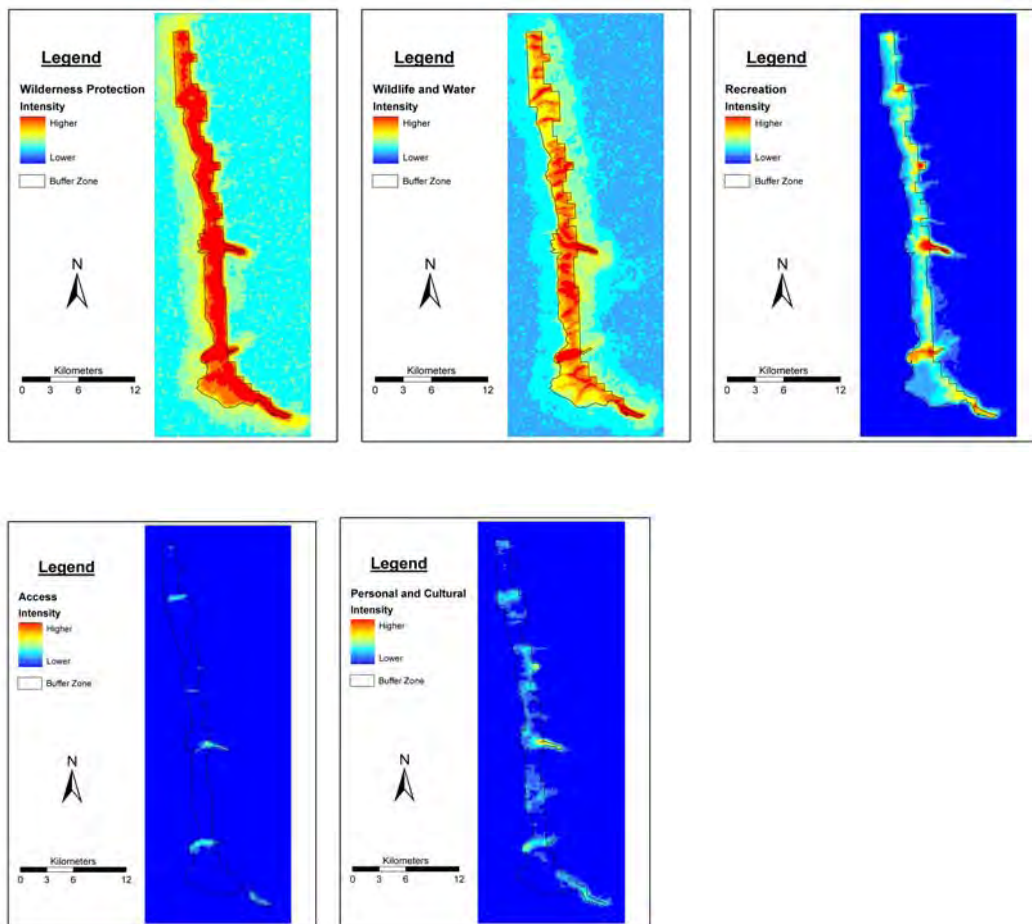


Figure 3-- Results for all 5 layers of meanings attached to the Buffer Zone by Tribal and non-tribal residents (10 categories – Jenks method from Overall Average)

Of the five themes, protection of wilderness shows the greatest uniformity, perhaps as a result of the general view among respondents of the Buffer Zone as a policy zone with universal value throughout. A significant proportion of users used the “Paint All” button to apply a uniform spray density over the whole area for this theme to indicate value that is broad in scale (covering the whole Buffer Zone). The access theme exhibits the least extent of coverage of important places, likely due to the presence of privately owned land within the buffer zone and the limited number of access points to the wilderness. Hot spots within the recreation and scenic values layer reflect the location of access corridors and are possibly driven by frequency of visits to several popular sites within the Buffer Zone or Wilderness. It is clear that more remote and inaccessible areas are also highly valued and have meaning for several of the layers. The map for wildlife and water quality shows perhaps the greatest spatial variation of all the five themes with users identifying areas not in easily accessed or frequently used areas, but on their environmental credentials for wildlife and water protection.

Since “protecting the wilderness” is the broadest meaning assigned to the buffer zone among the subjects, for illustrative purposes, the results of threats reported by subjects is presented here. For thirty-four tribal and non-tribal residents, the perceived threats to this community meaning were basically in four categories: threat of wildfire, intense logging, roads and development, and off-highway vehicle use.

The threat of wildfire was prominently attributed to “80 plus years of fire restriction,” and fears they would potentially be “started by careless people.” “Uncontrolled fires now would be disastrous,” due to “fire exclusion for so long.” “Doing nothing” remains to be a threat to the function of the buffer zone to function as a protector of the wilderness. People realize the buffer zone is “over stocked” or “dense,” there is a “fuel buildup,” of concern, particularly the potential of “a stand replacing fire now.” The “hazard” associated with potential wildfire due to changes in vegetation and fire exclusion is a dominant theme for threats to this area’s ability to protect the wilderness.

While potential for wildfire was broadly recognized by many subjects, logging is also commonly listed among threats, giving rise to the dilemma tribal resource managers face. The threats are most commonly described as “over use by modern machinery,” “intense logging,” “commerce,” “extreme logging,” “commercial logging,” and “large scale logging,” giving suggestion that people are concerned not just about logging, but the scale and intensity it might entail.

Not particularly related to the purpose of this paper, but also significant threats to the buffer zone are concerns residents have about perceived growth in road access, subdivision of property, and ATV and motorcycle use on and off roads. Some miscellaneous threats attached to specific areas in the buffer zone were cattle grazing, recreation over use, horses, litter, weeds, impacts to water quality, and insect outbreaks. While a larger proportion of subjects indicated this meaning was attached broadly to the buffer zone than for other, more specific

meanings, many of these threats were attached to specific places in the buffer zone, providing some opportunity to base discussions about priorities for management actions.

An additional level of analysis is presented for the “protection of wilderness” layer. In this case (Figure 4) the Jenks method was used to map averages across all subjects (30) for this meanings layer. Within this data set, some highest priority areas emerge

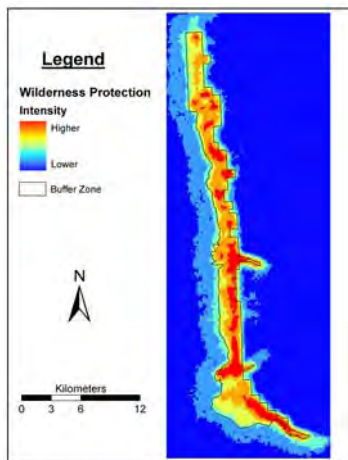


Figure 4-- Results for all “protection of wilderness” layer of meanings attached to the Buffer Zone by Tribal and non-tribal residents (6 categories – Jenks method)

Conclusions

This paper describes a new planning support system aimed at collecting spatial and contextual information about public perceptions of landscapes to develop better understanding of place-based values. The three phase approach used here demonstrates a rigorous approach to participation and data collection in developing publicly acceptable management strategies and actions in the face of multiple, spatially variable and sometimes conflicting viewpoints. The process described involves a mix of both face-to-face and automated methods of data collection using key informant interviews to inform the development and application of automated methods of spatial and attribute data capture using map-based computer interfaces.

Mapping results assume prior success in capturing the richness of meanings attached to the complex buffer zone landscape. The combination of user-defined fuzzy areas and qualitative data collection methods has enabled a wide range of personal and community meanings to be spatially delimited across a broad area. Automated data collection and 24/7 availability of the online version of the system also means that the work can span a far greater audience than would be possible via traditional face-to-face or paper-based social survey methods, making detailed and disaggregated analyses possible with higher numbers of respondents. In addition, the

linkage of themed spray patterns and tagged attributes with user profiles makes detailed analysis of differences between different demographic and/or stakeholder groups possible. For example, in the final analysis, focus will likely be on Tribal member responses, though understanding of non-tribal responses is also of interest to land managers and the Tribal Council. The resulting dataset and possibilities for further analysis represents an extremely rich resource for policy development in regard to resource management that takes both public perceptions and the realities of the physical world into account.

Acknowledgements

The collaboration between the Confederated Salish & Kootenai Tribes, the Aldo Leopold Wilderness Research Institute, the University of Leeds and the University of Montana was primarily supported by these institutions with funding from the U.S. National Fire Plan and the Bitterroot Ecosystem Management Research Project.

References

- Aplet, G.H. 2006. Evaluation of wilderness fire policy. *International Journal of Wilderness* 12(1):9-13.
- Beebe, J. (1995) Basic concepts and techniques of rapid appraisal, *Human Organization* 54(1): 42-51.
- Carver, S., Evans, A., Kingston, R. and Turton, I. (2001) Public participation, GIS and cyberdemocracy: evaluating on-line spatial decision support systems, *Environment and Planning B: Planning and Design*. 28(6): 907-921.
- Confederated Salish and Kootenai Tribes (CSKT). (2005a) *Confederated Salish and Kootenai Tribes Forestry Department Wilderness Buffer Zone Reclamation Environmental Assessment* (Report prepared by the Buffer Zone Interdisciplinary Team), Confederated Salish and Kootenai Tribes of the Flathead Indian Reservation, Pablo, MO.
- Confederated Salish and Kootenai Tribes (CSKT). (2005b) *Fire on the land: An interactive educational DVD*. Confederated Salish and Kootenai Tribes of the Flathead Indian Reservation, Pablo, MO.
- Confederated Salish and Kootenai Tribes (CSKT). (2005c) *Ecosystem Management on the Flathead Indian Reservation* Confederated Salish and Kootenai Tribes Forestry Department, Pablo, MO.
- Evans, A.J. and Waters, T. (2007), 'Mapping Vernacular Geography: Web-based GIS Tools for Capturing "Fuzzy" or "Vague" Entities', *International Journal of Technology, Policy and Management* 7(2): 134-150.
- Gunderson, K. (2006) Understanding place meanings for wilderness: personal and community values at risk, *International Journal of Wilderness* 12(1): 27-31.
- Gunderson, K and Watson, A. (2007) Understanding place meanings on the Bitterroot National Forest, Montana, *Society and Natural Resources* 20: 705-721.
- Jenks, G.F. (1967) The Data Model Concept in Statistical Mapping, *International Yearbook of Cartography* 7: 186-190.
- Johnson, E.A., Miyanishi, K and Bridge, S.R.J. (2001) Wildfire Regime in the Boreal Forest and the Idea of Suppression and Fuel Buildup, *Conservation Biology* 15(6): 1554-1557.
- Lewis, J.L. and Sheppard, S.R.J. (2005) Ancient values, new challenges: Indigenous spiritual perceptions of landscapes and forest management, *Society and Natural Resources* 18: 907-920.
- Liljeblad, A. and Borrie, W.T. 2006. Trust in wildland fire and fuel management decisions. *International Journal of Wilderness* 12(1): 39-43.
- Miller, C. (2006) Wilderness fire management in a changing world, *International Journal of Wilderness* 12(1): 18-21.
- Watson, A., Knotek, K., Matt, R. and Yung, L. (2007) *Understanding landscape meanings, attributes, and threats for the planning and application of fuel treatment and fire management on the Flathead Indian Reservation, Montana* (Report to the Confederated Salish & Kootenai Tribes of Montana), Aldo Leopold Wilderness Research Institute, Missoula, MO.
- Watson, A., Matt, R., Knotek, K., Williams, D. and Yung, L. (In press) Traditional wisdom – protecting wilderness as a cultural landscape, *Proceedings Sharing Indigenous Wisdom International Conference*, Green Bay, Wisconsin, June 2007.

FAO and Partners in Fire Management: A Participatory and Integrated Approach¹

Pieter van Lierop²

Abstract

The article describes the different roles of the Food and Agriculture Organization of the United Nations in fire management. Three roles are distinguished and described:

- Facilitating the development and implementation of global and regional strategies and guidelines and access to international agreements that promote international collaboration and review policies, plans and practices to adopt more integrated and holistic approaches to fire management.
- Producing and facilitating global access to fire management data, information and terminology
- Capacity building at national and regional level through publications, training, meetings, field projects in developing countries and other activities, with focus on participatory approaches, particularly with communities.

The FAO coordinated Fire Management Voluntary Guidelines, and the Fire Management Actions Alliance, a global partnership with a Secretariat at FAO, are important tools and mechanisms to strengthen capacity in fire management.

All activities under these roles include two approaches which are thought to be crucial:

- A participatory approach through which efforts are made to involve key stakeholder groups in fire management.
- An integrated, intersectoral approach to fire management with horizontal and vertical components:
 - The vertical approach includes all fire management related activities from fire monitoring and assessment, prevention, early warning, preparedness, suppression, monitoring and evaluation up to restoration of damaged lands; and
 - The horizontal approach includes vegetation related land uses (forests, woodlands, shrublands, grasslands, agricultural lands, including the rural-urban interface). The majority of fires start outside forests from other land uses, but some fires can begin inside forests and impact other land-uses, so integrated approaches to vegetation fires are necessary rather than an isolated focus on forest fires.

¹ An abbreviated version of the paper was presented at the Third International Symposium on Fire Economics, Planning, and Policy: Common Problems and Approaches, April 29 – May 2, 2008, Carolina, Puerto Rico.

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Introduction

Over the past 20 years, FAO has produced more than 100 reports on forest fires and implemented more than 60 field projects in some 40 countries, supported by the FAO Technical Cooperation Programme, the United Nations Development Programme (UNDP) and a number of bilateral donors.

In the past these projects mostly took place at national level, although some regional activities were organized in the Mediterranean. Fire management activities by FAO are increasingly being developed at global level, like the coordination of a strategy to enhance international cooperation in fire management. The different roles of FAO in fire management can now be described as:

- Facilitating the development and implementation of global and regional strategies,
- Producing and facilitating global access to fire management data and information
- Building capacity at national and regional levels
- Enhancing international cooperation in fire management.

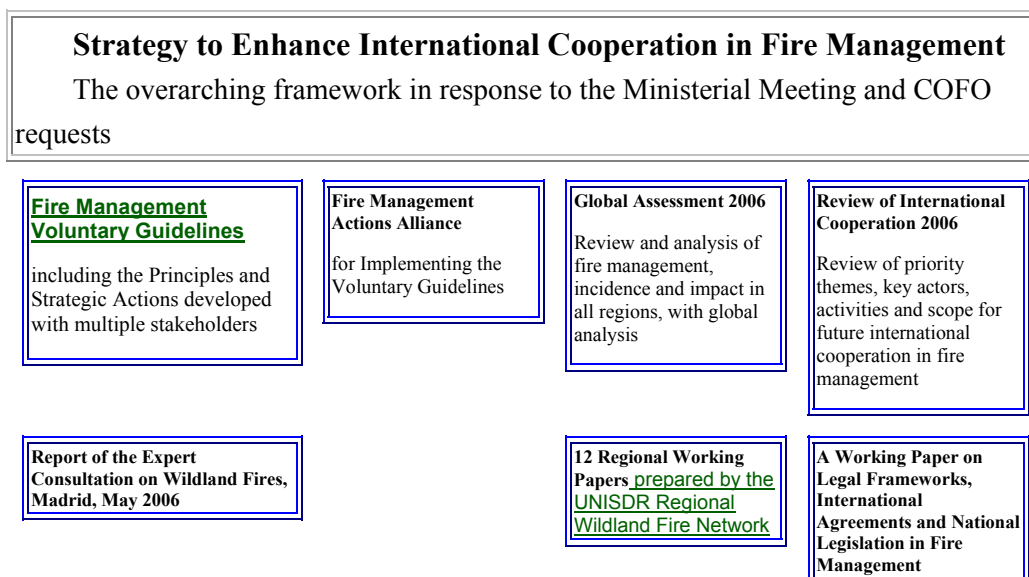
Most activities in fire management developed by FAO are implemented through partnerships and with a participatory and integrated approach.

A strategy to enhance international cooperation

The FAO Ministerial Meeting on Forests and the 17th Session of the FAO Committee on Forestry, March 2005 (Rome, Italy 2005) called upon FAO, in collaboration with countries and other international partners, including the UNISDR, to develop a strategy to enhance international cooperation in fire management, that advanced knowledge, increased access to information and resources and explored new approaches for cooperation at all levels. They also requested preparation of voluntary guidelines on the prevention, suppression and recovery from forest fire. The need for such tools to assist in international cooperation had also been highlighted at the 3rd International Wildland Fire Conference and the International Wildland Fire Summit (Sydney, Australia 2003) because of the increasing incidence and severity of impacts of major fires globally.

An international expert consultation in wildland fires (Madrid, May 2006) agreed that the non-legally binding Strategy to Enhance International Cooperation in Fire Management include the overarching framework for component parts: i) Fire Management Voluntary Guidelines; ii) Implementation Partnership or Alliance; iii) Global Assessment of Fire Management; and iv) Review of International Cooperation in Fire Management.

Figure 1. Strategy and components to Enhance International Cooperation in Fire Management coordinated by FAO.



These tools have been tailored primarily for land-use policy makers, planners and managers in fire management, including the Governments, the private sector and non-governmental organizations to assist in the formulation of policy, legal, regulatory and other enabling conditions and strategic actions for more holistic approaches to fire management. Their scope includes the positive and negative social, cultural, environmental and economic impacts of natural, of planned and of unplanned fires in forests, woodlands, rangelands, grasslands, agricultural and rural/-urban landscapes. The fire management scope includes early warning, prevention, preparedness (international, national, sub-national and community), safe and effective initial attack on incidences of fire and landscape restoration following fire.

The guidelines were used in two regional workshops in the Caribbean in 2007 to develop national action plans and national project proposals.

The purpose of the Fire Management Actions Alliance is to stimulate improved fire management and reduce damage from fire worldwide. The Objectives are to:

- review and update the Fire Management Voluntary Guidelines
- encourage stakeholders at all levels to adopt and use the Voluntary Guidelines;
- review experiences from applying the Voluntary Guidelines;
- strengthen international cooperation in fire management.

The Alliance was launched at the International Wildland Fire Congress in Seville 2007 and has now 43 members from 23 countries, including government agencies, research institutes, universities, associations, private enterprises etc.

FAO provides communications, coordination and related services to the

Alliance through the Secretariat. Any organization, agency, or group, can apply for membership. Membership applications should be to the Secretariat stating involvement in fire management, the intention to join the Alliance, and to adhere to the Purpose, Objectives and Principles of the Alliance. An Advisory Group approves memberships. Members are informed regularly about fire management activities of the other members and will be able to establish partnerships to meet the challenges they are facing.

It is important to understand that the components of the strategy were developed by a group of partners and coordinated by FAO. Key collaborating partners include the US Forest Service, Global Fire Monitoring Center, Australasian Fire Authorities Council, Corporación Nacional Forestal de Chile, South African Forestry Research Centre Jonkershoek, Servicio Nacional contra Incendios Forestales of Spain, The Nature Conservancy (TNC), New Zealand National Rural Fire Office, Institut National de la Recherche Agronomique of France, the UNISDR Regional Wildland Fire Networks and the Russian Training Institute in Ecology and Nature Management. However, a wide range of fire management organizations were involved in the multi-stakeholder process.

FAO is member of the International Liaison Committee which assists the organizing steering committee of the International Wildland Fire Congresses that take place each 4 years.

Recognizing the importance of regional cooperation, FAO also supports the UNISDR regional networks on fire management.

Capacity building at national and regional levels

All FAO projects at national level (actually: Syrian Arab Republic, Croatia, Nicaragua, Lebanon, Zimbabwe, Morocco, Cape Verde) have a national capacity building component. This may consist of training, often of local fire brigades made up of community members, but also of revising of existing, or developing a new legal framework and/or national policies regarding fire management.

FAO, together with partners, also has realized regional training workshops on Community Based Fire Management: in South Africa (2004) together with the Global Fire Monitoring Centre (GFMC) and in Belize (2005) and Indonesia (2007) with The Nature Conservancy (TNC).

Another regional capacity building activity has been the development of a regional policy for cooperation regarding fire management in Latin America and the Caribbean, as well as a strategy for each subregion: South America, Central America and the Caribbean.

Regional capacity building took also place during two workshops in Cuba and

Trinidad. National stakeholders in fire management discussed and analyzed the Voluntary Guidelines and developed logical frame works for 3 to 5 year national action plans and project proposals for the English and Spanish speaking islands.

A global access to fire management data and information

The Fire Information for Resource Management System (FIRMS) project delivers through a Website, e-mails and sms messages (mobile phones) data on detected active fires using the MODIS active fire locations processed by the MODIS Rapid Response System. It is a joint initiative of the University of Maryland, NASA and FAO.

Over the years FAO has produced or cooperated with many publications on fire management both in hard copy as well as digital versions on the website.

To give some examples of publications since 2000:

- The Fire Management Global Assessment 2006 with the UNISDR Regional Wildland Fire Networks
- The Voluntary Guidelines on Fire Management (2007), currently available in English, French, Spanish, Russian, Bahasa, Korean and being translated into Portuguese and Nepalese
- A revision of a trainer handbook (2007) on fire management developed by FINNIDA, available in English and soon available in Spanish
- Two publications on Community Based Fire Management (2002, 2003) with many case studies from all around the world together with FireFight South East Asia.
- A Handbook on Forest Fire Protection in the Mediterranean (2001) together with the French Research Institute for agriculture and Environment (Cemagref) and the French Ministry of Land and Environmental Management, and the Ministry of Agriculture, Fishery and Food, soon available in three languages.
- A report on the last Expert Consultation on Wildland Fires in Madrid (2006)
- A working paper on Legal Frameworks for Forest Fire management: International Agreements and National Legislation (2004)³
- A working paper on International Wildland Fire Management Agreements Template (2004)

On the Internet we maintain a website with FAO activities, events and publications on fire management (www.fao.org/forestry/site/firemanagement/en) and we maintain also the website of the Fire Management Actions Alliance (www.fao.org/forestry/site/firealliance).

³ All FAO Fire Management Working Papers can be found at: www.fao.org/forestry/site/35853/en |

This website provides a bibliography of the fire management actions carried out by the Alliance members, based on their inputs. The actions list will be a key tool for sharing knowledge and experience on fire management.

A participatory approach and partnerships

FAO promotes a participatory approach in its activities related to fire management by:

- Involving a variety of institutions, both geographically and according to stakeholder representation, when developing global and regional information and instruments like the development of the Voluntary Guidelines and the Global Fire Assessment.
- Organizing regional workshops on Community Based Fire Management.
- Applying principles of Community Based Fire Management in projects at national and village level.

In the projects and regional workshops, the need for participatory approaches to forest management is stressed, including the involvement of local people in the planning and execution of programmes; in the prevention, detection and control of wildfires; and in the sound management of the use of fire as a tool in planned land clearing and in the management of grazing lands.

Many of the FAO Fire Management Activities (publications, global instruments, regional capacity building) are developed through partnerships. The Fire Management Actions Alliance will serve as a platform where many partnerships can be formed and strengthened.

An integrated approach

Broader landscape approaches are necessary because fires are caused in and outside forests and affects both forests and other land-uses. The concept of fire management used by FAO encompasses all vegetation fires – forests, woodlands, shrublands, rangelands, grasslands, pasture lands and the rural-urban interface fires.

FAO believes that Fire Management Policies should be well balanced with attention and resources for all fire management activities from prevention, early warning, monitoring and assessment, preparedness, suppression of fires to restoration of damaged land. After big fire incidents too often there is a high demand for more heavy high tech fire suppression equipment, where as it is difficult to get support for prevention activities when fires have not occurred over some time.

FAO support rural fire authorities, particularly their understanding of vegetation fires and community participation. This can be lost in amalgamation of rural and

metropolitan (urban) fire authorities.

Many sectors and agencies are involved in fire management, which makes coordination very important. Legal frameworks from the different sectors should be adjusted to each other and not in contradiction; different sectors should work together in prevention, etc.

The complexity of fire incident management, coupled with the growing need for multiagency involvement has increased the need for a standard, interagency incident management system like the Incident Command System.

Future challenges

While the roles and approaches of FAO have changed, new challenges lay ahead; first of all helping countries to develop, adapt and implement their fire management policy, with the help of the guidelines, especially in these countries where integrated and participatory fire management are new concepts.

This is not only a challenge for FAO but also for the partnerships which have been so useful in developing the Strategy and Voluntary Guidelines. The recently established Fire Management Actions Alliance will play an important role in this.

Another challenge will be to link the fire management activities with adaptation and mitigation of climate change; the links are more than obvious.

According to the Global Forest Resources Assessment (GFRA) 2005, there is at present no global classification that distinguishes between beneficial and detrimental fires, and consequently no detailed information on fire types in forests and other wooded lands. FAO considers it a challenge to produce global data on total areas affected by fire according to type of land (forest, other wooded land and other land) and type of fire (wildfire or prescribed fire) with GFRA 2010.

But FAO would also like to call also upon the sector of fire economics to provide data on the global economical impact of wildland fires in order to be able to develop a stronger base for activities at global level in fire management and convince national, regional and international institutes, agencies and governments to support these activities.

References

- Colin et al. 2001. Protection des forêts contre l'incendie. Cahier FAO Conservation n° 36 Rome, 2001
- FAO. 2007. *Fire Management – global assessment 2006*. FAO Forestry Paper 151
- FAO. 2006. *Fire Management: Voluntary guidelines. Principles and strategic actions*. Fire Management Working 17. Rome
- FAO, 2006. *Global Forest Resources Assessment 2005. Progress towards sustainable forest management*. FAO Forestry Paper 146.
- FAO (2004). *Legal Frameworks for Forest Fire Management: International Agreements and National Legislation. Follow-up Report to FAO/ITTO International Expert Meeting on Forest Fire Management, March 2001*. Forest Protection Working Papers, Working Paper FFM/3/E. Forest Resources Development Service, Forest Resources Division. FAO, Rome
- FAO and FireFight South East Asia (2003): *Community based Fire Management: case studies from China, The Gambia, Honduras, India, the Lao People's Democratic Republic and Turkey*. RAP Publication 2003/08, Bangkok, Thailand
- ILC (2003). *Legal International Wild land Fire Management Agreements Template*. The Template was prepared for the International Wild land Fire Summit held in Sydney, Australia in October 2003 by the International Liaison Committee. Working Paper FFM/2/E. Forest Resources Development Service, Forest Resources Division, FAO, Rome
- Moore et al (eds). 2002: *Communities in flames: proceedings of an international conference on community involvement in fire management*. FAO and FireFight South East Asia, RAP Publication 2002/25, Bangkok, Thailand