



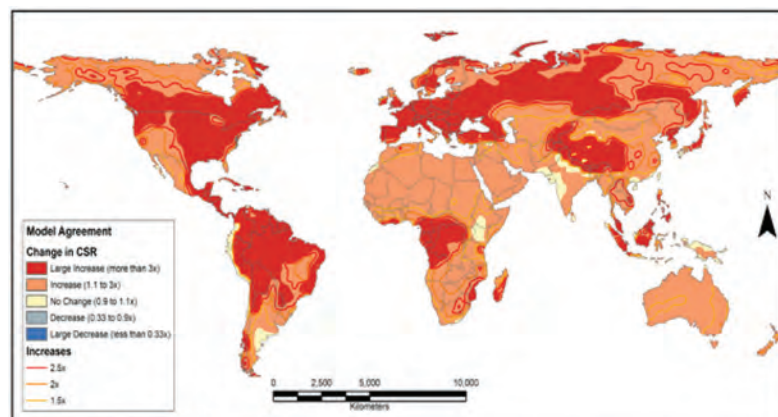
United States Department of Agriculture
Forest Service

Pacific Southwest
Research Station

General Technical
Report
PSW-GTR-245
(English)

August 2013

Proceedings of the Fourth International Symposium on Fire Economics, Planning, and Policy: Climate Change and Wildfires



Non-Discrimination Policy

The U.S. Department of Agriculture (USDA) prohibits discrimination against its customers, employees, and applicants for employment on the bases of race, color, national origin, age, disability, sex, gender identity, religion, reprisal, and where applicable, political beliefs, marital status, familial or parental status, sexual orientation, or all or part of an individual's income is derived from any public assistance program, or protected genetic information in employment or in any program or activity conducted or funded by the Department. (Not all prohibited bases will apply to all programs and/or employment activities.)

To File an Employment Complaint

If you wish to file an employment complaint, you must contact your agency's EEO Counselor (PDF) within 45 days of the date of the alleged discriminatory act, event, or in the case of a personnel action. Additional information can be found online at http://www.ascr.usda.gov/complaint_filing_file.html.

To File a Program Complaint

If you wish to file a Civil Rights program complaint of discrimination, complete the USDA Program Discrimination Complaint Form (PDF), found online at http://www.ascr.usda.gov/complaint_filing_cust.html, or at any USDA office, or call (866) 632-9992 to request the form. You may also write a letter containing all of the information requested in the form. Send your completed complaint form or letter to us by mail at U.S. Department of Agriculture, Director, Office of Adjudication, 1400 Independence Avenue, S.W., Washington, D.C. 20250-9410, by fax (202) 690-7442 or email at program.intake@usda.gov.

Persons with Disabilities

Individuals who are deaf, hard of hearing or have speech disabilities and you wish to file either an EEO or program complaint please contact USDA through the Federal Relay Service at (800) 877-8339 or (800) 845-6136 (in Spanish).

Persons with disabilities, who wish to file a program complaint, please see information above on how to contact us by mail directly or by email. If you require alternative means of communication for program information (e.g., Braille, large print, audiotape, etc.) please contact USDA's TARGET Center at (202) 720-2600 (voice and TDD).

Supplemental Nutrition Assistance Program

For any other information dealing with Supplemental Nutrition Assistance Program (SNAP) issues, persons should either contact the USDA SNAP Hotline Number at (800) 221-5689, which is also in Spanish or call the State Information/Hotline Numbers.

All Other Inquiries

For any other information not pertaining to civil rights, please refer to the listing of the USDA

Technical Coordinator

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

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

Proceedings of the Fourth International Symposium on Fire Economics, Planning, and Policy: Climate Change and Wildfires

Armando González-Cabán
Technical Coordinator

U.S. Department of Agriculture, Forest Service
Pacific Southwest Research Station
Albany, California
General Technical Report PSW-GTR-245 (English)
August 2013

Abstract

González-Cabán, Armando. 2013. Proceedings of the fourth international symposium on fire economics, planning, and policy: climate change and wildfires. Gen. Tech. Rep. PSW-GTR-245 (English). Albany, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station. 405 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 climate change and wildland fires: reality or illusion?, theory and models for strategic fire planning, economic analysis and integrated wildland fire management, forest fires and sustainable forest management, public policies (national and international level) and the wildland fire management problem, hazardous fuels treatment, wildland fire use and fire suppression activities: reduction or contribution to green house gases emissions?, a poster session presenting examples of fire management plans and strategic fire resource allocation, and a final round table on climate change and mega fires discussing and exploring potential solutions. Representatives from international organizations with fire protection responsibilities in 18 countries presented and discussed their experiences on the same issues. Forty invited and contributed papers and 20 posters were presented at the symposium that described the issues and presented state-of-the-art techniques to address technical issues on fire economics, planning, and policy currently faced by land and fire managers.

Keywords: Climate change, 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 due to increased expenditures for suppressing large wildfires and fires in the wildland-urban interface. Frequent siege-like fire (most recently being called mega fires) incidents have enormous costs in loss of life, property, natural resources and welfare. 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 like Australia, Canada, Italy, Portugal, and Spain, and Latin American countries like Argentina, Chile, Colombia, Costa Rica, Guatemala, Honduras, Mexico, Nicaragua, and Panama, with significant wildland fire problems. In the Caribbean basin countries like Cuba and the Dominican Republic are also experiencing similar situations.

Political and social pressures, such as those encountered in the wildland-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 comparison between prescribed fire and other fuel 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, 1998, 2000, and 2003 fire seasons, suggest a clear need for a forum in which policy makers, natural resource managers, and fire managers and practitioners can exchange ideas and learn from mutual concerns and experiences. The harsh realities of the most recent fire seasons from 2007 to 2011 have made painfully clear the urgency to retake discussion of the topic and search for integrated solutions to the problem.

In the spring of 2008, the Third International Symposium on Fire Economics, Planning, and Policy: A World View was held in Carolina, Puerto Rico to address the issues outlined here. Since then, disastrous events in the 2007 to 2011 fire seasons, in Australia, China, Mexico, Russia, Spain, and United States, among others, 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 agencies managers and practitioners, natural resource managers, researchers, foresters,

economists, students and policy makers to discuss and share recent problems, experiences and responses to the wildland fire challenges. The purpose of the proposed symposium is 1) to bring together individuals interested in exchanging ideas regarding the economics, planning and policies of wildland fire management, 2) sharing the most recent developments and technologies for optimizing fire management expenditures, 3) analyze and evaluate the potential relationship between climate change and wildland fires; 4) exploring the tradeoffs between hazardous fuels treatments and wildland fire use, and suppression expenditures, and 5) sharing recent developments in strategic fire planning models.

Thank you!
Armando González-Cabán
Mexico City, Mexico
November 5, 2012

Contents

- 1 **Climate Change and Wildfires**
William J. de Groot, Michael D. Flannigan, and Brian J. Stocks
- 11 **SEILAF: Tactic Optimization**
Carlos Abrego Aguilar, F. Javier Romera López, Regina de la Rosa Calancha, and Domingo Villalba Indurria
- 27 **Managing the Risks of Risk Management on Large Fires**
Donald G. MacGregor and Armando González-Cabán
- 36 **Simulation Analysis of a Wildfire Suppression System**
Abílio Pereira Pacheco, João Claro , and Tiago Oliveira
- 50 **Forecasting Productivity in Forest Fire Suppression Operations: A Methodological Approach Based on Suppression Difficulty Analysis and Documented Experience**
Francisco Rodríguez y Silva and Armando González-Cabán
- 66 **Hazardous Fuel Treatments, Suppression Cost Impacts, and Risk Mitigation**
Matthew P. Thompson, Michael S. Hand, Julie W. Gilbertson-Day, Nicole M. Vaillant, and Darek J. Nalle
- 81 **Economics of Forest Fire Management: Spatial Accounting of Costs and Benefits**
José J. Sánchez, Ken Baerenklau, Armando González-Cabán, and Kurt Schwabe
- 98 **Economic Analysis of Prescribed Burning for Wildfire Management in Western Australia**
Veronique Florec, David Pennell, Michael Burton, Joel Kelso, Drew Mellor, and George Milne
- 111 **Does Personal Experience Affect Choice-Based Preferences for Wildfire Protection Programs?**
Armando González-Cabán, Thomas P. Holmes, John B. Loomis, and José J. Sánchez
- 127 **Economic Information on the Historical Behavior of Forest Fires in the Forest Lands in the State of Parana, Brazil**
Vitor Alfonso Hoefflick, Alexandre França Tetto, and Antonio Carlo Batista
- 139 **Forest Fire Impact on Bird Habitat in a Mixed Oak-Pine Forest in Puebla, Mexico**
Laura P. Ponce-Calderón, Dante A. Rodríguez-Trejo, Beatriz C. Aguilar-Váldez, and Elvia López-Pérez
- 147 **Catastrophic Fat Tails and Non-Smooth Damage Functions- Fire Economics and Climate Change Adaptation for Public Policy**
Adriana Keating and John Handmer

- 152 **Methodology Used in Cuba for Estimating Economic Losses Caused by Forest Fires**
Marcos Pedro Ramos Rodríguez and Raúl González Rodríguez
- 163 **VISUAL-SEVEIF, a Tool for Integrating Fire Behavior Simulation and Economic Evaluation of the Impact of Wildfires**
Francisco Rodríguez y Silva, Juan Ramón Molina Martínez, Miguel Ángel Herrera Machuca, and Jesús M^a Rodríguez Leal
- 179 **Fighting Forest Fires in Brazil**
José Carlo Mendes de Moraes
- 191 **Mega Wildfire in the World Biosphere Reserve (UNESCO), Torres del Paine National Park, Patagonia—Chile 2012: Work Experience In Extreme Behavior Conditions in the Context of Global Warming**
René Cifuentes Medina
- 202 **Spatiotemporal Distribution Patterns of Forest Fires in Northern Mexico**
Gustavo Pérez-Verdín, M. A. Márquez-Linares, A. Cortes-Ortiz, and M. Salmerón-Macías
- 213 **Spatial Allocation of Market and Nonmarket Values in Wildland Fire Management: A Case Study**
John W. Benoit, Armando González-Cabán, Francis M. Fujioka, Shyh-Chin Chen, and José J. Sanchez
- 225 **Shift in Fire-Ecosystems and Weather Changes**
Bongani Finiza
- 235 **Recreational Use Management and Wildfires in Southern California: Using GIS and Visual Landscape Simulation Models for Economic Assessment**
Daniel Moya, Armando González-Cabán, José J. Sánchez, and José de la Heras
- 246 **Adaptive Management of Forest Fires in Periurban Areas in the Federal District, Brazil: A Case Study From the Urubu Valley Rural Community**
Gabriel Constantino Zacharias and Renata Marson Teixeira de Andrade
- 256 **Evaluation of the Flammability of Trees and Shrubs Used in the Implementation of Green Barriers in Southern Brazil**
Antonio Carlos Batista, Daniela Biondi, Alexandre França Tetto, Rafaela de Assunção, Andressa Tres, Raquel Costa Chiao Travenisk, and Bruna Kovalsyki
- 265 **A Community in the Wildland-Urban Interface**
María Cecilia Ciampoli Halaman
- 274 **Fuel Load Modeling From Mensuration Attributes in Temperate Forests in Northern Mexico**
Maricela Morales-Soto and Marín Pompa-García

- 281 **Methodological Approach for Assessing the Economic Impact of Forest Fires Using MODIS Remote Sensing Images**
Francisco Rodríguez y Silva, Juan Ramón Molina Martínez, and Miguel Castillo Soto
- 296 **Assessment of Post-Fire Forest Structural Diversity Using Neighborhood Parameter in the Sierra Madre Oriental, Mexico**
Diana Yemilet Ávila Flores, Marco Aurelio González Tagle, Javier Jiménez Pérez, Oscar Aguirre Calderón, and Eduardo Treviño Garza
- 304 **Land Suitability for Establishing Rainwater Harvesting Systems for Fighting Wildfires**
José María León Villalobos, Manuel Anaya Garduño, Enrique Ojeda Trejo, Dante Arturo Rodríguez Trejo, José Luis Oropeza Mota, and Jorge Luis García Rodríguez
- 313 **Culture of Fire and Environmental Education in Wildfire-Prone Areas: Current Situation in Spain**
Clara Quesada-Fernández and Daniel Quesada-Fernández
- 326 **Fire Risk in the Road Landscape Patterns of the State of Paraná, Brazil – Planning Grants for the Wildland-Urban Interface**
Daniela Biondi, Antonio Carlos Batista, and Angeline Martini
- 338 **Advances in Integrated Fire Management in Central Mexico**
Dante Arturo Rodríguez Trejo and Arturo Cruz Reyes
- 357 **Management Adaptation to Fires in the Wildland-Urban Risk Areas in Spain**
Gema Herrero-Corral
- 370 **Villaflores: Municipal Forest Fire Management Model**
Pedro Martínez Muñoz and Carlos Alberto Velázquez Sanabria
- 382 **Wildfire Management Policies in Algeria: Present and Future Needs**
Ouahiba Meddour-Sahar, Armando González-Cabán, Rachid Meddour, and Arezki Derridj
- 396 **Forest Fuel Characterization Using Direct Sampling in Forest Plantations**
Eva Reyna Esmeralda Díaz García, Marco Aurelio González Tagle, Javier Jiménez Pérez, Eduardo Javier Treviño Garza, and Diana Yemilet Ávila Flores

Climate Change and Wildfires¹

William J. de Groot², Michael D. Flannigan³, and Brian J. Stocks⁴

Abstract

Wildland fire regimes are primarily driven by climate/weather, fuels and people. All of these factors are dynamic and their variable interactions create a mosaic of fire regimes around the world. Climate change will have a substantial impact on future fire regimes in many global regions. Current research suggests a general increase in area burned and fire occurrence but there is a lot of global variability. Recent studies of future global fire weather under different climate change scenarios using several General Circulation Models are reviewed. A widespread increase in future fire weather severity was found over almost all the earth with increasing fire season length occurring in many regions, particularly at northern latitudes. In the boreal forest region, which represents about one-third of global forest cover, increased area burned over the last four decades has been linked to higher temperatures as a result of human-induced climate change. This trend in the boreal region is projected to continue as fire weather severity and fire intensity will sharply rise by up to 4-5 times current peak values by the end of the century. Many national fire management organizations already operate at a very high level of efficiency, and there is a very narrow margin between suppression success and failure. Under a warmer and drier future climate, fire management agencies will be challenged by fire weather conditions that could push current suppression capacity beyond a tipping point, resulting in a substantial increase in large fires.

Keywords: General Circulation Models, IPCC climate change scenarios, fire weather severity, fire intensity, fire management

Introduction

Wildland fires burn 330-431 M ha of global vegetation every year (Giglio and others 2010). About 86% of wildland fire occurs in tropical grassland and savannahs, and 11% in forest (Mouillot and Field 2005). There is charcoal evidence that global fire

¹ An abbreviated version of this paper was presented at the Fourth International Symposium on Fire Economics, Planning, and Policy: Climate Change and Wildfires, November 5-11, 2012; Mexico City, Mexico.

² Natural Resources Canada – Canadian Forest Service, 1219 Queen Street East, Sault Ste. Marie, ON Canada P6B6H6 bill.degroot@nrcan.gc.ca

³ University of Alberta, Dept. of Renewable Resources, 713A General Services Building, Edmonton, AB Canada T6G 2H1 mike.flannigan@ualberta.ca

⁴ B.J. Stocks Wildfire Investigations Ltd., 128 Chambers Ave., Sault Ste. Marie, ON Canada P6A 4V4 brianstocks@sympatico.ca

has increased since the last glacial maximum about 21,000 years ago, with increased spatial heterogeneity during the last 12,000 years (Power and others 2008). During the last millennium, the global fire regime appears to have been strongly driven by precipitation, and shifted to an anthropogenic-driven regime during the Industrial Revolution (Pechony and Shindell 2010). In the last few decades, there is evidence of greater area burned and increasing fire severity in many different global regions (Pyne 2001, FAO 2007, Bowman 2009). There are varied reasons for regional increases in wildland fire activity, but the primary factors are fuels, climate-weather, ignition agents, and people (Flannigan and others 2005, 2009b). In future, fire regimes are expected to be temperature-driven (Gillett and others 2004, Pechony and Shindell 2010), with warmer conditions and longer fire seasons leading to increased area burned and fire occurrence (Flannigan and others 2009b). However, a review of global research papers showed mixed results for fire severity and intensity (Flannigan and others 2009a). In the boreal forest region, which represents about one-third of global forest cover, fire records document increased fire activity in recent decades (Stocks and others 2003, Kasischke and Turetsky 2006) due to increased temperature (Westerling and others 2006). Under current climate change scenarios, global temperature increase is expected to be greatest at northern high latitudes (IPCC, 2007). For that reason, the boreal forest region is anticipated to experience the earliest and greatest increases in wildland fire activity under future climate change. The purpose of this paper is to summarize recent research on future global fire regimes, resulting impacts on fire behavior in circumpolar boreal forests, and implications for fire management.

Future global fire regimes

In a recent study of future global wildland fire (Flannigan and others 2013), the potential influence of climate change on fire season length and fire season severity was examined by comparing three General Circulation Models (GCM) and three possible emissions scenarios (nine GCM-emission scenario combinations). The GCMs used in the study were: 1) THE CGCM3.1 from the Canadian Centre for Climate Modeling and Analysis, 2) the HadCM3 from the Hadley Centre for Climate Prediction in the United Kingdom, and 3) the IPSL-CM4 from France. The models were selected to provide a range of expected future warming conditions. There are four emission scenario storylines (A1, A2, B1, and B2) that set out distinct global development direction to the end of this century (IPCC, 2000). The Flannigan and others (2013) study used the following three scenarios: A1B, representing a world of very rapid economic growth with global population peaking by mid-century, rapid development of efficient technology, and a balanced use of fossil fuel and non-fossil

fuel sources; A2, representing a world of increased population growth, slow economic development, and slow technological change (business-as-usual scenario); and B1, representing the same population as A1, but more rapid change in economic structure, and moving towards service and information technology.

The GCM-emission scenarios were used to calculate fire weather conditions during the next century. Fire weather data (temperature, relative humidity, wind speed, 24-hr precipitation) were used to calculate daily component values of the Canadian Forest Fire Weather Index (FWI) System (Van Wagner 1987). Fire season length was calculated using a temperature approach, with the start of the fire season defined as three consecutive days of 9°C or greater, and the end of the fire season by three consecutive days of 2°C or lower. Fire severity was calculated using the Daily Severity Rating (DSR), which represents the increasing difficulty of control as a fire grows (Van Wagner 1970) and is a simple power function of the Fire Weather Index component of the FWI System. In the Flannigan and others (2013) study, changes in fire severity were measured using the Cumulative Severity Rating (CSR), which was the sum of DSR values during the fire season divided by the fire season length. In this way, the CSR was a seasonal length-scaled version of the DSR. Changes in future fire season length and CSR were summarized by decade as anomalies from the 1971-2000 period (results were only presented for mid-century and end of century).

Figures 1 and 2 from the Flannigan and others (2013) study show examples of CSR for the HadCM3 model and the A2 scenario for 2041-2050 and for 2091-2100. These examples (Figures 1 and 2) are representative of all the GCMs and scenarios maps that show a significant world-wide increase in CSR especially for the northern hemisphere. With these increases, we expect more area burned, increased fire occurrence, and greater fire intensity that will result in more severe fire seasons and increased fire control difficulty.

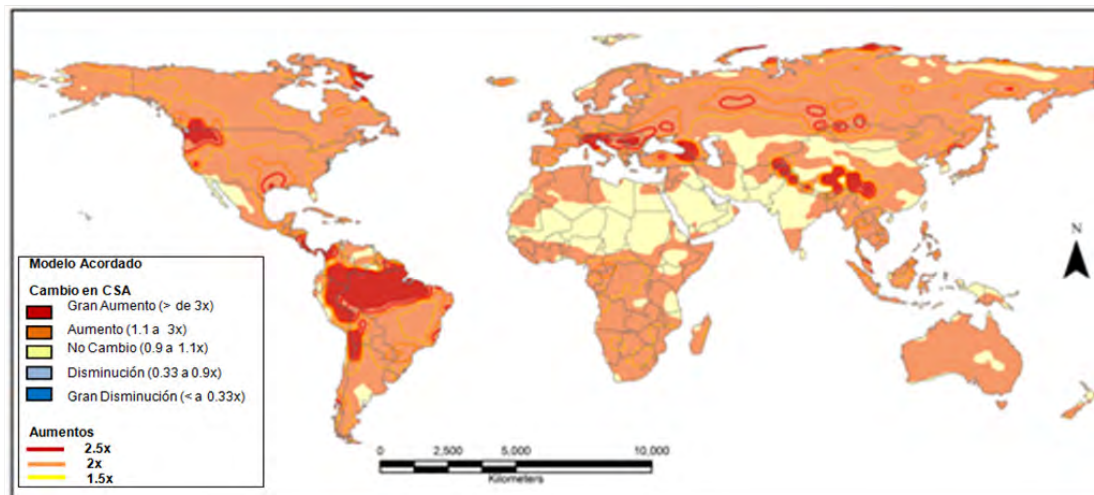


Figure 1—Cumulative Severity Rating anomalies for the HadCM3 A2 scenario for 2041-2050 relative to the 1971-2000 base period.

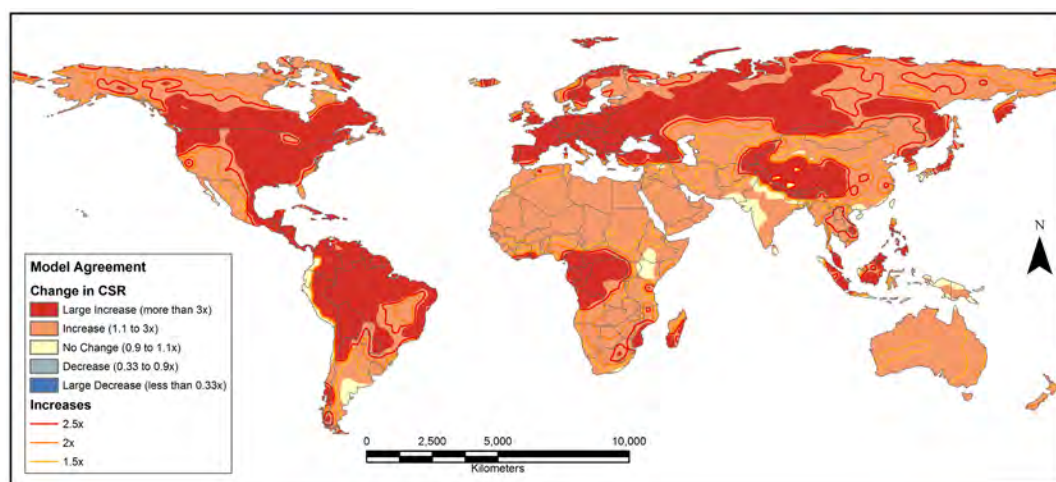


Figure 2—Cumulative Severity Rating anomalies for the HadCM3 A2 scenario for 2091-2100 relative to the 1971-2000 base period.

Future boreal fire regimes

There are several studies that indicate an increasing trend in area burned across the North American boreal zone during the last several decades (Podur and others 2002, Kasischke and Turetsky 2006) that is closely aligned with an increasing temperature trend, and is a result of human-induced climate change (Gillett and others 2004). A steadily increasing temperature trend is expected to continue at northern latitudes as climate change progresses. Fire regimes of the northern circumpolar boreal forest are changing rapidly and will continue to do so, and may serve as an early indicator of

potential change in other global fire regimes. The boreal forest covers 1.35 B ha, representing about one-third of global forest cover (Brandt 2009, FAO 2001). There is an average of 9 M ha (ranging 4–18 M ha) burned annually in the boreal forest region (Giglio and others 2010). A change in boreal fire regimes can have substantial impact on atmospheric greenhouse gasses because the boreal zone is the source of 9% (182 Tg C yr^{-1}) of global wildland fire C emissions (van der Werf and others 2010).

Over 70% of the boreal forest is in Eurasia, with the remainder in North America. Although the boreal forest is primarily represented by *Pinus*, *Picea*, *Larix*, *Abies*, *Populus* and *Betula* spp. across the entire forest region, there is a distinct difference in continental fire regimes. This dichotomy in fire regimes is due in great part to differences in forest composition and tree species morphology, and the influence of those characteristics on fire regime. The major difference between the two continents is that the North American boreal forest is dominated by *Picea* and *Abies* (44% by area) and *Pinus* (22%), which have highly flammable foliage and either a low branching habit (*Picea*, *Abies*) or a relatively low live crown base height (*Pinus*) that promote crown fires. In northern Asia, the boreal forest is dominated by *Larix* (30%), which has foliage with high moisture content, and relatively tall-growing *Pinus* (28%) species, which have a higher live crown base height; both of these factors substantially reduce the occurrence of crown fire in northern Asia.

A recent modeling study comparing boreal fire regimes in western Canada and central Siberia (de Groot and others 2012a) indicates that there are many more large ($>200 \text{ ha}$) fires occurring in northern Asia than North America. Therefore, there is a much higher annual area burned rate, and shorter mean fire return interval in northern Asia (1.89 M ha per 100 M ha of forest land; MFRI=53 years) than in western North America (0.56 M ha per 100 M ha of forest land; MFRI=180 years). However, the average large fire size in western North America (5930 ha) is much larger than in northern Asia (1312 ha). Most fires in boreal North America occur as crown fires (57%), which appears to be limited by the total amount of coniferous cover (63% of the study area of de Groot and others 2012a). In northern Asia, only 6% of large fires occurred as crown fires in the de Groot and others (2012a) study, due to two-thirds of the study area being covered by non-crowning fuel types (*Betula*, *Larix*, *Populus*) and higher average live crown base heights for crown fire-susceptible species (*Pinus sibirica*, *Pinus sylvestris*). As a result, North American fire regimes are typically dominated by infrequent fast-spreading crown fires of very high intensity, and northern Asia fire regimes are characterised by relatively frequent surface fires of moderate to high intensity. Although there is a higher C emissions rate (t/ha) in North American boreal fires due in part to greater crown fuel consumption, there is a much higher total C emissions from wildland fires in the Asian boreal ($128 \text{ Tg C year}^{-1}$, vs

54 Tg C year⁻¹ in North America) due to a much higher annual area burned rate and a larger total forest area.

A follow-up study by de Groot and others (2012b) examined the impact of climate change on these circumpolar boreal fire regimes. Future boreal fire regimes were simulated with the CGCM3.1, HadCM3, and IPSL-CM4 GCMs and the A1B, A2, and B1 scenarios, using the same procedures as Flannigan and others (2013). The resulting fire weather data and FWI System parameters were used in the Canadian Fire Effects Model (CanFIRE; de Groot 2006, 2010) to simulate future expected fire behavior and C emissions. The results showed that fire weather severity increased across the circumpolar boreal region, and that the DSR and head fire intensities also increased, although conditions were slightly more extreme in North America. All of these parameters indicate that there will be greater difficulty in controlling future wildland fires across the boreal forest. All three GCMs showed general agreement in long-term trends of increasing fire weather severity and fire behaviour activity, but the Hadley and IPSL models in particular, indicated future burning conditions that far-exceed current conditions. By the end of the 21st century, all GCM and scenario combinations indicated that average monthly head fire intensities will exceed airtankers suppression capability in most months of the fire season (April to September) across the boreal region; the IPSL and Hadley models indicate that this suppression threshold will be surpassed in every month from April to October. The results of the de Groot and others (2012b) study, combined with the increasing fire season length in the boreal region found by Flannigan and others (2013) and other studies suggesting that annual area burned could increase 2–5.5 times in boreal North America (Flannigan and others 2005, Balshi et al, 2009) and increased fire activity in Russia (Dixon and Krankina 1993, Stocks and others 1998), indicate that there will be a huge increasing demand on fire management in the future, regardless of climate change scenario.

Climate change and fire management

Current climate change models are in agreement that there will be increased fire weather severity in the future. This is anticipated to increase both fire occurrence and severity, resulting in larger fires and more area burned, which raises serious doubts over the ability of fire management agencies to effectively mitigate future fire impacts. Forest fire management agencies currently operate with a very narrow margin between success and failure when suppressing fires, and a warmer and drier climate would result in more fires escaping initial suppression efforts and growing large (Stocks 1993). In addition, given competing fiscal demands, governments

would be unlikely to provide funding increases necessary to maintain current effectiveness levels.

In a study within the boreal region, McAlpine (1998) suggested that increased frequency of drought years and extreme climatic events, in combination with longer fire seasons, would increase fire activity and area burned in Ontario, Canada. Minimizing the increases in area burned associated with climate change would require significant increases in fire management expenditures. Simulation studies using the Ontario initial attack system (McAlpine and Hirsch 1998) showed that reducing the number of escaped fires from current levels would require a very large investment in additional resources, and that incremental increases in fire suppression resources result in diminishing gains in initial attack success. Wotton and Stocks (2006) used Ontario's initial attack simulation system in combination with scenarios of expected fire occurrence and fire weather to show that a doubling of current resource levels would be required to meet a modest increase of 15% in fire load (which is based on number of fires and difficulty of control). More recently, Podur and Wotton (2010) expanded this work, combining GCM-derived scenarios of future fire weather with a fire growth and suppression model in Ontario. Results indicated a 2-fold to 5-fold increases in area burned over the next century, driven by more frequent fire weather conducive to large fire growth and an increasing number of fires escaping initial attack. The recent development of the Canadian Wildland Fire Strategy (CWFS), approved by federal, provincial, and territorial governments (CCFM 2005), is in direct response to the growing consensus that climate change-driven forest fire and forest health issues, along with diminishing fire management capacity and an expanding wildland urban interface, will combine to create unprecedented fire effects across Canada in the near future. Under this scenario, maintaining current levels of fire protection success will be economically and physically impossible, as well as ecologically undesirable. A new accommodation with fire, in which fire assumes its natural role across more of the Canadian landscape, seems a likely outcome of this confluence of factors.

The substantial increases in CSR predicted globally across climate change scenarios by the end of this century are truly noteworthy for wildland fire managers. Increases of up to 300% in CSR, particularly in the northern circumpolar region, will place unprecedented demands on fire suppression resources. Some of the CSR increase is due to longer fire seasons (about 20-30 days); however the DSR on low and even moderate days (the most frequent days in the fire season) is quite small relative to DSR values on high and extreme days, and thus the vast majority of the increase is due to the increase in potential fire intensity and subsequent control difficulty. Fire suppression action most often fails during high intensity crown fires (Stocks and others 2004), and the climate change scenarios of this study indicate that

this type of fire behavior will occur with greater frequency in the future. Many countries of the world operate highly efficient fire management organizations that have a high fire control success rate. However, climate change may cause a disproportionate increase in uncontrolled fires because many fire management organizations already operate at near to optimum efficiency; thus any further increase in fire control difficulty will force many more fires beyond a threshold of suppression capability (cf Flannigan and others 2009b, Podur and Wotton 2010). Perhaps we are already experiencing what is to come with recent disastrous fires in Australia in 2009 and 2012, Russia in 2010 and in the USA in 2011 and 2012. Increased wildland fire on the landscape in the future will force fire management agencies to re-assess policy and strategy. All wildland areas cannot be protected from fire, and many high value areas that are managed with a policy of fire exclusion will be threatened by wildfire.

References

- Balshi, M.S., McGuire, A.D., Duffy, P., Flannigan, M., Walsh, J., Melillo, J. 2009.** Assessing the response of area burned to changing climate in western boreal North America using a Multivariate Adaptive Regression Splines (MARS) approach. *Global Change Biology* 15, 578-600.
- Bowman, D.M.J.S., Balch, J.K., Artaxo, P., Bond, W.J., Carlson, J.M., Cochrane, M.A., D'Antonio, C.M., DeFries, R.S., Doyle, J.C., Harrison, S.P., Johnston, F.H., Keeley, J.E., Krawchuk, M.A., Kull, C.A., Marston, J.B., Moritz, M.A., Prentice, I.C., Roos, C.I., Scott, A.C., Swetnam, T.W., van der Werf, G.R., Pyne, S.J. 2009.** Fire in the Earth System. *Science* 324, 481-484.
- Brandt, J.P. 2009.** The extent of the North American boreal zone. *Environmental Reviews* 17, 101-161.
- [CCFM] Canadian Council of Forest Ministers. 2005.** Canadian wildland fire strategy: a vision for an innovative and integrated approach to managing the risks. A report to the Canadian Council of Forest Ministers, prepared by the Canadian Wildland Fire Strategy Assistant Deputy Ministers Task Group. Can. For. Serv., North. For. Cent. Edmonton, AB. (http://www.ccfm.org/pdf/Vision_E_web.pdf)
- de Groot, W.J. 2006.** Modeling Canadian wildland fire carbon emissions with the Boreal Fire Effects (BORFIRE) model. In: Viegas, D.X. (Ed.), 5th International Conference on Forest Fire Research. Elsevier, Figueira da Foz, Portugal.
- de Groot, W.J. 2010.** Modeling fire effects: Integrating fire behavior and fire ecology. In, 6th International Conference on Forest Fire Research. ADAI/CEIF University of Coimbra, Coimbra, Portugal.
- de Groot, W.J., Cantin, A.S., Flannigan, M.D., Soja, A.J., Gowman, L.M., Newbery, A. 2012.** A comparison of Canadian and Russian boreal forest fire regimes. *Forest Ecology and Management*, in press.
- de Groot, W.J., Flannigan, M.D., Cantin, A.S. 2012.** Climate change impacts on future boreal fire regimes *Forest Ecology and Management*, in press.
- Dixon, R.K., Krankina, O.N. 1993.** Forest fires in Russia: carbon dioxide emissions to the atmosphere. *Canadian Journal of Forest Research* 23, 700-705.

- FAO. 2001.** Global forest resources assessment 2000: Main report. In. United Nations, Food and Agriculture Organization, Rome, Italy.
- FAO. 2007.** Fire management - global assessment 2006. In. Food and Agriculture Organization of the United Nations (FAO), Rome, p. 135.
- Flannigan, M., Logan, K., Amiro, B., Skinner, W., Stocks, B. 2005.** Future area burned in Canada. *Climatic Change* 72, 1-16.
- Flannigan, M.D., Cantin, A.S., de Groot, W.J., Wotton, B., M., Newbery, A., Gowman, L.M. 2013.** Global wildland fire season severity in the 21st century. *Forest Ecology and Management*, in press.
- Flannigan, M.D., Krawchuk, M.A., de Groot, W.J., Wotton, B.M., Gowman, L.M. 2009a.** Implications of changing climate for global wildland fire. *International Journal of Wildland Fire* 18, 483-507.
- Flannigan, M.D., Stocks, B.J., Turetsky, M.R., Wotton, B.M. 2009b.** Impacts of climate change on fire activity and fire management in the circumboreal forest. *Global Change Biology* 15, 549-560.
- Giglio, L., Randerson, J.T., Van der Werf, G.R., Kasibhatla, P.S., Collatz, G.J., Morton, D.C., DeFries, R.S. 2010.** Assessing variability and long-term trends in burned area by merging multiple satellite fire products. *Biogeosciences* 7, 1171-1186.
- Gillett, N.P., Weaver, A.J., Zwiers, F.W., Flannigan, M.D. 2004.** Detecting the effect of climate change on Canadian forest fires. *Geophysical Research Letters* 31, L18211.18211-L18211.18214.
- IPCC. 2000.** Emissions Scenarios. Cambridge University Press, Cambridge.
- IPCC. 2007.** Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, Pachauri, R.K and Reisinger, A. (eds.)]. In. IPCC, Geneva, Switzerland, p. 104.
- Kasischke, E.S., Turetsky, M.R. 2006.** Recent changes in the fire regime across the North American boreal region-Spatial and temporal patterns of burning across Canada and Alaska. *Geophysical Research Letters* 33, L09703.
- McAlpine, R.S. 1998.** The impact of climate change on forest fires and forest fire management in Ontario. Pp. 15-18 *in* The Impacts of Climate Change on Ontario's Forests. Ont. Min. Nat. Resour., Ont. For. Res. Inst., Sault Ste. Marie, ON. For. Res. Info. Pap. No. 143.
- McAlpine R.S. and Hirsch K.G. 1998.** LEOPARDS—Level of Protection Analysis Software. *For. Chron.* 75: 615-621.
- Mouillot, F., Field, C.B. 2005.** Fire history and the global carbon budget: a 1°× 1° fire history reconstruction for the 20th century. *Global Change Biology* 11, 398-420.
- Pechony, O., Shindell D.T., 2010.** Driving forces of global wildfires over the past millennium and the forthcoming century *Proceedings of the National Academy of Sciences* 107, 19167-19170.
- Podur, J., Wotton B.M. 2010.** Will climate change overwhelm fire management capacity? *Ecol. Model.* 221, 1301-1309.
- Power, M., Marlon, J., Ortiz, N., Bartlein, P., Harrison, S., Mayle, F., Ballouche, A., Bradshaw, R., Carcaillet, C., Cordova, C., Mooney, S., Moreno, P., Prentice, I., Thonicke, K., Tinner, W., Whitlock, C., Zhang, Y., Zhao, Y., Ali, A., Anderson, R., Beer, R., Behling, H., Briles, C., Brown, K., Brunelle, A., Bush, M., Camill, P., Chu, G., Clark, J., Colombaroli, D., Connor, S., Daniau, A.L., Daniels, M.,**

- Dodson, J., Doughty, E., Edwards, M., Finsinger, W., Foster, D., Frechette, J., Gaillard, M.J., Gavin, D., Gobet, E., Haberle, S., Hallett, D., Higuera, P., Hope, G., Horn, S., Inoue, J., Kaltenrieder, P., Kennedy, L., Kong, Z., Larsen, C., Long, C., Lynch, J., Lynch, E., McGlone, M., Meeks, S., Mensing, S., Meyer, G., Minckley, T., Mohr, J., Nelson, D., New, J., Newnham, R., Noti, R., Oswald, W., Pierce, J., Richard, P., Rowe, C., Sanchez Goni, M., Shuman, B., Takahara, H., Toney, J., Turney, C., Urrego-Sanchez, D., Umbanhowar, C., Vandergoes, M., Vanniere, B., Vescovi, E., Walsh, M., Wang, X., Williams, N., Wilmshurst, J., Zhang, J. 2008.** Changes in fire regimes since the Last Glacial Maximum: an assessment based on a global synthesis and analysis of charcoal data. *Climate Dynamics* 30, 887-907.
- Pyne, S.J. 2001.** *Fire: A Brief History*. University of Washington Press, Seattle.
- Stocks, B.J. 1993.** *For. Chron.* 69(3), 290-293.
- Stocks, B.J., Fosberg, M.A., Lynham, T.J., Mearns, L., Wotton, B.M., Yang, Q., Jin, J.-Z., Lawrence, K., Hartley, G.R., Mason, J.A., McKenney, D.W. 1998.** Climate change and forest fire potential in Russian and Canadian boreal forests. *Climatic Change* 38, 1-13.
- Stocks, B.J., Mason, J.A., Todd, J.B., Bosch, E.M., Wotton, B.M., Amiro, B.D., Flannigan, M.D., Hirsch, K.G., Logan, K.A., Martell, D.L., Skinner, W.R. 2003.** Large forest fires in Canada, 1959 - 1997. *Journal of Geophysical Research* 108, 8149.
- Stocks, B.J., Alexander, M.E., Lanoville, R.A. 2004.** Overview of the International Crown Fire Modelling Experiment (ICFME). *Can. J. For. Res.* 34, 1543-1547.
- van der Werf, G.R., Randerson, J.T., Giglio, L., Collatz, G.J., Mu, M., Kasibhatla, P.S., Morton, D.C., DeFries, R.S., Jin, Y., van Leeuwen, T.T. 2010.** Global fire emissions and the contribution of deforestation, savanna, forest, agricultural, and peat fires (1997–2009). *Atmos. Chem. Phys.* 10, 11707-11735.
- Van Wagner, C.E. 1970.** Conversion of Williams severity rating for use with the fire weather index. In: *Can. Dep. Fisheries and For., Petawawa Forest Expt. Stn., Petawawa, Ontario.*
- Van Wagner, C.E. 1987.** Development and structure of the Canadian forest fire weather index system. In: *Canadian Forest Service, Ottawa, Canada.*
- Westerling, A.L., Hidalgo, H.G., Cayan, D.R., Swetnam T.W., 2006.** Warming and earlier spring increase western US forest wildfire activity. *Science* 313, 940-943.
- Wotton, B.M., Stocks, B.J. 2006.** Fire management in Canada: vulnerability and risk trends. In: *Hirsch, K., Fuglem, P. (Eds.), Canadian Wildland Fire Strategy: Background Synthesis, Analysis, and Perspectives. Canadian Council of Forest Ministers. Natural Resources Canada, Canadian Forest Service, Northern Forestry Centre, Edmonton, Alberta, pp. 49-55.*

SEILAF: TACTIC OPTIMIZATION¹

Carlos Abrego Aguilar², F. Javier Romera López³, Regina de la Rosa Calancha⁴, and Domingo Villalba Indurria⁵

Abstract

SEILAF is a system designed for training, simulation and research in the fight against forest fires in a 3D world of a great virtual realism. A consortium of technological centers CITIC and CATEC, enterprises such as INDRA and FASSA, and the University of Cordoba have taken part in the design. The simulation center is located in Aeropolis, near the airport of Seville in Andalusia, Spain.

The system is comprised by three interconnected simulators: a flight simulator of a 412 Bell helicopter, a flight simulator of a fixed wing aircraft to coordinate the tasks of the aerial coordinator and a launching command outpost simulator where the forest fire extinction technical direction team can be trained, all this in a relevant realistic scenery of high resolution. This idea is totally original. It will be the first time that a spreading fire server with the modeled action of extinction resources is included in a tactical environment.

Since the first fits and tests of the system we have been able to analyze and model hypotheses in the development of exercises, responding what resource management in a regime of determined fires is the most efficient and safe tactic of fire extinction.

Key words: virtual training, SEILAF, fire and smoke simulation.

Introduction

Response organizations to forest fire, in similarity to people (Maslow Pyramid), as meeting basic needs evolve into structures of more complex, efficient, intelligent and adaptable functioning to various socioeconomic contexts and fire regimes.

At the base of our pyramid there would be a basic organization and a minimum resource level, on a step above a standardized and certified formation, above a system of total security, above this a high reliability organization (HRO) and at the top there

¹ An abbreviated version of this paper was presented at the Fourth International Symposium on Fire Economics, Planning, and Policy: Climate Change and Wildfires, November 5-11, 2012; Mexico City, Mexico.

² Telecommunications Engineer and Deputy Director for Corporate Area FAASA.

³ JAA Instructor and Flight examiner, Head of Helicopter Training SEILAF.

⁴ Forest Engineer, Head of Forest Fire Research SEILAF.

⁵ Forest Engineer, Head of Forest Fire Training SEILAF.

would be the optimization of the knowledge management whose global indicator could be the maximum efficiency.

Moreover, the eternal search for the ultimate solution to the problem of emergency management that wildfires often cause also goes through several stages though this one in a little sequential way, as may be, the discovery of the miracle remedy, the final invention, the panacea of new technologies, to return to basic and robust extinction actions.

The studied organizations could be grouped in two distinct generic types and differentiated from strategic models of management of forest fires extinction:

1. Those of direct attack. Their main tendency is always to minimize the area affected by the fire directly attacking the advancing fronts.
2. Those of indirect attack. Their main tendency is always to contain the fire in a close perimeter established by means of already existent defense lines or to be built.

Both models, however, share the same common objective, namely, the extinction of the fire at the lowest and economical costs, minimizing all kind of direct and collateral effects,

Both trends need guidelines to enable them to size their resources always seeking the desired equilibrium point, although some issues will go on existing such as the appropriate initial dispatch of resources with the optimum level of resources. In economical booms we have extinguished some fires by flood. In contrast, in times of scarcity, inadequate level of resources along with a dispatch mediated by the phrase “wait and see” cause the effect you want to avoid, the exorbitant level of expenses to attend fires causing immeasurable losses.

Resource dispatches have always been considered as the initial Plan of Action whose strategies and adopted tactics greatly differ from the experience, training and administrative position of the person in charge. In Spain, according to the Autonomous Community and within this by province or region differences are remarkable. Some are based on the inconsistent fire regime but others just rely on a more or less knowledge management. This variation is what we want to validate and verify in SEILAF. And of all the answers be able to choose the most effective according to a typology context.

Our research efforts have initially been for tactical movements. As example, assume that by default the best and undoubted is always to concentrate first all the efforts and resources in stopping the front fire. Then trials have been raised to see if this tactic can be validated with the optimal efficiency.

As a note, SEILAF, as well as any other fire simulator cannot be “the true machine” (sic.) Rodriguez and Silva, F. Instead, the ability to acquire knowledge that the

system has allows certainly discovering and validating the modeled responses whose great advantages are economy of resource, risks and time.

Objectives:

We can determine the scope of the present communication on three main objectives:

- To publicize the SEILAF system by exposing research hypothesis and the first trials.
- To share our initiation into tactical knowledge management of virtual extinction maneuvers.
- To open new ways of study and research using SEILAF as a laboratory of experimentation and collaboration.

Methodology

Hypotheses

There are several postulates or hypotheses. Three have been chosen for their significance and importance to consolidate a common methodology to facilitate further testing and validation studies.

A- Initial attacks always to the head of a fire.

B- To cover an area or what are the consequences if another fire starts having the committed response

C- Minimum range of response

Components of the system

The system architecture is composed of six main elements.

Server room—

It is where the brain of the system resides. It has 9 L-shaped racks, full of COTS equipment that guarantees the maximum performance and control of each element of the system as well as a quick replacement in case of failure.

The system that coordinates all others is called HOST and its functionality is:

- Ensure real-time simulation.
- Manage the various commands, modes and phases
- Synchronize with all the systems that make up the simulators
- Execute and perform proper cycling simulation models

The three simulators are based on the same HW and SW and the main difference is the number of elements of each system. This favors the robustness of the system and dramatically reduces the response time to a contingency.



Figure 1—Equipment room

Bell 412 Helicopter simulator—

It consists of a Bell 412 helicopter cabin, equipped totally surrounded by a spherical dome of 3.25 m radius with a 6 projector system on a base that is supported by a hydraulic movement.

The simulator is designed to meet the requirements established by the standard JAR-FTD level 3A.



Figure 2—B412 helicopter simulator

ACP simulator (Advanced Command Post) —

The adopted solution is a vehicle with all simulated communication systems and a weather station in front of a display where two eight-meter high resolution projectors display the virtual scenario where the exercises are carried out.



Figure 3—Advanced Command Post (ACP) Simulator

COA Simulator (Certificate of Authorization) —

In a cabin of a KingAir airplane two monitors have been arranged in series of instrumentation of utility in air coordination. In this case a rear projection system was used which covers the entire field of vision necessary to achieve an improved immersion in the coordination and management of air operations.



Figure 4—Air Coordinator (COA) Simulator

Instructor Posts—

In the case of COA and ACP the instructor posts are not shipped. Each instruction post consists of a communication system and three monitors with the following tools:

- IOS (Instructor Operation System). Interface that the instructor uses both to plan and to execute exercises.
 - In execution mode the following actions can be enhanced.
 - To stop, load and execute an exercise previously defined in the planner (LPSG)
 - To modify the initial conditions
 - To control simulation (execution, pause, stop)
 - To follow the state of the system and messages of the instructor
 - Monitoring and control:
 - Flight position and parameters
 - Communications
 - Failures
 - Tactical entities
 - Environmental and visual conditions
 - Fire Propagation
 - Sessions and brands (Debriefing)
 - In planning mode the instructor can perform the following operations:
 - Stop, create, delete and modify exercises
 - Starting Position
 - Initial load
 - Preset failures (time, event, condition)
 - Environmental and visual conditions
 - Fire
 - Tactical environment
 - Edit maneuvers
- There is no distinction of type of simulator. The created exercises can be run in any of the three simulators
 - Maintenance of libraries
 - Radioaid database
 - Model database (ET)
 - Users
 - Way points & routes
 - Areas of interest (water points, lakes, etc.)

- Data packages (environmental, visual, position, failures, radio aids)

Debriefing station—

Recording system where the evolution of the missions, voice communications and camera images loaded in each simulator are recorded. The system has a storage capacity of up to 500 hours online simulation.

Tactical environment

The tactical environment is the system responsible for:

- simulating the participant entities in the scenario
- informing the rest of the subsystems the state of the entities
 - Instructor post
 - Host
 - Visual
 - Fire environment
 - sounds

The actions of each tactical element have been modeled according to their actual behavior in an automatic logic, being configurable their action perform under certain parameters, for example, when making a line of defense or in their extinguishing capacity in direct attack or in more basic parameters as their displacement speed.

Fire and local wind server

Developed by the University of Cordoba and CATEC, respectively, SEILAF has a server of fire and of local wind, specific to simulate propagation conditions in any ignition source that under given weather conditions could be established anywhere of a chosen geo-specific scenario.

A major feature of this server is that works in real-time based on the “Visual-Cardin” theoretical model of propagation. Thus due to the fit of the model we can visually see sizes, colors and shapes of flame and smoke with a physical sense of the dynamics of fire behavior. As great value added it has an answer to all actions taken by any tactical element in its task of extinction, even in conducting widening burns and technical fire.

The reality of the dynamics of spread of fire in forest ecosystems shows that under certain conditions and depending on the humidity of the live vegetation located in the canopy, as well as the vertical transmission of the convective effect from the surface displacement fire, processes can be generated which at high linear intensities

of advancing fire, individualized kinking phenomena of trees can be generated, causing passive or intermittent fire advancing through the crowns. This reality has been included in the mechanisms of fire progression, as well as the definition of areas potentially capable of generating ignition of new outbreaks of fire, depending on the occurrence of upward thermal energy, wind speed at height, type of fuel model and the fuel probabilistic state off the ignition. The origin of the sparks always has a prime position in the front of the fire and height taken up when the convection column moves from its vertical development to be moved by the head wind.

The output parameter of flame intensity (kW/m) has been used to differentiate areas of head or engine fire and geo-locate in said cells the base of convection columns. Torching and the step to crown fire are established according to the equations of critical intensity of tree crown (for torching) and burned crown fraction (to determine if the crown fire is passive or active).

Database

The large visual database is shared by the three simulators. In joint exercises from each position it has its specific vision. It is started from 15 detail scenarios of 20x20 km where different types of fires have tried to be incorporated; orographical, wind and convective fires, in diverse landscapes and conditions ranging from natural forest areas as Muniellos in Asturias to humanized landscapes and even extremes of forest-urban interface as Massanet in Girona.

The geo-specific SEILAF database consists of:

- The database comprises the Iberian Peninsula, Balearic Islands and Canary Islands.
 - Based on DTED2 and from Landsat satellite image of 15-meters resolution for the terrain in general
- Based on mdt and high detail resolution orthophotos or geo-specific scenarios
- Airports
- CEDEFOS/Bases of Air Resources
- Points of water of various types/and load difficulties
- Specific models:
 - Air elements
 - Ground tactical elements

The high detail scenarios have been performed on the restitution of 20km x 20km of each high detail area; the 3D elements to model required for training were determined:

- Barriers
- Checkpoints
- Wind elements
- antennas, repeaters
- Power lines
- Meeting points (flat area with heliport signal)
- Buildings with heliport, etc.

- Trajectory files have been generated (starting from 1:50,000 vector data) of roads and highways that are considered necessary for the movement of ground tactical elements.
- Forest areas have also been modeled based on the 1:50,000 vector data and data from the national forest map to determine the type of species to settle in each case.
- On forest areas 3D models of trees were added with a prefixed and randomly density (with the species obtained from the forest map)
- The different densities of forests have been taken into account from that observed in the orthophoto.
- Diversity of specific models or avatars of air elements with different camouflages and matriculates:
 - CL-415
 - AT 802
 - AT 802 FB
 - PZL DROMADER
 - CESSNA 337
 - B407
 - B412
 - A119KOALA
 - AS350B3AS355N
 - BO 105
 - SUPERPUMA
 - SOKOL PZL SWIDNIK W3
 - KAMOV K-32
 - SIKORSKY S70 FIREHAWK
 - M18 TV
- Specific models or avatars of Terrestrial Tactical Elements with a configuration tool of identification code:
 - Lightweight pump
 - Heavyweight pump

- o Nurse pump
- o Dozer on chains
- o Helicopter crew transport
- o Ground crews type II
- o Units type III
- o Firefighters
- o UME

Image generator

For the interaction between fire and visual interface protocols and interfaces of appropriate communications to communicate the fire server and other systems involved have been defined.

Initialization of fire—

Information on materials (fuel types and terrain) of the area chosen for the simulation is provided for the fire server and this area is reflected on a grid of cells of a size indicated by the user interface, always within some values and on an area of orography previously known and studied.

This grid will not be visible in simulation time, but will be available as Debug tool that helps us to verify the consistency of the data sent by the fire server and those that are represented visually.



Figure 5—Cell grid View

Particle system—

Columns of smoke are particle of systems with certain properties, characterized by different "affectors" which determine the type of smoke to represent.

Change of the vegetation status-

Models of vegetation will change to a "burned" status according to the advance of the fire. Therefore all trees within the fire area have been assigned previously to the cell occupied on the ground, so when changing this, trees in it change too. For this, it has been necessary to rearrange the trees in memory and restructure the way in which they were accessed to optimize individual change from one tree model to another.

Definition of extinguishing agents—

After consulting with experts, several types of agents have been defined, with their properties and behavior of the affected areas of land, establishing three types of agents: water, ammonium retardant and foam.

Download of extinguishing agents from air tactical entities—

One of the leading steps against wildfires and object of training will be the air downloads of extinguishing agents. This will affect the fire area interacting with the flames obtaining the right result for each cell. This action will be reflected in the visual interface with a download effect that varies depending on the type of agent used. The water discharge is another effect made from particle systems, and the same fitting criteria are applied for the fire and smoke.

Evolution of the fire—

The evolution of the fire is reflected with, in addition to the effects of fire and smoke, a burning field effect, in charcoal and burnt, using a technique of painting on the Framebuffer Object and projecting the state of each cell on the grid defined.

Action of the ground tactical entities—

Similarly to air entities, land vehicles perform downloads on terrain areas affected. The action of the brigades, a type of land tactical entity is reflected in the form of ditches on the land affected, the so-called defense lines, or in direct attack with a "batefuegos" —a fire bating device-, working as a spearhead and even they made firebreaks. To reflect the effect on the visual interface with the user the same technique to burn the ground is used.



Figure 6—Example of figurative action of extinction

TRIALS

Exercises performed so far are not representative either in number or in optimal system state but are significant as to variety of the organizational system of origin and they are guiding in determining or focalizing factors of tactical improvement.

Hypothesis A— Initial attacks always at the front. The designed exercise has been repeated 4 times.

Scenario: Sierra de la Culebra, Zamora, Castilla y León.

Day: July 15, 2003.

Weather conditions: T 42 °C, Rh 18%, 20 days last rainfall, HCFM 3%, HAINES 4

Ignition start time: 16:15 GTM

Starting area: 5000 m²

Location: 41° 55'40, 20" N; 6° 49' 31, 60" W

Level of resources: 1

Exercise duration: 63 minutes

Variable: Wind direction

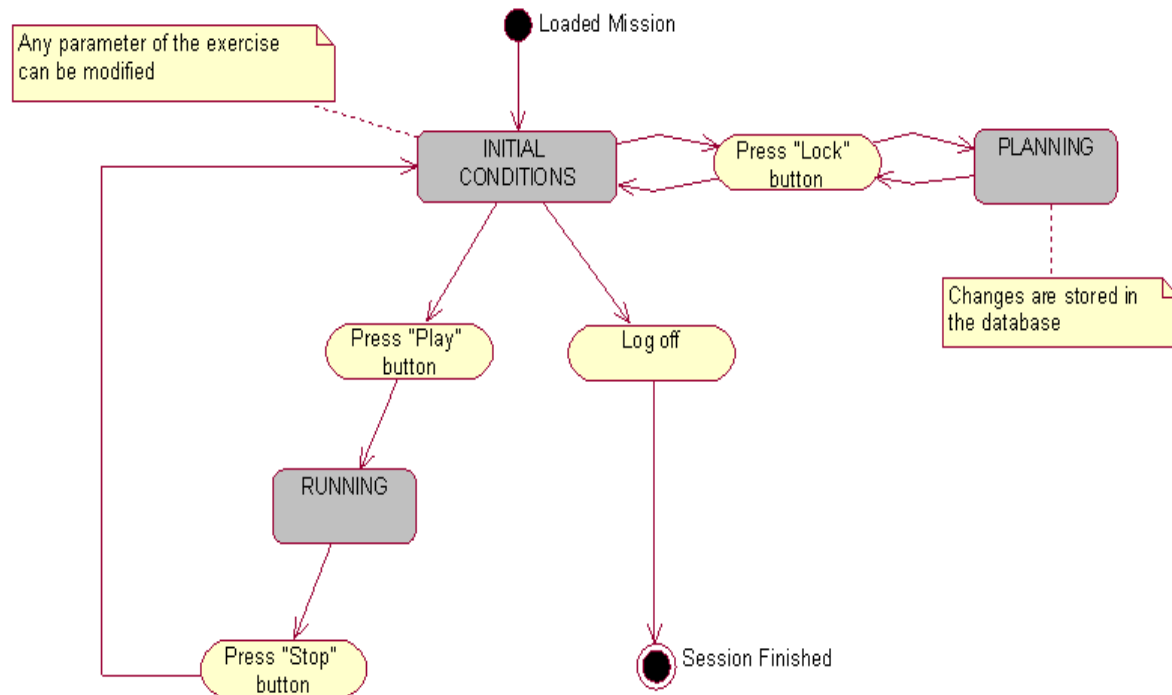


Figure 7—Flow chart of operation exercises

Hypothesis B— The myth of covering area

Scenario: Ibias, Asturias.

Day: July 15, 2013

Weather conditions: T 27 °C, Rh 14%, 12 days last rainfall, HCFM 9%, HAINES 3

Ignition start time: 20:30 GTM

Starting area: 3000 m²

Location: 43° 02'29, 35" N; 6° 19' 31, 60" W

Level of resources: 3

Location: IBIAS

Exercise duration: 87 minutes

Variable: Number of aircrafts on base

Hypothesis C— Minimum range of response

Scenario: Villaviciosa, Córdoba, Andalucía.

Day; July 15, 2013

Weather conditions: T 39 °C, Rh 8%, 40 days last rainfall, HCFM 1%, HAINES 4

Ignition start time: 16:12 GMT

Starting area: 1000 m²

Location: 38° 6' 14,39" N; 5° 0' 35,75" W

Level of resources: 2

Location: Northwestern impoundment

Exercise duration: 32 minutes

Variable: Delay in dispatch

Results (Discussion)

Hypothesis A— Initial attacks always on the head of a fire. This tactical premise is only efficient provided the extinguishing capability exceeds the intensity of the main front.

Other conditions were discovered. To stop the head is an advantage because it minimizes the area/perimeter and with only one resource fires can be controlled, whenever any side may have a greater potential danger. Constant conditions and control times not exceeding half an hour. The classic tactic and safe, from head to tail by the easiest flank to extinguish and anchor, has yielded very efficient results, as propagation conditions were changed or expected means passed to inoperative status.

Hypothesis B— The myth of cover area

The exercises have been developed in the IBIAS scenario due to the fact that a fire regime is typical with days of many simultaneous fires.

The created sequence of fires has been up to five simultaneous fires with an output of air resources of a BRIF (Tineo) comprising two Sokol, a Kamov (Ibias) as a high capacity bomber helicopter and a B3 aircraft with a heli-transported crew type 1.

The trials have focused on validating the tactical scheme of mass extinction as more optimal than done in parallel. The concentration of resources that can extinguish the fire as quickly as possible is always best until now where priority in value or in the danger of a new incipient fire triggers the urge to move all means to that new focus.

As a possible conclusion to be validated one can say that the best place to go for concurrency situations where resources can be is acting.

Hypothesis C— Minimum range of response.

The times between ignition, dispatch and arrival of the first mean are critical, and these can only be attenuated by an initial dispatch compensated and adapted to circumstances of risk and evolution of fire. If this opportunity is obviated the stepped dispatch did not usually resolve the situation of fire break always needing an extended attack strategy.

The battery of exercises conducted so far has been to prove how a ten-minute delay in the departure of the BRICA of the CEDEFO of Cabeza aguda may be offset by the dispatch of a KAMOV helicopter from the location of Villar de Buey and what would happen if we increase the delay in the arrival of this reinforcement until

checking out for which assumptions it would be in a borderline situation of reinforcement.

Conclusions

Tactical optimization strategies drawn from each of the hypotheses have been unified and classified into four sections.

Improvement of security

The various exercises have shown that a wrong initial decision making is what makes a very high percentage of concatenation of events until the disaster. Thus one of the first conclusions is the need to increase the initial assessment capabilities to optimize the first reactions without loss of opportunity. The exercises behaved like a chess game in which each movement from the opening causes endless possibilities and where false steps unbalance the game.

Therefore we see hard to bet by the concept of "the safest tactic" since to small changes of factors ranges of variability are exponential. On the other hand, the current procedures could be standardized and revised to adequate them to the most intense fire behavior and to the increase extinction capacities. The ineffective tactics are accompanied by the free risk-taking, in danger and goal achievement. So it becomes very important to have a strategic vision and a clear and evaluated intent in the planning of all actions.

Improvement of performance

The main causes of loss of detected efficiency can be summarized into three; inadequate dispatches, inoperativeness of tactical entities and widening gap in the transmission of orders of the Action Plan.

Optimization of economic efficiency

The conclusion is that the contribution from tactical optimization to economic efficiency is negligible compared with other external or far away factors such as preventive actions or land management.

What is valued as essence is to know extinguishing capabilities in relation to fire behavior to avoid unnecessary effort.

Response before unexpected

In the still few occasions where small contingencies have been introduced in the development of the exercises it has been proven that they do not disturb when actions are taking place with short-term planning. But when these are structured and they reach greater temporal horizons the reaction capacity resents having a strong inertia to change strategies. In the only case exercised where there was a Plan B, the result was much more effective. The experience/training factor we assume will be crucial to deal with these types of situations. The test plan will continue shortly.

Finally, to conclude SEILAF as environment of study has proved to be capable of responding to the simulation of multiple variables and cases that wanted to be analyzed. The tools available in the IOS have allowed proper planning for each trial as well as the follow-up in their execution and recording of all exercises. The immensity of data generated makes to raise the need to start having ad hoc analysis tools to achieve transform information created in knowledge.

Acknowledgements

We thank the Organization of Congress and the Scientific Committee's acceptance of this paper given the great opportunity of diffusion that this entails.

Managing the Risks of Risk Management on Large Fires¹

Donald G. MacGregor² and Armando González-Cabán³

Abstract

Large fires pose risks to a number of important values, including the ecology, property and the lives of incident responders. A relatively unstudied aspect of fire management is the risks to which incident managers are exposed due to organizational and sociopolitical factors that put them in a position of, for example, potential liability or degradation of their image as a leader. This paper explores the hypothesis that the concept of risk in large fire management extends beyond the potential for physical harm and includes perceived potential damages in the form of social harm that can accrue to fire management personnel. A set of fires from USDA Forest Service Regions 5 (Pacific Southwest) and 6 (Pacific Northwest) for the years 2009 – 2013 are selected based on cost (>\$5,000,000) and examined using a combination of structured interviews and a self-report protocol to elicit and codify the experiences of fire managers (including line officers, fire staff and incident commanders) with regard to a range of risks associated with incident management, including sociopolitical factors that influence incident management and perceptions of career risk. The resulting information will be modeled in terms of the relationship between incident manager perceptual factors and decisions on the incident. Identifying these factors not normally recognized and/or explicitly taken into account in fire managers' decision making process would, hopefully, lead to an acknowledgement and internalization of these factors in their decisions.

¹ An abbreviated version of this paper was presented at the Fourth International Symposium on Fire Economics, Planning, and Policy: Climate Change and Wildfires, 5-11 Nov 2012, Mexico City, Mexico.

² Principal & Senior Scientist, MacGregor Bates, Inc., 1010 Villard Avenue, Cottage Grove, OR, 97424; Email: donald@macgregorbates.com.

³ Research Economist with the Urban Ecosystem and System Dynamics Program, Pacific Southwest Research Station, USDA Forest Service, 4955 Canyon Crest Drive, Riverside, CA 92507; Email: agonzalezcaban@fs.fed.us.

Key Words: career risk, risk-based decision making, social capital

Introduction

The purpose of risk management is to reduce the potential for harm associated with exposure to hazardous conditions by taking appropriate actions. In general, risk management is conceptualized as a response to the findings or conclusions of a risk assessment by which hazards are identified, exposures are assessed and risks are characterized (National Research Council 2009). Essentially, risk management is a problem in risk-based decision making, and the central focus of risk management is deciding between alternative risk-reduction measures. Although this process gives explicit consideration to risk-related factors associated with exposure to hazards, it gives little to no consideration to the risks emergent from the risk management process itself. Indeed, given the inherent uncertainties associated with risk management, the outcomes of risk reduction actions cannot be known with certainty. As a result, even the best-intended risk assessment and risk management plans can lead to undesirable outcomes. From this perspective, risk management is an exercise in decision making under uncertainty for which the decision maker is accountable for the full range of outcomes, both intended and unintended.

To date, applications of risk management decision making have focused on the risk management problem as external to the decision maker, and is done on their behalf in support of a decision. That is, risk assessment provides the framework for the identification and implementation (including monitoring) of risk management efforts. Consider the case of wildland fire where fire managers use risk assessment as the basis for determining the potential impacts of fire on values at risk (e.g., natural resources, private property), as well as risks to those exposed to the hazards of wildland fire as part of risk management (e.g. wildland firefighters).

Two key elements receiving little attention in risk management research are related to the risk management decision maker as a personal agent, and the broader social context within which the decision maker operates. These two elements can be characterized as risk to career and risk to social capital.

Risk to Social Capital

With respect to social context, many risk-based decisions impact not only the organizations with which risk managers are associated, but also impact stakeholders outside of a risk manager's organization with consequences to social capital. In some risk management contexts, the impacts to social capital can have an influence beyond

a specific risk management situation (e.g., wildland fire) and into other management areas where social capital is critical to the risk manager's success as a decision maker (e.g., NEPA actions). Similarly, risk managers working together on a risk management situation (e.g., line officers and incident commanders) may rely on social capital to accomplish their work with quality and efficiency, but have social capital associated with their working relationship at risk due to elements of the situation (e.g., high stress, leadership capabilities).

We use the concept of social capital to refer to resources such as trust, information and social norms, as well as a tendency on the part of a decision maker to engage in collective actions with stakeholders that have mutual benefit (e.g., Bourdieu 1986, Coleman 1990, Fukuyama 2002, Paromita 2009). Implicit in this definition is a relatively stable social network of relationships that is somewhat durable though not necessarily fully resilient with respect to the impacts of unmet (implicit) social expectations. Hence, social capital is at risk whenever the actions of a decision maker could result in violations or breaches of social bonds established through patterns of interaction and negotiation.

Risk to Decision Maker Image and Career

Risk managers may face potential impacts to their image and career as a function of the outcomes of risk-based decisions that they make. For example, pre-tenure academics working across traditional disciplinary lines have been found to experience career risk when they pursue research agendas that are focused on interdisciplinary problems such as climate change (Fischer, et. al. 2012). As yet, we have little in the way of models of how career risk might factor into risk-based decision making as part of risk management, though we do have some anecdotal evidence that in the domain of professional investment decision making a significant challenge for investment professionals is dealing with career risk and job protection as an investment agent (e.g., Grantham 2012). Observations of investment professionals suggest that risk managers concerned about career risk may overly focus on what other risk managers are doing or have done in the past, thereby creating a herding tendency toward inefficiencies in investment behavior. Put more directly, perceptions of career risk may drive risk managers to excessive avoidance of error or negative outcomes (risk aversion), and over-attention to behaving as others have done to avoid being wrong or erroneous on their own.

Study Context

Risk is inherent to fire management. Large-scale incidents, such as those that cost millions of dollars to manage and suppress, present multiple sources of risk, including risks to incident personnel as well as risks to the resource base in the form of damage from fire and from fire suppression activities. Decision making in the context of large fires is the basis for risk management, and a complete understanding of how decisions are made cannot be had without understanding the multi-dimensional characteristics of the risks associated with fire and fire management on these large-scale events (MacGregor 2006).

In recent years, the focus of decision making on large fires has centered around cost and cost management. With growing evidence that not only are fires becoming more costly and larger in size is the disconcerting finding that firefighter fatalities have increased as well. Nonetheless wildfire costs on a per-acre basis, particularly for the largest of fires, are not reliably predictable from biophysical features of the fire context alone. It is clear at this point that however decisions drive large fire costs, they are not doing so based on exogenous features of fire, including size, values at risk, fuels, topography, etc.

This research takes the perspective that in the context of large fire management, risk is a multi-dimension construct that includes multiple hazards and consequences. Damage to the natural and built environment is among these hazards, as is potential harm to firefighters and the public. These forms of hazard are generally well accounted for in the decision making documentation that accompanies large fires. For some of these risks, mitigation measures are set in place, such as safety training for firefighters, evacuation of the public, and interventions that promote pre-incident preparedness for homeowners in the form of defensible space.

A feature of large fires that is commonly identified as contributing to cost is a relatively broad category of hazards that might be conceptualized as sociopolitical in nature. These include the potential damage or harm to the agency's image or the image of the fire managers for failing to take action even if that action is not likely to achieve a positive value with respect to managing the physical properties of the fire (e.g., spread, damage, intensity). Research on the role of trust (as an element of social capital) has suggested the importance of trust in effective and efficient natural resource management (e.g., Cvetkovich & Winter 2007, Liljeblad & Borrie 2006). However, we have no research to date that identifies the pathways by which social capital (and trust) enters into fire management decisions that occur at the time of an incident. Such decisions would include level of resources assigned, relative aggressiveness of strategies and tactics, overall efficiency of incident response, and responses to media events.

We hypothesize that the concept of risk in large fire management extends beyond the potential for physical harm and includes perceived potential damages in the form of impacts to career or impacts to perceptions of leadership or management social harm that can accrue to management personnel. These perceptions may arise from a generalized belief that it is better to do all that can be done even if that activity does not produce a positive physical result, but does produce a valued psychosocial result. The hypothesis is based on the notion that risk management can have as its goal or objective a variety of purposes, some of which are non-physical.

The implications of this hypothesis extend to alternative approaches for accounting for the costs of large fires. Fire management strategies and actions fielded in the interests of sociopolitical concerns, and to achieve sociopolitical objectives may significantly impact fire costs. These impacts may be well beyond those due to the physical attributes or characteristics of values at risk (e.g., critical infrastructure). The research proposed here will help lead us in the direction of a more complete identification of fire management strategies as a predictor of large-fire cost.

Methods

The methodology for this research is based on a combination of structured interviews and self-reports of fire managers, including agency administrators, fire management officers and incident command staff that synthesizes their experience on specific fire incidents. In addition, information is also gathered from a number of existing fire-related databases, particularly the Fire & Aviation Management web site (FAMWEB), the Wildland Fire Decision Support System (WFDSS), and the on-line incident website InciWeb.

A self-report protocol has been developed that also serves as a structured interview guide. The protocol was designed to be brief yet comprehensive with respect to the potential influences of social factors on incident decision making, and includes:

- Political influences and pressures, including direct involvement from influential individuals (e.g., elected officials), and influential groups (e.g., cultural/tribal, public groups).
- Media reporting and coverage, including type of media (e.g., broadcast, print, internet), timing of media reporting with respect to the incident timeline and actions taken in response to media reporting.
- Actions taken to manage sociopolitical pressures or objectives, including incident strategies, incident tactics, changes in objectives, and changes in number and type of suppression resources.

Additional information on each incident is obtained from the three databases indicated above. FAMWEB provides access to the daily reporting format ICS-209 that documents on a regular basis the status of an incident, including its size, staffing, values at risk and management objectives. WFDSS provides (in many cases) more comprehensive information on incident strategies, values at risk and decision rationale. InciWeb provides a highly accessible overview of incidents that is updated on an on-going basis, and provides an early indication of incidents that are suitable for study.

Incidents are selected over a five-year period, beginning in 2009 and ending with the 2013 fire season for USDA Forest Service Region 5 (Pacific Southwest – California), and Region 6 (Oregon & Washington). Only incidents that are wholly (or primarily) on lands under USDA Forest Service jurisdiction or are managed by a USDA Forest Service agency administrator are selected for study; are managed by either a Type I or Type II incident management team (IMT); and have a cost of \$5,000,000 or more. However, we have been tracking incidents down to the \$>2,000,000 level to increase the potential size of our database. Fire years 2009, 2010 and 2011 were relatively slow in Regions 5 and 6 and fire costs were somewhat lower than average.

For each incident, an Incident Time Line is prepared based on information from the various information documentation sources discussed above. In addition other incident information is encoded, including key events, fire cause, fire size, peak resource levels, strategies & tactics, occurrences of injuries & fatalities, and threats/losses to critical values (e.g., residences).

Preliminary Results

As of the date of this writing we have established a database of 32 large-fire incidents according to the criteria outlined above (23 in Region 5; 9 in Region 6). These fires are for the 2009, 2010 and 2011 fire season. For the 2012 fire season, we are currently adding cases to the database. Although it is too soon to draw firm conclusions, we do have some speculations based on preliminary results.

- The terminology “sociopolitical” appears to apply to a wide range of social factors that have a relationship to a fire incident; this can include factors that influence incident decisions (such as local interest groups, political stakeholders) and factors that are the result of incident outcomes. As one fire manager put it: “Values at risk that have sociopolitical implications depending on the outcome.” Thus, sociopolitical factors appear to be both an influence on fire management, as well as an outcome of fire management. Previous modeling efforts have identified distinct categories of sociopolitical

- factors and characterized them in terms of legacy, pre-incident and incident-specific influences (MacGregor & González-Cabán 2008).
- There appears to be a category of incidents that are *linked* to other incidents through elements of social capital. In these cases, a fire incident occurring at one place and time may have its management response guided in part by social capital considerations from an earlier fire in which social capital was lost or degraded by features of that earlier incident. Incidents linked in this way are not “visible” through the biophysical features of the fire environment, but are instead linked through social implications of incident management and incident outcomes.
 - Beginning in 2009, the USDA Forest Service undertook a significant national-level effort to introduce structured risk assessment and risk management principles into fire management. This effort placed emphasis on careful consideration of firefighter exposure to the inherent risks of wildland fire and called for balancing those risks against the likelihood of success of fire management operations. In addition, a structured approach to risk assessment was established that called for an explicit consideration of alternative fire management strategies or “prospects” that contrasted a range of levels of engagement from more aggressive (e.g., direct attack) to less aggressive (e.g., indirect attack, point protection). The effects of this effort are more visible in fire management for the years 2010 and 2011, and appear to be even more so in this year, 2012.
 - Social capital is a general resource that has value and utility across a wide range of unit management activities, and particularly non-fire projects that constitute the plan of work associated with resource management. When social capital is impacted by fire management there appears to be a *transfer effect* by which social capital is diminished for other non-fire uses such as projects requiring public scoping and review under the National Environmental Protection Act (see MacGregor & Seesholtz 2008). This effect may be moderated by the degree to which publics are clustered or segmented in terms of interests. The type and extent of this compartmentalization may be variable across management units and differ with management situations.
 - In some fire management circumstances we have observed that agency administrators may have difficulty assessing the extent to which they have social capital and may tend to over estimate the amount of social capital they have.
 - In general, media reporting appears to lag rather than lead incident decisions for the type of fires selected for study. However, more analysis on this point

is required before it is clear how and to what degree media reporting interacts with incident decision making.

- The concept of career risk, though anecdotally characterized in terms of termination, appears in reality to be more complex and better characterized in terms of ability to function effectively and efficiently.
- Fire managers have significant concerns about how they are perceived as leaders by both their staff and by stakeholders. Perception of leadership appears to be an important component of career risk in that loss of leadership image may significantly impact the ability of fire managers to function in roles that are part of their non-fire activities (e.g., agency administration).

Summary

Risk management is inherent to fire management, and in that context extends beyond the biophysical characteristics of fire to include social and managerial factors. Two broad classes of such factors include risk to fire managers' leadership image and risk to social capital. The present study, currently underway and not yet completed, suggests based on preliminary results that taking a broader perspective on risk may provide a pathway forward for understanding factors that influence risk-based decision making in ways as yet unaccounted for. Identifying these factors not normally recognized and/or explicitly taken into account in fire managers' decision making process would, hopefully, lead to an acknowledgement and internalization of these factors in their decisions.

Acknowledgement

This research was supported by Agreement No. 09-JV-11272165-072 between the USDA Forest Service, Pacific Southwest Research Station and MacGregor-Bates, Inc.

References

- Bourdieu, P.** 1986. The forms of capital. In J. Richardson (Ed.) *Handbook of theory and research for the sociology of education* (pp. 241-258). New York: NY: Greenwood.
- Coleman, J. S.** 1990. *Foundations of social theory*. Cambridge, MA: Harvard University Press.
- Cvetkovich, G. T., Winter, P. L.** 2007. The what, how, and when of social reliance on cooperative risk management. In: M. Siegrist, T.C. Earle, & J. Gutscher (Eds). *Trust in cooperative risk management: Uncertainty and skepticism in the public mind*. (pp 187-209). London, UK: Earthscan.
- Fischer, E.V., Mackey, K.R.M., Cusack, D.F., DeSantis, L.R.G., Hartzell-Nichols, L., Lutz, J.A., Melbourne-Thomas, J., Meyer, R., Riveros-Iregui, D.A., Sorte, C.J.B., Taylor,**

- J.R.White, S. A.** 2012. Is pretenure interdisciplinary research a career risk? *Eos Trans. AGU*, 92, 311.
- Fukuyama, F.** 2002. Social capital and development: The coming agenda. *SAIS Review*, 22, 23-37.
- Grantham, J.** 2012. Jeremy Grantham on investment management career risk. *The Reformed Broker*. Retrieved from: <http://www.thereformedbroker.com/2012/07/31>. Last retrieval: 28 August, 2012
- Liljeblad, A., Borrie, W. T.** 2006. Trust in wildland fire and fuel management decisions. *International Journal of Wilderness*, 12, 39-43.
- MacGregor, D. G.** 2006. The future of fire in environmental management. *Futures*, 38, 505-518.
- MacGregor, D. G., González-Cabán, A.** 2008. Decision modeling for analyzing fire action outcomes. Res. Pap. PSW-RP-258. Albany, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station. 67 p.
- MacGregor, D. G., Seesholtz, D. N.** 2008. Factors influencing line officers' decisions about National Environmental Policy Act project design and development. Gen. Tech. Rep. PNW-GTR-766. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, 27 p.
- National Research Council.** 2009. *Science and decisions: Advancing risk assessment*. Washington, DC: The National Academies Press.
- Paromita, S.** 2009. From credit to collective action: The role of microfinance in promoting women's social capital and normative influence. *American Sociological Review*, 74, 529-550.

Simulation Analysis of a Wildfire Suppression System¹

Abílio Pereira Pacheco², João Claro², and Tiago Oliveira³

Abstract

Rekindles and false alarms are unusually high in the Portuguese wildfire management system, representing a high burden on suppression resources in particular, and fire management resources in general. In 20,049 occurrences that the suppression system handled in the summer of 2010, 12.5% were false alarms and 15.0% were rekindles. We present a discrete-event simulation model of a wildfire suppression system, designed to analyze the joint impact of primary fires, rekindles and false alarms on system performance. The work contributes to fill a research gap concerning that impact, and features a novel application of simulation to suppression systems, as screening tools to support more holistic analyses. The model was implemented in @ARENA, and used for a study of a Portuguese district. We found that reducing false alarms and rekindles to benchmark values would significantly reduce pressure on firefighting teams, enabling more effective suppression operations.

Key Words: Arson, Discrete Event Simulation, False Alarm, Hoax Calls, Rekindles.

Introduction

During the summer of 2010 Portugal registered 2,497 rekindles, a 17.2% increment to the 14,551 primary forest fires, leading to a total of 17,048 wildfires (Pacheco and others 2012). However, this figure may in reality be more extreme. Several authors indicate that the number of rekindled forest fires is higher than what is officially reported (ANIF 2005, Lourenço and Rainha 2006), and experts that we have interviewed point to the double. Even assuming that the reported data are correct, the proportion of rekindles is too high (Beighley and Hyde 2009). This situation has worsened over the years (ANIF 2005), and is mostly the result of ineffective mop-up operations (Lourenço and Rainha 2006, Murdock and others 1999, Lourenço 2007, ISA 2005, ANIF 2005, Beighley and Hyde 2009), despite an effective initial attack

¹ An abbreviated version of this paper was presented at the Fourth International Symposium on Fire Economics, Planning, and Policy: Climate Change and Wildfires, November 5-11, 2012, México City, México.

² Graduate Student and Professor, respectively, INESC TEC (formerly INESC Porto) and Faculdade de Engenharia, Universidade do Porto, Rua Dr. Roberto Frias, 378, 4200-465 Porto, Portugal (e-mail: abilio.pacheco@fe.up.pt; jclaro@fe.up.pt)

³ Forest Protection, Grupo Portucel Soporcel; Edifício Mitrena, Apartado 55, 2901-861 Setúbal, Portugal (e-mail: tiago.oliveira@portucelsoporcel.com)

(ANIF 2005, Lourenço 2007, Lourenço and Rainha 2006). An ineffective mop-up and lack of surveillance (Lourenço 2007) lead to rekindles that often become large fires (ANIF 2005, Lourenço 2007, Lourenço and Rainha 2006). These are usually larger than the wrongly judged extinguished primary fire, with large burnt areas and considerable damage (ANIF 2005), even when the initial perimeter was just tens of meters (Lourenço and Rainha 2006).

In addition to rekindles, that are sometimes wrongly interpreted by the public as arson fires (Lourenço and Rainha 2006), the wildfire suppression system is also challenged by false alarms – malicious or good intent calls made to dispatch centers and fire departments. Because they cannot presume that a call is a false alarm and must respond as they would to a real fire (Ahrens 2003), hoax calls represent a waste of energy for the suppression teams. This means that 3,001 more events of this kind (20.6% of the primary fires) are added to the 17,048 wildfires, with rekindles and false alarms in total representing 27.4% of the 20,049 occurrences.

This huge proportion motivated us to analyze the joint impact of primary fires, rekindles and false alarms on the performance of the suppression system, using a discrete-event simulation (DES) approach.

The paper is organized as follows. In the next section, we explore the nature, sources and implications of rekindles and false alarms. The following section presents the data sources, describes the model, and briefly explains how the simulation was constructed. Subsequently, we present the results of the simulation and highlight the most relevant findings. The final section discusses the main points and offers conclusions.

Problem framing

In this section we use the literature and our interviews with experts, to suggest and describe three main sets of causes for rekindles: the characteristics of the physical site (soil and fuel type), ineffective firefighting technics (absence of use of tools, deficient fire line construction and patrolling), and the existence of a double-duty for firefighters. Next, we examine the nature and causes of false alarms, as well as strategies to decrease their number. Finally, we provide benchmark values for these two types of events, later used as targets in the DES study.

Bad mop-ups and rekindles

After establishing control lines around the fire perimeter, the fire crews start to solidify it working towards its interior (Martell 2007). When the fire is under control, mop-up begins, and later, the area must be patrolled before the fire may actually be

declared extinct (Alexander 2001, Martell 2007, Murdock and others 1999). Performed along the fire control line, mop-up involves the detection and neutralization of all hot areas (Figure 1). The hot spots can be identified by smoke smell, visible signs (smoke, white ash, clouds of gnats, heat waves, steam), audible signs (crackling of embers, hissing of escaping steam) or by touch (almost touching the ground with the hand). Indeed, a small spark near a control line can cause a later rekindle (Murdock and others 1999). The mop-up stage may take several days, even weeks (Martell 2007) and can easily takes three times as long as the time spent until the fire was declared under control, in fires with more than 100 ha (ANIF 2005). Overall, it is a very time-consuming and costly stage (González-Cabán 1984).



Figure 1—Before and after a rekindle: signs of a bad mop-up (left) and holes caused by underground fire (right).

Rekindles, or reignitions, by definition, are fires that reburn an area over which a previous fire has passed, leaving fuel that later ignites due to latent heat, sparks, or embers (NWCG 2011). They can occur, for instance, in fuel complexes that exhibit heavy fuel loads and deep organic layers. Primarily under the decomposing leaf litter, lies a compact organic layer in which ground or subsurface fires will remain burning slowly (Lourenço and Rainha 2006). Areas near rivers, peat bogs, old forests, and large decaying logs are prone to such fire persistence, as a result of the dryness left after the passage of the main fire front. This arises especially in major dry spells or droughts (Henderson and Muraro 1968, Alexander 2001). Such underground burning (Figure 1) in a smoldering stage can erupt into flames when it gets to the surface exposing this heated fuel to air (NWCG 2005). Physical site characteristics, however, do not fully explain the observed variation in mop-up costs (Donovan and Brown 2005). Thus natural (weather conditions, spatial-temporal concentration) and organizational (human resources management and of equipment) factors must be considered (AFN 2011). This is the case of Portuguese mainland, where across the 18 districts the increment of rekindles beyond primary fires varied from zero to 85%, with half of the districts featuring proportions above 9.3% (Pacheco and others 2012).

The main reasons for many of these rekindles in Portugal are: inappropriate mop-up when the fires occur in inaccessible areas (Beighley and Hyde 2009); absent or deficient fire line construction using existing roads or near houses (Beighley and Hyde 2009, Lourenço and Rainha 2006); and the fact that mop-ups are performed almost exclusively with water, typically without hand tools that could safely consolidate the perimeter (Lourenço and Rainha 2006, ANIF 2005, Beighley and Hyde 2009, ISA 2005). Actually, it is critical to make a trench down to the mineral soil (Oliveira 2011), or regolith, where water does not penetrate (Lourenço and Rainha 2006) and create a discontinuity between burnt and unburnt areas (Lourenço and Rainha 2006) to prevent the rekindling of hot spots (Murdock and others 1999).

The need to address these problems was acknowledged in 2005 (ISA 2005, ANIF 2005) and officially assumed in 2006 (CM 2006) after the disastrous fires of 2003 (Fernandes 2008), repeated two years later. The government commissioned a technical strategy (ISA 2005) to address this problem, and in 2006 a modified version (shifting from an emphasis on prevention to an increase in suppression capability) was approved and published (CM 2006) as the national strategy for forest protection against fires (Beighley and Hyde 2009). Training for the use of hand tools by the firefighters was mandated, along with the acquisition of tools and the use of excavators. The use of handheld infrared scanners for hot spot detection (Alexander 2001) was also suggested later (Oliveira 2011). Additionally, it was officially recognized that mop-up and surveillance are an integral part of firefighting operations (ANIF 2005, Lourenço and Rainha 2006). The need to improve command and control structure (ISA 2005), establish procedures and assign responsibilities was also recognized (ANIF 2005, Oliveira 2011). Finally the plan recognized the impact of rekindles and established their mitigation as a priority, with a goal of 1% by 2010 defined as an acceptable value for the rate of rekindles (Oliveira 2011). This goal was not ever achieved (AFN 2011) and may in fact be considered too ambitious when compared, for instance, with the same statistic for the U.S. between 2004 and 2008, which varies between 2% and 6% (Ahrens 2010).

The fact that the observed high number of rekindles may result from inadequate post-fire management and active surveillance (AFN 2011) has led some experts to suggest the creation of specialized hand crew brigades, properly trained in mop-up operations (Beighley and Hyde 2009, ISA 2005). In fact, the crews responsible for the mop-up operations are the same that are needed for the suppression of new fires (primary or rekindled), and this “double-duty” weakens the system: firefighters often leave a fire too early in order to engage in new initial attacks (Beighley and Hyde 2009). Analyzing rekindle genealogies and using linear regression analysis across Portuguese districts, we found evidence supporting that hypothesis for six of the seven districts with a relevant number of rekindles (Pacheco and others 2012).

False and nuisance alarm calls

A false alarm (FA) may have its origin in a malicious or mischievous report (hoax call), or in a good intent call, e.g. when dust originated by some kind of heavy works is mistaken for distant smoke (AFN 2011). A key motive for the recent strong growth of FA in Portugal, suggested in our interviews with experts, is the change to a "muscle attack" dispatch policy since 2006: aiming to eliminate a fire in the first intervention, a helicopter is sent if available. The knowledge of this fact leads some adults and children to alert the fire department, in the hope of seeing a helicopter from close.

There is scarce research available with statistics on this type of calls (Flynn 2009). Additionally, it is not easy to perform international comparisons, due to the fact that in Portugal the alarm systems are not connected to dispatch centers. In fact, the unintended malfunctioning of automatic alarms is responsible for approximately one third of the false alarms reported in the U.S. (Hershfield 1995, Karter 2010, 2011), 42% in London (Tilley 1997), 50% in New Zealand (Tu 2002) and 62% in Tasmania, Australia (Killalea 1998). Even so, accounting for hoax and good intent calls, the rates found in the U.S. were 4.4% in 2009, and 4.1% in 2010 (Karter 2010, 2011), and between 4.6% and 5.4% in New Zealand (Tu 2002). In the United Kingdom, considering all emergency calls, the rates of hoax calls were 5.0% in Derbyshire (Yang and others 2003), and 6.2% in South Wales (Corcoran and others 2007).

These figures suggest the possibility of decreasing the number of false alarms in Portugal. For instance, the Dispatch Center of the District of Porto (CDOS Porto) implemented a policy of returning a call if it originates in a school, and asking to speak to a parent in case a child's voice is recognized. According to our interviews, this policy enabled a reduction in the number of FAs and may explain the fact that the district rate is now 2/3 of the national rate (Pacheco 2011). Killalea (1998) also provides evidence of a similar reduction two years after the implementation of a policy to identify all the calling numbers. However, before considering concrete measures it is advisable to analyze and understand the specific local causes of this phenomenon. The differences found in various studies show the importance of not making premature assumptions about its causes (Corcoran and others 2011, Corcoran and others 2007). Only the collection of accurate information about FAs, namely their type and origin, allows authorities to identify risk areas and design policies and intervention strategies for their populations (Flynn 2009).

Data and Methods

For our study, we used data kindly provided by the Portuguese Forest Service (Autoridade Florestal Nacional in Portuguese) (AFN). This dataset has been stable for the last twelve years, and contains the fire location and time (i.e., alert, ignition

and extinction), burnt area, event type (e.g. false alarm, agricultural or forest fire), its cause and nature. The distinction between single or rekindled fire (its nature) is recorded since 1984 (Pereira and others 2011), but 2010 is the first year for which it is possible to connect a rekindle to the specific fire whose bad mop-up originated it.

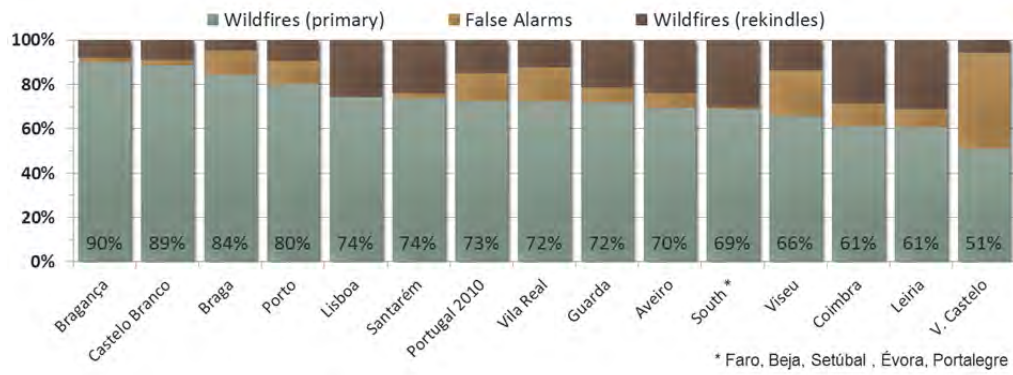


Figure 2—Share of primary fires, false alarms and rekindles (2010, summer).

The country mainland is divided in eighteen main districts (administrative regions) with their corresponding municipalities (278 counties). The significant geomorphologic, climatic and demographic differences along the country (Pereira and others 2011), and the heterogeneity of fire management policies, and suppression and prevention efforts (e.g. Figure 2), which are organized at the district level, justifies considering the district as a unit of analysis.

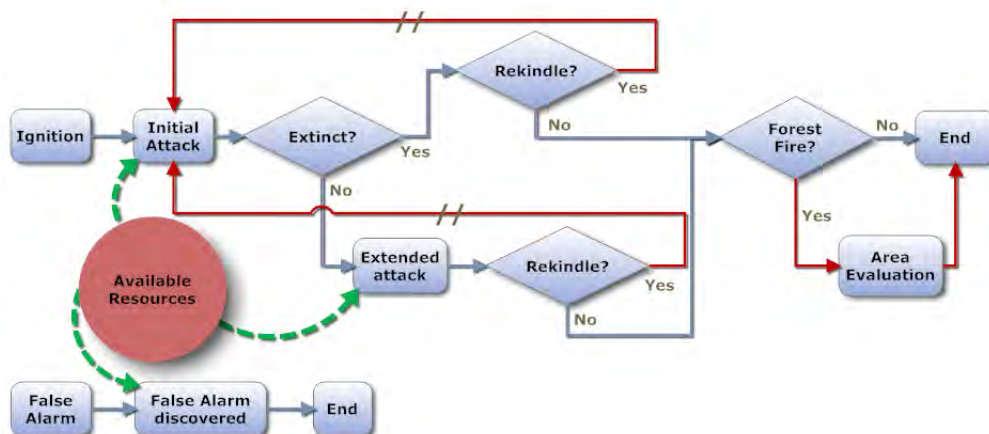


Figure 3—Conceptual model of a wildfire suppression system.

The design of our conceptual model for the wildfire suppression system (Figure 3) was based on literature review, fieldwork that included visits to firefighting dispatch centers, forest stands and wildfires, and informal and formal recorded expert interviews. To model explicitly the available firefighting crews, we used a second database (gently supplied by CDOS Porto) with the details of the fire suppression interventions. Finally the model was implemented in ®ARENA, and used for a study

of the district of Porto between the months of July and September 2010.

There are four motives for the choice of this case study: Porto features a high number of fire occurrences, and available detailed data on deployed resources; the proportion of rekindles and false alarms is slightly below, but still in line with national figures; 84% of the ignitions, corresponding to 96% of the burnt area, occur in this three-month period (Pacheco 2011); and 2010 is the first year for which appropriate data on false alarms are available, providing (as mentioned before) the opportunity to reconstruct the chains of bad mop-ups and rekindles starting from the primary fire, for the first time (Pacheco and others 2012).

The databases of AFN and CDOS Porto were merged and used to parameterize and validate the model, which was subsequently used with sensitivity and optimization analyses to better understand the impacts of the factors under study.

Preliminary Results

In this section we briefly describe the implementation of our model (Figure 3) as a DES in ®ARENA, and how we used the results of the data analysis of the combined AFN and CDOS Porto databases to parameterize it (Table 1).

Table 1—Essential parameters of the model (IA/EA: initial/extended attack).

Arrivals	New Fire	A Class	24	parameters	(hourly)
		B Class	24	parameters	(hourly)
	Rekindle	A Class	24	parameters	(hourly)
		B Class	24	parameters	(hourly)
	False Alarm	A Class	24	parameters	(hourly)
		B Class	24	parameters	(hourly)
Durations	New Fire	A Class	1	parameter	Empirical Dist.
		B Class	1	parameter	Empirical Dist.
	Rekindle	A Class	1	parameter	Empirical Dist.
		B Class	1	parameter	Lognormal Dist.
	False Alarm	A Class	1	parameter	Lognormal Dist.
		B Class	1	parameter	Lognormal Dist.
Initial Attack (End)	New Fire	A Class	2	parameters	end, tuning
		B Class	2	parameters	end, tuning
	Rekindle	A Class	2	parameters	end, tuning
		B Class	2	parameters	end, tuning
Resources	New Fire	A Class	2	parameters	(IA / EA)
		B Class	2	parameters	(IA / EA)
	Rekindle	A Class	2	parameters	(IA / EA)
		B Class	2	parameters	(IA / EA)
	False Alarm	A Class	1	parameter	no EA
		B Class	1	parameter	no EA
Burned Area	Stands	A Class	1	parameter	regression
		B Class	1	parameter	regression
	Forest	A Class	1	parameter	regression
		B Class	1	parameter	regression

The ®ARENA simulation model (ASM) has three main sections, modeling primary fires, rekindles and false alarms. In a fourth final section we compute the

total number of incidents, evaluate the forest and shrubland burnt areas as a function of the fire duration (including the waiting time), and compute value losses and CO₂ emissions (AFN 2011, Narayan and others 2007). Value losses are evaluated in two alternative ways: using the official guidelines of AFN (AFN 2011); according to the guidelines of the proposal for a National Plan for Prevention and Protection of Forest against Fires (ISA 2005), which includes non-timber (e.g. “recreational activities” and “indirect use”) value losses.

The three main sections of the ASM have in common two components: (1) the arrivals of primary fires, rekindles, and false alarms; and (2) the confirmation as primary fire or rekindle initial attack, or false alarm. A third (3) component is used to simulate the extended attack in the case of a fire escape, for the primary and rekindled fires. The latter two components also include resource allocation, namely for the false alarm verification operation (with an average duration of 62.8 minutes). Despite the separate modeling of primary fires and rekindles, we will simply call them “ignitions”, and name the three abovementioned components as “arrivals” (1), “initial attack” (2) and “extended attack” (3), respectively.

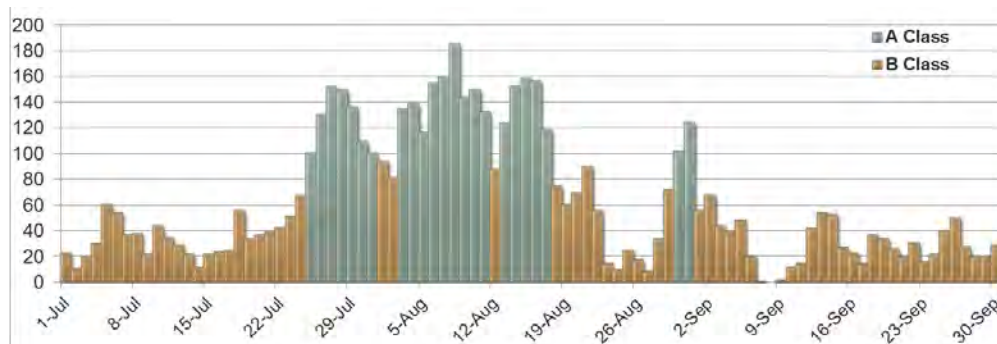


Figure 4—Day severity class along the 2010 summer in the district of Porto.

The “arrivals” component (1) distinguishes between two classes of severity for the days, which are related to the total number of occurrences (ignitions and false alarms) during the day. Studying the daily numbers of occurrences, we found a clear division around 100, and our interviews with CDOS Porto confirmed this threshold, i.e., up to 100 daily occurrences, resource allocation is easily managed and the response capability is clearly appropriate. We thus considered a severity “B class” below 100 occurrences/day, and a severity “A class”, above (Figure 4) that threshold.

Moreover, as the numbers of incidents change significantly along the day (Bookbinder and Martell 1979), we implemented the arrivals as a non-stationary Poisson process, considering rates of arrival that change hourly during the day. Using data from Bookbinder and Martell (1979), and analyzing the AFN database, in Figure 5 we show a comparison between the northwestern region of Ontario in Canada

(1967-69) and Portugal (2001-10), considering only the four coldest months (November to February), as well as the whole year. In the first two cases, the same camel-like shape is visible. As for the third case, the bell-like shape might be a result of the human footprint, since approximately 98% of the ignitions in Portugal were man-caused, in contrast with 65% for the first case (Cunningham and Martell 1973).

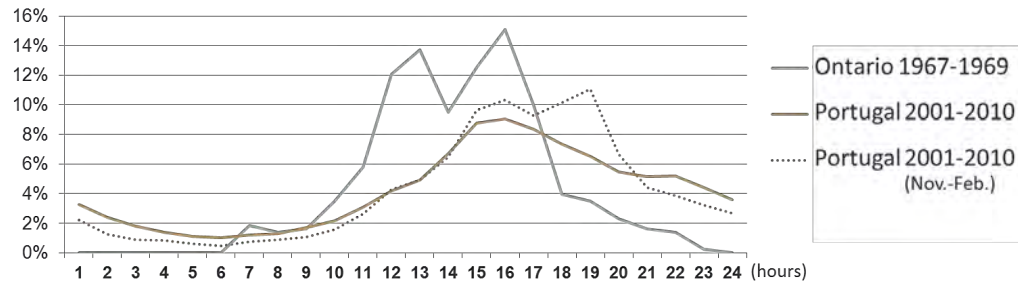


Figure 5—Arrivals as non-stationary Poisson process changing hourly along the day.

The “initial attack” component (2) starts by attributing to each arrival occurrence its duration and the resources needed (ground crews and, if available, a helicopter). In our model, the queue discipline is always FIFO and the resources have the same allocation priority. If the fire duration exceeds the maximum duration for an initial attack, it enters the extended attack component (3), otherwise the fire is considered extinguished and the resources are released.

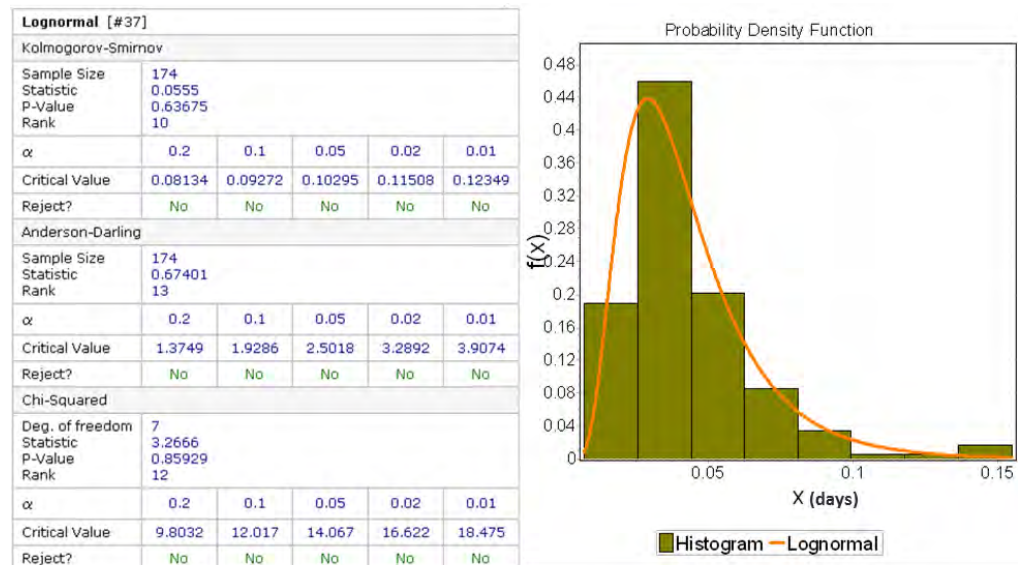


Figure 6—False Alarm duration in a B Class day (Porto, 2010, summer) and the lognormal distribution chosen: $\sigma=0.51079$, $\mu=-3.2822$, $\text{LOGN}(0.04278, 0.02336)$.

The duration of the fire is modeled with probability distributions. Among the classic probability distributions available in ®Arena, we chose the one with highest

fit and not rejected, at the $\alpha = .01$ level of significance. In half of the cases (Table 1), the lognormal distribution had the best fit and was chosen (e.g. Figure 6 for false alarms in B class days). When this was not possible we used an empirical distribution (Table 1) fitted with the ®Arena Input Analyzer. The lognormal distribution has the longest tail within the set of distributions offered by this software, and that could explain why it offered the best fit. We also tested our data with ®EasyFit and found that the Burr, Dagum, and Frechet distributions always proved to have better fit, but unfortunately none were available as an option.

To establish the threshold in the fire duration at which the transition between initial and extended attack occurs, i.e., distinguishing between fires suppressed in the initial attack and those that escaped, we used the merged datasets (AFN and CDOS Porto) and sensitivity analysis with this ASM to identify a value consistent with our field data for each type of ignition (primary fire or rekindle) and severity class.

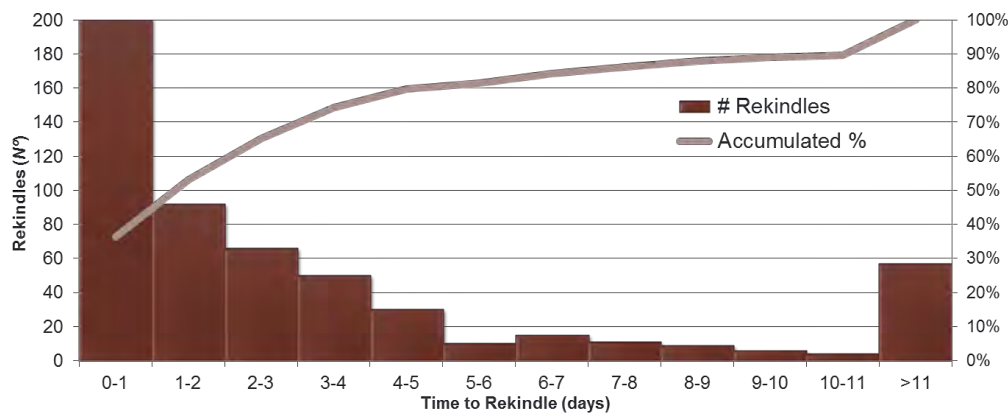


Figure 7—Rekindles as a function of the time to rekindle (Porto, 2010, summer).

We chose to model rekindles with the same logic as we modeled the primary fires, i.e., separately instead of as a result of bad mop-ups of primary fires, because the time to rekindle after a bad mop-up tends to be large – 3.96 days on average in the Porto district, during the summer of 2010 (Figure 7).

The fires that escape initial attack enter the “extended attack” component (3) and more resources are assigned to them for the remaining duration. Analyzing the abovementioned merged datasets, we were able to estimate the resources (number of crew teams) allocated to extended attack, again considering the two severity classes and for the two types of ignitions. As for the initial attack, we additionally considered the resources allocated to false alarms (under the two severity classes). In the six cases, we found evidence in the data, that the official rule of dispatching two crews for each initial attack is not being strictly applied in practice, a fact suggested in our interviews with experts, which could be attributed to insufficient resource capacity

during the summer in the Porto district.

All the four main components described, are governed by a last (fifth) control logic component, which implements the change of day, its severity class, and the process of creation of new occurrences. The essential parameters of the ASM are listed in Table 1, and Figure 8 shows an example of the regional parameterization for the Porto district.

	Name	Rows	Columns	Data Type	File Name	Expression Values
1	Wildfire_Length	1	2	Native		2 rows
2	FA_Discovery_Length	1	2	Native		2 rows
3	Reignition_Length	1	2	Native		2 rows
4	r.IA	1	2	Native		2 rows
5	r.AA	1	2	Native		2 rows
6	Reignition.r.IA	1	2	Native		2 rows
7	Reignition.r.AA	1	2	Native		2 rows
8	FA.r	1	2	Native		2 rows
9	Area_Stands			Native		1 row
10	Area_Forest			Native		1 row
11	At			Native		1 row
12	IA_N_MAX_Length	1	2	Native		2 rows
13	IA_R_MAX_Length	1	2	Native		2 rows
14	FFA.r			Native		1 row
15	FFA_Discovery_Length			Native		1 row
16	Losses_Products_Services_AFN			Native		1 row
17	CO2_Emissions			Native		1 row
18	Timber_Products_Value_Losses			Native		1 row
19	Non_Timber_Products_Value_Losses			Native		1 row
20	Recreational_Activities_Value_Losses			Native		1 row
21	Indirect_Use_Value_Losses			Native		1 row

Double-click here to add a new row.

Expression Values

1	2
CONT (0.000, 0.000, 0.184, 0.050, 0.567, 0.100, 0.727, 0.150, 0.808, 0.200, 0.856, 0.250, 0.887, 0.300, 0.898, 0.350, 0.906, 0.400, 0.921, 0.450, 0.934, 0.500, 0.942, 0.550, 0.955, 0.600, 0.955, 0.650, 0.955, 0.700, 0.961, 0.750, 0.966, 0.800, 0.971, 0.850, 0.971, 0.900, 0.974, 0.950, 0.976, 1.000, 0.979, 1.050, 0.982, 1.100, 0.982, 1.150, 0.984, 1.200, 0.990, 1.250, 0.990, 1.300, 0.990, 1.350, 0.992, 1.400, 0.995, 1.450, 0.995, 1.500, 0.997, 1.550, 0.997, 1.600, 0.997, 1.650, 0.997, 1.700, 0.997, 1.750, 0.997, 1.800, 0.997, 1.850, 1.000, 1.900, 1.000, 1.950, 1.000, 2.000)	LOGN(0.1096, 0.08878)

Figure 8—Expressions parameterization (detail of the @ARENA implementation).

Discussion and Conclusion

Throughout the implementation and parameterization of the AMS, we made sure that the results of the model were consistent with the real data, which we consider our base scenario. For the alternative benchmark scenario under analysis, and according to the second section of this paper (Problem framing), we considered for rekindles the official target of 1% (AFN 2011, ISA 2005), and for false alarms half of the current level in the Porto district – a reasonable reduction according to international benchmarks (Corcoran and others 2007, Karter 2010, 2011, Tu 2002, Yang and others 2003).

We ran the ASM for the two scenarios, with 500 replications, for each resource level from 90 to 128, stable during the summer fire season of 92 days (with “days” as the simulation clock time step) and calculating the average waiting time over the 500 replications. The results are presented in Figure 9, and as in the case of the study of Podur and Martell (2007) on large forest fires in Ontario, this number of replications

provided reasonable 95% confidence intervals.

False alarms deviate suppression resources from the real forest fires, and rekindles have much harder suppression operations. Our data analysis of forest fire resources management in the district of Porto during the summer of 2010 highlights the importance of addressing the phenomena of rekindles and false alarms. Jointly, they represented 27.4% of the occurrences: 5,498 out of 20,049 in the year. In other words, this addition of 5,498 to 14,551 primary fires brought to the fire suppression system an extra 37.8% of effort. Indeed, this additional pressure raises difficult challenges to the suppression system management. For instance, the fact that the average number of crews dispatched to initial attacks is much lower than the recommended (as we found in our data analysis), is an evidence of this pressure.

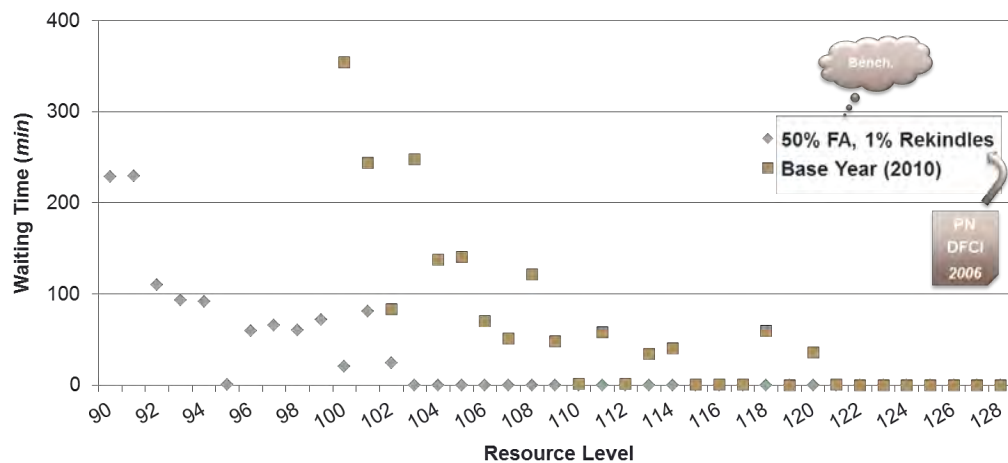


Figure 9—Average waiting times for different resource levels in the base and benchmark scenarios.

Our simulation study of the impact of rekindles and false alarms on suppression systems reveals that its reduction to target/benchmark values would release 14.9% of the resources, which would be available for effective mop-up operations. These results are more significant to the extent that 2010, within the first decade of this century, was an average year in terms of number of occurrences and burnt area (AFN 2011).

Acknowledgments

This work is financed by the ERDF – European Regional Development Fund through the COMPETE Programme (operational programme for competitiveness) and by National Funds through the FCT – Fundação para a Ciência e a Tecnologia (Portuguese Foundation for Science and Technology) within project FIRE-ENGINE – Flexible Design of Forest Fire Management Systems / MIT/FSE/0064/2009, and grupoPortucelSoporcel.

The authors are deeply grateful to Eng.º Rui Almeida (AFN), Coronel Teixeira Leite and Dr. Alberto Costa (CDOS Porto), Eng.º Manuel Rainha (AFN), Professor Paulo Fernandes (UTAD) and M.Sc. Ross Collins (MIT), for their invaluable input and feedback on this research. They would also like to thank Tenente-Coronel António Paixão (GIPS), Eng.º Paulo Bessa (GTF Penafiel), João Bandeirinha (Afocelca), Comandante José Morais (BV Paredes), Eng.ª Tânia Rodrigues Pereira (AFN), Isidro Alves da Costa (Portucel) and Comandante Elísio Oliveira (CDOS Lisboa), for their enthusiasm and advice.

References

- AFN. 2011. Relatório anual de áreas ardidas e ocorrências em 2010. Archived by WebCite® at <http://www.webcitation.org/5xrU23Pfn>; Direção de Unidade de Defesa da Floresta, Autoridade Florestal Nacional.
- AFN, IESE. 2011. Monitorização e Avaliação do Plano Nacional de Defesa da Floresta Contra Incêndios, 2009/2010 - Relatório Final Preliminar. Autoridade Florestal Nacional.
- Ahrens, M. 2003. *The US fire problem overview report: leading causes and other patterns and trends*: National Fire Protection Association.
- Ahrens, M. 2010. Brush, Grass, and Forest Fires. National Fire Protection Association, Fire Analysis and Research Division.
- Alexander, M. E. 2001. "Fire behaviour as a factor in forest and rural fire suppression." *Forest Research in association with New Zealand Fire Service Commission and National Rural Fire Authority, Forest Research Bulletin* no. 197.
- ANIF. 2005. Relatório Final (Vol I). Autoridade Nacional para os Incêndios Florestais.
- Beighley, M.; Hyde, A. C. 2009. Systemic Risk and Portugal's Forest Fire Defense Strategy. Paper read at Portucel Conf.
- Bookbinder, J. H.; Martell, D. L. 1979. "Time-Dependent Queueing Approach to Helicopter Allocation for Forest fire Initial-Attack." *INFOR: Information Systems and Operational Research*.
- CM. 2006. Resolução do Conselho de Ministros n.º 65/2006, PNDFCI. Diário da República, I SÉRIE-B, nº102 (26 de Maio de 2006).
- Corcoran, J.; Higgs, G.; Brunsdon, C.; Ware, A.; Norman, P. 2007. "The use of spatial analytical techniques to explore patterns of fire incidence: A South Wales case study." *Computers, Environment and Urban Systems* no. 31 (6):623-647. doi: 10.1016/j.compenvurbsys.2007.01.002.
- Corcoran, J.; Higgs, G.; Higginson, A. 2011. "Fire incidence in metropolitan areas: A comparative study of Brisbane (Australia) and Cardiff (United Kingdom)." *Applied Geography* no. 31 (1):65-75. doi: 10.1016/j.apgeog.2010.02.003.
- Cunningham, A.A.; Martell, D.L. 1973. "A stochastic model for the occurrence of man-caused forest fires." *Canadian Journal of Forest Research* no. 3 (2):282-287.
- Donovan, G.H.; Brown, T.C. 2005. "An Alternative Incentive Structure for Wildfire Management on National Forest Land." *Forest Science* no. 51 (5):387-395.
- Fernandes, P.M. 2008. "Forest fires in Galicia (Spain): The outcome of unbalanced fire management." *Journal of Forest Economics* no. 14 (3):155-157. doi: 10.1016/j.jfe.2007.11.002.
- Flynn, J. D. 2009. *Fire Service Performance Measures*.
- González-Cabán, A. 1984. *Costs of firefighting mopup activities*. Vol. 367: US Dept. of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station.

- Henderson, R.C.; Muraro, S.J. 1968.** Effect of organic layer moisture on prescribed burning. In *Information Report BC-X-14*, edited by Forest Research Laboratory Canada Department of Forestry and Rural Development. Victoria, British Columbia.
- Hershfield, V. 1995.** "How the fire service responds." *NFPA Journal* no. 89:46-49.
- ISA. 2011.** *Proposta técnica de Plano Nacional de Defesa da Floresta contra Incêndios* 2005 [cited 2011-03-07 2011]. Available from <http://www.isa.utl.pt/pndfci/> (Archived by WebCite® at <http://www.webcitation.org/5zjuImZzu>).
- Karter, M. J. 2010.** False Alarm Activity in the U.S. 2009.
- Karter, M. J. 2011.** False Alarm Activity in the U.S. 2010.
- Killalea, D. 1998.** *Strategies to reduce false alarms to the Tasmania Fire Service.*
- Lourenço, L. 2007.** "Incêndios florestais de 2003 e 2005. Tão perto no tempo e já tão longe na memória!" *Colectâneas Cindínicas - Riscos Ambientais e Formação de Professores* no. 7:19-91.
- Lourenço, L.; Rainha, M. 2006.** "As mediáticas 'mãos criminosas dos incendiários' e algumas das 'lições dos fogos florestais de 2005 em álbum fotográfico. Contributo para a desmistificação dos incêndios florestais em Portugal." *Territorium* (13):71-82.
- Martell, D.L. 2007.** "Forest Fire Management." In *Handbook Of Operations Research In Natural Resources*, edited by Andres Weintraub, Carlos Romero, Trond Bjørndal, Rafael Epstein and Jaime Miranda, 489-509. Springer US.
- Murdock, J.I.; Borough, M.S.; Wasilla, A. 1999.** *Cross-training Standards for Structural and Forestry Personnel in Urban Interface Wildfires: One Alaskan Solution:* National Fire Academy.
- Narayan, C.; Fernandes, P.M.; van Brusselen, J.; Schuck, A. 2007.** "Potential for CO2 emissions mitigation in Europe through prescribed burning in the context of the Kyoto Protocol." *Forest Ecology and Management* no. 251 (3):164-173. doi: DOI: 10.1016/j.foreco.2007.06.042.
- NWCG. 2005.** *Wildfire Origin & Cause Determination Handbook, NWCG Handbook 1:* National Wildfire Coordinating Group, Fire Investigation Working Team.
- NWCG. 2011.** *Glossary of wildland fire terminology.* National Wildfire Coordinating Group ed. Vol. 2012.
- Oliveira, T. 2011.** Relatório da visita ao Chile. grupo Portucel Soporcel.
- Pacheco, A.P. 2011.** *Simulation Analysis of a Wildland Fire Suppression System*, DEIG, Faculty of Engineering, University of Porto.
- Pacheco, A.P.; Claro, J.; Oliveira, T. 2012.** Rekindle dynamics: validating the pressure on wildland fire suppression resources and implications for fire management in Portugal. Paper read at Forest Fires 2012.
- Pereira, M.G.; Malamud, B.D.; Trigo, R.M.; Alves, P.I. 2011.** "The history and characteristics of the 1980–2005 Portuguese rural fire database." *Natural Hazards and Earth System Sciences* no. 11 (12):3343-3358. doi: 10.5194/nhess-11-3343-2011.
- Podur, J.J.; Martell, D.L. 2007.** "A simulation model of the growth and suppression of large forest fires in Ontario." *International Journal of Wildland Fire* no. 16 (3):285-294. doi: 10.1071/WF06107.
- Tilley, G. 1997.** *Managing false alarms.* Borehamwood, ROYAUME-UNI: Fire Protection Association.
- Tu, Y.F. 2002.** *Assessment of the Current False Alarm Situation from Fire Detection Systems in New Zealand and the Development of an Expert System for Their Identifications*, School of Engineering, University of Canterbury.
- Yang, L.; Gell, M.; Dawson, C.; Brown, M. 2003.** "Clustering Hoax Fire Calls Using Evolutionary Computation Technology." In *Developments in Applied Artificial Intelligence*, edited by Paul Chung, Chris Hinde and Moonis Ali, 644-652. Springer Berlin / Heidelberg.

Forecasting Productivity in Forest Fire Suppression Operations: A Methodological Approach Based on Suppression Difficulty Analysis and Documented Experience¹

Francisco Rodríguez y Silva² and Armando González-Cabán³

Abstract

The abandonment of land, the high energy load generated and accumulated by vegetation covers, climate change and interface scenarios in Mediterranean forest ecosystems are demanding serious attention to forest fire conditions. This is particularly true when dealing with the budget requirements for undertaking protection programs related to the state of current and future forest landscapes. Based on economic analysis, suppression costs represent a significant proportion of the total budget available for forest fire protection programs. The need to make efficient use of available budgets requires directing funding towards areas with the lowest costs and maximum benefits. Accordingly, incorporating econometric tools enables establishing criteria to optimize budget allocation.

In trying to optimize budget allocation experience capitalization⁴ takes on great importance. Modeling the fire suppression process and budget allocation requires knowing how suppression is managed, how resources are dispatched and how costs are incurred. Advances in the design of fire management tools have benefited from current techniques, (e.g., knowledge capitalization, utility analysis, efficiency analysis) for economic analysis of the potential hazard posed by forest ecosystems conditions and related fire suppression operations difficulties based on fire behavior expectations. Incorporation of econometric tools based on efficiency, productivity, and utility functions help fire managers define budgetary requirements to ensure ecosystem protection compatible with the value of the resources being protected and associated suppression difficulties and costs. The methodological approach presented here allows forecasting fire suppression operations

¹ An abbreviated version of this paper was presented at the Fourth International Symposium on Fire Economics, Planning, and Policy: Climate Change and Wildfires. November 5-11, 2012, Mexico City, Mexico.

² Professor and Director, Forest Fire Protection Laboratory, Department of Forestry Engineering, Graduate Technical School of Forestry and Agronomic Engineering, University of Cordoba, Leonardo DaVinci Building, Rabanales Campus, 14071, Cordoba, Spain; Email: ir1rosif@gmail.com.

³ Research Economist, USDA Forest Service, Pacific Southwest Research Station, 4955 Canyon Crest Drive, Riverside, CA 92507 USA; Email: agonzalezcaban@fs.fed.us

⁴ A set of recorded and organized experiences of suppression plans and associated organizations used in different fires available to fire incident commanders as references or *lessons learned* from prior fires.

productivity, based on suppression difficulty and cost, as well as records from documented fire suppression operation plans from prior fires.

Keywords: fire economics, econometrics, fire management, fire program planning, operational plans, fire budgets

Acquiring knowledge and experience of suppression operations

Capitalizing on the experience of documented operations/attack plans allows information exchanges among fire managers. It provides validation of lived events and helps improve operational decisions and human behavior in suppression work. Capitalization converts experiences from being individual to collective, isolated to shared, and forgotten to reused; in this way, the experience becomes available, locatable, and accessible (Fig. 1) (Rodríguez y Silva and others 2007).

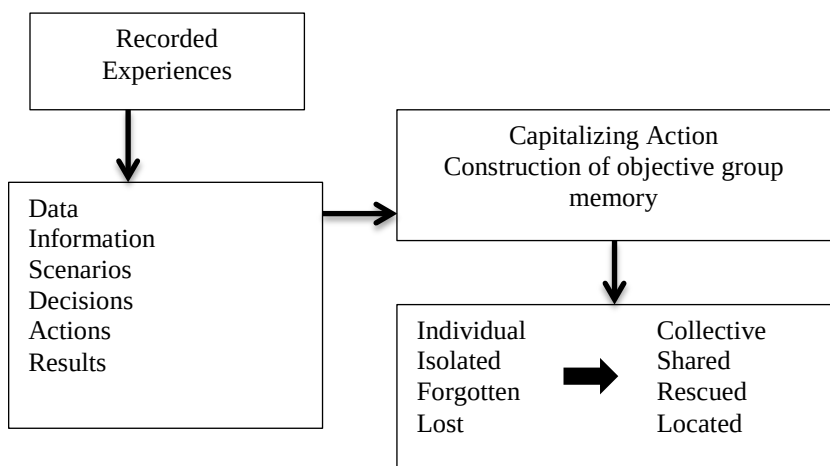


Figure 1—Experience capitalization procedure.

The operations/attack plans for an incident can be described as the objective group memory of those managing the fire at the time. The primary reason for capitalization (organization of prior incidents fire management operations/attack plans information in a lesson learned type files) is to share the data extracted from the experience and obtained through the fire events (Rodríguez y Silva and others 2007, MacGregor and González-Cabán 2008). Sharing events and knowledge acquired from real-life situations facilitates exchanges of experience regarding the behaviors during development of operations/attack plans. The benefit is access to knowledge among various officials and firefighters regardless of whether they had been eyewitnesses to the event or not.

The officials involved in organizing and directing the suppression work play a pivotal role in the capitalization function because they are the main actors and witnesses to the events. These officials are in the best positions to report on the actions taken and review their own experiences in the process of developing an operational attack plan.

During the capitalization process the managers and firefighters involved in the incident analyzed are essentially the producers of information. However, they may also be receivers of information when discussing information or events unknown to them during the incident; thus, incorporating a new set of descriptive information on the actions included in attack plans (Rodríguez y Silva and others 2007).

When managing suppression work, the requested resources are managed by the Incident Commander and its Staff at all different levels. These managers gather all possible information on the current fire situation to evaluate and analyze it to make appropriate decisions regarding the most appropriate operations/ attack plan; thus implementing the most efficient and safe distribution of available suppression resources.

In the process of analyzing the potential operation/attack plan for a current incident, the capitalized experience can play a significant role. For example, knowing and understanding how firefighting resources and operational plans were implemented in similar situations (i.e., objective group memory information) allows managers to use previous lessons learned information to develop an operation/attack plan for the current incident.

The **objective group memory** is held in an updatable database of operations/attack plans. These databases include behavior patterns (human factors), environmental conditions at the time of incident, and operations/attack strategies adopted. This gives access to past experiences, facilitating knowledge sharing. This enables building of an **experience exchange network** among the different people in the organization responsible for controlling and suppressing forest fires.

The databases described above provide the necessary information for selection of the variables and parameters that enables studying, analyzing and evaluating the productivity and efficiency of the suppression operations. Basically the following variables should be considered:

- Fireline production rate (fireline produced by unit of time; measured as m/min)
- Area contraction factor, or ACF (difference between the unit and the ratio between the actual area affected by the fire and the potential area affected by a free-burning fire, i.e., without suppression operations; considering the time elapsed from detection until the fire is controlled) (Rodríguez y Silva and others 2007), (Rodríguez y Silva and González-Cabán 2010).
- Average area affected per recorded forest fire (ha/fire)

- Average suppression costs per affected area (\$/ha, €/ha); Ratio between suppression cost and natural resources net value change

Choosing suppression resources and the associated utility function

Utility theory (Fishburn 1970, Mongin 1997) can be used to help decide the amount and type of suppression resources for incorporation into an organizational forest fire suppression model, or an individualized treatment according to suppression operations. Using a maximization technique gives us the benefit derived from the consumption of a certain amount of goods previously selected. Application of utility theory to fire suppression operations requires consideration of the law of diminishing marginal utility. The fundamental tenet of this law is that the first unit dispatched (first unit consumed in terms of personal satisfaction) provides the highest level of utility for the fire suppression organization (highest level of utility for a consumer). Each of the next units dispatched provides a lower utility level to the suppression efforts (or to a consumer satisfaction); until the point in which one additional unit dispatched to a suppression organization does not contribute anything or nearly anything to the suppression capability (or utility) of the organization (i.e., the marginal utility of the unit is very small or zero). At this point the total utility does not appreciably increase (and might even decrease); yet operational costs continue to rise.

Given a fire suppression/attack plan for an incident and the variety and combinations of firefighting resources that can be dispatched, the plan must rank them according to the utility that each generates (contribution to total fire suppression efforts) through a preference ordering system. The consumer preference ordering system that best meets the above conditions is the *indifference curve* (Muñoz 2006).

An *indifference curve* shows the same level of utility for all the combinations of resources along that curve (see figure 2). That is, the manager is indifferent to whether there are, for example, 10 20-persons hand crews and 5 1,000-gallons fire engines or only 3 1,000-gallons engines and 12 20-persons hand crews because both combinations produce the same level of utility (i.e., same level of protection capability). Given this definition, an *indifference curve* to the right of and higher than any previous curve will represent a higher utility level. The slope of the *indifference curve* measures the marginal rate of substitution (MRS) between the resources (Y and X)¹ (Eq. 1). That is, how many units of one resource a consumer (suppression /attack

¹ We understand that all numbers used in the paper have associated estimation errors. However, for ease of presentation and computation we have chosen to ignore sample and measurement errors here. However, future application of the methodology should provide information on the error associated with parameters estimates to indicate their precision.

plan) needs to obtain the same level of utility (suppression capability) from another type of resource or combination of resources thereof.

$$MRS = \Delta Y / \Delta X \quad (1)$$

Then, we can integrate the set of forest fire suppression resources (X_i , Y_j) or possible combinations thereof into the utility function (U) (Eq. 2),

$$U = f(X_i), \text{ and } MRS = [\partial Y_j / \partial X_i] U \quad (2)$$

Given the existing utility function, changes in the utility of the suppression system can be determined for changes in the amounts of each of the fire suppression resources assigned (dispatched). That is, the marginal utility of each suppression resource, or the resulting percentage increase in utility level (suppression efficiency in terms of decrease in area affected per fire attacked) resulting from increasing the specific fire suppression resource used in the marginal analysis by one unit (Eq. 3).

$$\partial U = \sum (\partial U / \partial X_i) \partial X_i = 0 \quad (3)$$

The solution to the problem of choosing between available resources or a combination thereof requires having the necessary information. This consists of the suppression resources to choose from, the budget constraint (maximum budget available to cover operational costs) and the *indifference curves* map (Fig. 2). The budget constraint tangential to the *indifference curve* at point (A) represents the marginal rate of substitution (MRS) between resource X_i and resource X_j ; this is exactly the ratio between the relative prices of X_i (P_i) and X_j (P_j) (Fig. 2). This can be expressed as follows:

$$MRS_{X_i} / P_i = MRS_{X_j} / P_j \quad (4)$$

At this point, when measuring the productivity and efficiency of the system we must make an important conceptual change relative to the *indifference curves*. Because the *suppression capacity*, as well as the *operational constraints* inherent to *each resource* the MRS between firefighting resource X_i and X_j cannot be considered only as a ratio relationship between their relative prices. Accordingly, it is necessary to construct a new variable that identifies each resource, including their suppression capacity and inherent operational constraints. The definition of each resource is given by the following expression (Eq. 5):

$$Y^e = \alpha P + \varphi R + \mu L, \quad (5)$$

where α , φ , μ represent weighting coefficients of each one of the parameters, P represents the resource price per unit of time (e.g., \$/h, €/h), R represents the suppression capability, expressed in terms of the corresponding production rate by unit of time (e.g., m/min), and L represents the operational constraints.

Thus, to choose between two firefighting resources or combinations thereof, given an allocated budget, a manager will distribute the budget between them so that the marginal utilities of the resources are proportional to their respective prices. Therefore, at equilibrium, the system (the consumer in economic terms) gets the same marginal utility per monetary unit spent on resource X_i (or combination thereof) as on resource X_j .

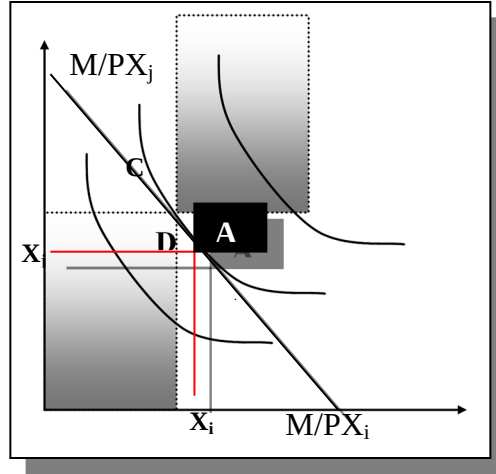


Figure 2—Graph showing marginal utility isoquants or *indifference* curves for two products.

The algebraic solution to the problem of choice can be determined by using Lagrange multipliers. To do this using the utility function (for example, minimum area affected), the available budget (M), the amounts of each one of the resources (X_i) and their corresponding prices (P_{xi}) are transformed algebraically through the composition of the Lagrange function (t_i represents the use time of the resource (i) (Eqs. 6-9), (Rodríguez y Silva and others 2007).

$$M > \sum P_{X_i} X_i t_i(Y^e) \quad (6)$$

$$V = u(X_{1,2,3,...,n}) + \lambda(M - \sum P_{X_i} X_i t_i(Y^e)_i) \quad (7)$$

$$\partial V / \partial X_i = \partial U / \partial X_i - P_{X_i} = 0 \quad (8)$$

$$\partial V / \partial \lambda = M - \sum P x_i X_i = 0 \quad (9)$$

The Lagrange multiplier indicates how utility varies with increasing monetary spending on X_i ; therefore, it measures the marginal utility of the available suppression budget.

The management index, a tool for assessing efficiency

Assessing management efficiency is always necessary for responding to inquiries about investments made and the results obtained. Applying econometric tools to the evaluation of investments in forest fire protection is always difficult due to the lack of variables that define suppression costs and effectiveness in suppression operations in an integrated way. To help clear the uncertainties arising from the lack of integrated variables, an integrative variable was defined that enables including information on costs and effectiveness in suppression operations; we call this variable the *Management Index* (MI) (Carmona and Rodriguez y Silva 2009). MI is defined as the ratio between ACF and the cost per hectare

$$MI = ACF / C_{tot} / A_q - 100[(1 - A_q / A_v)A_q] / C_{tot} \quad (10)$$

where MI is the management index, ACF is the area contraction factor, C_{tot} is the total suppression cost, A_q is the area affected, and A_v is the area affected in a simulated free-burning fire (without suppression operations) for the time between detection and control.

Conducting a differential analysis of the model, relative to the behavior of each of the three variables (A_q , A_v , C_{tot}), permits us to obtain the expression that determines the maximum condition for the behavior of MI (Eq. 11).

(11)

Solving for the first derivative to be zero then the values that make the second derivative of the determining function of MI negative will provide the sufficient condition for MI to reach its highest value under those conditions; though not necessarily a single global maximum.

Using this procedure, one can study each fire individually or analyze a given district or province for a particular time period. The comparison between periods allows tracking MI behavior. With this system of equations, the efficiency analysis permits determination of a point at which MI is most efficient. As seen in figure 3, the joint graphic representation of the regressions between MI versus Ca and ACF shows that there is a corresponding cut point below which Ca exceeds the efficiency of the resources represented by ACF. The further to the right of the Point of **Minimum Efficient Management** (Pme, zone B), the greater the efficiency; therefore, the more positive the assessment of fire management. On the contrary, MI values located to the left of Pme (zone A) are poorly managed fires, in which the ACF is below the Ca.

The mathematical representation of the minimum efficient management point takes the following general form (Eqs. 12 and 13):

$$Ca = a.e^{b.MI} \quad (12)$$

$$ACF = e.MI^d \quad (13)$$

The values for the coefficients (a) and (c), as well as for the powers (b) and (d), are obtained from historical records of fire occurrence for a period of time and district or region in which the analysis is performed.

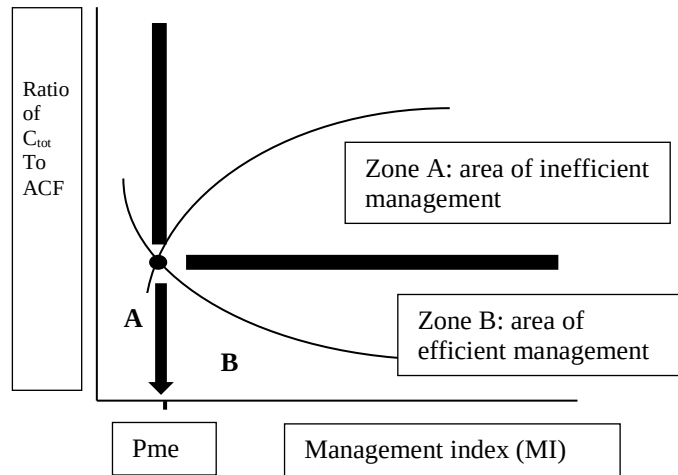


Figure 3—Graph showing the most efficient management program. Zone A represents an inefficient management area, while zone B represents an efficient management area.

The MI utilities range is very broad within the analytical framework that integrates the results of suppression operations and associated costs. Regular monitoring of MI helps identify operational deficiencies in the different districts where the analysis is applied. Internally the ACF provides information regarding the effectiveness of suppression operations by including a comparison ratio between the area affected and the area that the fire could have reached if suppression actions had not been undertaken. This comparison is done for the period of time between the start of the fire and the time fire is declared controlled. Applying the model to different provinces provides numerical information for the coefficients and powers of equations 12 and 13. The example that follows is for a study of the province of Cadiz, Spain, for the years 2001 to 2011.

Based on the MI for the area, estimates for Ca and AFC are shown in equations 14 and 15 respectively.

$$CA = 3754,25e^{-13,991MI} \quad (14)$$

$$ACF = 297,16MI^{0,508} \quad (15)$$

Estimation of the efficiency of suppression methods with nonparametric methods; Data envelopment analysis

Determining the efficiency of production systems can be understood as an econometric technique through which the existing relationship between the resources employed or assigned and the results obtained, or the target previously set as a goal to be reached, is addressed. That is, it can be understood as the relationship between revenues and expenditures or inputs and outputs generated in a given production system. Conceptually and when evaluating suppression operations, efficiency can be associated with estimating a ratio that allows getting information from the results obtained from using a particular set of suppression resources and their incurred costs on a specific incident or fire.

The study and determination of efficiency can be approached either through parametric methods by determining the stochastic production possibility frontier²,

² This refers to the maximum possible production of a product given a set amount of resources. See chapter 2 in Kumbhakar and Lowell (2000).

which is a deterministic procedure, or by nonparametric methods using linear programming techniques (Parra and others 2009).

For simplicity, consider the case of two types of suppression resources whose costs or prices derived from their use are (X_1) and (X_2) , respectively. Moreover, Y , can be defined as the final product obtained by their marginal utility. In other words, as the final product obtained after fire control (e.g., area controlled per unit of time, ACF reached, etc.). A graphical representation of the efficiency analysis permits us to define two important concepts that allow obtaining explanatory components of efficiency, these are **technical efficiency** (TE) (maximum output with a given set of inputs) and **allocative efficiency** (AE) (reduction in production costs if the unit produced used its production inputs most efficiently) (Fig. 4; adapted from Farrell 1957).

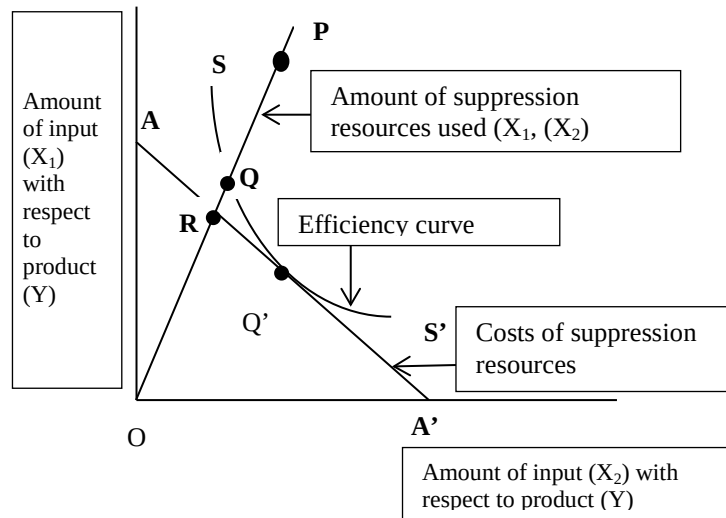


Figure 4—Graphic representation of efficiency analysis, relating the amount of inputs to their prices and the amount thereof used in suppression.

The curve SS' represents the production isoquant for the combination of suppression resources (X_1) and (X_2). The segment (QP) determines both the **technical inefficiency** (TIE) and the reduction in the amounts of the suppression resources (X_1) and (X_2), without producing changes in the output target (or initially agreed final suppression variable). From the graph it is clear that the amounts used are above the efficient production isoquant curve (SS'). The value of TIE is determined by the ratio between the distances defined by the segments (QP) and (OP) (Eq. 16).

Based on the above expression, **technical efficiency** (TE) is determined as one minus the value of *TIE*.

$$TE = 1 - TIE = OP - QP / OP = OQ / OP \quad (17)$$

Knowing the price variation between suppression resources with the same classification or type (e.g., transport and attack helicopters), one can determine AE (reduction in production costs, if the unit produced (assigned) was efficient in the allocation of suppression resources). AE is represented by the segment (RQ) and determines the cost reduction by switching the efficiency point (Q) to position (Q') (Fig. 4). Finally, **economic efficiency** (EEI) can be obtained by the product of TE and AE (Eq. 18)

$$EEI = (OQ / OP)(OR / OQ) = OR / OP \quad (18)$$

The efficiency isoquant curve is estimated using data from the fire occurrence database in the forest region or district in which the efficiency analysis is performed.

Once the econometric components of the efficiency and its conceptual identification have been achieved the analysis and study of the results of forest fire control and suppression operations can proceed. Using the analysis method presented here for determining efficiency requires the prior definition of the following econometric model applied to forest fire suppression operations (Eq. 19).

Inputs refer to the economic value of the area that has been successfully protected based on suppression activities defined when planning the suppression operations.

$$I = Vr - Vr(Fd) = Vr(1 - Fd), \quad (19)$$

where *I* represents the inputs (total economic value saved from the impact of the fire within the fire perimeter), *Vr* is the economic value of each of the resources in the area where the wildfire has evolved (area bounded by the final fire perimeter), expressed in monetary units (€, \$), and *Fd* is the depreciation factor of the economic value due to the effect or impact of the fire (Molina and others 2009, Rodríguez y Silva and González Cabán 2010, Rodríguez y Silva and others 2012).

The total input or value for all existing resources is given by equation 20.

$$\sum Vr - \sum Vr(Fd) - \sum Vr(1 - Fdi) \quad (20)$$

On the other hand, the outputs or suppression costs are the sum of the individual costs of all suppression resources dispatched to the fire. In terms of efficiency analysis, *outputs* are the resulting solutions from the combination of suppression resources with a production rate level allocated to the economic value of the resources at risk saved from the impact of the fire. This is the output or suppression costs of the operational suppression system. Accordingly, the efficiency expression can be written as follows, where ET is the efficiency estimator, and all other variables as previously defined:

$$ET = 1 - \frac{\sum_{j=1}^{j=m} Ce_j}{\sum_{i=1}^{i=n} Vr_i x(1 - Fdi)} \quad (21)$$

From equation 21, ET values result from the ratio between revenues (outputs) and expenditures (inputs); therefore, it can generalize that:

If $0 < ET < 1$, then the efficiency is low to very high

If $ET = 1$, then the efficiency is in balance

To establish measurement consistency, adjustments are necessary to the ET equation (Eq. 21). To do this, weights are introduced that normalize the measurement heterogeneity among the variables in the equation. The weights help put all variables in terms of the ratio of its value to the total overall value for that variable. Thus, for the case of the different suppression resources used (outputs), the weights (β_j) represent the time each resource was used in relation to the total elapsed time from the start of suppression actions until the fire is under control. For the *inputs or* economic value of each natural resource, the weights (α_i) represents the economic value of each resource relative to the total economic value of all natural resources in the area affected by the fire. By applying the weighting criteria to ET, we obtain the following equation:

$$ET = 1 - \frac{\sum_{j=1}^{j=m} \beta_j (Ce_j)}{\sum_{i=1}^{i=n} \alpha_i Vr_i x(1 - Fdi)} \quad (22)$$

For simplicity, we suggest a somewhat arbitrary qualitative classification of the results to establish an efficiency ranking (Table 1) by associating the ET estimates to four categorical levels: Low, Moderate, High, and Very High.

Table 1—Qualitative classification to establish an efficiency ranking

Efficiency value interval (ET)	Qualitative classification
$0 < ET < 0.26$	LOW
$0.26 \leq ET < 0.6$	MODERATE
$0.6 \leq ET < 0.7$	HIGH
$0.7 \leq ET < 1$	VERY HIGH

We used the Almonaster fire that occurred in 2008 in the Huelva Province, Spain as a case study to test the applicability of the methodology. Determining the economic valuation of the natural resources and their economic depreciation as a result of a fire enables obtaining their residual economic value and therefore, the equivalent output volume that forms the numerator of eq. 18 that provides the economic efficiency value EEI (Table 2).

Table 2—Economic valuation of the natural resources and losses due to the impact of the fire

Resource\Economic Value (€)	Existing Value	Value Lost	Value Saved	Weighting (α_i)
TIMBER	246.658,20	145.321,64	101.336,56	0,4485
FIREWOOD	65.426,34	31.734,26	33.692,08	0,1491
FRUIT	38.195,25	12.726,71	25.468,54	0,1127
BIODIVERSITY	75.436,24	45.386,75	30.049,49	0,1323
RECREATION	35.124,62	25.761,24	9.363,38	0,0414
HUNTING	87.356,42	61.324,15	26.032,27	0,1152
TOTAL	548.197,07	322.254,75	225.942,32	

For the costs of suppression resources, a descriptive table (Table 3) was prepared that identifies for each suppression resource its cost, intervention time and weighting value (β_j).

Table 3—Costs of suppression resources dispatched

No. of units	Type of suppression resource	Suppression cost (€)	Intervention time in minutes	Weighting (β_j)
2	CL-215T Aircraft	62.940,09	826.0	0,043
3	Bell 412 Helicopter	38.430,40	1.261	0,066
1	KAMOV K32 Helicopter	25.423,18	726.0	0,038
2	Air Tractor 802 Aircraft	15.247,33	1.401	0,074
10	Crew (15 components)	73.990,37	8.057	0,420
1	Bulldozer	1.155,56	946.0	0,050
8	Pumper truck	8.781,86	5.605	0,290

The resulting Efficiency Factor (ET) for the 2008 Almonaster fire from applying the weighted efficiency expression EEI, as shown in equation 23, is 0,33.

$$ET = 1 - \sum_{j=1}^{j=m} \beta_j (C_{ej}) / \sum_{i=1}^{i=n} \alpha_i V_{rix} (1 - F_{di}) = 1 - 41017/60728 = 0.33 \quad (23)$$

The results from equation 23 show that the efficiency achieved with the combination of suppression resources listed in Table 3 was 0.33 or 33%. As shown in Table 2 this efficiency ratio enabled saving 41%³ of the economic value of the natural resources in the area affected by the fire. In our qualitative ranking (Table 1) 33% efficiency corresponds to a classification of moderate efficiency.

Efficiency analysis can be directed beyond the individualized study of forest fires. Indeed, it enables comparative evaluations between fires and even determines the efficiency of a given forest fire protection program in a forest district. For example, we can assume that each of the (N) fires has (K) inputs (suppression resources) and (M) outputs (revenues or benefits obtained by protecting the economic values of natural resources). Then, the i^{th} fire is represented by the vectors X_i and Y_j , respectively. The matrix (KxN) of inputs X and the matrix (MxN) of outputs Y represent the data of the (N) fires considered in the analysis. The purpose of applying data envelopment analysis is to build through a nonparametric method a production possibility frontier on the reference points, such that all observed points are either on or inside the frontier.

The efficiency for each fire is obtained from the ratio of all the outputs over all the inputs ($U'y_i/V'x_j$), where (U') is the vector of output weights (dimension Mx1) and V' is the vector of input weights (dimension Kx1). The selection of the optimum weights is obtained from equation 24.

$$Max_{u,v} (U'y_i/V'x_j), \text{ subject to } U'y_i/V'x_j \leq 1, U, V \geq 0, \text{ and } j = 1, 2, 3 \dots N \quad (24)$$

³ Computed as Value saved/Existing value or 225.942,32/548.197,07.

This implies determining the values of U (weight associated with the generic i^{th} output) and V (weight associated with the i^{th} generic input), such that the efficiency of the i^{th} forest fire of the total fires (N) under study is maximized, subject to the efficiency measures being less than or equal to one; considering the following restriction:

$$Vx_j = 1, \quad \max_{(u,v)} (U'y_j), \text{ subject to } U'y_j - V'x_j \leq 0 \quad (25)$$

Applying linear programming, the above expressions are as follows,

$$-y_i + Y\lambda \geq 0 \quad (26)$$

$$\Theta x_i - X\lambda \geq 0 \quad (27)$$

$$\lambda \geq 0 \quad (28)$$

where λ is the efficiency of the i^{th} fire. A linear programming solution is necessary for each of the N fire records being analyzed, at the spatial-geographic or temporal scale.

The methodological approach presented here provides options for the combined study of suppression costs and residual economic valuation of natural resources after the impact of a forest fire. For example, the information produced permit managers not only to analyze and classify the results of agreed upon and applied fire suppression options, but also to make adjustments in the combination of suppression resources assigned if necessary. They also allows forecasting fire suppression operations productivity, based on suppression difficulty and cost, as well as records from documented fire suppression operation plans from prior fires. This is an objective tool for use in fire economic planning and decision making.

Acknowledgements

We like to express our special thanks to the INFOCA project (RTA2009-00153C03-03), funded by the National Institute of Agrarian Research (INIA in Spanish), for their support of this work. We also thanks Dr. Jim Baldwin, Pacific Southwest Research Station for his statistical review of the system of equations presented in this work.

References

- Carmona, C., Rodríguez y Silva, F.** 2009. Capitalización de la experiencia en las operaciones de extinción de incendios forestales en la provincia de Málaga. TPFC. Universidad de Córdoba.
- Farrell, M.J.** 1957. The measurement of productive efficiency. *Journal of the Royal Statistical Society (Series A)*. 120 Part III, 253-290.
- Fishburn, P.C.** 1970. *Utility theory for decision making*. NY, NY: John Wiley and Sons, Inc. 234 p.
- Kumbhakar, Subal C.; Lowell, C.A. Knox.** 2000. *Stochastic Frontier Analysis*. New York, NY: Cambridge University Press. 348 p.
- MacGregor, Donald G.; González-Cabán, Armando.** 2008. Decision modeling for analyzing fire action outcomes. Res. Pap. PSW-RP-258; Albany, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station. 67 p.
- Molina, J.R., Rodríguez y Silva, F., Herrera, M.A., Zamora, R.** 2009. A simulation tool for socio-economic planning on forest fire suppression management. *Forest Fires: Detection, Suppression and Prevention*. Nova Science Publishers. USA.
- Mongin, P.** 1997. "Expected utility theory" in: Davis, J., Hands, W., Maki, U., eds., London, UK: Edward Elgar. Pp 342-350
- Muñoz, A.** 2006. **Introducción a la Economía**. Master de Economía Aplicada. Universidad Nacional de Educación a Distancia (UNED). Madrid.
- Parra Rodríguez, F., Muñoz Cabanes, A., Herrero de Egaña, A.** 2009. Análisis de la eficiencia y productividad. Universidad de Educación a Distancia. Facultad de Ciencias Económicas y Empresariales. Departamento de Economía Aplicada y Estadística. Fundación General UNED. Madrid.
- Rodríguez y Silva, F., Molina, J.R., 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. Sevilla. (www.wildfire07.es).
- Rodríguez y Silva F., Molina, J.R., Herrera, M.A., Zamora, R.** 2009. The impact of fire and the socioeconomic vulnerability of forest ecosystems: A methodological approach using remote sensing and geographical information systems. General Technical Report PSW-GTR-227. Pacific Southwest Research Station. Forest Service, U.S. Department of Agriculture; 151 - 168.
- Rodríguez y Silva, F., González-Cabán, A.** 2010. "SINAMI": a tool for the economic evaluation of forest fire management programs in Mediterranean ecosystems. *International Journal of Wildland Fire* 19: 927-936.
- Rodríguez y Silva, F., Molina, J.R., González-Cabán, A.; Herrera, M.A.** 2012. Economic vulnerability of timber resources to forest fires. *Journal of Environmental Management* 100: 16-21.

Hazardous Fuel Treatments, Suppression Cost Impacts, and Risk Mitigation¹

Matthew P. Thompson², Michael S. Hand³, Julie W. Gilbertson-Day⁴, Nicole M. Vaillant⁵, and Darek J. Nalle⁶

Abstract

Land management agencies face uncertain tradeoffs regarding investments in preparedness and fuels management versus future suppression costs and impacts to valued resources and assets. Prospective evaluation of fuel treatments allows for comparison of alternative treatment strategies in terms of socioeconomic and ecological impacts, and can facilitate tradeoff analysis. This presentation will demonstrate recently developed methodologies for estimating potential suppression cost impacts of fuel treatments. The approach pairs wildfire simulation outputs with a regression cost model, estimating the influence of fuel treatments on distributions of wildfire size and suppression cost. A case study focuses on a landscape within the Deschutes National Forest in central Oregon, USA, and results suggest substantial treatment effects. An auxiliary analysis demonstrates the impacts of fuel treatments in terms of reduced exposure of values at risk, to quantify the broader potential benefits of fuel treatments. Effectiveness of treatments in the case study is contingent on large-scale implementation of fuel treatments across the landscape, and sufficient maintenance to ensure treatment effectiveness over the duration of the analysis period. Future applications and integration with other modeling approaches will be highlighted.

Key Words: exposure analysis, hazardous fuels, risk assessment, suppression cost

Introduction

The U.S. Forest Service (USFS) and other public land management agencies spend considerable amounts of money managing wildland fires every year, to the

¹ An abbreviated version of this paper was presented at the Fourth International Symposium on Fire Economics, Planning, and Policy: Climate Change and Wildfires, Nov 5-11, 2012, Mexico City, Mexico.

² Research Forester, Human Dimensions Program, Rocky Mountain Research Station, USDA Forest Service, Missoula, MT 59807 (mpthompson02@fs.fed.us)

³ Research Economist, Human Dimensions Program, Rocky Mountain Research Station, USDA Forest Service, Missoula, MT 59807 (mshand@fs.fed.us)

⁴ Biological Scientist, Human Dimensions Program, Rocky Mountain Research Station, Missoula, USDA Forest Service, MT 59807 (jgilbertsonday@fs.fed.us)

⁵ Fire Ecologist, Western Wildlands Environmental Threat Assessment Center, Pacific Northwest Research Station, USDA Forest Service, Prineville, OR 97754 (nvaillant@fs.fed.us)

⁶ Post-doctoral Research Forester, Fire, Fuel and Smoke Program, Rocky Mountain Research Station, USDA Forest Service, Missoula, MT 59808 (djnalles@fs.fed.us)

point where a busy fire season can threaten the ability of agencies to meet non-fire needs and maintain forest health (Thompson and others 2013a). Yet wildland fires continue to cause significant damage to forest ecosystems and the built environment. While investments in suppression responses may help protect valuable resources from the damaging effects of fire, suppression is costly and also puts firefighters in harm's way.

Investments in fuels management hold promise for reducing potential costs and damages of wildland fire by reducing the size and intensity of future fires (Ager and others 2010, Moghaddas and others 2010). But managers face uncertain tradeoffs over the potential effects of fuel treatments, including reduced future suppression costs (and risks to firefighters involved in suppression), damage to ecological values, and damage to homes and other structures in the wildland-urban interface (WUI). That is, the payoffs of an investment in fuel treatments are not well known in advance, which makes it difficult to design and implement an efficient fuels treatment program.

In this paper we illustrate a method for assessing the potential effects of a fuel treatment project, and demonstrate its use on a case-study landscape in the Deschutes National Forest in the United States. We build on previous efforts to model how fuel treatments affect the growth, size, and costs of future fires (Thompson and others 2013b) by interacting simulated fire perimeters with the geographic distribution of highly valued resources and assets (HVRAs) that are exposed to fire. This analysis can be used to describe the likely effectiveness of fuel treatments in reducing the exposure of HVRAs to the damaging effects of fire, and as a means of comparison between different proposed fuel treatment options.

Assessing Fuel Treatment Effectiveness

The primary purpose of this paper is to examine how a landscape-scale fuel treatment program is likely to change future fire outcomes. At the heart of this assessment is a comparison of likely fire outcomes under existing fuel conditions (EC) and post-treatment (PT) fuel conditions. Formally, we use the simulations to calculate an expected treatment effect as the change in expected fire outcomes:

$$\Delta E(Z) = E(Z_{PT}) - E(Z_{EC}), \quad (1)$$

where Z is a vector of k measures of fire outcomes, $Z = \{Z_1, Z_2, \dots, Z_k\}$. The treatment effect $\Delta E(Z)$ represents the difference in outcomes for the average fire¹. For the case study in this paper, Z is comprised of suppression costs (C), area burned

¹ In this case study we explicitly specify that fuel treatments do not affect the number of ignitions, and we do not model differential initial attack efforts. Treatment effects may indicate fewer escaped, "large" fires on the basis of reduced rate of spread and increased containment likelihood. The effects of these fires on HVRAs may still be modeled, but suppression costs cannot be estimated for these smaller fires.

in the wildland-urban interface (WUI), area burned in threatened and endangered species habitat (TE), and area burned in old-growth forest stands (OG)².

The simulation method described in the next section, combined with calculations of suppression costs and HVRA exposure, generates distributions of fire outcomes under existing and post-treatment fuel conditions. That is, each element of Z is associated with a simulated distribution under each condition:

$$\text{EC: } f^{EC}(Z_k) \sim (\mu_k^{EC}, \sigma_k^{EC}) \quad (2)$$

$$\text{PT: } f^{PT}(Z_k) \sim (\mu_k^{PT}, \sigma_k^{PT}) \quad (3)$$

Estimated expected outcomes under EC and PT ($\hat{\mu}_k^{EC}$ and $\hat{\mu}_k^{PT}$) are the mean value of the simulated distribution of each element of Z . Standard errors used to calculate confidence intervals for $\hat{\mu}_k^{EC}$ and $\hat{\mu}_k^{PT}$ are generated via bootstrapping (Efron 1979).

Estimates of $\hat{\mu}_k^{EC}$ and $\hat{\mu}_k^{PT}$ can be interpreted as the expected marginal effect of fire on the untreated and treated landscape, respectively. The expected treatment effect, $\Delta E(Z)$, is the difference in marginal effects due to fuel treatments. Thus,

$$\Delta E(Z_k) = \mu_k^{EC} - \mu_k^{PT} \quad \forall k. \quad (4)$$

Methods

The evaluation of potential treatment effects involves first modeling how treatments will impact fire behavior, and, in turn, modeling how altered fire behavior may impact suppression costs and exposure of HVRAs to fire.

Wildland Fire Simulation Modeling

The results in this paper are based on simulations of fires before and after a fuel treatment has been applied to the landscape. We compare potential changes in fire sizes by altering the surface fuel models and canopy variables resulting from treatment. This approach explicitly seeks to capture both on-site and off-site effects of fuel treatments, which is especially important in areas like the western U.S. where the predominant source of burn probability is large fire spread from remote ignitions.

Fires are simulated using the large fire simulation model, FSim (Finney and others 2011). FSim uses an ensemble method that combines a logistic model to generate fire ignitions, a simulated stream of daily weather (wind speed and

² If all outcomes in Z could be expressed in commensurate units, such as dollars, then the treatment effects is the change in expected total costs for the average fire, where total costs for a given fire are: $TC = \sum_k Z_k$.

direction, relative humidity) for each simulated fire “season,” an algorithm that grows the fire from burned to unburned nodes (the Minimum Travel Time fire spread algorithm, see Finney 2002), and a containment algorithm (see Finney and others 2009). Fire occurrence and the growth and containment of each fire ignition are simulated over thousands of simulated fire seasons for a given landscape. The individual fire outcomes are summarized across all simulated seasons to characterize a landscape’s fire regime.

Inputs for FSim include information that describes the spatial fuels and terrain on the landscape (elevation, slope, aspect, surface fuel model, canopy cover, canopy height, canopy base height, and canopy bulk density), and data on historical weather drawn from a representative Remote Automated Weather Station (RAWS). Fuels and terrain data are static on the landscape in the sense that FSim does not alter these variables from one simulated day to the next, or from season to season). FSim generates simulated weather streams for every day in each simulated fire season based on statistical analysis of historical fire weather data.

FSim produces raster-format calculations of burn probability and fireline intensity at a 30-meter pixel resolution, and vector-format layers of each simulated wildfire perimeter. Burn probability is quantified as the number of times a given pixel burns (either from random ignition within the pixel or fire spread from an adjacent pixel) divided by the number of simulated fire seasons. Typically exposure analysis explores expected area burned and intensity using burn probabilities aggregating exposure from multiple fires (Scott and others 2012a). Use of the individual perimeters allow for an alternative analysis of exposure to fire on the landscape, quantifying the conditional distribution of acres burned from any single fire (Scott and others 2012b). That is, in addition to summarizing the distribution of fire sizes and burned area, the perimeters can be paired with other spatial data to characterize potential fire effects on the landscape (described below).

In our simulations we parameterized FSim to use identical ignition locations and weather conditions for the EC and PT scenarios, in order to directly attribute changes in fire outcomes to treatment effects³. Because the only difference between the pre- and post-treatment simulations is the surface and canopy fuel conditions across the landscape, the effect of fuel treatments is isolated from potential differences in weather, ignition frequency, and fire management policy. The simulated fires from each scenario are then used to compare pre- and post-treatment differences in fire size and intensity, estimated suppression costs, and exposure of HVRAs to fire.

Suppression Cost Modeling

³ There can also be differences in fire size that result from spotting, which is stochastically determined in FSim, although this is assumed to account for negligible differences in fire outcomes.

Fuel treatments do not directly affect the cost of suppressing large wildland fires, but could indirectly affect costs by altering fire outcomes that are likely to change the strategies used to manage fires. Fuel treatments could lead to reductions in burn severity (Wimberly and others 2009, Martinson and Omi 2008), which may allow fires to be managed with less aggressive suppression responses and could lead to lower suppression costs. However, a less aggressive suppression response may ultimately lead to longer-duration fires and increased area burned, which could result in costs on par with or higher than more aggressive strategies (Gebert and Black 2012). Alternatively, fuel treatments could allow for more aggressive suppression responses, for instance more opportunities for direct attack because of reduced fire intensity (Hudak and others 2011). Our modeling approach does not directly account for the impacts of changed suppression tactics.

Changing fire size distributions resulting from a fuel treatment could also affect suppression costs. Fire size (i.e., burned area) is a primary factor associated with suppression costs. Fuel-treated areas may slow the spread of fires, increasing the chance that a given fire can be contained earlier and at a smaller size. In this study, the difference in burned area is the primary factor that results in suppression costs differences resulting from fuel treatments.

The effects of fuel treatments on suppression costs are estimated using a regression cost model developed by the U.S. Forest Service. The large fire cost model (Gebert and others 2007) is a regression model built from historical fire cost data that estimates per acre and final fire costs as a function of total fire size, fire environment variables (e.g., slope, aspect, fire weather), and values at risk (e.g., distance to town, total housing value within 20 miles). For the purposes of the fire cost model, large fires are defined as fires at least 300 acres in size. The cost model is embedded within the Wildland Fire Decision Support System for cost containment guidance and is used as a performance measure to identify extreme high cost fires (Calkin and others 2011, Noonan-Wright and others 2011). The cost model was used in this analysis to estimate suppression costs for all simulated large fires that grew to at least 300 acres (~121 hectares).

Table 1 lists the variables and regression coefficients used to calculate costs for each simulated fire⁴. The model predicts suppression costs per acre for each fire, which is then multiplied by acres burned to get total costs for each fire. Because fires are simulated using the same ignition points and weather information, the only factors that can change a fire's post-treatment predicted cost are burned area and fuels at ignition. Note that some fires that ignite where fuels are unchanged may still have a different burned area post treatment if they burn into a fuel-treated parcel.

⁴ We present and describe the model in its native format, using the English System. We later present results using metric units however.

Table 1— Variables and regression coefficients for predicting per-fire suppression costs. The model we present is a modified version of the original cost model presented in Gebert and others (2007), updated with additional years of data and adjusted to return only USFS suppression expenditures.

Variable	Regression format	Coefficient
Burned area	Natural log of acres burned	-0.3207
Aspect (radians)	Cosine of aspect	-0.1431
	Sine of aspect	-0.0509
Elevation (feet above sea level)	Natural log of elevation	0.3603
Distance to nearest town (miles)	Natural log of distance	-0.2623
Energy release component, cumulative frequency	Percentile (1 – 100)	0.0195
Total housing value within 20 miles of ignition (\$)	Natural log of Value / 100,000	0.1422
Ignition within a Wilderness Area	Binary, =1 if ignited within Wilderness	0.3922
If ignition within Wilderness, distance from ignition point to nearest Wilderness Area boundary	Natural log of distance to boundary	-0.5856
Slope	Natural log of slope	0.1134
Fuel model at ignition:	Binary categorical variables	
Grass		(reference category)
Brush		-0.0023
Brush 4		0.5128
Timber		0.8553
Slash		0.5673
Region identifier – USFS region 6	=1 for all fires in case study	1.2028
Regression constant		1.9823
Smearing factor ¹		2.0200

¹The smearing factor (SF) corrects for retransformation bias when converting the natural log of cost per acre (the regression dependent variable) to cost per acre in dollars (see Duan 1983).

Analysis of HVRA Exposure to Wildland Fire

We present two complementary methods to quantify HVRA exposure to wildland fire, which differ in their use of fire simulation outputs. The fundamental premise of both approaches is the coupling of spatially resolved fire characteristics with maps of HVRAs. For illustrative purposes we drew spatial data for three socioeconomic and ecological HVRAs from a broader set of HVRAs identified collaboratively by Deschutes staff and stakeholder groups (Northwest Fire Learning Network 2012): the wildland-urban interface (WUI), stream reaches and key watersheds identified as habitat for Threatened and Endangered aquatic species (TE), and old-growth

ponderosa pine (*Pinus ponderosa*) and dry mixed conifer trees (OG). Comparative exposure analysis illustrates effects of treatment by comparing results for the existing conditions and post-treatment modeling scenarios.

In the first exposure analysis method, we adopt a novel approach that overlays fire perimeters with HVRA maps. Unlike the use of aggregated pixel-based burn probabilities, this approach enables the quantification of the potential impacts on a per-fire basis. In turn this allows for quantifying the distribution of conditional HVRA area burned. In cases where fuel treatments reduce fire spread potential, we anticipate that HVRA area burned will decrease under the post-treatment modeling scenario. This information can be especially useful where the spatial extent of burning can influence HVRA response to fire. This approach is limited, however, in that simulation results do not output fire intensities (flame lengths) on a per fire basis.

As a complementary method, therefore, we also quantify differences in HVRA exposure by comparing expected area burned by flame length category. Conditional burn probabilities output by FSim quantify the likelihood of fire at a given flame length, conditioned on the pixel burning. Using these outputs, expected area burned is calculated as the sum of the area for a given HVRA expected to burn under each of the six flame length categories⁵ and is calculated as:

$$\text{Expected Area} = \sum_{i=1}^6 BP_{fl_i} \times A \quad (5)$$

where BP_{fl_i} is the burn probability at the i^{th} flame length category and A is the area for each 30 x 30- m pixel (i.e. 0.09 hectares). Fire intensity is an important fire outcome because even if an area of HVRA burns, a low-intensity fire may cause relatively little damage as compared with a high intensity fire. Assessing only the area burned may understate potential impacts of a fuel treatment if the distribution of fire intensity shifts due to treatment. In cases where fuel treatments reduce fire likelihood and/or intensity, we expect the distribution of expected area burned to shift towards lower intensities under the post-treatment modeling scenario.

Case Study: Deschutes National Forest, Oregon, U.S.

Figure 1 provides a map of the analysis landscape (209,207 hectares) and the project area, most of which is located within the Deschutes National Forest (DNF) (58,680 hectares total; 45,320 hectares Forest Service) in west-central Oregon. The analysis landscape extends beyond project boundaries to account for fire spread from remote ignitions onto the project area, and vice versa. Most of the landscape is comprised of ponderosa pine (*Pinus ponderosa*) and dry mixed conifer forest types, characterized

⁵ FSim generates conditional burn probabilities for six flame length categories: < 2 ft (0.6 m), 2–4 ft (0.6–1.2 m), 4–6 ft (1.2–1.8 m), 6–8 ft (1.8–2.4 m), 8–12 ft (2.4–3.7 m), > 12 ft (3.7 m)

by frequent, low-severity fire. The western portions of the landscape, however, include wet mixed conifer forest types, with mixed fire severity and return intervals between 35 and 150 years. The broad treatment goals are restoring forest ecosystems, promoting resiliency, and protecting HVRAs.

DNF staff provided data on vegetation and fuel layers reflecting existing conditions (pre-treatment) as well as treatment polygons and post-treatment fuel conditions. In total 27,036 hectares (about 46% of the project area) are projected to receive treatment during the planning period from 2010 - 2019⁶.

⁶ Details on the how fuel treatments were modeled, including changes to surface and canopy fuels and assumed treatment longevity, are presented in Thompson and others [in review] and can be made available from the authors.

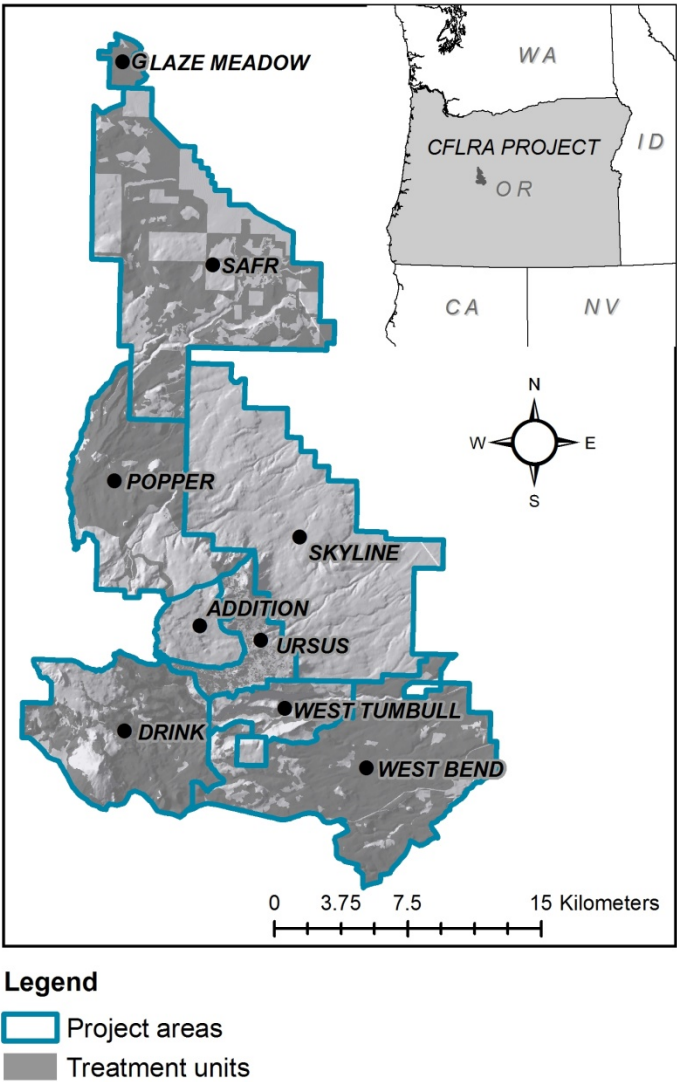


Figure 1— Map of case study landscape, with project areas and treatment units highlighted. The project areas (excluding Skyline) are located within the Deschutes National Forest, in west-central Oregon.

Results

Table 2 presents estimates of the expected outcomes for total area burned, area burned in the wildland-urban interface (WUI), threatened and endangered aquatic species habitat (TE), and old-growth forest stands (OG). Treatment effects (the difference between existing conditions and post-treatment outcomes) are also presented. Results suggest that fuel treatments are effective at reducing the expected final size of fires, which then reduces expected suppression costs and expected HVRA area burned. Suppression costs for the average fire are reduced by nearly \$600,000 after treatment (about 6%). Exposure to potential damage from fire is also lower, with HVRA area burned reduced by between 10 and 16% post treatment.

Table 2—Mean simulated fire outcomes under existing and post-treatment fuel conditions, with bootstrapped errors presented in parentheses. The regression model used to estimate per-fire suppression costs is not valid for fires smaller than about 121 hectares (see Gebert and others 2007). Some ignitions in the simulated dataset that were greater than 300 acres under existing conditions were less than 300 acres in size post treatment; these observations are excluded from the PT suppression cost estimates.

	Fire size, ha	Suppression cost, 2010 \$	Highly Valued Resource and Asset (HVRA) Area Burned		
			Wildland-urban Interface, ha	Threatened and Endangered aquatic species habitat, ha	Old growth stands, ha
Existing Conditions (EC)	3,855 (77.13)	8,990,166 (130,967)	3,368 (75.78)	844.0 (22.53)	1,206 (25.45)
Post-Treatment (PT)	3,431 (73.49)	8,407,933 (135,815)	2,996 (72.06)	701.4 (20.61)	1,077 (24.47)
Difference (PT – EC)	-423.9 (18.13)	-582,233 (185,860)	-372.2 (17.04)	-142.6 (6.425)	-129.0 (5.474)

Bootstrapped standard errors estimated using 1,000 replicate samples, where the size of each sample is equal to the total number of fires in the simulated distribution, or 5,667. Sampling for each replicate occurs with replacement.

The effects of fuel treatments can be further clarified by examining the intensity at which fires burn pre- and post-treatment in areas with HVRAs. Figure 2 summarizes the distribution of area burned for each HVRA by flame length category. Shorter flame lengths (category one) indicate a low-intensity fire, while longer flame lengths (up to category six) indicate high-intensity fire.

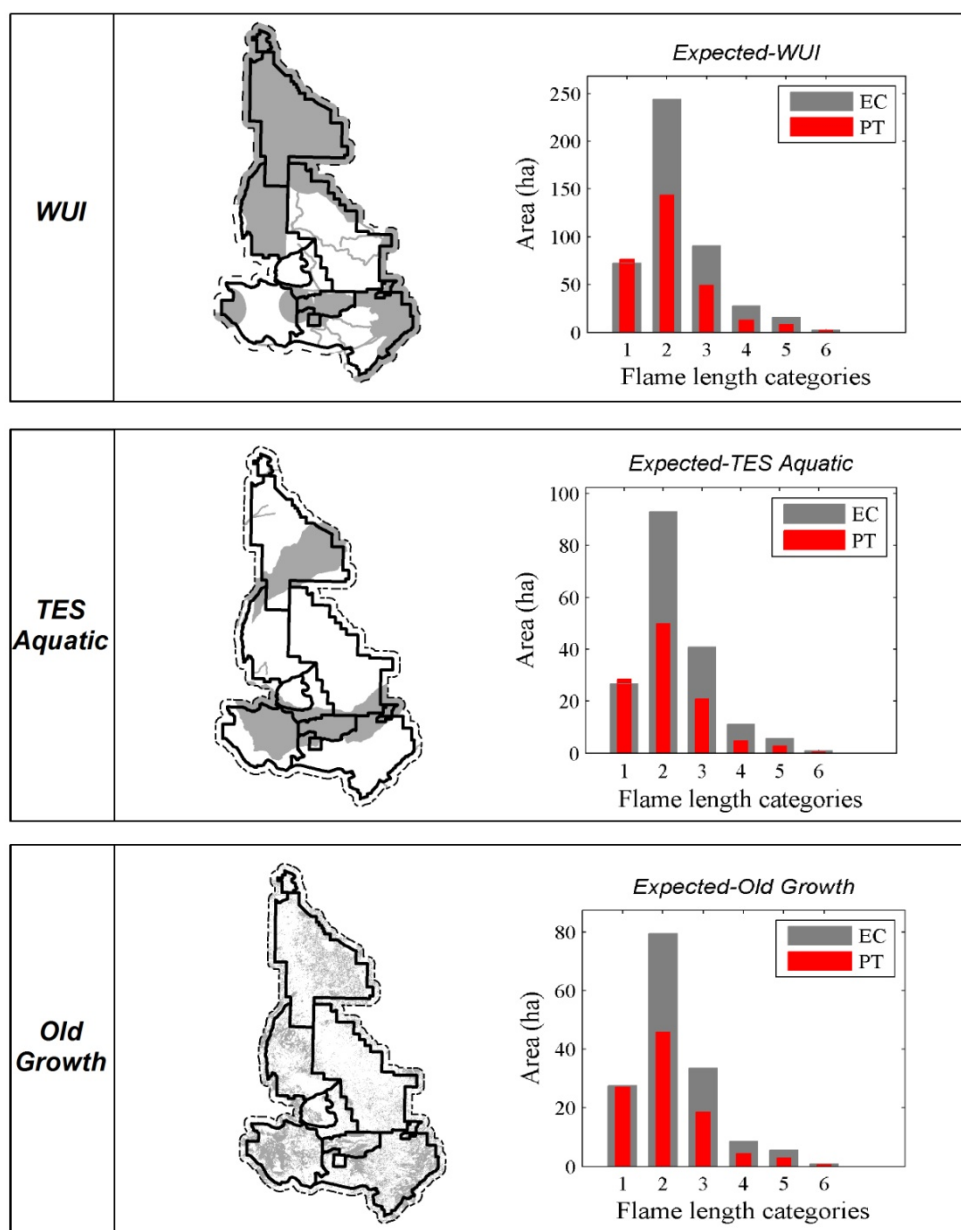


Figure 2— Distribution of expected HVRA area burned by flame length categories on existing conditions (EC) and post-treatment (PT) landscapes. Panels on the left indicate the current geographic distribution of each mapped HVRA, which influences the degree of likely exposure to wildland fire.

Unlike results from Table 2, which include all simulated fires within the analysis area, results in Figure 2 are clipped to a 1-km buffer around project areas. The expectation is a stronger signal of treatment effect, due to capturing a relatively higher proportion of fires that do intersect with treated areas. Consistent with the results of Table 2, Figure 2 shows that less area of each HVRA is burned after

treatment (i.e., the bars are lower on average). But there is also evidence that the relative distribution of shifts towards lower fire intensities after treatment. For example, area burned at the shortest flame length increases after treatment in the WUI and in threatened and endangered species habitat, but area burned at longer flame lengths decreases. Similarly, area burned in old-growth forest stands decreases at the highest intensities, but stays about the same at the lowest intensities.

Discussion

The primary benefit of this case-study analysis is that it gives managers and planners a common language and set of metrics to make decisions over potential fuel treatments. We do not, in this exercise, make a conclusion about whether the proposed treatment on the Deschutes National Forest should proceed. However, managers could compare treatment effects across multiple landscapes when deciding how to allocate limited fuel treatment budgets to achieve the greatest beneficial impact. How managers might weigh changes in risk to the different HVRAs is not known, but the simulation results provide enough information to facilitate tradeoffs in decision making.

There are several limitations and conditioning factors to the existing study. First, results are contingent on the respective accuracies of input landscape and fuels data, of assumed changes to fuel conditions after treatment, and of wildfire simulation and suppression cost models. Second, the suite of prospective landscape treatments we modeled could change due to the realities of budgets and project planning, and in fact there have already been changes made to plans for treatment implementation. Third, presentation of only average results could mask important variability in the distribution of possible fire outcomes. Fourth, conclusions from the results are limited to assessments of exposure to risk, rather than predictions of effects on HVRAs. The fire simulations allow us to examine the likelihood that a particular parcel is burned pre- and post-treatment, but we do not make any predictions of the magnitude of potential impact on HVRAs due to fire. Fifth, we do not model any activities related to the initial attack suppression efforts. Changes in fuels may create more favorable conditions for containing a fire early; we assume that all ignitions that “escaped” prior to fuel treatments would have also escaped after treatment. Modeling initial attack efforts would enable exploration of tradeoffs across management investments in preparedness, fuels, and suppression response. This is left as an area of future research.

Another logical research extension would be to compare, both within and between landscapes, the relative effects of varying treatment sizes and spatial patterns, rather than the single proposed treatment analyzed here. It may be that

spatially targeted treatments, even at a smaller scale, can provide the greatest return on investment for a fuel treatment program. Finally, decision support for fuel treatments cannot be complete without comparing the potential effects of the treatment to the costs of treating the landscape. These costs are not explicitly considered here, but would be useful for comparing a menu of potential treatment options.

Yet another potential avenue of research is determining the appropriate spatial scale at which to assess the effectiveness of treatments. Only considering simulated fires that intersected treated areas would over-predict treatment effectiveness, due to the fact that in any given area, there is a very low probability a treatment will actually experience fire over the course of a fire season (Campbell and others 2012). This is a critical rationale for the use of burn probability modeling to analyze effectiveness (Ager and others 2010). By contrast, considering a very large study area would tend to dampen treatment effectiveness by including a large set of fires that never interact with treated areas. For instance, suppression cost reductions for fires igniting within treated areas averaged 35% (Thompson and others 2013b), whereas across the entire analysis area, suppression cost reductions averaged 6% (Table 2). We might expect similar variation in estimates of treatment effect were the results from Figure 2 to include a different buffer width. Future work could explore how estimates of treatment effectiveness are sensitive to spatial scale, and with geospatial techniques, could possibly seek to generate smoothed treatment response surfaces.

Summary

This paper examines the question of whether landscape-scale fuel treatments can reduce risks and costs associated with large wildland fires. A simulation-based assessment of fire outcomes before and after a proposed treatment in a case-study landscape (the Deschutes National Forest) suggests that treatment can reduce area burned of highly valued resources and assets, and reduce direct costs of managing large wildfires. Fires that burn the treated landscape also tend to be less intense, leading to a reduction in the area of highly valued resources and assets that burn at the highest and most damaging intensities. These treatment effects can be interpreted as the effect of fuel treatments on the exposure to risk from wildland fire.

Acknowledgments

We thank the staff at the Deschutes National Forest. This research was supported by the National Fire Decision Support Center.

References

- Ager, A. A.; Vaillant, N. M.; Finney, M. A. 2010. A comparison of landscape fuel treatment strategies to mitigate wildland fire risk in the urban interface and preserve old forest structure. *Forest Ecology and Management*, 259(8): 1556-1570.
- Calkin, D. E.; Thompson, M. P.; Finney, M. A.; Hyde, K. D. 2011. A Real-Time Risk Assessment Tool Supporting Wildland Fire Decisionmaking. *Journal of Forestry* 109(5): 274-280.
- Campbell, J.L.; Harmon, M.E.; Mitchell, S.R. 2012. Can fuel-reduction treatments really increase forest carbon storage in the western US by reducing future fire emissions? *Front. Ecol. Environ* 10(2):83-90.
- Duan, N. 1983. Smearing estimate: a nonparametric retransformation method. *Journal the American Statistical Association* 78(383): 605-610.
- Efron, B. 1979. Bootstrap methods: another look at the jackknife. *The Annals of Statistics*, 7(1), 1-26.
- Finney, M. A.; McHugh, C. W.; Stratton, R. D.; Riley, K.L. 2011. A simulation of probabilistic wildfire risk components for the continental United States. *Stochastic Environmental Research and Risk Assessment* 25(7): 973-1000.
- Finney, M. A.; Grenfell, I. C.; McHugh, C. W. 2009. Modeling containment of large wildfires using generalized linear mixed-model analysis. *Forest Science* 55(3): 249-255.
- Finney, M. A. 2002. Fire growth using minimum travel time methods. *Canadian Journal of Forest Research* 32(8):1420-1424.
- Gebert, K. M.; Black, A. E. 2012. Effect of Suppression Strategies on Federal Wildland Fire Expenditures. *Journal of Forestry* 110(2): 65-73.
- Gebert, K. M.; Calkin, D. E.; Yoder, J. 2007. Estimating Suppression Expenditures for Individual Large Wildland Fires. *Western Journal of Applied Forestry* 22(3): 188-196.
- Hudak, A. T.; Rickert, I.; Morgan, P.; Strand, E.; Lewis, S. A.; Robichaud, P. R.; Hoffman, C.; Holden, Z. A. 2011. Review of fuel treatment effectiveness in forests and rangelands and a case study from the 2007 megafires in central, Idaho, USA. Gen. Tech. Rep. RMRS-GTR-252. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 60 p.
- Martinson, E. J.; Omi, P. N. 2008. Assessing mitigation of wildfire severity by fuel treatments – an example from the Coastal Plan of Mississippi. *International Journal of Wildland Fire* 17: 415-420.
- Moghaddas, J. J.; Collins, B. M.; Menning, K.; Moghaddas, E. Y.; Stephens, S. L. 2010. Fuel treatment effects on modeled landscape-level fire behavior in the northern Sierra Nevada. *Canadian Journal of Forest Research* 40(9): 1751-1765.
- Noonan-Wright, E. K.; Opperman, T. S.; Finney, M. A.; Zimmerman, G. T.; Seli, R. C.; Elenz, L. M.; Calkin, D. E.; Fiedler, J. R. 2011. Developing the U.S. Wildland Fire Decision Support System (WFDSS). *Journal of Combustion*, Article ID 168473, 14p.
- Northwest Fire Learning Network. 2012. Deschutes Forest and Landscape-level Treatments Incorporating Multiple Values. Available at: http://nw.firelearningnetwork.org/region_files/deschutes/DeschutesValuesExercise_Methods.pdf Last accessed 25 Aug 2012.
- Scott, J. J.; Helmbrecht, D.; Thompson, M. P.; Calkin, D. E.; Marcille, K. 2012a. Probabilistic assessment of wildfire hazard and municipal watershed exposure. *Natural Hazards* doi: 10.1007/s11069-012-0265-7

- Scott, J. H.; Helmbrecht, D. J.; Parks, S. A.; Miller, C.** 2012b. Quantifying the Threat of Unsuppressed Wildfires Reaching the Adjacent Wildland-Urban Interface on the Bridger-Teton National Forest, Wyoming, USA. *Fire Ecology* 8(2): 125-142.
- Thompson, M. P.; Calkin, D. E.; Finney, M. A.; Gebert, K. M.; Hand, M. S.** 2013a. A Risk-Based Approach to Wildland Fire Budgetary Planning. *Forest Science* 59(1): 63-77.
- Thompson, M. P.; Vaillant, N. M.; Haas, J. R.; Gebert, K. M.; Stockmann, K. D.** 2013b. Quantifying the Potential Impacts of Fuel Treatments on Wildfire Suppression Costs. *Journal of Forestry* 111(1): 49-58
- Wimberly, M. C.; Cochrane, M. A.; Baer, A. D.; Pabst, K.** 2009. Assessing fuel treatment effectiveness using satellite imagery and spatial statistics. *Ecological Applications* 19(6): 1377-1384.

Economics of Forest Fire Management: Spatial Accounting of Costs and Benefits¹

**José J. Sánchez^{2,3}, Ken Baerenklau⁴, Armando González-Cabán³,
and Kurt Schwabe⁴**

Abstract

To better evaluate the potential impacts of wildland fire in the San Bernardino National Forest, we developed a geographic information system (GIS) data layer containing non-market economic values for the San Jacinto Ranger District. Each pixel in the data layer contains an estimate of the most prominent nonmarket values at that location. This information can be used by forest managers as a decision making aid when deciding how to allocate resources to protect high value areas. To estimate the recreation value component and potential losses due to wildfire, backcountry hikers entering the San Jacinto Wilderness were recruited to complete a web-based survey during the summer of 2012. A travel cost model was used to calculate the associated values. This paper presents preliminary results from the survey and ongoing modeling work.

Keywords: GIS, Nonmarket valuation, recreation value, travel cost method, viewshed analysis

Introduction

Wildland fires affect millions of people worldwide. Globally it is estimated that 350 million hectares are burned annually (González-Cabán 2008). In the U.S., an annual average of 3.5 million hectares of wildlands burned from 2004 to 2008, at an annual average suppression cost of \$1.6 billion.

The loss of natural resources, property and life from wildfires is also a major concern. Forested areas are particularly relevant because of their multiple uses (residential, recreation, and carbon sequestration among others). The forest also offers other amenities that are not directly useable but that people enjoy in some other way (e.g., knowledge that unique ecosystems exist, preservation for future

¹ An abbreviated version of this paper was presented at the Fourth International Symposium on Fire Economics, Planning, and Policy: Climate Change and Wildfires, November 5-11, 2012, Mexico City, Mexico.

² Ph.D. student, Department of Environmental Sciences, University of California, Riverside, Riverside, CA. 92521, U.S.A.

³ Economist and Research Economist respectively, Pacific Southwest Research Station, USDA Forest Service, Riverside, CA. 92507, U.S.A. Email: jsanchez@fs.fed.us; agonzalezcaban@fs.fed.us

⁴ Associate Professor, Department of Environmental Sciences, University of California, Riverside, Riverside, CA. 92521, U.S.A.

generations or future use). To promote efficient land management strategies, it is necessary to determine both the use and nonuse values of those areas. Some use values can be directly identified from market transactions (e.g., the price of residential land, entrance fees). For other nonmarket uses and nonuse values, resource economists use techniques such as the Contingent Valuation Method (CVM) (Loomis and others 2002), Travel Cost Method (TCM) (Hesseln and others 2003), Hedonic Price Method (HPM) (Mueller and others 2009), and Stated Choice Experiment Method (CE) (Louviere and others 2000) to determine economic values. However, traditional nonmarket valuation analyses do not attempt to determine the specific value of each piece of a landscape or how welfare is affected if only part of a forest area is impacted by fire.

Recent increases in computing power have given researchers the ability to make greater use of geographic information systems (GIS). As use of this tool has become more popular, researchers have begun combining GIS software with nonmarket valuation methods to assist land and forest managers (e.g., see Baerenklau and others 2010, González-Cabán and others 2003). This combination has allowed researchers to derive spatially-explicit representations of landscape values; however, such studies are uncommon and little is known about how the aggregate value of a forest area should be allocated to the landscape. Having this information will enable resource managers, stakeholders and policy makers to make better-informed decisions on how to use resources more efficiently.

In this paper we provide a framework to determine the economic value of the San Jacinto Wilderness. The resulting information would allow fire managers plan fire management strategies to reduce potential losses from wildfires. Knowing level of potential losses from fire could help them decide to relocate existing distribution of firefighting resources to reduce losses. The travel cost method is implemented to estimate recreation benefits. Data collection via a web-based survey is ongoing and will be concluded by end of September 2012. Therefore, in this paper we present preliminary results for the forest access value.

Fire management

Wildfire has been a constant threat to western United States ecosystems, but it has become a more serious problem in part due to increasingly dry conditions and forest management practices that have promoted ladder fuel accumulation. In a recent annual assessment, the U.S. Department of Agriculture Forest Service (USDAFS) reported that 1.7 million acres burned in the US while it suppressed more than 230 large fires and expended \$1.46 billion for firefighting (USDA 2009). Recently fire suppression costs have increased dramatically while congressional funding levels

have remained flat (USDA 2009). Therefore, land and forest managers need tools to understand which management strategies are more efficient. However, current tools only consider cost of fire prevention or suppression, not the economic benefits provided by forests.

Forest Benefits

A forest provides several benefits to society ranging from conservation of ecosystems to recreation use. Resource economists have different nonmarket valuation methods that can be used to estimate the use and nonuse values associated with natural resources. Loomis and González-Cabán (1998) used a CVM survey to estimate the economic benefits of reducing fires in old growth forest. Fix and Loomis (1998) examined the economic benefits of mountain biking, in Moab, Utah, using a TCM, while Powe and others (1997) used an HPM to estimate the benefits residents received from woodland access. Hanley and others (1998) used CE to estimate the values of environmental assets (forests, rivers). Knowledge of the benefits and values produced from the forests would allow managers to prioritize their decisions to protect most valuable lands potentially affected from fires.

Fire impacts

There are many types of natural and human-made disasters that damage or affect natural resources. Although fire is a natural part of many landscapes, catastrophic fires--often produced by a combination of both natural and human factors--are particularly damaging to forests. The impact of fire on natural resources and the associated economic consequences are difficult to estimate (González-Cabán and others 2003). The difficulty arises because there is limited information about the effects of fire on nonmarket values provided by forests. Early studies (Vaux and others 1984, Flowers and others 1985) found that intense fires are likely to have negative impacts on recreation. Recent studies have explored these negative effects. Loomis and others (2001) surveyed visitors of National Forests in Colorado to study the effects of fire on hiking and mountain biking visits and benefits. Using TCM, the authors found that crown fires indirectly affected recreation benefits for mountain bikers, but had no significant effect on hiking trips.

Also using TCM, Hesseln and others (2003) found that both hikers and mountain bikers in New Mexico reacted similarly to recovering prescribed fires and crown fires, with each group decreasing its visitation rate. Hesseln and others (2004) also found similar results when surveying hikers and mountain bikers in four national forests in western Montana. Differences in results between Loomis and others (2001)

and Hesselin and others (2003, 2004) suggest that the type of recreation activity may help determine how users react to fire.

In studying two hiking trails in the Cascade Mountains affected by a large scale forest fire (40,000 acres), Hilger and Englin (2009) found that the forest ecosystem had a short-run increase in visitation and the trip values were the same as before the fire. Englin and others (2001) examined the long term effects of fire in three different states: Colorado, Wyoming, and Idaho. Using TCM the authors found that visitation increased for recent fire, then decreased for the following 17 years, and then rebounded for the remaining 8 years of their observation period. In a similar study by Boxall and Englin (2008) for canoeing in the Canadian Shield boreal forest, damages occurred immediately following a fire, but after 35 years of regrowth, the forest amenity values returned to pre-fire levels.

Geographic Information Systems

Increased computing power has made geographic information systems (GIS) more accessible and useable in conjunction with nonmarket valuation methods to derive spatially explicit landscape values. For example, Eade and Moran (1996) developed an “economic value map” for the Rio Bravo Conservation Area in Belize using the benefit transfer method and GIS to spatially allocate ecosystem service values. Troy and Wilson (2006) used a similar approach to produce a map of ecosystem service flow values based on land cover types for three case studies. González-Cabán and others (2003) estimate the effect of prescribed burning on deer harvest by using time-series data and GIS approaches with TCM and CVM; while Cavailhès and others (2009) evaluated landscape values and their effect on housing prices using GIS and HPM. A more relevant study is the GIS-based landscape valuation application by Baerenklau and others (2010). The authors used recreation permit data and a zonal TCM to estimate aggregate recreation value and spatially allocated the value to the landscape using GIS-based “viewshed” analysis.

Using similar GIS techniques as Baerenklau and others (2010) we will develop an economic data layer, which allows us to allocate the recreation values throughout the wilderness, and thus understand how economic welfare is affected if only part of the forest area is impacted by fire. This approach provides decision makers information to evaluate trade-offs between location based on potential expected losses.

Study Objectives

This work uses GIS tools and nonmarket valuation methods to obtain a spatial representation of recreation value for the San Jacinto Wilderness, San Bernardino National Forest, California. The research has four main objectives:

Objective 1-Estimate trailhead access values for hypothetical burn scenarios

A web-based survey is being administered in the San Jacinto Wilderness. Using both CVM and TCM, the economic use values (trailhead access) will be estimated and used to help determine how changes in viewshed (due to hypothetical fire intensity, percentage of area burn, and viewing distance) affect trip behavior.

Objective 2-Derive spatially explicit landscape values

The study by Baerenklau and others (2010) used TCM and readily available data from recreation permits and census demographics to estimate wilderness access values. The authors also used a viewshed analysis technique to derive spatially explicit landscape values. However, this technique used untested assumptions about perceptions of scenic quality that recreation permit data alone cannot validate. The web-based survey used here also will provide the necessary information to spatially allocate the wilderness recreation value. These values will be compared against Baerenklau and others (2010) to determine if their simpler and less data-intensive method yields reliable results.

Objective 3-Estimate a transferrable hedonic price function

The HPM indirectly values environmental characteristics by comparing two closely related goods, with one having extra environmental attributes. A hedonic landscape value function will be produced using parcel characteristics (e.g., slope, elevation, distance from trails, vegetation) collected from the San Jacinto Wilderness and derived landscape values, thus making the results obtained from the more data-intensive method proposed in this study potentially transferrable to other wilderness areas.

Objective 4-Determine how landscape values recover after wildfires

Responses to the hypothetical burn scenarios in the survey will provide information about individual preferences and visitation behavior as a result of fire, fire age, and intensity, thus allowing determination of how recreation values recover after

wildfires and whether if there is significant spatial heterogeneity in the recovery process across the landscape.

Survey Design

Study Site

This study focuses on backcountry hikers who visit the San Jacinto Wilderness Area, San Bernardino National Forest, Southern California (Figure 1). The wilderness covers 13,350 hectares and is located within a 2.5 hour drive from Orange, Los Angeles, San Diego, Riverside and San Bernardino counties near the town of Idyllwild. The town has a population of 14,846, average annual household income is \$67,061, and 14.3% of the population has at least a bachelor's degree (U.S. Census Bureau, 2010). Elevations range from 1,800 to 3,300 meters. The wilderness area gets approximately 60,000 visitors annually and another 350,000 people visit Mt. San Jacinto State Park via the Palm Springs Aerial Tramway. The wilderness area is regulated by USDA FS. The most popular activity is day hiking. Recreationists enter the wilderness area via the tramway or by driving to the trailheads located in Idyllwild.

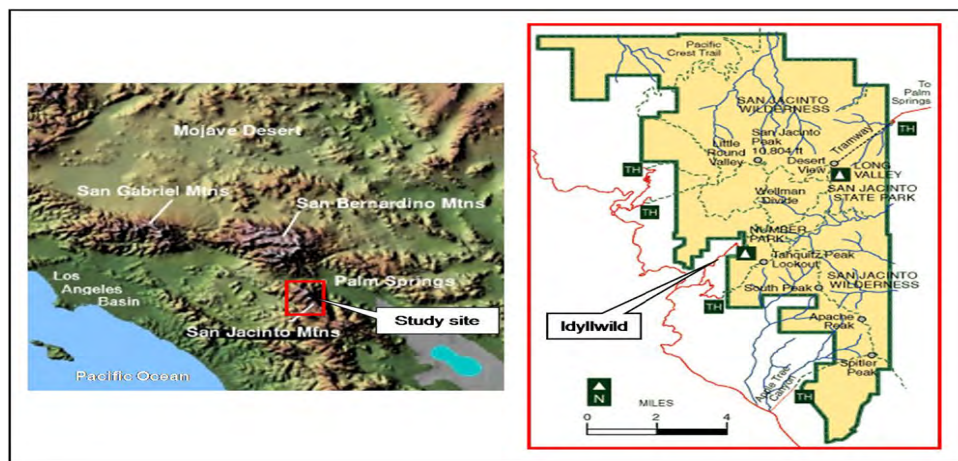


Figure 1— Site location-San Jacinto Wilderness Area. Map provided by Baerenklau and others (2010).

Focus Group and Pre-test

An initial version of the survey⁵ was presented to 3 focus groups (October 2011 to March 2012) to evaluate study design, clarity of wording, use of graphics, range of

⁵ This survey is being conducted as part of the senior author's Doctoral thesis research at the University of California Riverside; no Federal Government financial resources were used in the design or implementation of the survey.

values used, and to consider if important issues were omitted or obscured. Revised versions of the survey were pre-tested (May and June 2012) to evaluate whether or not respondents were answering questions in a sensible manner, verify that the web-based survey was working properly (i.e., survey link is active, pictures are loading correctly), and verifying the time required to complete the survey (approximately 20 minutes).

Sample Design

Recreationists were recruited into the survey while obtaining their wilderness permits at the USDAFS Ranger Station in Idyllwild and the Mt. San Jacinto State Park Ranger Station in Long Valley during the summer months of June 2012 to September of 2012. The recruitment flyer (Figure 2) included the study objective, incentive information for participants who complete the survey, and the researcher's contact information. To decrease self-selection bias and increase response rate, a University of California -Riverside (UCR) undergraduate student was stationed at the Idyllwild Ranger Station during the weekends and once during the weekday, providing more study information as well as collecting e-mail addresses from interested participants. A similar protocol was followed in the Long Valley Ranger Station, but a student was there only on the two highest visitation days, Friday and Saturday.

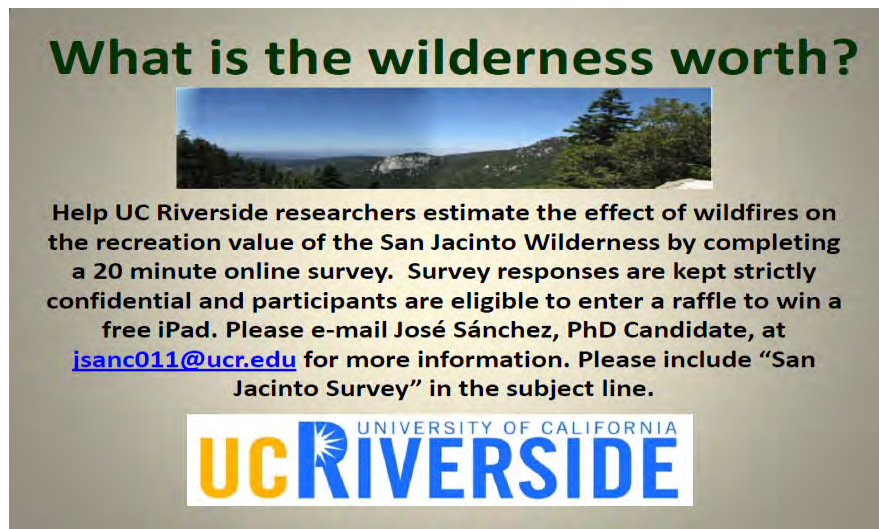


Figure 2— Recruitment Flyer

The web-based survey was implemented using a modified Dillman (2007) approach. The researcher initially notified participants via e-mail that a survey link would be sent within a day by SurveyMonkey, a web-based survey software and questionnaire tool. Approximately a week after receiving the survey link, non-

responders received a friendly e-mail reminder to complete the survey. The reminder included the link to the survey and incentive information for completing the survey. A final e-mail reminder was sent to non-responders approximately 3 weeks after the initial contact. Non-responders were removed from the participation list a week after sending the final e-mail reminder.

Interested participants who did not provide their e-mail address when obtaining the wilderness permit could e-mail the researcher directly requesting the survey link. Within a day of receiving a participant's e-mail address, the researcher sent an e-mail thanking them for agreeing to participate. The email from SurveyMonkey followed shortly thereafter.

Survey Instrument

The web-based survey is divided into three sections. The first section elicits the recreation trip behavior and cost-related information. The second section consists of hypothetical burn scenarios that contain five attributes of interest: percent of viewshed burned (25%, 50%, and 75%), intensity of fire (low, medium, and high), time since burn (0-5 years, 6-15 years, and more than 15 years), viewing distance (foreground, middle ground, and background), and trail affected by fire; in Idyllwild there are four trails: Deer Springs, Devil's Slide, Marion Mountain, South Ridge; in Long Valley: Long Valley. The five trails were selected because they have the highest visitation rates based on 2005 data⁶. The final section of the survey collects demographics and personal information, including gender, ethnicity, age, education level, employment status and income.

There are a total of 405 ($3^4 \times 5$) possible treatment combinations for the burn scenarios. A full factorial design was not implemented because higher order interactions are considered negligible. We were only interested in the main effects and 2-way interactions. It was decided that the most efficient strategy was to implement a fractional factorial design (Montgomery 2005) for the burn scenarios to reduce the cognitive burden faced by respondents. A D-efficient design of 100%, which contained 45 runs (treatment combinations), was selected for the fractional factorial design using the %mktruns and %mkteval programs in SAS statistical software (SAS Institute Inc., 2010).

Survey participants were shown a set of five burn pictures, each representing the landscape of the San Jacinto Wilderness if a fire were to occur there in the future. For example, a hypothetical burn scenario would be represented by a picture of a recent low-intensity burn in the foreground along with a description of the extent

⁶ Out of a total of 34,218 permitted visitors to the San Jacinto Wilderness in 2005, 33,194 visited the 5 trails (Baerenklau and others 2010).

(50% of the viewable area) and location (along the Deer Springs trail) of the burn (Figure 3). Participants were asked to report how many trips would have they taken in the past 12 months to each of the 5 trails if the trail conditions changed as in the picture shown.



12. This picture shows a 0-5 year-old low-intensity burn viewed from up-close. If 50% of the foreground scenery along the Deer Springs trail was similar to this picture, how many recreation trips would you have taken to each trail during the past 12 months?

	Number of recreation trips
Deer Springs Trail	
Devil's Slide Trail (Humber Park)	
Marion Mountain Trail	
South Ridge Trail	
Long Valley (Palm Springs Aerial Tram)	

Figure 3— Web-based survey hypothetical burn scenario example

Econometric Model

An incomplete demand system approach (von Haefen 2002) was used to estimate the TCM and associated welfare measures (i.e., forest access value) and welfare changes due to the hypothetical wildfire scenarios.

Travel Cost Model

The basic concept of the TCM is that travel cost to the site is used to proxy for the price of access to the site. The method is based on the cost incurred by the individual to visit the resource being valued, which includes both out of pocket expenses and the opportunity cost of time. Out of pocket expenses may include driving costs (e.g., gas, tolls, and vehicle depreciation), food, equipment, etc. Opportunity cost of time is the cost associated with time of traveling to and from the area visited and is an important element of the TCM (see, for example, Hagerty and Moeltner 2005, McConnell and Strand 1981, McKean and others 1995, and Smith and others 1983.) In this study, driving costs are a function of distance (estimated from Google Maps) and the average per-mile cost of operating a typical car (\$0.585/mile; AAA, 2012).

Time costs are a function of travel time (estimated from Google maps) and the opportunity cost of time is assumed to be one-third of the individual's reported average hourly income (Hagerty and Moeltner 2005).

The TCM is estimated using an incomplete demand system approach. An incomplete demand system provides a theoretically correct framework for modeling the demand for multiple goods and deriving welfare estimates. Multiple systems have been developed along with the associated welfare formulas. The demand specification for trips used here is given by (von Haefen, 2002):

$$x_j = \alpha_j(q) \text{Exp}\left(\sum_{k=1}^J \beta_{jk} p_k + \gamma_j y\right), \forall j \quad (1)$$

where x_j is demand for trips to site $j \in \{1, \dots, J\}$; p_k is the cost of access site k ; each β is an estimable parameter describing the effect of the cost to access site k on the demand for trips to site j ; y is an individual's annual household income, α_j is an estimable function, and γ_j are estimable parameters. To guarantee that we can derive theoretically correct welfare estimates for the demand system in Eq. (1), we need to make the following assumptions (LaFrance, 1990, von Haefen, 2002):

$$\begin{aligned} \alpha_j(q) &> 0, \forall j \\ \gamma_j &= \gamma, \forall j \\ \beta_{jk} &= 0, \forall j \neq k \\ \beta_{jj} &< 0, \forall j \end{aligned} \quad (2)$$

Imposing these restrictions on Eq. (1) gives:

$$x_j = \exp(a_j(q)\beta_j p_j + \gamma y), \forall j \quad (3)$$

where $a_j \equiv \ln(\alpha_j(q))$ and each β_j is restricted to be negative.

The model parameters are usually estimated using either the Poisson or the negative binomial distribution because the demand for trips is non-negative ($x_j \geq 0$). Here we specify that the individual demand for each site follows an independent Poisson distribution (Cameron and Trivedi, 1986):

$$\text{Pr}(x_j = x_j^*) = \frac{\exp(-\lambda_j) \lambda_j^{x_j^*}}{x_j^*!} \quad (4)$$

with mean and variance equal to λ_j . The log-likelihood function is given by:

$$L = \sum_{j=1}^J [-n\lambda_j + x_j^* \ln \lambda_j - \ln x_j^*!] \quad (5)$$

with $\lambda_j \equiv \exp(\delta'q_j + \beta p_j + \gamma y)$.

LaFrance (1990) and von Haefen (2002) derived a quasi-indirect utility function from this system of demand:

$$\phi(p, q, y) = -\frac{1}{\gamma} \exp(-\gamma y) - \sum_{j=1}^J \frac{\alpha_j(q)}{\beta_j} \exp(\beta_j p_j) \quad (6)$$

The consumer surplus (CS) is derived from the demand curve as the difference between individual's willingness to pay (e.g., the entire area under the demand curve) and what they actually pay (e.g., their travel cost). The average CS per trip is calculated as:

$$CS_j = \frac{1}{-\beta_{tc}} \quad (7)$$

where β_{TC} is the estimated parameter for the travel cost variable.

Results

The web-based survey was implemented in June and will conclude on September 30, 2012. Preliminary analysis was done to estimate the forest access value using the first 100 observations. Observations with travel time greater than 3 hours and travel cost over \$1,000 were removed from the database. A total of 87 observations were analyzed (51 from Idyllwild and 36 from Long Valley).

Descriptive statistics for respondent characteristics used in the empirical model are shown in Table 1. Both sites have similar visitation rates and travel cost (an average of 3 trips per year and \$71 to \$75 cost per trip). The most interesting statistics are the income, age and education (expressed as college degree) variables. Visitors to the wilderness are high income earners (\$92,211), older than Idyllwild residents (45 years), have more education (79% have at least a Bachelor's degree) and take few trips a year.

Table 1—Descriptive statistics of survey responses for variables included in the econometric model specification

Variable	Description	Mean (std. dev.)
Trips_ID	Annual trips to Idyllwild site	2.89 (5.99)
Trips_LV	Annual trips to Long Valley site	2.98 (5.43)
TC_ID	Per trip travel cost to Idyllwild	\$75.89 (43.82)
TC_LV	Per trip travel cost to Long Valley	\$71.33 (47.68)
Age	Respondent's age	44.94 (12.86)
Degree (dummy variable)	Having at least a Bachelor's degree; if Yes = 1; else = 0	.79 (.41)
Employed (dummy variable)	Being employed in the past year; if Yes = 1; else = 0	.64 (.48)
EnvGrp	Belonging to an environmental group; if Yes = 1; else = 0	.18 (.39)
Gender (dummy variable)	Respondent's gender; Male =1 Female = 0	.61 (.49)
Income	Household annual income	\$92,211 (46,183)

In the standard Poisson model (Table 2), the parameter estimates on the cost, gender, and environmental group variables were negative and statistically significant at the 0.01 and 0.05 levels, respectively. The cost variable agrees with economic theory. The higher the trip cost, the fewer trips an individual will take to the site. The environmental group variable (*EnvGrp*) has a negative sign and is statistically significant; meaning that, contrary to our expectations, individuals belonging to an environmental group exhibit less demand. Overcrowding is seen as major concern to the preservation of the wilderness. Therefore, a plausible explanation for the negative sign of this variable is that environmentalists prefer visiting less crowded sites. Income and employment parameter estimates were negative, but not significant. However, site, age and degree (not significant) are associated with greater demand for trips to each site. Hiking in a remote area, like the San Jacinto Wilderness, requires a large amount of time. Therefore, it may be more appealing to older (age) and high income individuals (66% in sample have higher than Idyllwild mean income level) and those that have more time available (for example, retired and/or unemployed individuals). The access values were calculated using Eq (7). The average CS per trip for Idyllwild is \$89.29 and for Long Valley the value is \$23.87.

Table 2— Poisson model estimates. The dependent variable is the number of trips taken in the past 12 months.

Variable	Model	
	Estimate	Std. Err.
Constant	-42.05***	(5.21)
Site	31.72***	(5.87)
TC_ID	-0.0112***	(0.0022)
TC_LV	-0.0419***	(0.0052)
Income	-0.0015	(0.00146)
Gender	-0.2201*	(0.1245)
Age	0.0452***	(0.0058)
EnvGrp	-0.3617**	(0.1702)
Degree	0.1375	(0.1601)
Employed	-0.0006	(0.0005)
N	87	
McFadden R ²	0.3227	

Note: * indicates significance at the 0.10 level, ** indicates significance at the 0.05 level, *** indicates significance at the 0.01 level. N is the number of observations. McFadden R² is a goodness of fit measure that is based on estimates of the log-likelihood function including the intercept only versus the full model, and ranges between 0 (no explanatory power) and 1(perfect explanatory power.)

Conclusion and Discussion

This analysis should be interpreted carefully. Data collection is still ongoing and the sample size used in the analysis represents less than 20% of the expected total.

Preliminary results show that the San Jacinto Wilderness visitors are different from the Idyllwild residents. As mentioned above, sample visitors are high income earners (\$92,211) and highly educated with 79% having at least a bachelor's degree, while Idyllwild residents have lower annual household income (\$67,061) and only 14.3% have at least a bachelor's degree (U.S. Census Bureau 2010). We think the same pattern will remain when analyzing the full dataset.

The econometric model used in the analysis shows that the average values of CS per trip are not the same for both sites. Idyllwild has more than double the per person access value than Long Valley. We expected the values to be similar because both sites have access to the same destinations as well as similar travel costs. However, the difference in CS is due to having different demand curves for each site. Having

larger CS (smaller β_{TC}) means that the demand curve is less elastic (e.g., less sensitive to changes in travel cost), while having smaller CS (larger β_{TC}) demand is more sensitive to travel cost (more elastic). One possible reason for the difference is that campers are being captured in our day use survey. In the sample there were 18 individuals that reported camping as an activity done when visiting the area. Twelve of those visited Idyllwild and six visited Long Valley. Overnight trips are more costly than day trips. This can be seen in our survey data. Individuals that engaged in camping activities had a self-reported trip cost of \$150, while non-campers reported \$45. A model removing campers from dataset resulted in minor variations in estimates. Therefore, this information can help explain some of the difference in per person access value for Idyllwild and Long Valley.

Overall, our preliminary results show that visitors of the San Jacinto Wilderness are different (high income earners, have higher education, and older) from the Idyllwild population, and potentially have higher welfare estimates than the general Southern California population. The econometric model demonstrated that the per person access values are different for both sites due to possible overnight trips. Further analysis will be done on the entire dataset, considering only individuals on day use trips.

Using GIS techniques, future analyses will estimate specific values for each piece of the landscape and how economic welfare is affected if only part of the forest area is impacted by fire. This information can be used by forest managers and stakeholders as a decision aid for evaluating tradeoffs associated with alternative fire management strategies that would promote more sustainable future wildland fire management programs. Spatially explicit landscape values also could be used for evaluating preservation of wilderness areas, trail network design, campground development, zoning and building regulations for rural communities, location of scenic byways and overlooks, shoreline development regulations, and design of location-specific development impact fees.

Summary

To better evaluate the potential impacts of wildland fire in the San Bernardino National Forest, we developed a geographic information system (GIS) data layer containing non-market economic values for the San Jacinto Ranger District. Each pixel in the data layer contains an estimate of the most prominent nonmarket values at that location. This information can be used by forest managers as a decision making aid when deciding how to allocate resources to protect high value areas. To estimate the recreation value component and potential losses due to wildfire, backcountry hikers entering the San Jacinto Wilderness were recruited to complete a

web-based survey during the summer of 2012. A travel cost model was used to calculate the associated values. This paper presents preliminary results from the survey and ongoing modeling work.

Acknowledgements

We thank Andy Smith and the staff at San Bernardino National Forest San Jacinto Ranger District, and Bart Grant and staff at Mount San Jacinto State Park & Wilderness for assistance in distributing recruitment flyers. Also, UC Riverside students Noemi Villegas-Valadez and Yi-Chia Chu, and Hispanic Association of Colleges and Universities intern José Román for field work assistance; and Rich Alldredge, John Loomis, Pete Schuhmann, and Javier Suarez for their useful comments provided in developing the survey design.

References

- American Automobile Association (AAA), 2012.** Cost of Owning and Operating Vehicle in U.S. Increased 1.9 Percent According to AAA's 2012 'Your Driving Costs' Study. Available at: <<http://newsroom.aaa.com/2012/04/cost-of-owning-and-operating-vehicle-in-u-s-increased-1-9-percent-according-to-aaa%E2%80%99s-2012-%E2%80%98your-driving-costs%E2%80%99-study/>>. Accessed July 2012.
- Baerenklau, K.A., González-Cabán, A., Paez, C., Chavez, E. 2010.** Spatial allocation of forest recreation values. *Journal of Forest Economics* **16**(2):113-126
- Boxall, P. and Englin, J. 2008.** Fire and recreation values in fire-prone forests: exploring an intertemporal amenity function using pooled RP-SP data. *Journal of Agricultural and Resource Economics* **33**:19-33.
- Cameron, A. and Trivedi, P. 1986.** Econometric models based on count data: comparisons and applications of some estimators and tests. *Journal of Applied Econometrics* **1**:29-54
- Cavailhès, J., Brossard, T., Foltête, JC, Hilal, M., Joly, D., Tourneux, FP, Tritz, C., and Wavresky, P. 2009.** GIS-based hedonic pricing of landscape. *Environmental Resource Economics* **44**:571-590.
- Dillman, D.A. 2007.** Mail and internet surveys, 2nd Edition. *John Wiley & Sons, Inc.*
- Eade, J.D.O. and Moran, D. 1996.** Spatial economic valuation: benefit transfer using geographic information systems. *Journal of Environmental Management* **48**:97-110.
- Englin, J., Boxall, P., and Watson, D. 1998.** Modeling recreation demand in a poisson system of equations: an analysis of the impact of international exchange rates. *American Journal of Agricultural Economics* **80**(2):1837-1844
- Englin, J., Loomis, J., and González-Cabán, A. 2001.** The dynamic path of recreational values following a forest fire: a comparative analysis of states in the intermountain west. *Canadian Journal of Forest Research* **31**:1837-1844.
- ESRI. 2006.** ArcMap 9.2. Using ArcGIS Spatial Analyst. *Environmental Systems Research Institute, Redlands, CA.*
- Fix, P and Loomis, J.B. 1997.** The economic benefits of mountain biking at one of its meccas: An application of the travel cost method to mountain biking in Moab, Utah. *Journal of Leisure Research* **29** (3):342-352.

- Flowers, P.J., Vaux, H.J., Jr., Gardner, P.D., and Mills, T.J. 1985.** Changes in recreation values after fire in the northern Rocky Mountains. *USDA Forest Service Research Note Pac. RN-PSW-373*.
- González-Cabán, A. 2008.** Proceedings of the second international symposium on fire economics, policy, and planning: a global view. Gen. Tech. Rep. PSW-208, Albany, CA: *Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture*. pp. 720
- González-Cabán, A., Loomis, J., Griffin, D., Wu, E., McCollum, D., McKeever, J., and Freeman, D. 2003.** Economic value of big game habitat production from natural and prescribed fire. *U.S. Forest Service Pacific Southwest Research Station Research Paper #249*. Available at: http://www.fs.fed.us/psw/publications/documents/psw_rp249/ Accessed October 2010.
- Hagerty, D. and Moeltner, K. 2005.** Specification of driving costs in models of recreation demand. *Land Economics* **81**(1):127-143.
- Hanley, N., Wright, R.E, and Adamowicz, V. 1998.** Using choice experiments to value the environment. *Environmental and Resource Economics* **11**(3-4):413-428.
- Hesseln, H., Loomis, J.B., González-Cabán, A. 2004.** The effects of fire on recreation demand in Montana. *WJAF* **19**(1):47-53.
- Hesseln, H., Loomis, J.B., González-Cabán, A. and Alexander S. 2003.** Wildfire effects on hiking and biking demand in New Mexico: a travel cost study. *Journal of Environmental Management* **69**:359-368.
- Hilger, J., and Englin, J. 2009.** Utility theoretic semi-logarithmic incomplete demand systems in a natural experiment: Forest fire impacts on recreational values and use. *Resource and Energy Economics* **31**:287-298.
- LaFrance, J.T. 1990.** Incomplete demand systems and semilogarithmic demand models. *Australian Journal of Agricultural Economics* **34**(2):118-131.
- Loomis, J. B., and González-Cabán, A. 1998.** A willingness-to-pay function for protecting acres of spotted owl from fire. *Ecological Economics* **25**:315-322.
- Loomis, J., González-Cabán, A., and Englin, J. 2001.** Testing for differential effects of forest fires on hiking and mountain biking demand and benefits. *Journal of Agricultural and Resource Economics* **26**(2):508-522.
- Loomis, J. B., Griffin, D., Wu, E., González-Cabán, A. 2002.** Estimating the Economic Value of Big Game Habitat Production from Prescribed Fire Using a Time Series Approach. *Journal of Forest Economics* **8**(2):119-129.
- Louviere, J.J., Hensher, D.A., Swait, J.D. 2000.** Stated Choice Methods. Cambridge University Press, Cambridge, UK.
- Mueller, J., Loomis, J., and González-Cabán, A. 2009.** 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 California. *Journal of Real Estate Finance Economics* **38**:155-172.
- Powe, N.A., Garrod, G.D., Brunsdon, C.F. and Willis, K.G. 1997.** Using a geographic information system to estimate an hedonic price model of the benefits of woodland access. *Forestry* **70**(2):139-149.
- SAS Institute Inc. 2010.** SAS 9.3. SAS Institute Inc., Cary, NC.
- Troy, A. and Wilson, M.A. 2006.** Mapping ecosystem services: practical challenges and opportunities in linking GIS and value transfer. *Ecological Economics* **60**(2): 435-449.

- US Census Bureau. 2010.** 2006-2010 American Community Survey. Available at: <http://factfinder2.census.gov/faces/nav/jsf/pages/searchresults.xhtml>. Accessed July 2012.
- USDA. 2009.** Fire and Aviation Management Fiscal Year 2008 Accountability Report. *United States Department of Agriculture, Forest Service*. Washington, DC.
- Vaux, H.J., Jr., Gardner, P.D., and Mills, T.J. 1984.** Methods for assessing the impact of fire on forest recreation. *USDA Forest Service GTR-PSW-79*.
- von Haefen, R.H. 2002.** A complete characterization of the linear, log-linear, and semi-log incomplete demand system models. *Journal of Agricultural and Resource Economics* 27(2):281-319.

Economic analysis of prescribed burning for wildfire management in Western Australia¹

Veronique Florec², David Pannell³, Michael Burton⁴, Joel Kelso⁵, Drew Mellor⁶, and George Milne⁷

Abstract

Wildfires can cause significant damage to ecosystems, life and property, and wildfire events that do not involve people and property are becoming rare. With the expansion of the rural–urban interface in Western Australia and elsewhere, objectives of life and property protection become more difficult to achieve. We applied the cost plus net value change (C+NVC) model to a synthetic landscape, representative of the northern jarrah forest of the south west of Western Australia. The most economically efficient level of prescribed burning corresponds to a strategy where 5% of the simulated landscape is prescribed-burned per year. Our results are sensitive to changes in the average cost per hectare of prescribed burning, the probabilities of fire occurrence, urban area values (in average dollars per hectare) and suppression costs.

Keywords: wildfire, fire management, economic analysis, cost plus net value change.

Introduction

Wildfires can cause significant damage to ecosystems, life and property and in many parts of the world the frequency of large, disastrous fires, often referred to as mega-fires, appears to have increased (Morgan 2009, Williams *and others* 2011).

Catastrophic wildfires have occurred in Australia, the United States, Canada, Russia, China, South Africa, and Spain, among others. The Black Saturday fires in Victoria,

¹ An abbreviated version of this paper was presented at the IV International Symposium on Fire Economics, Planning, and Policy: Climate Change and Wildfires, November 5-11, 2012, Mexico City, Mexico.

² PhD candidate, School of Agricultural and Resource Economics, The University of Western Australia, Crawley, Australia (email: veronique.florec@uwa.edu.au)

³ Winthrop Professor, School of Agricultural and Resource Economics, Director, Centre for Environmental Economics and Policy, The University of Western Australia, Crawley, Australia.

⁴ Professor, School of Agricultural and Resource Economics, The University of Western Australia, Crawley, Australia.

⁵ Post-doctoral researcher, School of Computer Science and Software Engineering, The University of Western Australia, Crawley, Australia.

⁶ Post-doctoral researcher, School of Computer Science and Software Engineering, The University of Western Australia, Crawley, Australia.

⁷ Winthrop Professor, School of Computer Science and Software Engineering, The University of Western Australia, Crawley, Australia.

Australia on 7 February 2009 resulted in the highest loss of life and property from a wildfire in Australian history (Teague and others 2010), causing the death of 173 people and widespread destruction of assets and infrastructure. Since 1998, nine states in the US have suffered their worst wildfires in history (Williams and others 2011). Although these fires are usually rare, they cause profound and long-lasting social, economic and environmental impacts where they occur (Handmer and Proudley 2008).

Urban development in fire prone areas has amplified the complexity of the problem. Wildfire events that do not involve people and property are becoming rare (Mutch and others 2011). The number of houses and infrastructure located within or close to areas of high fire risk continues to increase in Australia (Morgan and others 2007) and elsewhere (USA, Canada, Europe, among others, see Smalley 2003, Mozumder and others 2009, Mell and others 2010, Stockmann and others 2010, Mutch and others 2011), increasing the wildfire risk to life and property.

In light of the increasing wildfire threat, fire agencies have often responded with greater suppression capacity, involving increasing suppression costs. However, this has not solved the problem of catastrophic wildfires (Williams and others 2011). In Australia suppression expenditures have followed an escalating trend and the country “currently runs the risk of spending ever-greater amounts of money on wildfire suppression, while becoming even less successful in its management of fire in the landscape than is currently the case.” (Morgan and others 2007, p. 1). Other countries with fire-prone landscapes appear to face similar issues. In the US annual suppression expenditures have increased remarkably over the past several years while the western part of the country has been severely affected by large and intense wildfires since the 1980s (Calkin and others 2005).

Economics can provide improved understanding and comprehensive appraisals of wildfire costs and benefits in order to devise wildfire mitigation and management programs that optimally allocate resources and express informed, evidence-based judgements about trade-offs between available options (Handmer and Proudley 2008). However, the use of economics in the wildfire literature is still relatively limited. Despite the abundance of theoretical studies on the subject, empirical economic analyses of wildfire management are scarce (Mercer and others 2007).

In this paper we apply the cost plus net value change (C+NVC) model to a synthetic landscape, representative of the northern jarrah forest of the south west of Western Australia (WA). The purpose of the study is to determine the most economically efficient pre-suppression strategy for the synthetic landscape and evaluate which parameters significantly affect the results. We focus on prescribed burning as the main pre-suppression strategy. The primary objective of this model is to provide preliminary results which may inform the development of a more

complete model based on actual areas of WA.

Methods

We simulated wildfires in a synthetic landscape under varying climatic conditions and different prescribed burning (pre-suppression) strategies using the AUSTRALIS Wildfire Simulator, which was developed at the School of Computer Science and Software Engineering, The University of Western Australia (see Johnston and others 2008 for a description of the fire simulator). The synthetic landscape generated for the simulations is a square landscape of 100,000 ha, containing a flat terrain with homogenous northern jarrah forest fuel.

We tested three prescribed burning strategies, each with three patch sizes. The strategies involved prescribed-burning 5, 10 or 20 % of the total area per year, corresponding to rotation cycles of 20, 10 and 5 years respectively. The landscape was partitioned into square-shaped patches of 50, 500 and 4000 ha, and each strategy could be carried out in burning patches of these sizes. The age of the fuel in each patch was a random integer value from $[0, n]$, where $n = 5, 10$ or 20 , depending on the burning strategy. In addition to these 9 combinations ($3 \text{ strategies} \times 3 \text{ patch sizes} = 9$), we defined a baseline strategy for comparison where the fuel age was uniformly set at 15 years across the entire treatment area and used this baseline as the 0% prescribed burning or no-strategy case. Each strategy-patch size combination was simulated under high, very high, extreme and catastrophic forest fire danger conditions (FFDI), giving $(9+1) \times 4 = 40$ scenarios. Finally, each scenario was tested under 30 random ignitions, making a total of $30 \times 40 = 1200$ simulations.

We used the “McArthur Mk V” forest fire meter (Noble *and others* 1980; Sirakoff 1985) to determine the rate of spread. Fuel load was determined using the fuel accumulation table for Jarrah forest in Sneeuwjagt and Peet (1998), which gives fuel load as a function of fuel age. Fire ignition points were generated according to a random uniform distribution. The weather was constant during simulation. Spotting effects were not modelled. **Error! Reference source not found.** summarises the simulator settings. It is assumed that if fire intensity is below a threshold of 2,000 kW/m, then the fire is suppressed.

We used the C+NVC model, which is currently the most commonly accepted model for economic evaluations of wildfire management programs (Ganewatta 2008, Gebert and others 2008). From Donovan and Rideout (2003), the C+NVC model can be expressed as:

$$\text{Min } C + NVC = W^P P + W^S S(P) + NVC(P, S(P)) \quad (1)$$

in which W^P is the price of pre-suppression; P is the pre-suppression effort; W^S is

the price of suppression; S is the suppression effort, which is dependent on pre-suppression; and NVC is the net fire damage (fire damage less fire benefit).

Table 1— Summary of simulator settings for prescribed burning experiments

	Value				
Scenario parameters					
Patch sizes	50, 500, 4000 ha				
Rotation cycles	5, 10, 20 y				
Weather conditions	High, Very High, Extreme, and Catastrophic				
Ignition points	Uniformly randomly placed across the entire landscape				
Weather conditions	Temperature (°Celsius)	Relative Humidity (%)	Wind direction	Wind speed (km/h)	Drought factor
High	30	25	North	30	5
Very High	35	20	North	30	7
Extreme	35	10	North	30	9
Catastrophic	40	10	North	50	10
Fuel					
Rate of spread meter	McArthur Mk V, Forest (Sneeuwjagt and Peet 1998)				
Fuel accumulation rules	Northern Jarrah Fuel				
Canopy cover	60%				
Topography	Flat				
Cell grid					
Cell spacing	50 m				
Cell neighbourhood	Cells up to 6 links away are considered adjacent				
Simulator configuration					
Lateral rate of spread	Rate of spread at zero wind speed				
Maximum duration of simulated time	36 h				

In our model, we assumed a negative relationship between prescribed burning effort (annual prescribed-burned area as a proportion of the entire landscape) and suppression costs. Prescribed burning is generally expected to improve directly the probability of successful suppression (Fernandes and Botelho 2003) because prescribed burning decreases the intensity with which wildfires burn. Preliminary results of both empirical and modelling studies suggest that the relationship between the percentage of landscape prescribed-burned and the probability of unplanned high intensity fire at a point may be represented by a complex multiplicative model with a convex shape (Cary and others 2003). Hence, as the intensity of fires increases, suppression becomes more difficult and more costly (Chatto and Tolhurst 2004), since more expensive resources such as water bombers are needed when direct attack methods can no longer be used.

The functional relationship between prescribed burning effort and suppression

costs is expressed as $s = ke^{-ax}$, where s is suppression expenditure; x is the proportion of area prescribed-burned; k represents the maximum suppression expenditure and a is a coefficient of prescribed burning effectiveness that affects the marginal benefit of each extra prescribed-burned hectare in the landscape. *Ceteris paribus*, the higher coefficient a is, the lower the expenditure on suppression for a given proportion of prescribed-burned area.

Since we simulated fires under different weather conditions, which have different probabilities of occurrence, we multiplied the outcomes of the fires by their probabilities of occurrence and assumed that under low and moderate weather conditions the fires would be suppressed relatively quickly and have only a minimal effect on the results. **Error! Reference source not found.** shows the probabilities that we used for fire occurrence.

Table 2—Probabilities of fire occurrence

<i>Fire category</i>	<i>Probability of incident occurrence per year</i>
Catastrophic	0.0001770
Extreme	0.0002360
Very High	0.0007080
High	0.0475789

We assumed in our analysis that a small town of 1,500 ha is located within the synthetic landscape in order to approach our evaluation of a rural-urban interface scenario. Thus, we included values of urban structures and public infrastructure and smoke and fire-related (prescribed or wildfire) health costs. Although the economic literature on human health impacts from exposure to wildfire or prescribed burning smoke is scarce⁸ and the differences in estimates between available studies is large, omitting health impacts in economic evaluations of fire management programs could result in underinvestment in pre-suppression activities (Richardson and others 2012).

In our analysis, we have not accounted for number of days of exposure to the smoke caused by wildfires but linked intensity and area burned to health costs. We assumed an exponential relationship between area burned by wildfire and health costs, which changes with the level of intensity. As intensity and area burned by wildfires increase, fuel combustion and biomass burning emissions (such as particulate matter with an aerodynamic diameter less than 2.5 μm , PM_{2.5}) escalate, and ultimately, as they become greater, wildfires may cause serious injuries and

⁸ Some studies that have estimated the adverse health effects from prescribed burning or bushfires smoke exposure include Richardson *and others* (2012), Butry and others (2001), Martin and others (2007), Rittmaster and others (2006). For a comprehensive review of the literature analysing economic cost of smoke-related health effects see Kochi and others (2010).

casualties. Hence we use an exponential relationship that increases as area burned and wildfire intensity become extreme. The relationship can be expressed as $h = be^{c\omega}$, where h is health costs per person at risk; ω is the size of the simulated fires (area burned); b is a coefficient that integrates the effects of intensity on health costs and a is a coefficient that reflects the impact of area burned on health costs per capita, both coefficients determine the marginal cost of each extra hectare burned by wildfires at a particular level of intensity in the landscape.

Some fires however, can be relatively small and still cause an increase in $PM_{2.5}$ concentration levels in a neighbouring town. We have then to assume that a smoke plume of a rectangular shape is released by the fire and has a probability of reaching the town $P(m, A) = m(\omega)/A$, with m the size of the smoke plume, which is dependent on the size of the fires; and A the size of the whole landscape.

Results and Discussion

Our results indicate that the most efficient level of prescribed burning corresponds to a strategy where 5% of the simulated landscape is prescribed-burned per year. With our assumed costs of prescribed burning (\$/ha), this is equivalent to an annual investment in prescribed burning of approximately AU\$405,000 over an area of 100,000 ha. The minimum of the C+NVC curve equals about AU\$785,000. **Error! Reference source not found.** show the curves obtained from the C+NVC model.

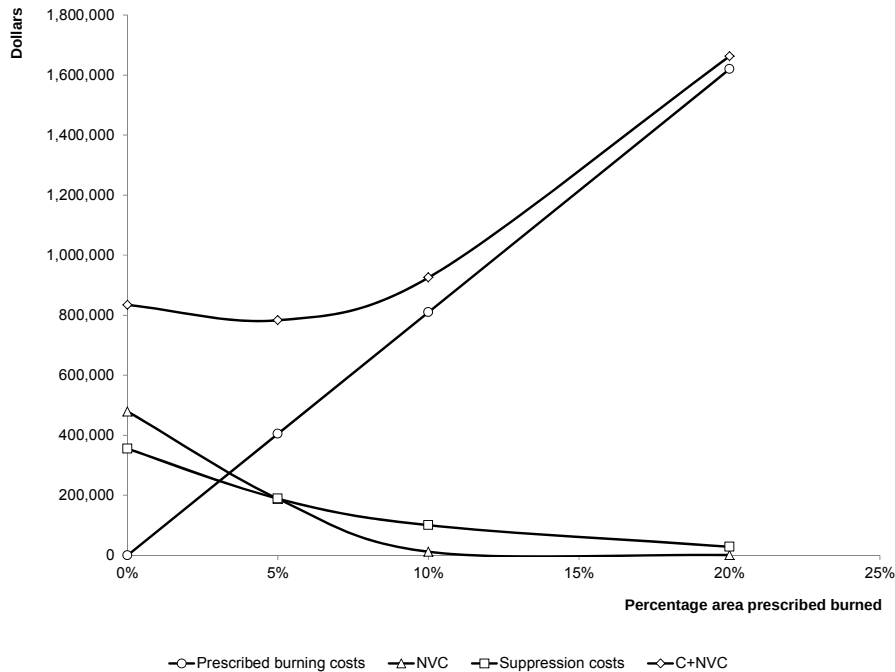


Figure 2—The cost plus net value change (C+NVC) curve

We conducted a sensitivity analysis to evaluate the robustness of the results and determine which parameter values most affect the results. **Error! Reference source not found.** shows the change in the minimum of the costs plus net value change curve in dollars when some parameter values are reduced by 50% or increased by 50%. The parameters shown are those to which the results are most sensitive. As shown in **Error! Reference source not found.**, a change in prescribed burning costs (in average dollars per hectare) greatly affects the results.

As prescribed burning costs increase, they quickly become a large proportion of the C+NVC curve. If the slope of prescribed burning costs changes, the point where marginal costs equal marginal benefits shifts accordingly. If the average cost per hectare for prescribed burning is very high, then the minimum of the C+NVC curve corresponds to a strategy of 0% prescribed burned area. This case is illustrated in **Figure 2**—Change in the minimum of the costs plus net value change curve with an increase and a decrease of 50% in the value of selected parameters

. The minimum value of the C+NVC curve is then the sum of suppression costs and damages for the 0% strategy.

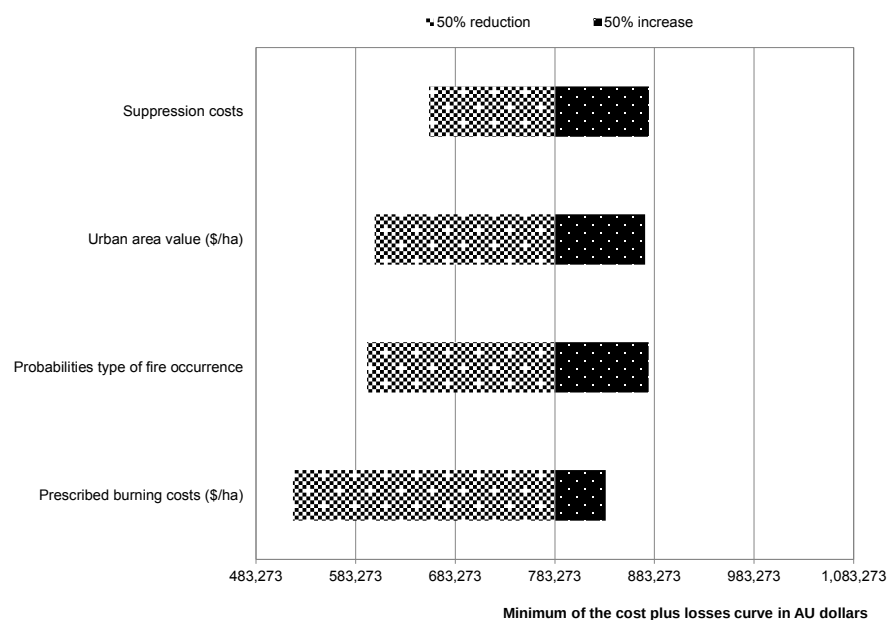


Figure 2—Change in the minimum of the costs plus net value change curve with an increase and a decrease of 50% in the value of selected parameters

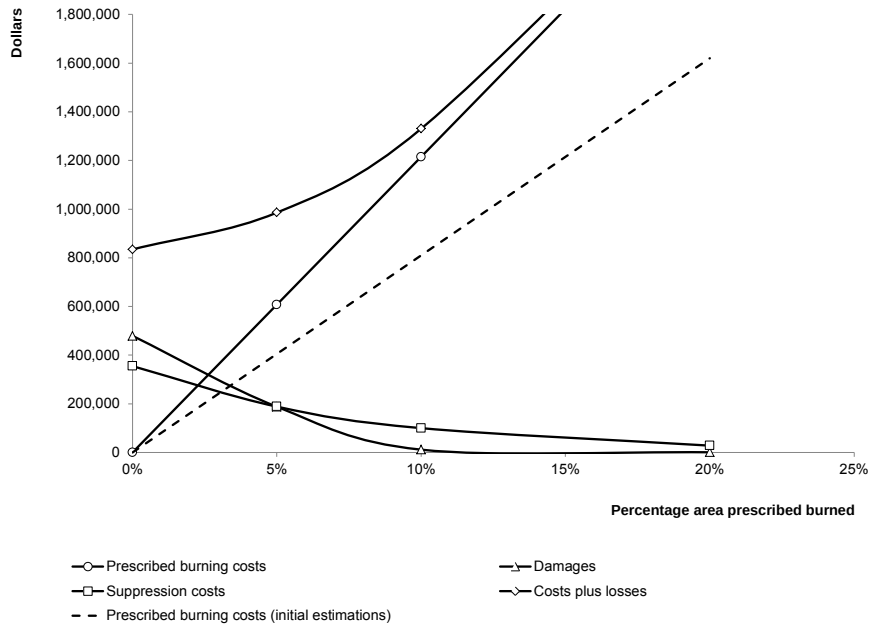


Figure 3—50% increase in average prescribed burning costs per hectare

When the average prescribed burning cost per hectare is reduced by 50%, the minimum value of the C+NVC curve decreases by 34% (**Error! Reference source not found.**) and the most efficient strategy is between 5 and 10% area prescribed burned per year (**Error! Reference source not found.**). Comparing the three figures of the C+NVC curve, it can be seen that in our initial estimation () there is a wide range of prescribed burning levels that is near-optimal, but this is not the case when the cost of prescribed burning is modified (**Error! Reference source not found.** and **Error! Reference source not found.**).

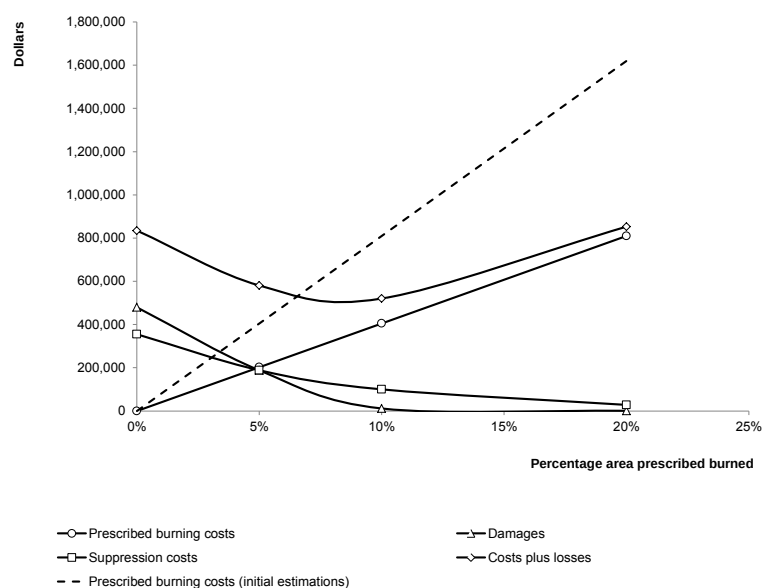


Figure 4—50% decrease in average prescribed burning costs per hectare

Our results are also sensitive to changes in the probabilities of fire occurrence, urban area values (in average dollars per hectare) and suppression costs. **Error! Reference source not found.** shows how the most efficient prescribed burning strategy changes when we increase or reduce the value of the selected parameters described above.

Table 3—Change in the most efficient prescribed burning strategy

	<i>Most efficient prescribed burning strategy (% of landscape prescribed burned)</i>		
	Initial estimation	50% reduction	50% increase
Prescribed burning costs (\$/ha)	5%	>5% and <10%	0%
Probabilities type of fire occurrence	5%	0%	>5% and <10%
Urban area value (\$/ha)	5%	0%	>5% and <10%
Suppression costs	5%	0%	>5% and <10%

This encapsulates the main challenges faced by fire agencies in developing sustainable fire management practices: climate change, the rural-urban interface and the effectiveness of suppression. Numerous uncertainties still exist regarding the behaviour of wildfires under severe weather conditions and the sustainability of different fire management practices in the context of climate change (Thornton 2010). With the expansion of the rural-urban interface, objectives of life and property

protection become more difficult to achieve. Smalley (2003) identifies the expansion of the rural-urban interface as “one of the three major factors that will propagate the pressures of the interface on communities. The other two are unusually severe weather events (from prolonged drought to severe heating periods and floods that erode soils and vegetation) and inadequate infrastructure due to the rapidity of growth or aging.” (p. 5)

The patch size of the prescribed burns had no significant effect on the results of the analysis. The severity measures obtained from the simulated fires were not significantly affected by changes in patch size (which is consistent with previous studies that use simulation to examine the efficacy of prescribed burning, e.g. Finney and others 2007, King and others 2008) and hence they had no significant impact on the economic analysis.

Although the C+NVC model has been extensively used to assess annual investments in fire prevention and protection, the model has been through some reformulation in the past two decades. Rideout and colleagues (Rideout and Omi 1990, Donovan and others 1999, Hesseln and Rideout 1999, Donovan and Rideout 2003, Rideout and Ziesler 2008) identified three inherent errors in the model that have been perpetuated from the earlier least cost plus loss model formulated by Sparhawk (1925). First, suppression expenditure is determined solely as a function of fire occurrence. Donovan and Rideout (2003) argued that both pre-suppression and suppression should be modelled as endogenous decision variables, with the benefits of suppression depending on the level of pre-suppression. As commonly applied, the C+NVC minimum may differ from the one obtained when pre-suppression and suppression are modelled correctly.

Second, suppression and pre-suppression expenditures are incorrectly modelled as negatively correlated (Donovan and Rideout 2003, Rideout and Ziesler 2008). And third, by analysing a single fire season, the long term effects of natural fuel accumulation processes, unplanned fires, fuel treatments and land management strategies on wildfire risk are overlooked (Hesseln and Rideout 1999). Fire scars, whether caused by fuel reduction treatments or unplanned fires, affect fire behaviour and intensity for longer than one year. Likewise, natural fuels accumulate over time and if left undisturbed, they gradually increase the risk of catastrophic fires year by year. Despite the limitations mentioned above, the application of the C+NVC model in its current formulation can help fire managers identify potential benefits and costs of different fire management options for a given year, even if a global minimum is not obtained (Rodriguez y Silva and Gonzalez-Caban 2010). We recognise the limitations of the model and their implications, and hope to address them in future work. The C+NVC framework has been used here as a first step towards a more comprehensive analysis.

Summary

We applied the cost plus net value change (C+NVC) model to a synthetic landscape of 100,000 ha, representative of the northern jarrah forest of the south west of Western Australia. We used the AUSTRALIS Wildfire Simulator to simulate wildfires in this landscape under varying climatic conditions. We tested three different prescribed burning (pre-suppression) strategies and a no-strategy option. We found that the most economically efficient level of prescribed burning corresponds to a strategy where 5% of the simulated landscape is prescribed-burned per year over an area of 100,000 ha. Our results are sensitive to changes in the average cost per hectare of prescribed burning, the probabilities of fire occurrence, urban area values (in average dollars per hectare) and suppression costs.

Acknowledgments

We thank Neil Burrows from the Department of Environment and Conservation Western Australia for his valuable contributions. We also thank the Bushfire Cooperative Research Centre, Australia for funding.

References

- Butry, D., Mercer, D.E., Prestemon, J.P., Pye, J.M., Holmes, T.P. 2001. What is the price of catastrophic wildfire? *Journal of Forestry* **99**, 9.
- Calkin, D.E., Gebert, K.M., Jones, G., Neilson, R.P. 2005. Forest service large fire area burned and suppression expenditure trends, 1970-2002. *Journal of Forestry* **103**, 179-183.
- Cary, G., Lindenmayer, D., Dovers, S. (Eds). 2003. 'Australia Burning: Fire Ecology, Policy and Management Issues.' (CSIRO Publishing: Collingwood, VIC)
- Chatto, K., Tolhurst, K.G. 2004. A Review of the Relationship between Fireline Intensity and the Ecological and Economic Effects of Fire, and Methods Currently Used to Collect Fire Data. Report commissioned by Fire Management, Department of Sustainability and Environment, Victoria Available at <http://www.dse.vic.gov.au/fire-and-other-emergencies/living-with-fire-victorias-bushfire-strategy/fire-research-reports/research-report-67>.
- Donovan, G.H., Rideout, D.B. 2003. A reformulation of the cost plus net value change (C+NVC) model of wildfire economics. *Forest Science* **49**, 318-323.
- Donovan, GH, Rideout, DB, Omi, PN, Usda. 1999. 'The economic efficiency of the National Fire Management Analysis System and FIREPRO, Proceedings of Symposium on Fire Economics, Planning and Policy: Bottom Lines.' Available at <Go to ISI>://WOS:000167781700012
- Fernandes, PM, Botelho, HS .2003. A review of prescribed burning effectiveness in fire hazard reduction. *International Journal of Wildland Fire* **12**, 117-128.
- Finney, MA, Seli, RC, McHugh, CW, Ager, AA, Bahro, B, Agee, JK. 2007. Simulation of long-term landscape-level fuel treatment effects on large wildfires. *International Journal of Wildland Fire* **16**, 712-727.

- Ganewatta, G. 2008.** The economics of bushfire management. In 'Community Bushfire Safety.' (Eds J Handmer, K Haynes.) pp. 151-159. (CSIRO Publishing: Collingwood, VIC)
- Gebert, K, Calkin, DE, Huggett, RJ, Abt, K. 2008.** Toward a unified economic theory of fire program analysis with strategies for empirical modelling. In 'The Economics of Forest Disturbances: Wildfires, Storms and Invasive Species.' (Eds TP Holmes, JP Prestemon, K Abt.) pp. 295-322. (Springer: Dordrecht, The Netherlands)
- Handmer, J., Proudley, B. 2008.** The economics of interface wildfires. In 'Gonzalez-Caban, A. (technical coordinator) 'Proceedings of the second international symposium on fire economics, planning, and policy: a global view'. Cordoba, Spain', 19-22 April 2004. (General Technical Report PSW-GTR-208, U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station. Available at http://www.fs.fed.us/psw/publications/documents/psw_gtr208en/psw_gtr208en_fm.pdf
- Hesseln, H, Rideout, DB. 1999.** 'Using control theory to model the long-term economic effects of wildfire, Proceedings of Symposium on Fire Economics, Planning and Policy: Bottom Lines.' Available at <Go to ISI>://WOS:000167781700013
- Johnston, P, Kelso, J, Milne, GJ. 2008.** Efficient simulation of wildfire spread on an irregular grid. *International Journal of Wildland Fire* **17**, 614-627.
- King, KJ, Bradstock, RA, Cary, GJ, Chapman, J, Marsden-Smedley, JB. 2008.** The relative importance of fine-scale fuel mosaics on reducing fire risk in south-west Tasmania, Australia. *International Journal of Wildland Fire* **17**, 421-430.
- Kochi, I, Donovan, GH, Champ, PA, Loomis, JB.2010.** The economic cost of adverse health effects from wildfire-smoke exposure: a review. *International Journal of Wildland Fire* **19**, 803-817.
- Martin, WE, Brajer, V, Zeller, K. 2007.** Valuing the health effects of a prescribed fire. In 'Wildfire Risk: Human Perceptions and Management Implications.' (Eds WE Martin, C Raish, BJ Kenny.) pp. 244-261. (Resources for the Future:: Washington, DC, USA)
- Mell, WE, Manzello, SL, Maranghides, A, Butry, D, Rehm, RG. 2010.** The wildland–urban interface fire problem – current approaches and research needs. *International Journal of Wildland Fire* **19**, 238–251.
- Mercer, DE, Prestemon, JP, Butry, DT, Pye, JM. 2007.** Evaluating alternative prescribed burning policies to reduce net economic damages from wildfire. *American Journal of Agricultural Economics* **89**, 63-77.
- Morgan, G. 2009.** Asia and Australasia wildfire management: a regional perspective. In 'Gonzalez-Caban, A. (Technical Coordinator) Proceedings of the third international symposium on fire economics, planning, and policy: common problems and approaches. Carolina, Puerto Rico', 29 April - 2 May 2008. pp. 8-23. (General Technical Report PSW-GTR-227, U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station. Available at http://www.fs.fed.us/psw/publications/documents/psw_gtr227en/psw_gtr227_en.pdf
- Morgan, G, Bartlett, T, Leonard, M.2007.** Fire management and the bush – from an ad hoc seasonal pre-occupation to 'policy centre-stage'. In 'Tassie Fire Conference Proceedings. Hobart, Tasmania', 18 - 20 July 2007. Available at http://proceedings.com.au/tassiefire/papers_pdf/thurs_gmorgan.pdf
- Mozumder, P, Helton, R, Berrens, RP. 2009.** Provision of a wildfire risk map: informing residents in the wildland–urban interface. *Risk Analysis* **29**, 1588-1600.

- Mutch, RW, Rogers, MJ, Stephens, SL, Gill, MA. 2011.** Protecting lives and property in the wildland–urban interface: communities in Montana and southern California adopt Australian paradigm. *Fire Technology* **47**, 357-377.
- Noble, IR, Gill, AM, Bary, GAV. 1980.** McArthur's fire-danger meters expressed as equations. *Austral Ecology* **5**, 201-203.
- Richardson, LA, Champ, PA, Loomis, JB. 2012.** The hidden cost of wildfires: Economic valuation of health effects of wildfire smoke exposure in southern California. *Journal of Forest Economics* **18**, 14-35.
- Rideout, DB, Omi, PN. 1990.** Alternate expressions for the economic theory of forest fire management. *Forest Science* **36**, 614-624.
- Rideout, DB, Ziesler, PS. 2008.** 'Three Great Myths of Wildland Fire Management. In Gonzalez-Caban, A. (Coordinator) Proceedings of the second international symposium on fire economics, planning, and policy: a global view.' Albany, CA, USA, 19-22 April 2004. (U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station, General Technical Report PSW-GTR-208. Available at http://www.fs.fed.us/psw/publications/documents/psw_gtr208en/psw_gtr208en_319-326_rideout.pdf
- Rittmaster, R, Adamowicz, WL, Amiro, B, Pelletier, RT. 2006.** Economic analysis of health effects from forest fires. *Canadian Journal of Forest Research* **36**, 868-877.
- Rodriguez y Silva, F, Gonzalez-Caban, A. 2010.** 'SINAMI': a tool for the economic evaluation of forest fire management programs in Mediterranean ecosystems. *International Journal of Wildland Fire* **19**, 927-936.
- Sirakoff, C. 1985.** A correction to the equations describing the McArthur forest fire danger meter. *Austral Ecology* **10**, 481-481.
- Smalley, J. 2003.** Firewise communities: Recasting the future of the wildland-urban interface. In 'Paper presented at the 3rd International Wildland Fire Conference and Exhibition, Sydney. Available at <http://www.fire.uni-freiburg.de/summit-2003/3-IWFC/Papers/3-IWFC-017-Smalley.pdf>
- Sneeuwjagt, RJ, Peet, GB. 1998.** 'Forest Fire Behaviour Tables for Western Australia.' (Department of Conservation and Land Management, Perth, Western Australia:
- Sparhawk, WN. 1925.** The use of liability ratings in planning forest fire protection. *Journal of Agricultural Research* **30**, 693-762.
- Stockmann, KD, Burchfield, J, Calkin, DE, Venn, TJ. 2010.** Guiding preventative wildland fire mitigation policy and decisions with an economic modeling system. *Forest Policy and Economics* **12**, 147-154.
- Teague, B, Mcleod, R, Pascoe, S. 2010.** The 2009 Victoria Bushfires Royal Commission Final Report. Government Printer for the State of Victoria, Melbourne, VIC. Available at <http://www.royalcommission.vic.gov.au/Commission-Reports/Final-Report>.
- Thornton, R. 2010.** Research Programs: An Overview. Bushfire CRC, Melbourne, VIC. Available at http://www.bushfirecrc.com/sites/default/files/1009_researchlist_lowres.pdf.
- Williams, J, Albright, D, Hoffmann, AA, Eritsov, A, Moore, PF, Mendes De Morais, JC, Leonard, M, San Miguel-Ayanz, J, Xanthopoulos, G, van Lierop, P. 2011.** Findings and implications from a coarse-scale global assessment of recent selected mega-fires. In 'FAO at the Vth International Wildland Fire Conference. Sun City, South Africa', 9-13 May 2011. pp. 27-40. (Forestry Department, Fire Management Division Working Paper FM/27/E, Food and Agriculture Organization of the United Nations. Available at <http://www.fao.org/docrep/014/am663e/am663e00.pdf>

Does Personal Experience Affect Choice-Based Preferences for Wildfire Protection Programs^{1,2}

Armando González-Cabán³, Thomas P. Holmes⁴, John B. Loomis⁵, and José J. Sánchez³

Abstract

In this paper, we investigate homeowner preferences and willingness to pay for wildfire protection programs using a choice experiment with three attributes: risk, loss, and cost. A phone-mail-phone survey was used to collect data from homeowners predominantly living in medium and high wildfire risk communities in Florida. We tested three hypotheses: (1) homeowner preferences for wildfire protection programs are risk averse, (2) past personal experience with wildfires increases homeowners' willingness to pay for protection programs, and (3) subjective perception of risk influences willingness to pay for protection programs. Preference heterogeneity among survey respondents was examined using two econometric models and risk preferences were evaluated by comparing willingness to pay for wildfire protection programs against expected monetary losses. The results showed that nearly all respondents had risk seeking preferences. Only respondents who had personal experience with wildfire impacts consistently made trade-offs among risk, loss, and cost and these respondents were willing to pay more for wildfire protection programs than were respondents without prior experience of wildfire impacts. Respondents living in neighborhoods that they viewed as being at high risk from wildfires also were willing to pay more than other respondents.

Keywords: Expected utility, heuristics, natural disasters, prospect theory, risk seeking, risk aversion

Introduction

¹ An abbreviated version of this paper was presented at the Fourth International Symposium on Fire Economics, Planning, and Policy: Climate Change and Wildfires, November 5-11, 2012, Mexico City, Mexico.

² OMB control approval number 0596-0189.

³ Research Economist and Economist respectively, Pacific Southwest Research Station, USDA Forest Service, Riverside, CA; Email: agonzalezcaban@fs.fed.us; jsanchez@fs.fed.us.

⁴ Research Forester, Southern Research Station, USDA Forest Service, Research Triangle Park, NC; Email: tholmes@fs.fed.us.

⁵ Professor, Department of Agricultural and Resource Economics, Colorado State University, Fort Collins, CO; Email: jloomis@lamar.colostate.edu.

Wildfires pose a risk of catastrophic loss of life and property for people living in fire-prone natural landscapes. The increasing frequency and severity of wildfires in forested 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 (National Fire Plan 2001). However, little is known about the efficacy of these approaches or the factors that influence the degree to which homeowners and communities are willing to invest time, effort, and money in hazard mitigation (Holmes and others 2007). Understanding the factors that influence decisions of whether, and how much, to invest in wildfire hazard mitigation activities will help to identify obstacles to the implementation of efficient and effective fire mitigation programs and policies. In this paper we do this using a survey regarding homeowners willingness to pay (WTP) for private and public fire risk reduction programs.

One popular approach for evaluating WTP for environmental programs is the contingent valuation method (CVM), which asks people to respond to payment questions regarding hypothetical scenarios (Boyle 2003). This method has been applied to homeowner's WTP to reduce fire risk by Winter and Fried (2001) in Michigan and, recently Talberth and others (2006) of New Mexico homeowners

Loomis and others (2009) used a binomial choice response format to ask respondents whether or not they would vote in favor of fuel reduction programs in their state if it cost them a specified amount of money⁶.

An alternative method for estimating WTP for environmental programs is based on a choice experiment (CE) in which survey respondents are asked to choose among alternative programs that vary in program attributes and price (Holmes and Adamowicz 2003). One advantage of the choice experiment is that it allows analysts to evaluate WTP for a wide variety of program attribute levels in a single survey. In this paper, we use a choice experiment to estimate WTP for wildfire programs that would reduce both wildfire risk and potential value lost to homeowners due to wildfire damage. We evaluate the reasonableness of survey responses by comparing estimated values with the predictions of alternative theoretical models of decision-making under risk as well as with other empirical studies reported in the literature.

Decision making under risk

Several alternative theoretical models are available that describe decision-making under conditions of risk, and the standard economic model is based on expected utility (EU) theory (Shoemaker 1982). EU theory is based on the proposition that

⁶ This response format is preferred to the open-ended format as it closely mimics actual market decisions (Boyle 2003).

people make choices so that expected utility is maximized, where expected utility is computed as the sum of the utility associated with each possible outcome multiplied by its probability. It is assumed that the individual's utility function is concave in wealth (increases at a decreasing rate as wealth increases) and, when faced with risky choices, decision-makers are risk averse regarding losses (Deaton and Muellbauer 1980). Within the context of wildland fire, the EU model predicts that homeowners would be willing to invest in wildfire protection programs an amount that exceeds the actuarial value of the potential loss of wealth due to wildfire damage.

Responding to various critiques of EU theory, an alternative theory of choice under risk known as prospect theory has gained popularity (Kahneman and Tversky 1979). In contrast to EU theory, the value function proposed by prospect theory predicts that when faced with the risk of a loss of wealth, people are generally risk seeking. Thus, when considering how much to invest in a wildfire protection program that reduces the expected loss from wildfire, prospect theory predicts that people will be willing to pay less than the actuarial value of a potential loss. Kahneman and Tversky (1979) argue that this type of behavior results because people overweight a certain loss (the payment) relative to a probable loss (the gamble).

Although the annual risk of a wildfire damaging or destroying a home is generally very low in fire prone landscapes, the consequences of wildfire can be very high to homeowners. It has been recognized that individuals tend to reject insurance under low-risk high-consequence (LRHC) conditions, despite the fact that standard economic theory suggests that people would purchase insurance against the low probability of a catastrophic loss (Kunreuther and Slovic 1978). In contrast to this idea, it has been shown that, under conditions of low risk, people tend to use *ad hoc* decision rules or heuristics that simplify decision-making (Camerer and Kunreuther 1989). Another salient heuristic that is used when evaluating LRHC events is to overestimate or exaggerate the risk, especially if similar events are easy to recall (Tversky and Kahneman 1973). It has been found, for example, that past personal experience of a catastrophe makes individuals more pessimistic regarding potentially catastrophic future events (Cohen and others 2008).

Empirical methods

In this study, a CE was designed to estimate homeowner WTP for programs that reduce the risks (probabilities of damage) and economic losses. Recognizing that risk perceptions and preferences may vary across individuals and that homeowners may select from a variety of decision rules when making choices regarding wildfire mitigation, three types of econometric models that focus attention on preference heterogeneity were estimated and compared. The standard multinomial logit model

(MNL) allows analysis of preference heterogeneity by interacting respondent characteristics with the attributes of choice set alternatives. However, MNL cannot capture *unobserved* preference heterogeneity or handle correlations induced by panel data arising from multiple responses from the same person. Consequently, we specified two further models that address these limitations - random parameter logit (RPL) and latent class analysis (LC). In all three models we test the hypothesis that preferences regarding the risk and economic loss reduction aspects of wildfire mitigation programs reflect, to some degree, the prior experience of respondents with actual wildfires as well as their subjective perception of risk.

Econometric models

The standard MNL model is based on the idea that when faced with more than one alternative in a given choice set, respondents choose the alternative that provides them with the greatest utility. Random utility models are based on the notion that utility is the sum of systematic (V_{nj}) and random (ε_{nj}) components:

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

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 stochastic variable. In the MNL model, the unobserved stochastic variable is assumed to be independently and identically distributed (IID) following a type I extreme value distribution.

The probability of individual n choosing alternative j from the set Θ is:

$$P_n(j) = \exp(\mu\beta\chi_{jn}) / \sum_{j \in \Theta} \exp(\mu\beta\chi_{jn}) \quad (2)$$

where μ is a scale parameter that is typically set equal to one. The RPL model is a generalized form of the MNL model, and allows for random variation in preferences, unrestricted substitution patterns, and correlations among unobserved factors (Train 2002). The independence of irrelevant alternatives assumption, which is imposed to estimate the MNL model, 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 directly incorporate heterogeneity:

$$\beta_{nk} = \beta_k + \Gamma_{unk} \quad (3)$$

where β_k is the mean value for the k^{th} preference parameter, v_{nk} is a random variable with zero mean and variance equal to one, and Γ is the main diagonal of the lower triangular matrix that provides an estimate of the standard deviation of the preference parameters across the sample.

Probabilities in the RPL model are weighted averages of the standard logit formula evaluated at different values of β , where the weights are determined by the density function $f(\beta|\theta)$ where θ is a parameter vector describing the distribution of $f(\bullet)$. Let π_{nj} be the probability that an individual n chooses alternative j from set J , such that

$$\pi_{nj} = \int L_{nj}(\beta\chi_j) f(\beta) d\beta \quad (4)$$

where

$$L_{nj}(\beta\chi_j) = \exp(\mu\beta\chi_{jn}) / \sum_{j=1} \exp(\mu\beta\chi_{jn}) \quad (5)$$

The function $f(\beta|\theta)$ can be simulated using random draws from various functional forms (Train 2002). The RPL model captures heterogeneity via a continuous probability distribution for preference parameters.

Model specifications

One of the dominant challenges associated with evaluating preferences regarding wildfire protection is that the risk of a home being damaged or destroyed by wildfire is very low. In this study, we modified Krupnick and colleagues (2002) 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. To simplify the conceptualization of the risk of a wildfire damaging a home, we asked respondents to consider the actual risk that their home might be damaged by wildfire during the next decade⁷. Our survey 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 new investments in wildfire protection programs⁸. Damages from wildfires were posed in terms of economic *loss* to property values with dollar amounts ranging from \$10,000-\$100,000. The *cost* of the wildfire risk reduction programs varied from \$25-\$1,000 for the public program and from \$50-\$1,000 for the private program.

⁷ Because of space limitations figures are not include here, but you can see them in Holmes and others (2012; In print).

⁸ We use *italics* to denote variables used in the empirical analysis.

The public program would include activities commonly used in Florida for managing vegetation and reducing fuels in forests and undeveloped areas near neighborhoods (prescribed burning, mechanical treatment, and herbicide treatment), and would be funded by a tax increase. The private program would increase the defensible space (*DS*) on the respondents' property by managing vegetation, such as removing trees close to the house. Alternative-specific constants (ASCs) were specified in the empirical models for the public (*public_program*) and private (*private_program*) wildfire protection programs. We created a dummy variable to identify respondents who indicated that they perceive their home is located in a high (versus medium or low) fire risk area. This variable was then interacted with ASCs to create two new variables (*public program*high risk*, *private program*high risk*). To test whether people who have previously conducted private wildfire protection activities on their property may have a lower WTP for public risk protection programs, we created a variable (*public program*DS*) to test for this effect.

Two variables were used to capture the influence of respondent experience with actual wildfires. First, we created a dummy variable using responses regarding whether or not people suffered smoke related illnesses because of wildfires, which was coded as unity if the response was affirmative and zero otherwise. Second, another dummy variable was created based on whether respondents altered their travel plans because of wildfires, again with unity representing the affirmative response. If either of these two variables was coded as unity, a new variable, *personal experience*, was coded as unity. The influence of *personal experience* on the mean of the preference parameters for *risk* and *loss* was evaluated by interacting *personal experience* with these variables in both the MNL and RPL models.

Experimental design and survey development

A completely randomized experimental design was used to construct the choice sets (Holmes and Adamowicz 2003). Potentially unique combinations of attribute levels were thus created for each choice set and respondent. Three alternatives were given in each choice set (Figure 1). The first two alternatives represented public and private risk mitigation programs. In addition, a status quo alternative was included at zero cost, representing a typical current situation, and a series of three choice questions were asked to each respondent.

An initial version of the survey was presented to 3 focus groups to evaluate study design, clarity of wording, use of graphics, range of values used, and to consider if important issues were omitted or obscured. Revised versions of the survey were then pre-tested on a sample of 100 respondents to evaluate whether or not

respondents were answering questions in a sensible manner. The final version of the survey was distributed using a stratified random sample.

Figure 1 presents an example of the choice task given to the respondent in the survey.

Q18.	Alternative #1a	Alternative #2a	Alternative #3
	Public Fire Prevention	Private Fire Prevention	Do nothing additional
Chance of your house being damaged in next 10 years	1 in 1,000 (1%)	40 in 1,000 (4%)	50 in 1,000 (5%)
Damage to property	\$75,000	\$50,000	\$100,000
Expected 10 year loss = Chance x damage	\$750 during 10 years	\$2,000 during 10 years	\$5,000 during 10 years
One time cost to you for the ten-year program	\$200	\$1,000	\$0
I would choose: Please check one box	☐	☐	☐

Figure 1—Example of a choice question included in the homeowners survey to evaluate trade-offs between wildfire risk, damage and program costs.

Survey sample

A stratified random sample of households living in single-family, owner-occupied residences was drawn from the population of households in Florida. Considering that people living in areas with higher risk of damage from wildfires would be more concerned about wildfire protection programs, we developed a weighting scheme where, for each household sampled from low risk communities, two households were sampled from medium risk communities and three households were sampled from high risk communities (as defined by the Florida Forest Service). Households were recruited using random digit dialing. 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. Overall, our analysis is based on 922 complete interviews.

Estimating WTP and risk profiles

The choice experiment framework permits a WTP measure to be estimated for each attribute, which is often referred to as the implicit price or part-worth of that attribute (Bennett and Adamowicz 2001, Holmes and Adamowicz 2003). The implicit price of an attribute is computed as the parameter estimate on that attribute divided by the (negative of the) parameter estimate on price. The WTP value of a new wildfire protection program, which combines risk level i and loss level j within a public or private program, is computed as

$$WTP_{ij} = (V_{ij}(p) - V_{00}) * (-1/\beta_p) \quad (6)$$

where $V_{ij}(p)$ is the (indirect) utility of wildfire program p (public or private), V_{00} is the utility of the status quo, and β_p is the parameter estimate on the price (cost) variable. The utility of the status quo is computed as

$$V_{00} = \beta_1 * risk_0 + \beta_2 * loss_0 \quad (7)$$

where $risk_0$ ($loss_0$) is the risk (loss) level for the status quo, and the β values are the parameter estimates for each of the attributes. The utility of a new wildfire protection program is

$$V_{ij}(p) = ASC(p) + \beta_1 * risk_i + \beta_2 * loss_j \quad (8)$$

where $ASC(p)$ is the parameter estimate on the ASC for either the public or private program. The specification of our empirical model allows us to estimate the actuarial value (AV) of a loss for any combination of wildfire risk and economic loss contained in our survey design:

$$AV_{ij} = (risk_i) * (loss_j) \quad (9)$$

which is simply the expected value loss associated with risk level i and loss level j . Using equation (9), we compute the actuarial value of (decadal) loss for the status quo (AV_{00}) as $(0.05) * (\$100,000) = \$5,000$. The reduction in the expected value loss ($REVL_{ij}$) due to a specific wildfire program provides an incentive to purchase that program, and is computed as the difference between actuarial values:

$$REVL_{ij} = AV_{00} - AV_{ij} \quad (10)$$

These computations allow us to evaluate the risk preferences of survey respondents by computing the ratio of WTP for any specific wildfire protection

program (WTP_{ij}) to the reduction in expected value loss associated with that program ($REVL_{ij}$). In particular, risk preferences are risk averse, risk neutral, or risk seeking if $WTP_{ij} / REVL_{ij}$ is greater than, equal to, or less than unity, respectively. The EU model postulates that risk preferences are risk averse, so we would expect that if this were the case then $WTP_{ij} / REVL_{ij} > 1$. In contrast, prospect theory suggests that people hold risk seeking preferences regarding losses so, if this were the case; we would anticipate that $WTP_{ij} / REVL_{ij} < 1$.

Empirical Results

Descriptive statistics for respondent characteristics used in the empirical models are shown in Table 1. The stratified sample included a substantial proportion of respondents with personal experience of wildfire impacts (about 43% of the sample). We note that nearly 15% of our respondents reported health effects from smoke produced by wildfires and roughly 35% reported that they had revised travel plans because of wildfires. Given that one-half of our stratified sample was drawn from communities identified as being at high risk for wildfires, it is surprising that only about 10 percent of respondents reported that they lived in an area that they perceived to be at high risk for wildfires. We also note that roughly three-fourths of respondents indicated that they had previously improved the defensible space on their property.

In the basic MNL model that does not include respondent heterogeneity, the parameter estimates on the *cost*, *risk* and *loss* variables were negative and statistically significant at the 0.01 level, all of which appears to be consistent with rational economic decision-making (Table 2). However, the parameter estimates on the *public program* and *private program* ASCs indicate that, on average, respondents favor the status quo (do nothing) alternative. Only respondents living in subjectively judged *high risk* areas prefer paying for new wildfire protection programs, and have a slightly higher WTP for public programs. Using equation (10), it is straight-forward to compute that the reduction in expected value loss due to a 50 percent reduction in both wildfire risk and economic loss, relative to the status quo, is \$3,750 over the 10-year program period. Comparing the WTP estimates for wildfire protection programs that reduce wildfire risk and economic damage by 50 percent to the reduction in expected value loss, we see that preferences for wildfire protection programs for respondents living in neighborhoods that they consider to be at *high risk* of wildfires are risk seeking or essentially WTP less than the expected losses ($WTP/REVL = 0.40$ for public programs and $WTP/REVL = 0.21$ for private programs.)

Table 1—Descriptive statistics of homeowner survey responses for variables included in the econometric model specifications

Variable	Description	Mean (std. dev.)
health (dummy variable)	Health of respondent or family member suffered from breathing smoke from wildfire; if Yes = 1; else = 0	0.15 (0.35)
travel (dummy variable)	Household travel plans changed because of a wildfire; if Yes = 1; else = 0	0.35 (0.48)
personal experience (dummy variable)	If either (health = 1 or travel = 1) = 1; else = 0	0.43 (0.50)
defensive space (DS) (dummy variable)	Household conducted at least one activity that reduces wildfire risk; if Yes = 1; else = 0	0.76 (0.43)
high risk (dummy variable)	Respondent indicated that home is located in a high fire risk neighborhood; if Yes = 1; else = 0	0.10 (0.30)

Although the basic MNL model suggests that, on average, respondents are sensitive to *risk*, *loss*, and *cost* attributes in making choices for wildfire protection programs, these results conceal significant heterogeneity across respondents. As demonstrated by the parameter estimates in the MNL model allowing heterogeneous preferences, it is only the respondents with *personal experience* of wildfire impacts that consistently evaluated *risk-loss-cost* trade-offs in a fully compensatory manner (Table 2). Other respondents apparently simplified decision-making by ignoring the risk attribute. Further, despite the fact that respondents with *prior experience* made sensible trade-offs between program attributes, the WTP/REVL ratios for respondents with *personal experience* living in subjectively judged *high risk* areas indicate they held risk seeking preferences (WTP/REVL ratios for a 50% decrease in both risk and economic loss were 0.46 and 0.39 for public and private programs, respectively). As might be anticipated, respondents with *personal experience* have higher WTP values for wildfire protection programs than the WTP values held by other respondents. We note that this result, found across all of the econometric models, is consistent with prior research indicating that WTP for environmental programs estimated using contingent valuation, increases along with respondent experience (Cameron and Englin 1997).

Table 2—Multinomial logit (MNL) estimates of homeowner preference parameters for wildfire hazard mitigation programs among survey respondents. The dependent variable is the alternative selected in the choice questions.

Variable	MNL model	MNL model w/ personal experience
risk (%)	-.074*** (0.02)	-0.032 (0.027)
risk *personal experience	--	-0.086*** (0.035)
loss (\$1,000)	-0.004*** (0.01)	-0.002** (0.001)
loss*personal experience	--	-0.004*** (0.001)
cost (\$)	-0.0007*** (0.0001)	-0.0007*** (0.0001)
public program	0.034 (0.111)	0.047 (0.111)
public program*high risk	0.677*** (0.164)	0.695*** (0.164)
public program*DS	-0.162* (0.095)	-0.167* (0.095)
private program	-0.337*** (0.90)	-0.329*** (0.090)
private program*high risk	0.833*** (0.167)	0.838*** (0.168)
N	922	922
McFadden R ²	0.032	0.037

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. N is the number of observations. McFadden R² is a goodness of fit measure that is based on estimates of the log-likelihood function including the intercept only versus the full model, and ranges between 0 (no explanatory power) and 1(perfect explanatory power.)

The results of the RPL model specification confirm that respondents with *personal experience* of wildfire impacts consistently made fully compensatory *risk-loss-cost* trade-offs while other respondents did not (Table 3). Respondents without personal experience appeared to be confused about the risk and loss attributes, often exhibiting the wrong sign on parameter estimates associated with these attributes, and tended to anchor on the program labels. We note that, in the RPL model that includes *personal experience* in the model specification, the dispersion parameters on *risk* and *loss* are not significantly different than zero, indicating that the preferences of this subgroup were virtually fixed regarding these two attributes. Computing the WTP/REVL ratios for programs that reduce risk and loss by 50 percent, we found that respondents demonstrated risk seeking preferences. For example, the ratio values

for respondents with *personal experience* living in subjectively judged *high risk* areas were 0.64 and 0.58 for public and private wildfire protection programs, respectively (which are similar to, but somewhat higher than, the ratios computed using the results of the MNL model).

Table 3—Random parameter logit model estimates of homeowner preference 712 parameters for wildfire hazard mitigation programs among survey respondents, with random parameters estimated for risk and loss variables. The dependent variable is the alternative selected in the choice questions.

Variable	RPL model (mean)	RPL model (std. dev.)	RPL model w/ personal experience (mean)	RPL model w/ personal experience (std. dev.)
<i>risk (%)</i>	0.034 (0.046)	0.877*** (0.066)	0.119** (0.060)	0.871*** (0.066)
<i>risk* personal exp.</i>	--	--	-0.183** (0.082)	0.009 (0.343)
<i>loss (\$1,000)</i>	0.002 (0.002)	0.042*** (0.003)	0.007** (0.003)	0.042*** (0.003)
<i>loss* personal exp.</i>	--	--	-0.012*** (0.004)	0.002 (0.014)
<i>cost (\$)</i>	-.001*** (0.0001)	-- (0.0001)	-.001***	--
<i>public program</i>	0.924*** (0.161)	-- (0.161)	0.935***	--
<i>public pro.*high risk</i>	1.100*** (0.308)	-- (0.308)	1.131***	--
<i>public pro.*DS</i>	-0.258*** (0.140)	--	-0.262* (0.140)	--
<i>private program</i>	0.352*** (0.228)	--	0.360*** (0.125)	--
<i>private pro.*high risk</i>	1.453*** (0.311)	--	1.475*** (0.311)	--
N	922	--	922	--
McFadden R ²	0.152	--	0.155	--

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. N is the number of observations. McFadden R² is a goodness of fit measure that is based on estimates of the log-likelihood function including the intercept only versus the full model, and ranges between 0 (no explanatory power) and 1(perfect explanatory power.)

Conclusions and Discussion

The econometric models used for analysis revealed several common themes in the data as well as some nuanced responses. The most striking feature of our analyses, is that only those respondents that had prior experience of wildfire impacts consistently

made fully-compensatory trade-offs between the *risk*, *loss*, and *cost* of wildfire protection programs. Although we cannot unambiguously explain why respondents with prior experience attended more carefully to each of the wildfire program attributes, two alternative perspectives seem pertinent. The first is based on the idea that prior valuation and choice experience mimics market behavior and improves the accuracy of non-market valuation (Cummings and others 1986).

The second perspective derives from a psychological, process-based view of decision-making for choices that are emotion-laden. In a foundational study, Luce and others (1997) concluded that negative emotions induced by a choice problem contribute to more extensive processing of attributes (i.e., more attributes are considered) and that decision-making proceeds more by focusing on one attribute at a time (rather than the holistic assessment of alternatives) – conclusions entirely consistent with our results.

Our choice experiment posed analytical challenges for respondents and the econometric models helped to reveal some of the nuances of simplified decision making among those respondents that did not use fully-compensatory decision rules. The MNL model demonstrated that respondents lacking *prior experience* with wildfires focused on trade-offs between *loss* and *cost* and generally failed to consider *risk* in making decisions. This simplification strategy is consistent with the dual-focus model discussed by Ganderton and others (2000) as well as the editing phase of decision-making inherent to prospect theory (Kahneman and Tversky 1979). This model also indicated that most respondents favored the status quo over either a public or private wildfire protection program, and that only those respondents living in subjectively judged high fire risk areas would support new wildfire protection programs.

The RPL model, which faces fewer estimation restrictions than the MNL model, revealed that many respondents appeared to be confused regarding the *risk* and *loss* levels presented in the experiment, as the dispersion parameter estimates on these attributes indicated a wrong sign for more than one-half of the respondents without *prior experience* of wildfire impacts. The results also indicated that respondents simplified decision-making by focusing attention on the *cost* attribute and anchoring on the *public/ private program* labels.

A second theme consistently revealed across econometric models is that WTP for wildfire protection programs was substantially greater for respondents who perceived that they lived in an area at high risk of wildfire. We note that whereas only about 10 percent of respondents reported that they lived in what they considered to be a high fire risk area, one half of our sample was drawn from areas objectively assessed as being at high risk of wildfires.

A third theme consistent across all econometric models is that the vast majority of respondents made choices that reflected risk seeking preferences or were willing to pay less than the expected loss for the wildfire protection programs. Thus, while the studies by Winter and Fried (2001) and Talberth and others (2006) appealed to expected utility theory to explain their results (which predicts that individuals are risk averse), our results suggest that other theoretical models of decision-making under uncertainty need to be considered. This theme of risk seeking preference is consistent with the prediction of prospect theory that people overweight a certain loss (the payment) relative to a probable loss (Kahneman and Tversky 1979). Further, the prevalence of risk seeking preferences regarding wildfire protection programs suggests the importance of keeping fuel reduction costs as low as possible while providing community members with believable estimates of wildfire risks and losses.

Overall, our results suggest that community members having prior experience with the consequences of wildfires in residential areas may be instrumental in communicating their views to other members of the community regarding fuel reduction measures. The fact that all econometric models demonstrated that individuals with prior experience thought more carefully about *risk-loss-cost* tradeoffs, and that these individuals had higher WTP values for wildfire protection programs, suggests that they may be persuasive in articulating a well-informed rationale for making investments today to protect their communities from potential wildfire impacts in the future.

Summary

Results from a stated preference survey indicate that most homeowners in Florida living in fire-prone communities tend to under-invest in programs designed to reduce wildfire risk. Willingness to pay for wildfire protection programs increases for homeowners who have prior personal experience with the consequences of wildfire. Therefore, these people may be influential in encouraging other community members to invest in wildfire protection.

References

- Bennett, J., Adamowicz, W.L. 2001.** Some fundamentals of environmental choice modeling. In: Bennett, J., Blamey, R., eds. *The choice modeling approach to environmental valuation*, Northampton MA: Edward Elgar Publishing, Inc.; 37-69.
- Boyle, K. 2003.** Contingent valuation in practice. In: Champ, P., Boyle, K., Brown, T., eds. *A primer on non-market valuation*. Dordrecht, The Netherlands: Kluwer Academic Publishers; 111-170.
- Camerer, C.F., Kunreuther, H. 1989.** Decision processes for low probability events: policy implications. *Journal of Policy Analysis and Management* **8**, 565-592.

- Cameron, T.A., Englin, J. 1997.** Respondent experience and contingent valuation of environmental goods. *Journal of Environmental Economics and Management* **33**, 296-313.
- Cohen, M., Etner, J., Jeleva, M. 2008.** Dynamic decision making when risk perception depends on past experience. *Theory and Decision* **64**, 173-192.
- Cummings, R.G., Brookshire, D.S., Schulze, W.D. 1986.** Valuing environmental goods: an assessment of the contingent valuation method. Totowa, NJ: Rowman & Allanheld.
- Deaton A, Muellbauer J. 1980.** Economics and consumer behavior. Cambridge 571 University Press: New York.
- Ganderton, P.T., Brookshire, D.S., McKee, M., Stewart, S., Thurston, H. 2000.** Buying insurance for disaster-type risks: experimental evidence. *Journal of Risk and Uncertainty* **20**, 271-289.
- Holmes, T.P., González-Cabán, A., Loomis, J., Sánchez, J. 2012.** The effects of personal experience on choice-based preferences for wildfire protection programs. *International Journal of Wildland Fire* (<http://dx.doi.org/10.1071/WF11182>).
- Holmes, T.P., Abt, K.L., Huggett, Jr. R.J., Prestemon. J.P. 2007.** Efficient and equitable design of wildfire mitigation programs. In: Daniel, T.C., Carroll, M.S., Moseley., Raish, C., eds. *People, fire, and forests: A synthesis of wildfire social science*. Corvallis, Oregon: Oregon State University Press; 143-156.
- Holmes, T.P., Adamowicz, W. 2003.** Attribute-based methods. In: Champ, P., Boyle, K., Brown, T., eds. *A primer on non-market valuation*. Dordrecht, The Netherlands: Kluwer Academic Publishers; 171-220.
- Kahneman, D., Tversky, A. 1979.** Prospect theory: an analysis of decision under risk. *Econometrica* **47**, 263-292.
- Krupnick, A., Alberini, A., Cropper, M., Simon, N., O'Brien, B., Goeree, R., Heintzelman, M. 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.
- Kunreuther, H., Slovic, P. 1978.** Economics, psychology, and protective behavior. *American Economic Review* **68**, 64-69.
- Loomis, J., Hung, L.T., González-Cabán, A. 2009.** Willingness to pay function for two fuel treatments to reduce wildfire acreage burned: a scope test and comparison of White and Hispanic households. *Forest Policy and Economics* **11**, 155-160.
- Luce, M.F., Bettman, J.R., Payne, J.W. 1997.** Choice processing in emotionally difficult decisions. *Journal of Experimental Psychology: Learning, Memory, and Cognition* **23**, 384-405.
- National Fire Plan. 2001.** A collaborative approach for reducing wildland 624 fire risks to communities and the environment: 10-year comprehensive strategy. National Fire Plan. <http://www.fireplan.gov/reports/7-19-en.pdf>.
- Schoemaker, P.J.H. 1982.** The expected utility model: It's variants, purposes, evidence and limitations. *Journal of Economic Literature* **20**, 529-563.
- Talberth, J., Berrens, R. McKee, M., Jones. M. 2006.** Averting and insurance decisions in wildland-urban interface: implications of survey and experimental data for wildfire risk reduction policy. *Contemporary Economic Policy* **24**, 203-223.
- Train, K.E. 2002.** Discrete choice methods with simulation. (New York, New York: Cambridge University Press.

- Tversky, A., Kahneman, D. 1973.** Availability: A heuristic for judging frequency and probability. *Cognitive Psychology* **4**, 207-232.
- Winter G., Fried, J. 2001.** Estimating contingent values for protection from wildland fire using a two-stage decision framework. *Forest Science* **47**, 349-360.

Economic Information on the Historical Behavior of Forest Fires in the Forest Lands in the State of Parana, Brazil¹

Vitor Afonso Hoeflich², Alexandre França Tetto³, and Antonio Carlos Batista²

Abstract

It is widely acknowledged that the fires have caused severe impact in the world, and their frequency and intensity tend to increase as a result of ongoing climate changes which have occurred over the past decades. It should be also noted that the urban-rural interface has attracted the attention of governments by the concentration of the number of fire occurrences and their specificities. The study aimed at determining economic indicators from the determination of the profile of forest fires in the study area during the period 1965 to 2009.

Statistical analysis related to the number of fires, the burned areas, the spatial distribution of the occurrence, the distribution through the months of the year, and the identification their main causes have been done. Costs associated with the incidence of fire were calculated as well the benefit-cost ratio related to the actions that have been taken into account for the prevention and control of fires in the area of the study. The results obtained allow indicate suggestions to the administration of the forestry enterprise in terms of the amount of investments that are required to implement activities related to prevention and control of fires, from the perspective of an economic analysis.

Keywords: economic damage valuation, economic return, forest fires.

Introduction

Despite the adoption of protection practices, each year fire damage or destroy each year large extension of forests in the world. In South America it is estimated that in the last three decades have occurred at least 290,000 forest fires, affecting 51.7 million hectares, of which about 300,000 hectares were of forest plantations of *Pinus* and *Eucalyptus* (Global Fire Monitoring Center -

¹ An abbreviated version of this manuscript was presented at the Fourth International Symposium on Fire Economics, Planning, and Policy: Climate Change and Wildfires, Nov 5-11, 2012, Mexico City, Mexico.

² Agronomist, Dr., Professor at the Rural Economics and Extension Department, Federal University of Parana. vitor.ufpr@gmail.com

³ Forest Engineer, Dr., Professor at the Forestry Science Department, Federal University of Parana – Av. Pref. Lothário Meissner, 900 – Jardim Botânico - CEP 80.210-170 Curitiba, PR, Brazil. tetto@ufpr.br, batistaufpr@ufpr.br

GFMC, 2007).

The predictions of the consequences of global climate change and particularly in regional basis indicate an increase in forest fires in various parts of the region. Therefore, the countries need, and are obliged to increase their mutual cooperation, in order to be coordinated and prepared to face these challenges related to more severe scenario.

According to the United Nations Food and Agriculture Organization - FAO (2006), in South America, 85.5% of forest fires, on average, are due to human causes, 5.5% to natural causes (lightning) and 9 % to unknown causes. Among the human causes of deforestation are the areas for agro industrial crops, mining activities, construction of road networks, ranching activities and illegal logging. According to FAO (2007), the occurrence of fires near to the urban-rural interface has intensified over the past decade, especially in countries like Argentina, Chile, Ecuador and Uruguay. Pellizzaro and others (2011) also observed in Sardinia, Italy, an increased occurrence of fires in the last three decades, especially in summer, due to the increase of tourists in the region and when weather conditions are more conducive to the initiation and spread of fire. Ribeiro and Viegas (2011) reported an increase in urban-rural interface fires in Portugal and Greece in 2007 and Australia in 2009. Based on its 38 years of fire occurrence in Sydney, Price and Bradstock (2011) identified seasons with more intense fire danger associated with the loss of homes, once or twice per decade.

Vosgerau and others (2006) reported that forest fires in Brazil are concentrated in winter and early spring seasons, by offering lower average rainfall and relative humidity. According to these authors, the normal period of fires in Brazil runs from June to October, when about 69% of fires occur and more than 90% of areas are burned. Soares, Batista and Santos (2006), analyzing the last 20 years the occurrence of forest fires in Brazil, found that the normal fire covers the months from June to November, with a greater number of recorded fires in the period from August to September.

Soares and Batista (1998) indicated that one of the biggest fires in the history occurred in 1963 burning 2 million hectares in the state of Paraná, about 10% of its surface, corresponding to 20,000 ha of forest plantations, 500,000 ha of forests and 1,480.000 ha of natural pastures, secondary forests and scrubs. In this fire, Klabin Paraná, a paper industry, had 85% of the area impacted, and, therefore, was the first to do so, since 1965, the systematic recording of events and worry about the subject (Figure 1).



Figure 1— (A) Helicopter used to transport fighters and (B) farmers leaving the region in the fire of 1963

Source: Paraná (1963)

Protective measures against fire should be taken even before the establishment of an area. Decisions related to the preparation of the ground, spacing, area of the stands, silvicultural practices and construction of firebreaks will affect the potential for the occurrence and spread of fire in the future. Annually, the forestry administrator should decide about the resources to be allocated for fire protection in areas that are under his care. Traditionally, this decision has been based on experience and judgment related to success or failure of measures previously adopted in the region. This practice can lead to large disparities in protection between different policy areas and, especially, the administrator makes it difficult to know whether resources are being calculated correctly (Soares 1978, Soares and Batista 2007).

Given the importance of establishing the amount to be appropriated for protection against forest fires, the objective of this study was to estimate the budget for the protection of forest fires in Fazenda Monte Alegre, state of Paraná, Brazil, based on data collected during 45 years, from 1965 to 2009.

Material and Methods

Characterization of the area

The research was conducted at Fazenda Monte Alegre, owned by the company Klabin Paraná, located in the municipality of Telemaco Borba, PR, central region of the State of Paraná, in its the second plateau, approximately between the coordinates 24° 03' and 24° 28' South Latitude and 50° 21' and 50° 43' West Longitude, becoming the largest continuous area of forest plantations in Brazil, with the activity beginning in 1943 (Figure 2).

The topography of the area is gently rolling and the most important geographical feature is the Tibagi River, main tributary of Paranapanema, which in turn is one of the main tributaries of the Paraná River. The average altitude of the study area is 850 m above sea level, with a range from 750 to 868 m (Soares 1972, Nunes and others 2009, Nunes and others 2010).

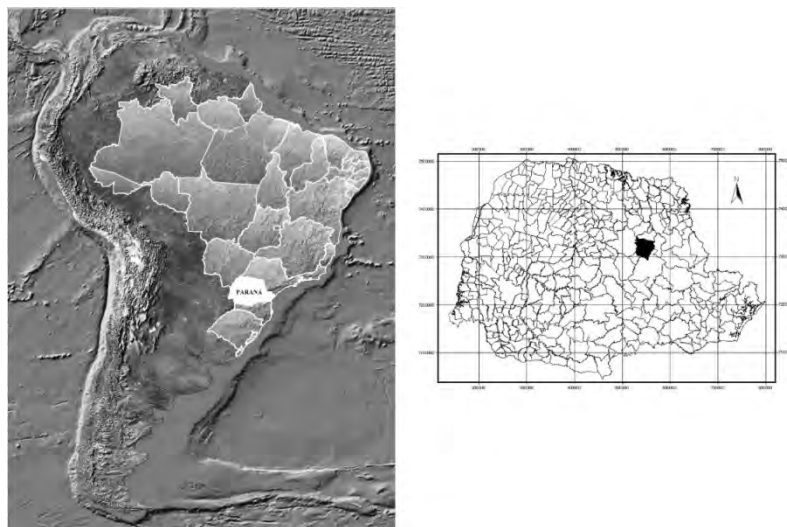


Figure 2—Location of the study area.

According to Köppen climate classification of the region belongs to Cfb, that means, humid temperate, without dry season, with cool summers and regular frosts. According to the classification of life zones of Holdridge, the region is located in the humid temperate forest eco training (Soares 1972)

The average annual rainfall of the region of was 1,608 mm which indicates, according to Nunes and others (2010), a water surplus of 557 mm/year distributed in all months of the year. Nunes and others (2009) analyzed data on monthly rainfall and number of rainy days in the period 1947-2005, and concluded that the wettest months were December, January and February, and the less rainy months were July and August. These results are also according the data generated by the Agronomic Institute of Paraná (IAPAR 2012). The quarter with the lowest number of rainy days was in July, August and September.

The average of the annual temperature was 18.6 °C and the coldest months are June, July and August, with minimum absolute temperature of -5 °C (June 1978), and the hottest months were December, January and February, with maximum temperature absolute at 38.2 °C (Nov. 2005). The average of the relative humidity of the air was 78.5%, with lower values during September, October and November. The wind has predominant direction southeast, with monthly average wind speed ranging

from 1.4 to 1.8 m/s, which corresponds to the wind classified as "too weak" to "weak" according to the Beaufort scale (Soares and Batista 2004).

Regarding to the natural vegetation, there were three basic formations in the region: *Araucaria angustifolia* forests, secondary forests resulting from the operation of the pine forests and fields with river formations. The cultivation of farm forestry, implanted especially in areas of the natural pastures and to replace the degraded secondary forests has been done mainly with *Eucalyptus* spp, *Pinus taeda*, and to a lesser extent, with *Araucaria angustifolia*. According to Santos (2007), Klabin Paraná is responsible for an area of 259,923 ha, 132,104 ha of those are forest plantations of *Pinus taeda*, *Pinus elliottii* and *Araucaria angustifolia* and *Eucalyptus* spp.

Forestry activities, including planting, harvesting and manufacturing of wood, are the basis of the local economy. Data from the Department of Rural Economy, the Ministry of Agriculture and Supply of the State, show that in 2009 the Gross Value of Production (GVP) in the county was R\$ 169.2 million, and the main products were: paper logs and cellulose (61%), pine logs for sawmills (28%), logs for firewood (3%) and pine seedlings (3%) (Paraná 2009a). This represented 5.7% of GVP of the state's forest products in 2009 (Paraná 2009b). The wood produced in the region is critical to supplying the largest producer, exporter and recycler in Brazil, which is located inside the Fazenda Monte Alegre (Klabin 2011).

The Fazenda Monte Alegre has an area of 131214,70 hectares and is divided administratively into 21 forest regions.

Data collection and analysis

The records of fires in the Fazenda Monte Alegre, since 1965 are individual sheets and contain the following information: a) forest region where the fire occurred, b) data c) burned area, d) type of vegetation affected, and) hours of the fire detection; f) hours of the beginning of combat; g) personnel and equipment used in combat; h) time the fire was controlled; i) the probable cause of the fire; j) additional comments; k) identification of the responsible for information.

The data from the questionnaires were tabulated, standardized and analyzed using the programs Visual FoxPro version 9 (Microsoft Corporation 1989 - 1993) and Microsoft Office 2007 (Microsoft Corporation 2006).

The Figure 3 shows schematically the flow chart of the estimated budget for forest fire protection, proposed by Urzua (1967) and modified by Soares (1978).

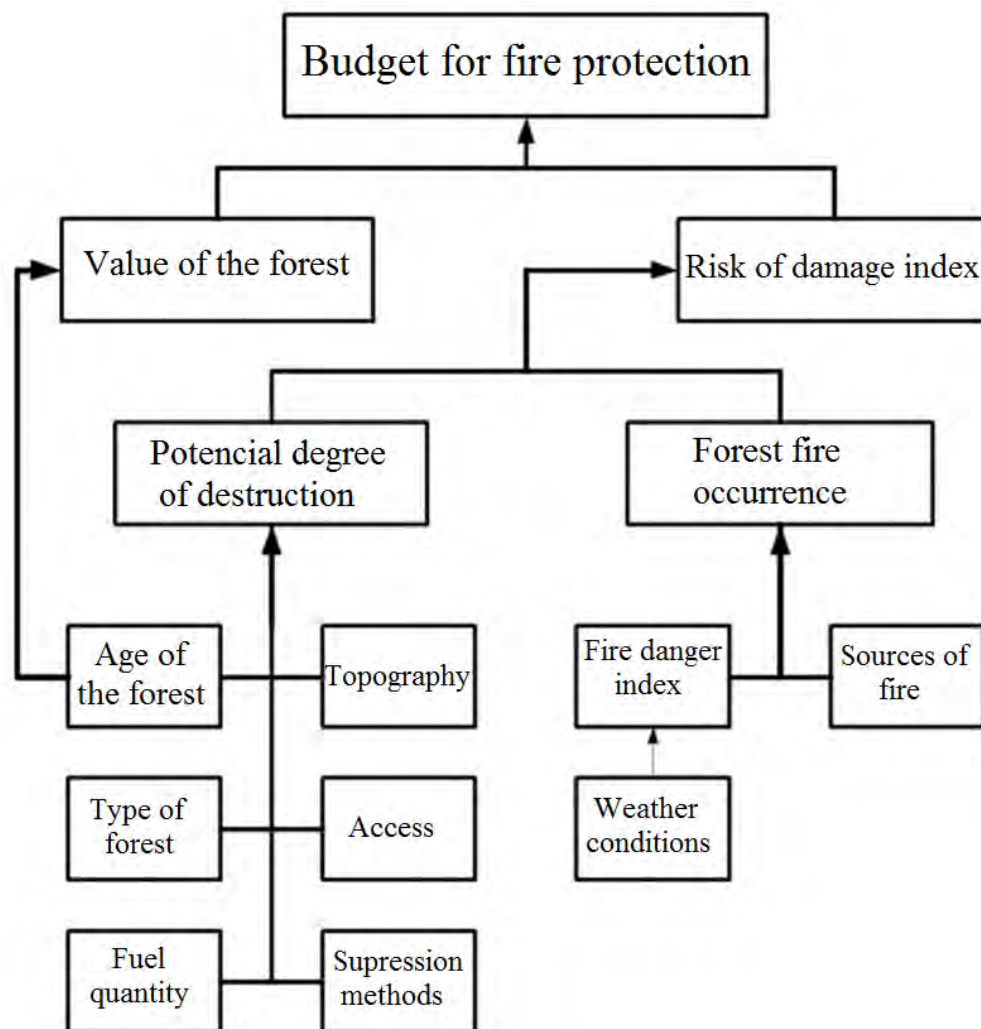


Figure 3—Flow chart of the estimated budget for forest fire protection
Source: Soares (1978)

The main assumption made in this study was that the budget for firefighting should be based on the current value of the forest.

The economic value of forestry production was obtained from estimates analyzed by Cubbage and others (2011). These authors have estimated productivities based on using a common Mean Annual Increment (MAI) for growth rates based on typical or representative stands for each species in the relevant region of the country. Then we estimated typical costs for establishment, stand management, administration, or other factors for each species/region. The authors also used relevant information on timber prices by product size was gathered from available literature or personal contacts with colleagues in the timber sector. These data were then used to calculate timber investment returns for forest landowners based on growing timber for typical rotations and selling stumpage. Common discounted cash

flow analyses including net present value (NPV), such as described in Wagner (2012) for reference, were used for measuring timber investment returns.

The estimated amount to be allocated to fire protection, was calculated based on the information obtained from the technical coordination area of firefighting in the region of study.

Results

In the period 1965 to 2009 were attended by firefighters from Klabin Paraná in, 1676 occurrences of forest fires, which reached an area of 2923.16 ha (Figures 4 and 5).

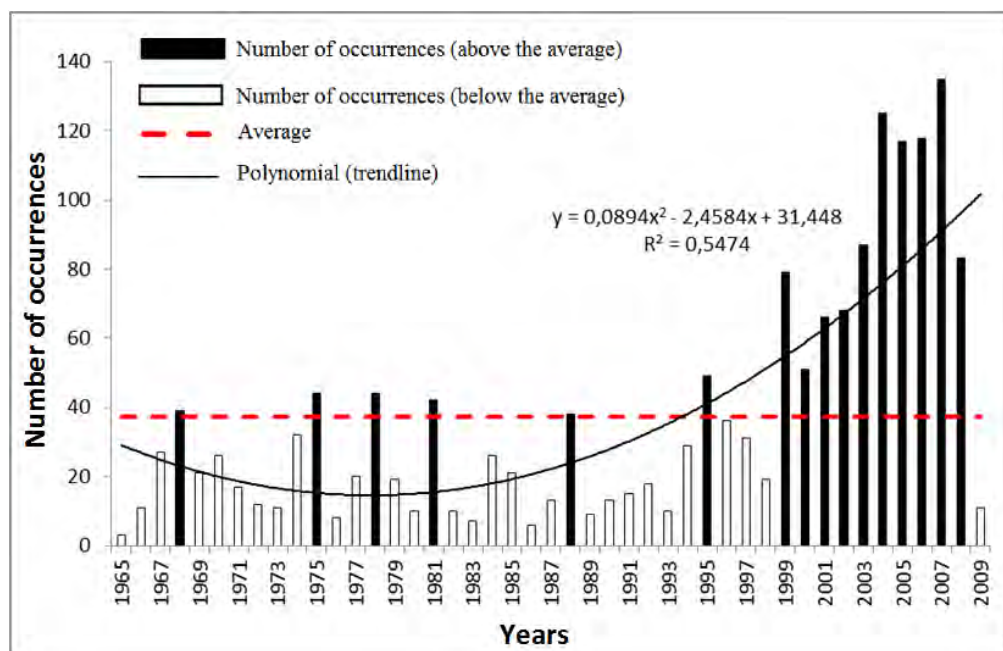


Figure 4—Forest fire occurrences in Fazenda Monte Alegre in the period 1965 – 2009.

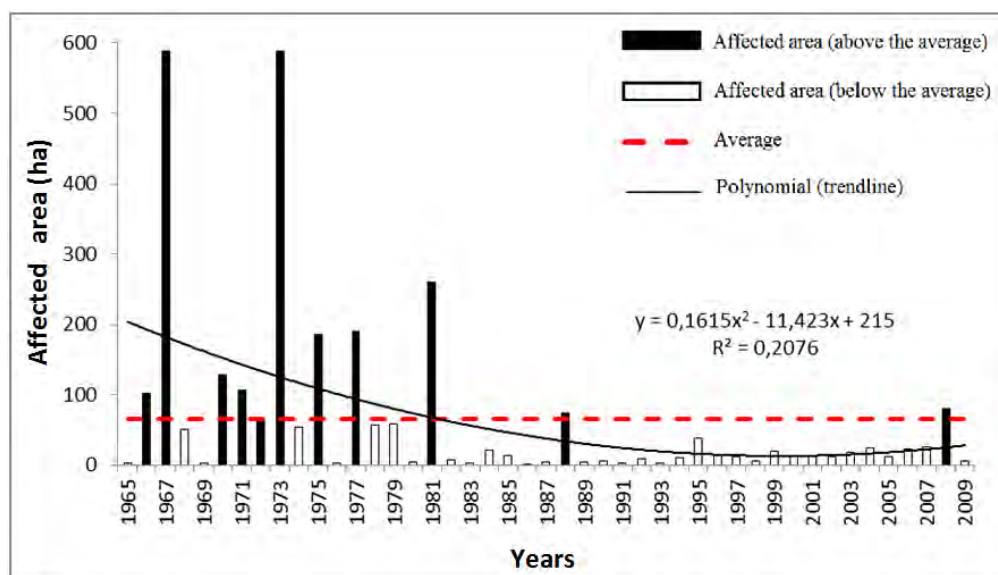


Figure 5—Affected area in the period 1965 to 2009.

It should be noted that the average area affected by fire was 1.74 ha, lower than that found by Soares and Rodriguez (2004) for the period 1998 to 2001, which was 40.34 ha. The average area affected by fire was below the amount cited by Medeiros (2007) that was 4.08 ha in Cenibra (MG) for the period 2002 to 2006, and by Freitas and Vique (2004) ranged from 5.17 to 188.34 hectares per year in V & M (MG) in the period 2000 to 2007.

In the economic analysis were performed considering the costs of actions related to fighting fires that are detailed in Table 1, corresponding to the use of a team of 20 helpers, a charge, a tanker car and a bulldozer.

Table 1—Composition of average cost per hectare in forest fires supression.

Costs items	Time required per hectare (h/ha)	Hourly (R\$/h)	Total value (R\$/ha) ^{1/}
Firefighters	120	14,00	1.680,00
Tanker car	3	80,00	240,00
Bulldozer	1	100,00	100,00
Total			2.020,00

^{1/} values prevailing in June 2012

Source: Technical coordination of firefighting

Estimates developed by Cubbage and others (2012) indicated that the net present value of a hectare of *Pinus taeda*, considering a rotation of 15 years and an average annual increment of 30 m³ per hectare-year, amount equivalent to US\$ 4,662.00/ha, (R\$ 9,324.00/ha, considering the value of the dollar observed in June/2012).

The estimates indicated that the costs required to fight forest fires correspond for approximately 22% of the net present value of timber production directly affected by the occurrence of the fire.

It is noteworthy that the damage caused by forest fires includes, besides the loss caused directly in terms of timber production, other intangible losses such as the impacts on watersheds, on the socioeconomic and environmental values related to non-timber products and on the conservation of biodiversity.

Considering the occurrence of fire in an area of 2,900 hectares, the losses caused by this action would result in reduction of the revenue of timber production equivalent to approximately US\$ 13,519,800.00 and the cost of fighting requires only the amount of US\$ 2,929,000.00 indicating that for every dollar invested in non-combat results, under the conditions studied, a loss of at least \$ 4.62

Considering, furthermore, that for each hectare devastated by fire the entrepreneur should have an additional hectare to not compromise its industrial process and economic results. That means, that for each every dollar not invested in practices to prevent and combat fires should result a loss of approximately US\$ 4.62 and would require also an investment of at least US\$ 900.00 for the establishment of an additional hectare of plantation forestry and US\$ 4,500.00 representing the cost of a hectare of land.

Given these additional constraints, should be estimated that for each dollar invested in fire fighting and prevention can result in a financial loss of about US\$ 10.00 which take into account the loss of revenue of timber and investment in additional area for getting the equivalent forestry production, besides the no tangible losses.

Final Comments

The historical fire occurrences in the study area indicated that forest fires reached an area of over 2,900 ha in the period.

The total loss of production in this area associated would reach the amount of US\$ 13,519,800.00 and the cost of fighting would require only the investment of US\$ 2,929,000.00, without considering that for each hectare devastated by fire the entrepreneur should have an additional hectare equivalent to not compromise his industrial process and outcome.

The analysis indicated that, under the conditions studied, investing one dollar in prevention and firefighting avoid a direct damage of at least \$ 4.62 in the income of the forestry business.

The needs for further acquisition and implementation of one hectare of forest plantation may result in additional financial outcomes of approximately US\$ 10.00 in

terms of loss of timber and additional area for investment in production, besides and the no tangible damages.

The analysis subject to the conditions of the study clearly indicate the highly importance of investments and actions in preventing and fighting fires in the conditions prevailing in the study region.

Summary

The study aimed at determining economic indicators of the profile of forest fires in the study area during the period 1965 to 2009. Statistical analysis related to the number of fires, the burned areas, the spatial distribution of the occurrence, the distribution through the months of the year, and the identification their main causes have been done. Costs associated with the incidence of fire were calculated as well the benefit-cost ratio related to the actions that have been taken into account for the prevention and control of fires in the area of the study. The results obtained indicate that, under the conditions studied, investing one dollar in prevention and firefighting avoid a direct damage of at least \$ 4.62 in the income of the forestry business. The needs for further acquisition and implementation of one hectare of forest plantation may result in additional financial outcomes of approximately US\$ 10.00 in terms of loss of timber and additional area for investment in production, besides and the no tangible damages. The analysis also clearly indicate the highly importance of investments and actions in preventing and fighting fires in the conditions prevailing in the study region.

Acknowledgments

The authors express their *appreciation* to Indústrias Klabin Paraná, *especially* to Cassiano Ricardo Schneider, Carlos Cesar Santos, Áurio de Souza Bueno, Nilton Luis Venturi e Alexandre Camargo Pontes.

References

- Agronomic Institute of Paraná (IAPAR). 2012.** Médias históricas em estações do IAPAR. Available at: <http://www.iapar.br/arquivos/Image/monitoramento/Medias_Historicas/Telemaco_Borba.htm>. Acesso em: 22/03/2012.
- Cubbage, F., Mac Donagh, P., Balmeli, G., Olmos, V.M., Bussoni, A., Rubilar, R., De La Torre, R., Kotze, H., Murara, M., Hoefflich, V.A., Hall, P., Yao, R., Lord, R., Huang, J., Monges, E., Pérez, C. H., Wikle, J., Adams, P., Gonzalez, R., Carrero, O. 2012.** Global Timber Investments and Trends, 2005-2011. 2012. 13 p. (Relatório técnico).
- Davis, K. P. 1966.** Forest management: regulation and valuation. New York, McGraw-Hill, 2. Ed. 519 p.
- Freitas, G.D. de; Vique, B. 2007.** Prevenção e controle de incêndios na VMFL. In: Simpósio Sul-Americano Sobre Prevenção E Combate A Incêndios Florestais, 4., 2007, Belo Horizonte. **Anais do...** Belo Horizonte: UFV, SIF, 2007. CD-ROM.
- Global Fire Monitoring Center (GFMC). 2011.** Regional South America Wildland Fire Network. Available at: <<http://www.fire.uni-freiburg.de/GlobalNetworks/SouthAmerica/SouthAmerica.html>>. Acesso em: 03/08/2011.
- Klabin. A. 2011.** Available at: < <http://www.klabin.com.br/pt-br/a-klabin/default.aspx>>. Acesso em: 13/10/2011.
- Medeiros, A.G. de B. 2007.** Prevenção e combate a incêndios florestais na Cenibra. In: Simpósio Sul-Americano Sobre Prevenção E Combate A Incêndios Florestais, 4., 2007, Belo Horizonte. **Anais do...** Belo Horizonte: UFV, SIF, 2007. CD-ROM.
- Microsoft Corporation. 1993.** Microsoft FoxPro language reference. Relational database management system for MS-DOS and Windows. Redmond, Wa, 1989 -1993. (Manual de software).
- Microsoft Corporation. 2007.** Microsoft Office 2007. USA, 2006. (Users Guide).
- Nunes, J.R.S., Batista, A. C., Soares, R.V., Fier, I. S. N. 2009.** Climatologia do comportamento da precipitação no Distrito Florestal de Monte Alegre. Floresta, Curitiba, v. 39, n. 4, p. 783 - 792, out./dez. 2009.
- Nunes, J.R.S., Fier, I.S.N., Soares, R.V., Batista, A. C. 2010.** Desempenho da Fórmula de Monte Alegre (FMA) e da Fórmula de Monte Alegre Alterada (FMA⁺) no Distrito Florestal de Monte Alegre. Floresta, Curitiba, v. 40, n. 2, p. 319 - 326, abr./jun. 2010.
- Organização Das Nações Unidas Para Agricultura E Alimentação (FAO). 2006.** Global forest resources assessment: progress towards sustainable forest management. Roma: FAO, 2006. 320 p. FAO Forestry Paper 147.
- Paraná. Corpo de Bombeiros da Polícia Militar do Estado. 1963.** Operação Paraná em flagelo: histórico. Curitiba: Secretaria de Segurança Pública; Secretaria da Agricultura; Governo dos EE. UU., 1963. s/p.
- . **Secretaria da Agricultura e do Abastecimento. 2009a.** Valor Bruto da Produção Agropecuária. 2009a. 227 p. Curitiba: DERAL. Disponível em: <<http://www.seab.pr.gov.br/arquivos/File/deral/Grafmunicipal09.pdf>>. Acesso em: 22/02/2011.
- . **Secretaria da Agricultura e do Abastecimento. 2009b.** Valor Bruto da Produção Agropecuária Paranaense. 2009b. 35 p. Curitiba: DERAL. Disponível em: < <http://www.seab.pr.gov.br/arquivos/File/deral/VBP2009.pdf>>. Acesso em: 22/02/2011.

- Pellizzaro, G., Arca, B., Pintus, G.V., Ferrara, R., Duce, P. 2011.** Wildland-urban interface dynamics during the last 50 years in North East Sardinia. In: International Conference On Fire Behaviour And Risk, 2011, Alghero, Itália. Book of abstracts. Itália: TAS, Tipografi Associati Sassari, 2011. p. 58.
- Price, O., Bradstock, R. 2011.** Patterns and drivers of wildfire occurrence at the urban interface in Sydney, Australia. In: International Conference On Fire Behaviour And Risk, 2011, Alghero, Itália. Book of abstracts. Itália: TAS, Tipografi Associati Sassari, 2011. p. 31.
- Ribeiro, L.M., Viegas, D.X. 2011.** An analysis on wildland urban interface in Portugal. In: International Conference On Fire Behaviour And Risk, 2011, Alghero, Itália. Book of abstracts. Itália: TAS, Tipografi Associati Sassari, 2011. p. 35.
- Rodriguez, M.P.R., Soares, R.V. 2004.** Análisis comparativo entre los incendios forestales en Monte Alegre, Brasil y Pinar del Río, Cuba. Floresta, Curitiba, v. 34, n. 2, maio/ago. 2004, p. 101 – 107.
- Santos, C.C. 2007.** Prevenção e controle de incêndios florestais na Klabin. In: Simpósio Sul-Americano Sobre Prevenção E Combate A Incêndios Florestais, 4., 2007, Belo Horizonte. *Anais do...* Belo Horizonte: UFV, SIF, 2007. CD-ROM.
- Soares, R.V. 1972.** Determinação de um índice de perigo de incêndio para a região centro-paranaense, Brasil. 72 f. Dissertação (Mestrado em Ciências) – Centro Tropical de Ensino e Investigação, Instituto Interamericano de Ciências Agrícolas OEA, Turrialba, Costa Rica, 1972.
- _____. **1978.** Alocação de recursos para proteção contra incêndios florestais. Floresta, v. 9, n. 2, 1978, p. 103 – 109.
- Soares, R.V., Batista, A.C. 1998.** Curso de prevenção e controle de incêndios florestais: o problema do fogo na floresta e meteorologia aplicada aos incêndios florestais: módulo 1. Brasília: ABEAS/UFPR, 1998. 32 p.
- _____. **2004.** Meteorologia e climatologia florestal. Curitiba, Brazil. 195 p.
- _____. **2007.** Incêndios Florestais: controle, efeitos e uso do fogo. Curitiba, Brazil. 250 p.
- Soares, R.V., Batista, A.C., Santos, J.F. 2006.** Evolution of forest fire statistics in brazilian protected lands in the last 20 years. In: International Conference On Forest Fire Research, 5, 2006, Portugal. *Anais do.....* Portugal, 2006.
- Urzua, J.D.V. 1967.** Determinación del valor destinado a protección contra incendios em uma plantación florestal. Turrialba, CATIE, 1967. 7 p.
- Vosgerau, J.L., Batista, A.C., Soares, R.V., Grodzki, L. 2006.** Avaliação dos registros de incêndios florestais do Estado do Paraná no período de 1991 a 2001. Floresta, Curitiba, v. 36, n. 1, p. 23 – 32, jan./abr. 2006.
- Wagner, J. E. 2012.** Forestry economics: a managerial approach. New York: Routledge. 382 p.

Forest Fire Impact on Bird Habitat in a Mixed Oak-Pine Forest in Puebla, Mexico¹

Laura P. Ponce-Calderón², Dante A. Rodríguez-Trejo², Beatriz C. Aguilar-Váldez², and Elvia López-Pérez³

Abstract

To assess the impact of different-severity wildfires on bird habitat, habitat quality was determined by analyzing the degree of richness association, abundance and diversity of bird species and vegetation structure (richness, abundance, diversity and coverage). These attributes were quantified with four sampling sites for birds and five for quadrant-centered points respectively, for each of three different conditions: oak forest burned years ago, and burned at low and high severity recently, in an oak-pine forest in Chignahuapan, Puebla, Mexico. More vegetation and birds were found in the first condition, while the lowest values correspond to the high-severity burn condition. No significant differences were found in terms of bird diversity between the low and high-severity burn areas ($t_{56(2)}=0.39$, $P>0.05$). The vegetation structure showed a different diversity between the burned years ago and high-severity burn conditions ($t_{250(2)}=14.70$, $P<0.05$). Only the correlation between bird and vegetation richness was associated, indicating that forest fires which occurred a year earlier can reduce plant richness and this, in turn, may represent an improvement in habitat quality for some birds. Such was the case with *Certhia americana*, a fire-adapted species that showed significant association with recent low-intensity burn sites.

Keywords: Association, birds, diversity, fire, vegetation

Introduction

Among the issues related to forest fires, fires within ecosystems have been mainly highlighted (Pantoja 2008). A fire is a change agent with negative effects; however, scientists are now recognizing fire's ecological role in creating a space in which new interactions occur between species (Pons 2005), as is the case with some birds that can colonize a burned area from nearby sites and which normally disappear years

¹An abbreviated version of this paper was presented at the Fourth International Symposium on Fire Economics, Planning, and Policy: Climate Change and Wildfires, November 5-11, 2012; Mexico City, Mexico.

²Forestry Sciences Division, Universidad Autónoma Chapingo, Estado de México, México. Email: quautli@hotmail.com; dantearturo@yahoo.com; cyrtonyxmontezumae@yahoo.com; loel50@hotmail.com

³Zootechnics Department, Universidad Autónoma Chapingo, Estado de México, México.

later with succession advance (Brotons and others 2005). Fire-maintained ecosystems provide habitat with an abundance and diversity of species, which respond differently depending on the frequency, intensity, severity and time of year that it was burned (Lyon 1978). The effect can be measured in different ways and with different approaches; for this reason, the objective of this paper is to determine bird habitat quality, both in oak-pine forests burned several years ago and in those burned at low and high intensity recently, taking as a hypothesis that areas burned by low-intensity and relatively frequent surface fires help maintain bird habitat and diversity in the oak-pine forest in Chignahuapan, Puebla.

Materials and methods

The study area is located in Chignahuapan, Puebla state, and its geographical coordinates are: 19°48'29" north latitude and 97°59'35" west longitude. The predominant climate is temperate, with a mean annual temperature of 12.6 °C, and a mean annual rainfall of 1096.6 mm (García 1973). Species richness and diversity was determined by bird and vegetation sampling, making a comparison between three conditions with different damage levels: oak forests not recently burned by fire (more than five years after its occurrence) (C1), and those burned at low (C2) and high (C3) intensity in the previous year (2008).

The conditions burned at low and high intensity recently were burned in April 2008, whereas condition 1 was burned five years previously (CONAFOR 2008).

The fieldwork included three visits for vegetation and bird sampling in June, October and November 2009.

Bird sampling: A sample size of 500 m² was defined for each condition, and directed sampling based on the degree of damage was established. Data collection for bird communities was performed by fixed-radius point count methods (Wunderle 1994) and mist nets. The points were distributed unevenly (zigzag) at 100-m intervals between each one, to give equal coverage to the area. The first method was to detect all the birds within a 25-m radius for a period of 15 minutes. Three fixed-radius points were located per condition in which the birds were observed with Bushnell 25x50m binoculars and identified using various field guides. Due to habitat conditions four mist nets, two 12 m and two 6 m in each condition, were operated to capture, identify and release the birds. Nets were placed alongside each fixed-radius point count and were hung where vegetation was thicker to go unnoticed by the birds. This activity was performed for each condition, from 7 to 12 and 16 to 19 hours, with reviews every 45-60 minutes, making a total of 288 reviews throughout the study.

Species richness was determined by adding the total number of species in each plot with two sampling methods (mist nets and point counts). Abundance was obtained by adding up the number of individuals of species *i* (Chi 2007). Diversity

was estimated for each condition using the Shannon-Wiener index (H'). The values obtained were subjected to Hutcheson t tests (Zar 1999).

The similarity of bird species between conditions was determined using the Jaccard Coefficient of Community (Magurran 1988); this coefficient considers qualitative data for comparing communities (Mostacedo and Fredericksen 2000).

Vegetation sampling. The quadrant-centered point method was used for arboreal vegetation and Ossting embedded squares were used for herbaceous vegetation, in a one-square-meter sampling area, whereas shrub vegetation was sampled in a 16-square-meter area (Müeller-Dombois and Ellenberg 1974). In each plot a 500-m zig-zag transect was established and a sampling point was located every 100 m, because the study area showed homogeneity in vegetation. For woody vegetation the variables were: species, distance from the central sampling point to the tree and canopy cover. For herbaceous and shrub vegetation, the variables were: species, number of plants and percent coverage.

The importance value (IV), which is an estimate of the ecological significance of a species in a community (Franco 1989), was determined. Species richness, abundance and the Shannon-Wiener diversity index (H') were obtained in each plot. The diversity values obtained between fire-damage conditions were compared with Hutcheson t tests (Zar 1999). To determine the similarity of species richness, the Jaccard Coefficient of Community was used (Magurran 1988).

Whether there was an association between condition and the presence of some common species in burned areas was analyzed through a χ^2 test that is applicable to a number of situations where counts are made and where the data do not follow a normal distribution (SAS 1999).

To determine the degree of association between bird variables (richness, abundance and diversity of species) and vegetation structure variables (cover, richness, abundance and diversity of vegetation), the relationship between the two sets of variables was explained using Pearson correlation analysis (SAS 1999).

Results and Discussion

During field observations 30 species of birds, belonging to 6 orders and 20 families, were recorded. The predominant families were Fringillidae (finches) with 8, Turdidae (thrushes) with 3 and Caprimulgidae (nightjars) with 2. In total, 23 individuals belonging to 19 species were caught in the nets in the three conditions (12 in the burned years ago condition, and 7 and 4 in the low- and high-intensity conditions, respectively).

Species diversity estimated in the mixed forest burned years ago differs from the diversity of both the forest burned at low intensity ($t_{50(2)}=3.51$, $P<0.05$) and the

mixed forest burned at high intensity ($t_{50(2)}=3.88$, $P<0.05$). However, the diversity in these forests burned at low and high intensity showed no statistically significant differences ($t_{56(2)}=0.39$, $P>0.05$) between each other. The Jaccard similarity index indicates that for low- and high-intensity burn areas, there is a greater similarity of bird species, as they share six of the 16 species that were detected in both conditions.

Differences in richness and diversity of bird species between conditions may be because in burned areas habitats become more diverse and open plant communities and, after a fire, these habitats recover, thus benefiting wildlife populations by providing the food and structural components they require (Main and Tanner 2003). Fire also creates mosaics and patches of vegetation in which many species, especially granivorous, find food and, as a result, there is an increase in their abundance after a fire (Whelan 1995). Studies like that of Castrale (1982) demonstrate the tolerance of birds to burns, a quality that could be better studied to know the frequency with which the habitat is naturally burned (Society for Range Management 1996).

Conner *and others* (2001) comment that the reason why some species decline is due to their biological and physical interaction with the ecosystem. The recovery process of an area and its wildlife after a fire varies depending on the intensity of the fire, habitat type, precipitation patterns and the time of year that it burned.

The high-intensity burn area shows a significant difference in diversity and richness. This could be because the severity of the burn temporarily eliminated several plant species and it can therefore reduce or delay the repopulation of wildlife in the burned site (Main and Tanner 2003). Bock and Bock (1983) observed that during the first year after a fire, species such as *Certhia americana* and *Zenaidura macroura* are attracted to burned areas. The results obtained in terms of species similarity between conditions were low, which may indicate that each condition has attributes that cause some species to be present and others absent, as is the case with *Certhia americana* which was limited to burned areas and showed preference for the low-intensity burn area; this supports Imbeau *and others* (1999), who claim that the extinction of fires affect this species, while Hobson (1999) shows that the density of *Certhia Americana* and *Turdus migratorius* increases after a fire. Main and Tanner (2003) note that fire has a positive effect on some wildlife populations because it stimulates fruit production, resulting in increased availability of seeds and berries that provide food for many species; this means that the eating habits of species must be considered in order to better understand this influence.

Conner *and others* (2001) mention species such as *Pipilo erythrophthalmus* and *Otus asio* as common species in fire-dependent communities; the latter often uses woodpecker cavities for nesting, and both were recorded in this study. The *Pipilo erythrophthalmus* has been shown to be twice as frequent and three times more abundant in fire-dependent sites (Beachy *and others* 2008).

For vegetation, a total of 58 species were obtained in the three conditions.

Generally, in the oak forest burned years ago, there was a diversity of 2.648 and a richness of 25, representing the highest diversity found for the three conditions studied. For the oak forest burned at low intensity, a diversity of 2.438 and a richness of 24 were obtained.

In the oak forest burned at high intensity, a richness of 29 species and a diversity of 1.6305 were obtained, meaning it is the least diverse of the three conditions.

When comparing the three conditions it was observed that the area burned years ago shows the same diversity as the low-intensity burn area ($t_{250(2)}=1.92$, $P>0.05$), just as the low- and high-intensity burn areas showed no differences in diversity ($t_{150(2)}=0.33$, $P>0.05$), but for the area burned years ago and the high-intensity burn area ($t_{250(2)}=14.70$, $P<0.05$) diversity differed.

The Jaccard similarity index indicates that the area burned years ago and the low-intensity burn area had 14 species in common, the area burned years ago and the high-intensity burn area shared 13 species, and the high- and low-intensity burn areas had 12 species in common.

In conducting the vegetation and avifauna association, a low negative correlation was found between richness of vegetation and richness, abundance and diversity of bird species; on the contrary, abundance, diversity and coverage were not associated with avifauna (Table 1), which may be mainly due to the samples not being statistically representative enough in order to have an association between vegetation structure and the structure of birds.

Table 1— Pearson correlation coefficients between the bird and vegetation variables with a significance of $P<0.05$.

Vegetation	Avifauna		
	Richness	Abundance	Diversity
Richness	-0.46139*	-0.48535*	-0.45126*
Abundance	-0.22573	-0.17915	-0.22895
Diversity	-0.11977	-0.28593	-0.02882
Coverage	-0.22377	-0.26465	-0.22248

The results indicate that a decrease in vegetation leads to an increase in the richness, abundance and diversity of bird species. This may be because the condition will have a greater richness of plant species that will provide shelter and roosting sites for birds. However, plants that are indispensable to their particular requirements may not be present. An example of this is that in recently burned conditions, a greater number of hummingbirds, possibly due to the presence of *Bouvardiaternifolia*, a

species with tubular flowers suitable for these birds, whose beak is adapted to take nectar from flowers like this, was found. Furthermore, this study found no association between tree cover and understory vegetation, but Chi (2007) found that tree density affects the abundance of birds, since when tree density increases, the abundance of bird species decreases. On the other hand, authors like Pons and Prodon (1996) mention that birds never leave areas burned by fire, returning any time from the day after the fire up to a year later.

The relationship between species and vegetation richness shows that by reducing the latter element, habitat quality for some birds can improve because they use these areas since they have a vegetation structure suitable for feeding, nesting and breeding, as shown in similar studies where unburned areas have a greater abundance of birds, but less richness (García-Ruiz *and others* 1996). Similarly, Jansen *and others* (1999) indicate that due to the abundance of grasses, it has a negative effect on the richness and demographics of birds. There are fire-adapted species that depend on this factor to maintain their habitat and which benefit from low intensity fires, as was the case with *Certhia americana*.

Acknowledgements

This work was carried out with the support of CONACYT (Mexico's Science and Technology Council), the graduate office and forestry department at the Universidad Autónoma Chapingo (UACH), and CONAFOR (Mexico's National Forestry Commission) branches in Puebla and the state of Mexico. This study is part of UACH's Ajusco Project on fire ecology, integrated fire management and restoration of burned areas.

References

- Beachy, L.; Robinson, R.** 2008. Divergence in Avian Communities Following Woody Plant Invasions in a Pine Barrens Ecosystem. *Natural Areas Journal* 28 (4): 395-403.
- Bock, E; Bock, J.** 1983. Responses of birds and deer mice to prescribed burning in Ponderosa Pine. *J. Wildl. Manage.* 47:836-840.
- Brotons, L.; Pons, P.; Herrando, S.** 2005. Colonization of dynamic Mediterranean landscapes: where do birds come from after fire? *J. Biogeogr.*, 32: 789-798.
- Castrale, S.** 1982. Effects of two sagebrush control methods on nongame birds. *J. Wildl. Manage.* 46:945-952.
- Chi, A.** 2007. Avifauna en bosque manejado de *Pinus patula* en la mojonera, Zacualtipán, Hidalgo. Tesis de maestría en ciencias. Colegio de Postgraduados, México. 19-38 pp.
- CONAFOR (Comisión Nacional Forestal).** 2008. Reporte de incendios. Estado de Puebla. Reporte inédito.

- Conner, N.; Craig, R.; Ray, W.** 2001. The red-cockaded woodpecker: surviving in a fire-maintained ecosystem. University of Texas Press, USA. 47-56 pp.
- Franco, J.** 1989. Manual de ecología. 2ª edición. Editorial Trillas. México. 93-131 pp.
- García, E.** 1973. Modificaciones al sistema de clasificación climática de Köppen. Universidad Nacional Autónoma de México. Instituto de Geografía. México. 164-170 pp.
- García, M.; Lasanta T.; Ruíz, P.; Ortigosa L.; White, s.** 1996. Land-use changes and sustainable development in mountain areas: a case study in the Spanish Pyrenees. *Landscape Ecology* 11: 267-277.
- Hobson, A.; Schiec, J.** 1999. Changes in bird communities in boreal mixed wood forest: Harvest and wildfire effects over 30 years. *Ecological Applications* 9(3):849-863.
- Imbeau, L.; Savard, L.; Gagnon, G.** 1999. Comparing bird assemblages in successional black spruce stands originating from fire and logging. *Canadian Journal of Zoology- Revue Canadienne de Zoologie* 77(12):1850-1860.
- Jansen, R.; Littler, M.; Crowe, M.** 1999. Implications of grazing and burning of grasslands on the sustainable use of francolins (*Francolinus spp.*) and on overall bird conservation in the highlands of Mpumalanga province, South Africa. *Biodiversity and Conservation* 8:587-602.
- Lyon, J.** 1978. Effects of fire on fauna, Gen. Tech. Rep, WO—6. Washington, DC: U.S. Dep. Agric., For. Serv. 41 p.
- Magurran, E.** 1988. Diversidad Ecológica y su medición. Princeton University Press. New Jersey, U.S.A. 200 p.
- Main, B.; Tanner, G.** 2003. Effects of Fire on Florida's Wildlife and Wildlife Habitat. Department of Agriculture, Cooperative Extension Service, University of Florida, IFAS, Florida, U. S. 1-4 pp.
- Mostacedo, B.; Fredericksen, S.** 2000. Manual de métodos básicos de muestreo y análisis en ecología vegetal. Proyecto de Manejo Forestal Sostenible (BOLFOR). 87 pp.
- Mueller-Dombois, D.; ElleMBERG, H.** 1974. Aims and methods of vegetation ecology. John Wiley and Sons, Inc. New York. 547 pp.
- Pantoja, V.** 2008. Las dos caras del fuego: Invitando a reflexionar sobre la "cara buena" y la "cara mala" del fuego. Informe Técnico del Equipo Global para el Manejo del Fuego 2008-1. The Nature Conservancy. Arlington, VA. 13 pp.
- Pons, P.** 2005. Consecuencias de los incendios forestales sobre los vertebrados y aspectos de su gestión en regiones mediterráneas. Consultado en: <http://www.udg.edu/portals/92/Bio%20Animal/pdf/Pons%20inCamprodon-Plana2007.pdf>. 229-245 pp.
- Pons, P.; Prodon, R.** 1996. Short-term temporal patterns in a Mediterranean shrubland bird community after wildfire. *Acta Oecol.*, 17:29-41.
- Sas, Institute.** 1999. SAS/STAT User's guide: statistics, statistical version 8. Cry. North Carolina, U.S.A.
- Society for Range Management.** 1996. Prescribed Fire. The Task Group on Unity and Concepts in Terms. *Rangeland wildlife*. 18(3):305.
- Whelan, R.** 1995. The ecology of fire. Cambridge University Press. Cambridge. UK. 220 pp.
- Wunderle, J. Jr.** 1994. Métodos para contar aves terrestres del Caribe. Gen. Tech. Rep. SO-100. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station. 28 pp.

Zar, J. 1999. Biostatistical Analysis. Fourth edition. Prentice Hall Inc., New Jersey, USA. 32-45 pp.

Catastrophic Fat Tails and Non-smooth Damage Functions-Fire Economics and Climate Change Adaptation for Public Policy¹

Adriana Keating² and John Handmer²

Abstract

South-eastern Australia is one of the most fire prone environments on earth. Devastating fires in February 2009 appear to have been off the charts climatically and economically, they led to a new category of fire danger aptly called ‘catastrophic’. Almost all wildfire losses have been associated with these extreme conditions and climate change will see an increase in these catastrophic fire danger days. Estimating the economic impacts of these fires is a key input into climate change adaptation decision-making for three key reasons: 1) a fattening of the tail of the fire disaster probability distribution, is widely held to be a significant climate change impact; 2) extrapolating current bushfire costs assumed to be a convenient and straightforward starting point for adaptation cost estimation, however a paucity of data means this assumption is over ambitious; and 3) fire disaster risk reduction is a low-regrets climate change adaptation policy, meaning it is believed to have a positive net benefits regardless of the actual future climate scenario, thereby bypassing the risks associated with uncertainty regarding future climate. This focus poses key challenges for fire economics in regards to full valuation of disaster impacts, particularly in regard to indirect and intangible impacts. Furthermore, extrapolating current impact estimates under future climatic and socio-demographic conditions is complicated by nonlinearity in the damage function with the majority of damages occurring during extreme conditions, changes to which are less certain than projections regarding means.

Key Words: adaptation, bushfire, climate change, damage function, extremes, wildfire.

South-eastern Australia is one of the most fire prone environments on earth. Devastating fires in February 2009 appear to have been off the charts climatically and economically, they led to a new category of fire danger aptly called ‘catastrophic’. It

¹ An abbreviated version of the paper was presented at the Fourth International Symposium on Fire Economics, Planning, and Policy: Climate Change and Wildfires, November 5-11; Mexico City, Mexico

² Research Economist and Director, respective, Centre for Risk and Community Safety, RMIT University, Melbourne, VIC, Australia 3001 (e-mail: adriana.keating@rmit.edu.au; john.handmer@rmit.edu.au)

is these conditions that pose the greatest difficulty to contemporary fire-fighting and that frequently overwhelm them regardless of the resources and technology used. Almost all wildfire losses have been associated with these extreme conditions. Such conditions, and the associated serious impacts, have historically been rare, but are precisely the conditions that will be more common under climate change and are the subject of interest for public policy. Coming to grips with complex uncertainties inherent in extremes is a key challenge for climate change adaptation economics.

Climate change will see an increase in these catastrophic fire danger days (Lucas and others 2007, IPCC 2012) and estimating the economic impacts of these fires is a key input into climate change adaptation decision-making. We propose that the extrapolation of the economic impacts of bushfire under climate change scenarios is complicated by several factors, in particular the nature of the damage function, which we suggest is neither linear nor smooth. We propose a theoretical stepped (or staged) damage function where damages become less predictable as dangerous fire conditions increase, and blow out significantly and unpredictably at levels of catastrophic fire danger.

Climate change adaptation is increasingly becoming a local and regional policy focus and is raising challenging questions in disaster economics. The IPCC (2012, pg. 3) defines adaptation: “In human systems, the process of adjustment to actual or expected climate and its effects, in order to moderate harm or exploit beneficial opportunities. In natural systems, the process of adjustment to actual climate and its effects; human intervention may facilitate adjustment to expected climate.”³ UNFCCC (2009, pg. 3) defines the costs of adaptation as “the costs of planning, preparing for, facilitating, and implementing adaptation measures, including transition costs” and the benefits of adaptation as “the avoided damage costs of the accrued benefits following the implementation of adaptation measure”. In this context the costs and benefits are not only financial but consider wider economic, societal and environmental impacts.

Considering the above definitions the standard economic approach to climate change adaptation is to estimate the cost of climate change with no adaptation and weigh it against the cost of climate change under various adaptation investments minus the cost of those investments. Hence the benefits of climate change adaptation investment are the climate change impact costs avoided due to the adaptation⁴. As such the first step in an economic assessment of climate change adaptation is to

³ Here adaptation does not include climate engineering initiatives such as carbon sequestration or ocean fertilization.

⁴ This definition of the benefits of adaptation being equal to the avoided impact costs is standard but not uncontested. Dobes (2009) identifies several issues with damage avoided methods, significantly that benefits are likely to be underestimated and the use of willingness to pay methods would more accurately capture the full benefit of the adaptation.

estimate the costs of climate change impacts in the future by estimating current costs and extrapolating under future social, economic and climatic conditions. Estimating the current and future costs of bushfires is seen as an important first step in climate change adaptation decision-making for three key reasons as outlined below.

Firstly, increases in the frequency and severity of extreme and catastrophic fire weather, or a fattening of the tail of the fire disaster probability distribution, is widely held to be a significant climate change impact (IPCC 2012). The probability distribution function (PDF) of bushfire events is predicted to change, with more fire and more extreme fires. Lucas and others (2007) predict that for southeast Australia, several factors influencing fire probability, not just temperature, are likely to increase under climate change. Catastrophic fire danger days are predicted to become more frequent.

Secondly, recent work in Australia has shown that the significant uncertainties associated with climate change adaptation economics have led to a perception that extrapolating current bushfire costs is a convenient and straightforward starting point for cost estimation. A paucity of data on the current costs of bushfire (Keating and Handmer 2011) and significant methodological challenges as described here mean that this perception is, unfortunately, overly ambitious.

Finally fire disaster risk reduction is a low-regrets climate change adaptation policy. Low-regrets adaptations are favoured in climate adaptation policy because they have positive net benefits regardless of the actual future climate scenario, thereby bypassing the risks associated with uncertainty regarding future climate (Ackerman & Stanton 2011). In the case of bushfire there are thought to be positive net benefits to fire disaster mitigation, prevention and preparedness (adaptation) regardless of the climate scenario that eventuates. Indeed Crompton and McAneney (2008) find that the current cost of disasters in Australia currently warrants increased investment in mitigation and prevention because they are likely to have significant payoffs.

A renewed focus on fire economics with a view to inform climate change adaptation decision-making presents challenges in regards to the valuation of indirect impacts and intangible assets. A full economic assessment of the impact of bushfire includes valuation of direct impacts such as loss of property or livestock, indirect impacts such as loss of business revenue and intangible impacts such as ecosystem services and cultural heritage. A significant proportion of data regarding the cost of bushfire comes from the insurance industry and as such accounts for only direct costs that are frequently insured (Keating and Handmer 2011). Therefore these estimates frequently omit significant impacts, with some authors estimating that indirect and intangible impacts equal 2-3 times that of direct impacts (IPCC 2012). While

economists have established methods for estimating indirect and intangible impacts, these are rarely utilised due to resource constraints.

A further significant challenge for fire economics in relation to climate change adaptation is how current estimates are extrapolated under future conditions. Empirically we can observe that the relationship between the FFDI on the day of a fire and the resulting damage is not linear. In Australia relatively very little damage is done on days where FFDI is below 50, the very majority of damage is done on days where FFDI exceeds 100 (Blanchi and others 2010). This nonlinearity needs to be taken into account when extrapolating future fire risk. The majority of future risk is based on increased frequency and severity of extreme temperatures and conditions rather than mean temperatures and conditions. Unfortunately projections regarding extremes are more uncertain than those projecting means.

The record-breaking fires of February 2009 in Victoria, Australia are thought to foreshadow the increase in frequency and severity of extreme weather events that is projected to occur under climate change. What this event shows is that when conditions facilitate a catastrophic situation conventional preparedness and response can often be seriously inadequate. These types of ‘extreme extremes’ are not well accounted for in traditional cost-benefit analysis because they have a low probability and imbue multiple uncertainties. However it is just this sort of event that is driving the impetus for climate change adaptation.

References

- Ackerman, F., Stanton, E. A. 2011.** Climate Economics: The State of the Art, Stockholm Environment Institute-U.S. Center, <http://www.sei-international.org>
- Blanchi, R., Chris L., Justin L., Klara, F. 2010.** Meteorological conditions and wildfire-related house loss in Australia. *International Journal of Wildland Fire* **19**, 914–926.
- Crompton, R.P., McAneney, K.J. 2008.** Normalised Australian insured losses from meteorological hazards: 1967-2006, *Environmental Science and Policy*, **11**: 371-378.
- Dobes, L. 2009.** People versus planners: Social Preferences for Adaptation to Climate Change, Environmental Economics Research Hub Research Reports No. 41, December 2009, ISSN 1835-9728
- IPCC 2012,** Summary for Policymakers. In: *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation* [Field, C.B., V. Barros, T.F. Stocker, D. Qin, D.J. Dokken, K.L. Ebi, M.D. Mastrandrea, K.J. Mach, G.-K. Plattner, S.K. Allen, M. Tignor, and P.M. Midgley (eds.)]. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK, and New York, NY, USA, pp. 1-19.

- Keating, A., Handmer, J. 2011.** The cost of disasters to Victoria and Australia – No straightforward answers, VCCCAR Project: Framing Adaptation in the Victorian Context Working Paper 3, http://www.vcccar.org.au/files/vcccar/Framing_project_workingpaper3_210611.pdf Accessed 29 November 2011.
- Lucas, C., Hennessy, K., Mills, G., Bathols, J. 2007.** Bushfire weather in southeast Australia: recent trends and projected climate change impacts. Consultancy report prepared for the Climate Institute of Australia. Bushfire CRC and CSIRO: Melbourne.
- UNFCCC. 2009.** Potential costs and benefits of adaptation options: A review of existing literature, Framework Convention on Climate Change, United Nations, Technical Paper 2009/2.

Methodology Used in Cuba for Estimating Economic Losses Caused by Forest Fires¹

Marcos Pedro Ramos Rodríguez² and Raúl González Rodríguez³

Abstract

Assessment of economic losses caused by forest fires is a highly complex but important activity. It is complicated first by the large number of effects, in different periods, brought about in the social, economic and environmental fields. Secondly, the difficulty of assigning a market value to resources such as biodiversity or endangered species should be mentioned. It is important because it allows showing, with numbers, how much is lost each time one of these phenomena occurs, which can help in the decision-making process for resource allocation. This paper presents the methodology used in Cuba for estimating economic losses caused by forest fires. It is the result of the practical experience gained with similar methodologies and research work carried out. It bases its estimates of direct losses on indicators such as: reforestation losses, harvested timber losses, standing timber losses, non-timber forest product losses, suppression losses, and protection work losses. In this methodology, indirect losses may be many times higher than the possible results obtained from factors such as fire size, the slope of the land, vegetation structure, the recovery time of vegetation cover and the percentage damage to vegetation cover. The application of the methodology in a 6 ha-area covered by a plantation of *Pinus caribae* Morelet, var. *caribaea* allowed estimating losses totaling 508,121.04 Cuban pesos (240,331.47 USD).

Keywords: Direct losses, indirect losses, indicators, Market value

Introduction

Assessing economic losses caused by forest fires is an activity of great complexity and importance. It is complex due to the large number of effects, in different periods, which they cause in the social, economic and environmental areas. Secondly, the difficulty of assigning a market value to resources such as biodiversity or endangered species must be mentioned. It is important because it

¹ An abbreviated version of this paper was presented at the Fourth International Symposium on Fire Economics, Planning, and Policy: Climate Change and Wildfires, 5-11 November 2013, Mexico City, Mexico.

² Professor, Forestry Department, School of Agronomy and Forestry, Pinar del Río University, Cuba; Email: cmramos@af.upr.edu.cu

³ Forest Management Department, Forest Rangers National Directorate, Cuba

can show, with numbers, how much is lost each time one of these events occurs, which can help in the decision-making process for the optimal allocation of resources for fire management activities.

Today, despite the progress made, the methodologies for assessing the economic effects caused by forest fires are not as accurate as one would like; nonetheless, they allow showing impressive values. According to González-Cabán (2000), from 1980 to 1994 the U.S. Forest Service participated in controlling 164,000 wildfires that affected approximately 3 million hectares of forests. The U.S. Forest Service spent more than \$5.5 billion US on fire suppression activities to protect national forests and other adjacent lands, both private and public. This amount represents only a fraction of the total loss caused by forest fires in the U.S.

In 1998 in the area of Yellowstone National Forest (Palzin and others, cited by González-Cabán 2000), direct losses of \$21 million in tourism revenue due to wildfires were estimated. Between 1988 and 1990, the estimated loss was \$60 million, and fires also caused a decrease in the rate of visits almost equal to a year's growth. The long-term impacts on tourism in the area were difficult to assess because the surrounding communities had different levels of dependence on the tourism industry. Other losses such as damage to wildlife habitat, threatened and endangered species, and soils or other resources or noncommercial services were not included in this estimate. The 1998 fire in Yellowstone National Park is an example of the hundreds of situations where fire damage and total losses have only been partially estimated.

In Cuba, according to Croton (2006), from 1961 to 2005 forest fires caused an economic loss of 545,115,000.00 pesos. The largest percentage of these have been estimated in the five-year period from 2001-2005, with losses of 103,069,000.00 pesos.

The objective of this paper is to present the methodology used in Cuba to estimate the economic losses caused by forest fires. It is the result of experience gained using similar methodologies and through research work.

Methods

Methodological elements considered in designing the methodology

According to Batista (2004) and Rodríguez (2010), the important elements found by them in different methodologies are:

- Some authors (Oharriz, 1991 and González-Cabán 2000) take into account the

growth stages of a tree. It has been shown that fire affects a sapling more than a juvenile or adult tree. They also consider for estimates that a sapling does not yet have any usable timber volume.

- The principle of stand persistence is considered applicable. This means that after the fire the woodland is not transformed into urban or agricultural use (González-Cabán 2000).
- Considered in the calculations are losses relating to non-timber forest products such as firewood, cork, resins, fruits, seeds, grasses, hunting, fishing, and protection values and recreation (Vélez 2000, Haltenhoff 2001).
- The concepts of damage and lost future value are used. Damage relates to what has been lost and lost future value estimates the potential value of the stand lost by having had to log it before the end of the rotation because of the fire (Vélez 2000).
- To determine indirect losses, Haltenhoff, 2001 introduces the idea of not just considering them as 4 or 7 times (Oharriz 1991) or 10 times (Soares 1985) greater than direct losses, but taking into account the size of the fire, the slope of the land, vegetation structure, the recovery time and the percentage damage to the vegetation cover.
- All methodologies (Oharriz 1991, Rodríguez 1998, Vélez 2000, and Haltenhoff 2001) take into account the wood affected by fire and its depreciation should it still be possible to use it for other purposes.
- Some authors (Vélez 1982, and Haltenhoff 2001) when trying to quantify losses caused by damage to the wood consider only standing timber, while others (Oharriz 1991, Rodríguez 1998) also take into account harvested timber located in piling areas or within the forest.

Methodology used in Cuba to assess economic losses

From 1979 to 1998, a methodology that considered four elements was used in Cuba: reforestation costs, m³ of timber lost, area clean-up costs and firefighting costs. In 1999 a new methodology resulting from a research project developed at the Universidad de Pinar del Río, entitled "Fire management in forest ecosystems," was introduced. In 2001, as a result of the FAO Project "Designing a strategy for controlling forest fires," which was developed in Cuba, the corresponding elements for assessing indirect losses was added to the 1999 methodology. This methodology, with some modifications resulting from work carried out by Batista (2004) and Rodriguez (2010), is presented below:

The methodology considers both direct and indirect losses. Data collection for the assessment can begin once the fire is extinguished. The amount of time required

for this activity depends on the size of the area affected and its characteristics. The work is performed by a team made up of specialists from the company or entity concerned, the State Forest Service (SEF) of the municipality and the Ranger Corps (CGB); the SEF is responsible for approving the estimate.

Direct losses are estimated by the following equation:

$$P_d = (P_r + P_{mt} + P_{mp} + P_{ex} + P_{tp}) \quad (1)$$

where P_d is the direct losses, P_r is reforestation losses, P_{mt} is harvested timber losses, P_{mp} is standing timber losses, P_{pnm} is non-timber forest product losses, P_{ex} is Suppression losses, and P_{tp} is protection work losses.

Reforestation losses (P_r) include the costs of all operations performed in the affected forest until the time of the fire, as expressed by the following equation:

$$P_r = (S_t * K)(C_{pt} + C_{pp} + C_{pl} + C_{ac} + C_{ts}) \quad (2)$$

where S_t is the total area affected, K is the coefficient of damage (per-unit basis of the affected area), C_{pt} is cost of land preparation, C_{pp} is Cost of seedling production, C_{pl} is cost of planting, C_{ac} is cost of stand improvement, and C_{ts} is cost of silvicultural treatments.

The factors that determine fire behavior during the development of a forest fire (topography, combustible material and weather conditions) are always different. As a result, fire behavior parameters (linear intensity, crown scorch, residence time, heat released per unit area, flame length, rate of spread) usually do not show uniform values for an entire burned area. Except when extreme fire behavior occurs, fire causes varying degrees of damage to the stand throughout the entire area. In order not to overestimate the losses caused by fire, it is desirable to determine the actual area affected. To determine both the total and actual area affected, the following points should be observed:

a). To determine the total area affected by the fire, first a sketch of the area must be made using any of the known methods such as using a compass and a tape measure, GPS or delineation on aerial photos. Then the calculation is done using a dot stencil, a polar planimeter, the grid method or by triangulation. Today this area can also be obtained through satellite imagery.

b). The actual area affected is determined by sampling 10% of the area; 100 m² systematically-distributed plots are used. Each plot is classified according to its degree of damage. For this, the degree of damage of the trees within them is taken into account, according to the following classification:

- Slight damage: Those trees that have only suffered slight damage to the bark and/or the first branches.
- Moderate damage: Those trees whose crowns have been affected by up to about 60 %.
- Total damage: Those trees whose crowns have been completely affected.

The plots are classified according to the degree of damage estimated for more than 70 % of the trees in them. Then the zoning is done by grouping together plots with the same degree of damage. The actual area affected corresponds to those classified as having total and moderate damage.

Knowing the total area and actual area affected, the coefficient of damage (K), which is no more than the per-unit basis of the area affected, is calculated.

The costs of site preparation, seedling production, planting and stand improvement are obtained from the accounting department of the different entities.

Harvested timber losses (P_{mt}) considers the volume of affected timber harvested that was in piling areas or in the forest. As this damage is sometimes not total, it is necessary to consider the wood that was not affected or despite being affected will be sold, which should be at a lower price than was planned before being affected by the fire. The following equation is used:

$$P_{mt} = \sum_{i=n}^{i=n+1} (V * P_v) - (V' * P'_v) \quad (3)$$

where n is the number of different types of timber, V is total volume of harvested timber affected by the fire (m^3), P_v is price of the timber prior to being affected by the fire ($\$.m^{-3}$), V' is volume of timber that despite its damage will be sold at another price (m^3), and P'_v is the new sale price ($\$.m^{-3}$).

Standing timber losses (P_{mp}) considers the volume of standing timber that is in an adult or juvenile state of development. An assessment must be performed to estimate the volume per type of timber. During the calculation, one must bear in mind if any amount of wood was sold, albeit at a price below that established for each type of timber before being affected by the fire. The following equation is used:

$$P_{mp} = \sum_{i=n}^{i=n+1} (S_t * K * V * P_v) - (S_t * K * V' * P'_v) \quad (4)$$

where P_{mp} is the standing timber losses, n is the number of different types of timber, S_t is total area affected, K is coefficient of damage (per-unit basis of the affected area), V is Total volume of standing timber that was affected by the fire ($m^3.ha^{-1}$), P_v is price of the timber prior to being affected by the fire ($\$.m^{-3}$), V' is volume of

timber that despite being damaged will be sold at another price (m^3), and P_v is new sale price ($\$.m^{-3}$).

Non-timber forest product losses (P_{pnm}) takes into account the different NTFPs in the affected area, both those already used and those intended to be used, including resin, seeds, foliage, flowers, fruits, mushrooms, medicinal plants, etc. In the case of resin, the volume already extracted and that which was lost or which would have been obtained if the affected forest is suitable for its extraction must be considered. Seed production is valued if it is a seed mass. In this case, the number of years expected for the new planting at the site to supply the same amount of seeds must be taken into account. The following equation is used:

$$P_{pnm} = \sum_{i=n}^{i=n+1} (S_t * K * V_n * P_v) \quad (5)$$

where n is the number of non-timber forest products, S_t is total area affected, K is coefficient of damage (per-unit basis of the affected area), V_n is volume or weight of product n ($m^3.ha^{-1}$ or $kg.ha^{-1}$), and P_v is sale price of product n .

Extinction losses (P_{ex}) can have great weight in the assessment of total losses. It includes losses incurred while suppressing the fire, and it takes into account the resources and crews involved. In the first case, the cost of a day's work (8 hours) of a resource is already established based on equipment wear and the operator's salary. In the second case, the average salary paid to a forestry worker for a day's work is used. In the case of Ranger Corps (CGB) resources and crews, equipment rental and workers' wages are not taken into account if the work is carried out during normal working hours. For the rest of the resources and crews, the time they are involved in firefighting operations during their normal working hours should be monitored. Outside of this time valuations are not made because participation is voluntary. All this can be recorded if the extinction crew boss tasks someone with this responsibility. The following equation is used:

$$P_{ex} = C_c + C_{al} + \sum_{i=n}^{i=n+1} (J_t * C_n) \quad (6)$$

where P_{ex} is the extension losses, n is the number of resources, C_c is total cost of fuel consumed, C_{al} is total food cost, J_t is working days, and C_n is equipment or salary costs.

Protection work losses (P_p) consider both the average cost of the various protection activities and the age of the trees. The calculation is done according to the

following equation:

$$P_{tp} = (S_t * K * C_p) \quad (7)$$

where P_{tp} is the protection work losses, S_t is total area affected, K = Coefficient of damage (per-unit basis of the affected area), and C_p = total protection cost.

Indirect losses: the following equation is used:

$$P_i = P_d \left(\frac{t + p + e + r + d}{5} \right) \quad (8)$$

Where P_i is the indirect losses, P_d is direct losses, t = fire size factor, p is slope of the land factor, e is vegetation structure factor, r is Vegetation cover recovery time factor, and d is percentage damage to vegetation cover factor.

Table 1 shows the factors to be used in each case (Herbert y otros 2001).

Table 1—Factors (F) per variable in each element.

Fire size (t) (ha)		Slope of the land (p) (%)		Vegetation structure (e)		Recovery (r) Time (years)		% damage to the cover (d)	
Variables	F	Variables	F	Variables	F	Variables	F	Variables	F
< 10	1	< 15	1	Meadows	1	Annual	1	< 25	1
10 - 50	2	15 a 25	2	Scrub	2	< 5	2	25 - 50	2
50 - 500	5	25 a 35	5	Plantation	5	5 - 10	5	50 - 75	5
> 500	10	> 35	10	Natural F	10	> 10	10	75 - 100	10

Results

In order to demonstrate the feasibility of using the methodology presented in previous sections, a practical example of its use is given below.

The methodology has been applied to an area affected by fire in the Pinar del Rio Forest Enterprise. The fire was caused by lightning and affected 6 ha of a 25-year-old plantation of *Pinus caribaea* Morelet var. *caribaea*. The quality II site consists of undulating terrain with slopes between 15 and 20 %. The plant spacing used was 2 x 2 m. Machinery was used to prepared the land and soil. Before the fire, the plantation had been weeded, screefed twice, fertilized and thinned in working conditions classified as regular. Resin was soon going to be collected from this plantation; additionally, in two hectares every year an average of 50 kg of seeds were collected per hectare. The fire also totally burnt 10 m³ of *P. caribaea* timber located in a piling area. During the firefighting operation, a bulldozer was used for five hours

and two trucks for a total of 18 hours. In addition, 35 men from outside the Ranger Corps worked an average of 4 hours each. The commission tasked with recommending how to rehabilitate the area concluded that it was not going to recover, so it had to be logged and the timber harvested and sold at a price 10% below its current price. Tables 2 and 3 show the data required for the calculation.

Table 2—*Cost of forestry activities and mechanized equipment*

Forestry activities & use of crews and mechanized equipment	Costs (Pesos)
Clearing 1 ha for mechanized planting in undulating soil	11,000.00
Producing 1,000 nursery seedlings	58.11
Planting 1 ha with <i>P. caribaea</i> in a 2 X 2 m spacing arrangement in undulating terrain	88.36
Weeding 1 ha de plantation in regular working conditions	356.67
Screefing 1 ha planted at 2 X 2 m in regular working conditions	170.34
Fertilizing 1 ha of plantation in regular working conditions	151.34
Thinning 1 ha of <i>P. caribaea</i> in regular working conditions	786.94
Protection work in 1 ha of conifer each year	3,060.00
A working day (8 hours) for a bulldozer	12.46
A working day (8 hours) for a truck	13.40
A working day (8 hours) for a man	12.92

Table 3—*Prices for the different products*

Products	Prices (Pesos)
1 m ³ of saw timber of <i>P. caribaea</i>	73.30
1 m ³ of round timber of <i>P. caribaea</i>	40.60
1 ton of resin de <i>P. caribaea</i>	784.05
1 kg of seed of <i>P. caribaea</i>	85.50

Other data:

- The *P. caribaea* in the quality II site at age 25 has a volume of 334.16 m³ha⁻¹, of which 98 % is saw timber and 2 % round timber.
- A resin collection should produce a yield of 320 kg.ha⁻¹. This species at age 25 should have a diameter of 40.65 cm, so resin can be collected from it twice.

To apply the methodology described in this work, the following facts were taken into account:

- To plant 1 ha at 2 x 2 m spacing, 2,500 seedlings are needed
- The average seed yield per hectare is 50 kg per year and a plantation of *P. caribaea* to achieve the production that was obtained at the time of the fire must be at least 15 years old, so 1,500 kg of seeds were left to be harvested
- The estimated standing timber affected was 1,376.86 m³ of saw timber and 28.1 m³ of round timber.

Table 4 shows the results for each one of the indicators of direct losses.

Table 4—*Estimated losses for each indicator*

Indicators	Losses (Pesos)	%
Reforestation losses	77,215.56	10.16
Harvested timber losses	733.00	0.10
Standing timber losses	91,858.22	12.08
Non-timber forest product losses	131,250.56	17.26
Extinction losses	264.03	0.03
Protection work losses	459,000.00	60.37
Total	760,321.37	100.00

Indirect losses were estimated by allocating the factors in Table 1. Accordingly, the factors used were:

- Fire size: 1
- Slope of the land: 2
- Vegetation structure: 5
- Recovery time (years): 10
- Percentage damage to the cover: 10

Based on the above, indirect losses amounted to 4,257,799.67 pesos. These losses are 5.59 times higher than direct losses. According to this methodology, in each case this value will change, that is, these losses are not 5, 7 or 10 times higher than direct losses.

Total losses caused by this fire totaled 5,018,121.04 pesos, approximately 240,331.47 USD.

Discussion

Table 4 shows that the highest value for direct losses corresponds to the money spent each year on protection work. However, it may be remarked that if in practice all that funding were used rationally and objectively on protection activities, the number of forest hectares affected by fire would be lower. Currently there are access roads in poor condition, hindering the arrival of firefighting crews and resources to remote locations. Nor are preventive forestry measures, such as reduction of combustible material or construction and maintenance of fuelbreaks, including hedgerows or greenbelts and artificial pruning, carried out.

The second largest direct losses value is for non-timber forest products. This shows once again that the most important thing in the forest is not necessarily wood. In addition to non-timber forest products, the forest provides other important services such as soil and water protection, biodiversity conservation and carbon sinks, all of which are elements that this methodology does not consider.

It is worth mentioning that indirect losses are generally undervalued and that in this methodology they are estimated in a very unique way.

Summary

This paper presents the methodology used in Cuba to estimate the economic losses caused by forest fires. It is the result of experience gained in practice with similar methodologies and through research. To estimate direct losses, the following indicators are used: reforestation losses, harvested timber losses, standing timber losses, non-timber forest product losses, extinction losses and protection work losses. Indirect losses are estimated from the allocation of factors to the variables fire size, slope, vegetation structure, recovery time of vegetation cover, and percentage damage to vegetation cover. The application of the methodology in a 6-ha area covered by a plantation of *Pinus caribaea* Morelet var. *caribaea* enabled estimating total losses of 5,018,121.04 pesos (240,331.47 USD).

References

- Batista, N. 2004.** Evaluación ambiental de los efectos producidos por los incendios forestales. Trabajo de Diploma. Universidad de Pinar del Río. Cuba.
- Cortón, A.M. 2006.** Los incendios forestales en Cuba. En: Memorias del IV SIMFOR y I Taller Internacional sobre Manejo del Fuego (ISBN 959 – 16 – 0408 – 4).
- González-Cabán, A. 2000.** La medición del daño. En: La defensa contra incendios forestales. Fundamentos y Experiencias. McGraw-Hill/Interamericana de España, S.A.U. España. 5.1 – 5.10 pp.
- Haltenhoff, H. 2001.** Evaluación del Daño de los Incendios Forestales: Una Perspectiva Económica. Diseño de una Estrategia para el Combate de los Incendios Forestales. La Habana. Cuba, 24 p.
- Oharriz, S. 1991.** Protección contra incendios forestales. Editorial Pueblo y Educación. Cuba. 76 p.
- Rodríguez, M.P.R. 1998.** Metodología para la obtención y reporte de la información estadística sobre incendios forestales. Resultado del Proyecto 03302005 “Manejo del Fuego en los Ecosistemas Forestales”. Universidad de Pinar del Río.
- Rodríguez, M.P.R. 2010.** Manejo del fuego. Editorial Félix Varela, la Habana, 243 p.
- Soares, R.V. 1985.** Incêndios Florestais. Controle e uso do Fogo. Fundação de Pesquisas Florestais do Paraná. Curitiba. 213 p.
- Vélez, R. 1982.** Defensa contra incendios en el medio natural. Tratado del Medio Natural. Tomo IV. Universidad Politécnica de Madrid. España. 293 - 348 pp.
- Vélez, R. 2000.** Evaluación de pérdidas económicas y estimación del impacto ambiental de los incendios forestales. En: La defensa contra incendios forestales. Fundamentos y Experiencias. McGraw-Hill/Interamericana de España, S.A.U. España. 5.11 – 5.20 pp

VISUAL-SEVEIF, a Tool for Integrating Fire Behavior Simulation and Economic Evaluation of the Impact of Wildfires¹

**Francisco Rodríguez y Silva¹, Juan Ramón Molina Martínez²,
Miguel Ángel Herrera Machuca¹, and Jesús M^a Rodríguez Leal²**

Abstract

Progress made in recent years in fire science, particularly as applied to forest fire protection, coupled with the increased power offered by mathematical processors integrated into computers, has led to important developments in the field of dynamic and static simulation of forest fires. Furthermore, and similarly, econometric models applied to economic evaluation of natural resources have generated algorithms of great scientific consistency that have allowed determining the monetary value of resources that have not traditionally had a commercial or market interaction treatment.

VISUAL-SEVEIF (Spanish acronym for System for the Economic Evaluation of Wildfires) is a software tool that allows working both in real time, simulating the spatial development of ground and canopy fires, and addressing the implementation of territorial studies by which possible fire evolutions are determined and characterized, subject to final spatial or temporal contour conditions. The spatial resolution of work will be conditioned by the quality and accuracy of fuel model mapping, as well as the characteristics of the digital terrain model, so that in high-precision models the results of the fire behavior dynamic can be up to a square meter.

The information layers required by the tool includes one that incorporates the characterization of the natural resources that exist in the area being analyzed and allows determining the economic value of these resources. VISUAL-SEVEIF integrates knowledge of fire behavior and its direct effect on the depreciation of natural resources, providing the total value of the losses in the area affected by the wildfire, and the value of the losses for each of the resources identified within the fire perimeter. The import and export possibilities

¹ An abbreviated version of this paper was presented at the Fourth International Symposium on Fire Economics, Planning, and Policy: Climate Change and Wildfires, November 5-11, 2012, Mexico City, Mexico.

² Laboratorio de Defensa contra Incendios Forestales. Departamento de Ingeniería Forestal. Escuela Técnica Superior de Ingeniería Agronómica y de Montes. Universidad de Córdoba, Edificio Leonardo da Vinci. Campus de Rabanales. 14071 Córdoba España. Email: ir1rosif@gmail.com.

² Departamento de Arquitectura y Tecnología de Computadores. Escuela Técnica Superior de Ingeniería Informática. Universidad de Sevilla.

of geo-referenced perimeters, in both vector and raster formats, allows easy transfer of the information generated to geographic information systems (GIS). VISUAL-SEVEIF enables carrying out diagnostic studies of an area that are aimed at the prevention and strategic management of wildfire defense.

Keywords: Strategic management, fire prevention, natural resources, GIS, environmental services valuation

Introduction

Forest fires are one of the biggest environmental problems facing the world today, generating significant consequences with regard to both damage and deterioration of forest landscape and its depreciation and economic and social valuation. The abandonment of forest settings, as areas inhabited and affected by humans in terms of actions related to subsistence and energy use, has generated an increase in the accumulation of high-energy biomass over the past few decades (Rodríguez y Silva and Molina 2010, Vélez 2009). This circumstance, coupled with worsening climatic conditions (Piñol and others 1998), has caused a rise in the potential energy released by fire and consequently the virulence of forest fires, resulting in an increase in fire damage to natural resources and the surrounding environment.

The need for strategic information, in relation to the dynamic, energy and expansive potential of fire runs, led to the development of both analytical and graphical simulators. Increased knowledge in fire science has allowed addressing prediction and simulation studies, thus facilitating their application in wildfire defense activities.

Today's technology provides appropriate prediction and simulation tools that allow effectively developing attack plans in which the priority focus is on safety; it can thus be concluded that prediction and simulation are an ongoing need in protecting forest areas from fire. Moreover, the prediction and simulation exercise allows reducing the time required to achieve control, while facilitating cost savings by providing critical information for the efficient distribution of firefighting resources.

While there has been significant progress in the quality and accuracy of fire behavior forecasts over recent years, important uncertainties remain to be resolved in relation to the simulation of complex phenomena such as energy feedback, the effect of turbulence on acceleration, and the transition and spread of ground fire to the forest canopy. Regardless of future advances in our understanding of fire's dynamic behavior, there is another important need in forest fire management, which is quantifying it in monetary and therefore budgetary terms. Indeed, it is indisputable that any application of a wildfire defense management model is inextricably linked to

budget availability and therefore the establishment of priority-based criteria to determine investment levels to implement the management model.

This discussion highlights the importance of studies, research and developments that enable applying econometric criteria to decision-making. Currently, new tools are available, such as the SINAMI econometric model, which allow analyzing in the context of the area and as a matter of strategic planning the most efficient budget allocation, by taking into account: the historical background in the frequency and distribution of fires, fire behavior conditions, the economic value of natural resources and the operational capabilities of the firefighting resources (Rodríguez y Silva and others 2010). However, the availability of this model and of its ECONOSINAMI software (Rodríguez y Silva 2009, Rodríguez y Silva and González-Cabán 2010) does not resolve in an integrated manner the expansive simulation of fire behavior and the economic evaluation of damages that the simulated fire can potentially generate. This paper presents the structure and operational flow line of the first simulation tool that incorporates the assessment of economic losses caused by fire based on the linear intensity level that the fire develops (kW/m) by each pixel of spatial resolution with which the simulation is performed.

The VISUAL-SEVEIF model has been determined by performing the integration in the VISUAL-CARDIN program (Rodríguez y Silva 1999, Rodríguez y Silva and others 2010) of the set of algorithms for the SEVEIF model (Molina and others 2008, Rodríguez y Silva and others 2007, 2010), which were developed for determining and assessing the impact of fire on natural resources in terms of intensity levels released by fire spread. This model offers real-time economic evaluation of losses from post-fire depreciation of natural resources affected.

Valuations of natural resources tend to underestimate the real value of a forest (Constanza and others 1997). Unlike traditional economic activity, the forest environment is characterized by the extraordinary importance of externalities that entail damages or benefits to others of considerable magnitude. From the socio-economic standpoint, all the natural resources must be expressed in monetary terms. The valuation of damages caused by forest fires requires individualized study of each of the resources (tangible and intangible) and their change in net value in relation to fire severity and ecosystem resilience (Molina and others 2009).

The recognition and valuation of natural resources is essential for spatiotemporal planning of preventive work and post-fire rehabilitation (Molina, 2008). Incorporating the concept of vulnerability extends the study beyond the sphere of traditional economic valuation work, integrating two concepts, on the one hand the value of the resource and on the other fire behavior. The integration of the two concepts is performed using a matrix of depreciation rates based on flame length,

called a "depreciation matrix" (Molina and others 2011, Rodríguez y Silva and others 2012).

The socio-economic vulnerability model was made through the configuration of a mathematical algorithm associated with a geographic information system (GIS), facilitating the development of spatiotemporal tracking cartography, both at the individual resource level and at the ecosystem's integral vulnerability level. The automation of the calculation and management through GIS is being conducted under the INFOCOPAS project (RTA2009-00153-C03-03) funded by the National Institute for Agricultural Research (INIA), in order to attain versatile geo-referenced knowledge in almost real-time of forest system vulnerability to forest fires.

Methodology

The process followed in the definition and development of the operational architecture of the VISUAL-SEVEIF program consisted of the following phases:

- Review of the VISUAL-CARDIN simulator's software structure in order to locate the assembly position of the economic evaluation module in the program's flow line.
- Selection of natural resources for which losses are to be evaluated based on energy intensity levels that simulated fires can develop.
- Programming of economic evaluation algorithms through C++ computer language.
- Development of interactive windows between the VISUAL-SEVEIF program and the user. Determination of input variables which must be entered in order to perform the calculations.
- Implementation of economic evaluation options included in the VISUAL-SEVEIF program:
 1. Calculation of the monetary value of natural resources located within an area or region (area included inside a polygon, both rectilinear and curvilinear). This option allows determining the economic value of the stocks.
 2. Calculation of the economic losses and depreciation in the economic value of resources as a result of fire spread. In this phase the procedure followed in the SEVEIF model (Rodríguez y Silva and others 2010) is applied by using the "matrix of economic depreciation factors."
- Assignment of the table of values for the different parameters included in the economic evaluation algorithms, in relation to the types of fuel models.
- Design and final construction of the windows for entering data, performing calculations and showing results.

- Validation of results with valuations available in the database of recorded fires.

VISUAL-CARDIN simulator architecture

Technological developments in the field of computer science have enabled the development of simulation software of great versatility and usability, offering many tool options that are of great help in decision-making. In this regard, forest fire protection requires specialized programs that provide information on forecasts of dynamic fire behavior associated with fires that evolve in different forest systems. In this sense, the VISUAL-CARDIN program is structured as a deterministic program that works subject to the following conditions:

- Simulation model through cellular automaton, using the Moore neighborhood.
- Considerations:
 1. Terrain topography.
 2. Fuel model in each pixel (cell).
 3. Tree height, crown base height, and crown density.
 4. Fuel moisture and degree of protection.
 5. Wind direction and intensity.
 6. Ambient temperature and humidity.
- The speed and direction of maximum spread at each point is calculated from the following expression:

$$\varphi = (V_0 + V_i \cdot \cos W) \cdot t \quad (1)$$

Where V_0 is the rate of spread with zero wind and slope, V_i is the increase in speed in the direction of maximum spread due to the combined effects of wind and slope, φ is the spread radius from the origin of the fire, W represents the angle formed with the maximum spread direction $V_i > V_0$,

The geometric figure adopted to model the surface expansion of the fire's figure is a cardioid. The excess width on the elliptical reference figure is corrected by a factor (perpendicular to maximum spread). This factor is the ratio between the maximum width provided by the simulation performed by Behave (Andrews 1986) and the maximum width of the theoretical figure produced by the geometry of the cardioid. The maximum width value is determined by the expression (Martínez-Millán 1990, Martínez-Millán and others 1991, Caballero and others 1994):

$$F = (3V_0 + (V_0^2 + 8V_i^2)^{0.5}) (4V_i^2 - 2V_0^2 - V_0 \times (V_0^2 + 8V_i^2) / 16V_i^2) \quad (2)$$

The input parameters required by the program for the simulation are entered via the module parameters, which allows including data associated with local characteristics through a set of commands. Through the *winds* command, the characteristics of wind speed and direction measured at six meters above the ground can be entered. The *moisture* command offers the ability to assign the moisture of both living and dead fuels, with the latter classified according to their geometric characteristics. Alternatively, dead fine fuel moisture can be obtained from a set of calculations based on data such as the date, effects of weather, terrain and vegetative state. The *protection* command allows assigning the fuel's degree of protection of against wind, whereas the *residence* command option establishes the flame and ember residence times, allowing assignments to each of the different fuel models. Adjustment of input data using this command allows simulation of the phenomenon of revival from increases in wind speeds. In the simulation, there are some scenarios in which the conditions of transition from a ground to tree-stand crown fire produce a shift in combustion towards the canopy and therefore the fire spreads through the treetops. That is, the model recognizes the possibilities and if conditions allow it, ground, mixed and crown spread are produced. This feature certainly offers great versatility and accuracy in determining the economic impact of fire, by being able to capture the strong energy increases associated with forest canopy spread and thus be able to relate it to damages and losses generated.

Conducting post-fire analysis, in order to reconstruct the behavior of the fire and corroborate the results obtained by the different attack plans applied to extinguish it, is another feature offered by the simulator. This option allows qualifying the final fire reports while at the same time evaluating the performance of the various resources deployed. In this same option, the possible application of educational and technical training courses in fire suppression and behavior can be incorporated.

From the simulation outcomes, a database can be built that interrelates the affected area simulated in freely-evolving spread dynamics, i.e. without the inclusion of firefighting actions, and the actual final area obtained after extinguishing the fire. The ratio between the two areas determines the spread rate control. This parameter facilitates the development of information bases on the experiences recorded in attack plans developed and implemented. This allows having a query file on those fires that may occur in the future and evolve under similar environmental conditions.

From this historical knowledge, firefighting simulations can be initiated on the set of resources that must be activated to control and extinguish the forest fire. To the extent that the integration of economic evaluation algorithms in the VISUAL-CARDIN software architecture has enabled the calculation of economic losses, the VISUAL-SEVEIF model opens a window to the possibility of making calculations and relationships that link firefighting operations and their costs with the value of the

natural resources and the economic losses resulting from fire spread. Efficiency studies on the results of firefighting operations will help in defining budget options and the best results in wildfire defense planning.

The current version responds to programming in C++ under the Windows operating system, but it will also soon be available for the Linux operating system, and includes significant improvements in pixel-by-pixel information processing, providing more precise information with regard to spread characteristics (rate of spread, linear intensity of the advancing front and flame length).

The graphical environment has also been taken into account in order to facilitate greater mapping options, as the simulation can be performed on raster coverages of the topographic map at different scales. It allows export of the perimeters in raster and vector format, as well as import of fire or area perimeters, measured with GPS and also in vector format. Shown below is the results window, which includes the area covered by the fire in yellow (Figure 1).

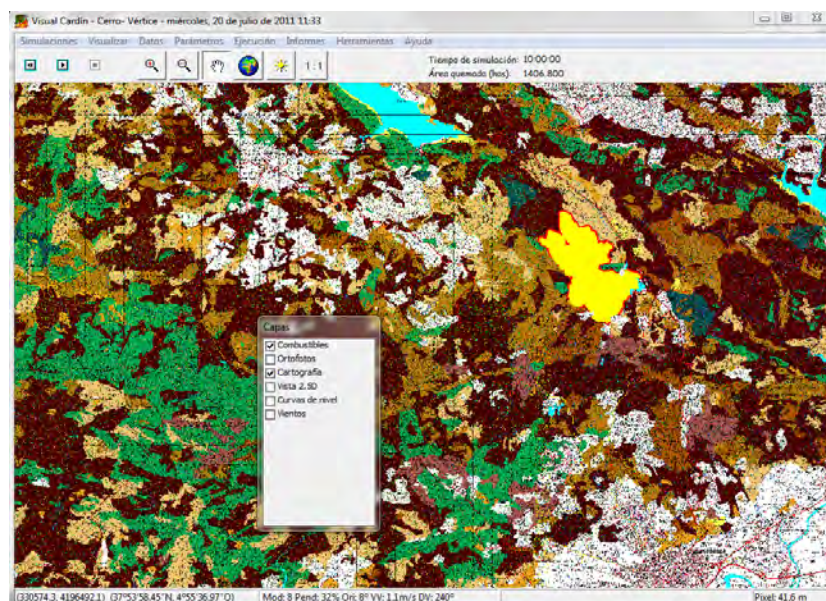


Figure 1—Simulation and analysis of fire behavior using VISUAL-CARDIN software for the Vértice Hill wildfire (2011. Cordoba, Spain).

Economic valuation of natural resources: SEVEIF Model

In the first version of the VISUAL-SEVEIF simulator, we have incorporated the most important algorithms corresponding to the natural resources that have high representativeness in forest scenarios and that with the development of the SEVEIF model (Rodríguez y Silva and others 2010) were identified as such.

The natural resources considered for economic valuation are the following:

- tangible resources, environmental services and landscape assets. The valuation of tangible resources including timber and non-timber products. The methodological approach for valuation of the impact on the timber resource is based on an algorithm that integrates the valuation tools, which include trees of both natural and artificial origin (Rodríguez y Silva and others 2012). The valuation of non-timber resources is based on expressions used in the Manual for the Valuation of Losses and Estimation of Environmental Impact by Wildfires (Martínez Ruíz 2000). The evaluation of the impact on the hunting resource is carried out through the adjustment proposed in Zamora and others 2010.
- The valuation of environmental services includes three resources: carbon fixation, erosion control and faunal biodiversity. The valuation of carbon fixation includes both the amount fixed at the time of the fire's occurrence and the amount unfixed from that time on, with prior knowledge of bark, aerial biomass and annual increment volumes being necessary (Table 1). The amount of carbon corresponding to the dry biomass is estimated at 50%. Erosion control will be expressed in economic income loss based on the potential amount of soil lost per unit area. The expression used for the valuation (Table 1) incorporates a sum in relation to losses incurred during the first rains (bare soil) and a second sum that includes progressive soil losses until recovery of vegetation with similar burn protection (Molina and others 2009). Valuation of faunal biodiversity or unique species is performed using the cost of species recovery programs, or if no specific program is available through the contingent valuation method (Molina 2008).

Table 1— Mathematical formulations used for economic valuation

Resource	Formula	Resource state	Source
Timber	$V_{tim} = (1,7 * E * B) / (E + 0,85 * B)$	Mature and immature	Rodríguez y Silva and others 2012
	$E = C_0 * p [i^e + g(i^e - 1)] + A * (i^e - 1)$	Immature	
	$E = (C_0/z) * t [i^e + g(i^e - 1)] + (C_0/z) * 0,5 * (i^e - 1)$	Sapling	
	$E = [P * V - P_1 * V_1] + P * V [(i^{(T-e)} - 1) / (i^{(T-e)})]$	Stem	
	$B = [(V * P * 1,025^n) / 1,04^n] * [1 - (1,025 / 1,04)^e] * [1 + X * h * p]$	Immature	
	$B = V * h * t [R * P + (1 - R) * P_1]$	Mature	
Firewood use	$V_{firewood} = P_x * R_x * [((1+i)^n - 1) / (i * (1+i)^n)]$	Mature	Martínez 2000, Molina and others 2011
Hunting	$V_{hun} = P_x * R_x * [(1+i)^n - 1] / (i * (1+i)^n) + S$	Hunting ground	Zamora and others 2010
Carbon fixation	$V_{carb} = CF * PM + IF * PM * RC * [((1+i)^{T-e} - 1) / (i * (1+i)^{T-e})]$	Stand	Molina, 2008
Erosion control	$V_{eros} = R_1 * P_1 + R_2 * P_2 [((1+i)^n - 1) / (i * (1+i)^n)]$	-	Molina and others 2009
Faunal biodiversity; Landscape resource; Leisure and recreation resource; Unused resource	$V_{biod/landscape/leis/unused} = R_x * [((1+i)^n - 1) / (i * (1+i)^n)]$	Unique species presence	Molina 2008

where E is the timber valuation based on the traditional Spanish approach (€/ha), B is the timber valuation adapted from the American Model (€/ha), Co is the cost of replanting one hectare of land (€/ha), p is the percentage of the stand affected by fire, i is the annual interest rate, g is annuity dependent on the rotation of the species, A is the value of a hectare of land without trees (€/ha), e is the estimated age of the stand at the time of the fire, V is the timber volume expressed in m³/ha, P is the m³ price of felled wood (€), n is the number of years remaining until the hypothetical harvesting rotation, X is the mortality rate dependent on the severity of the flames, h is the percentage of the species in the canopy, z is the reduction in replanting cost due to the self-regenerative phenomenon based on the rotation, P₁ is the price of damaged wood with commercial use (€/m³), V₁ is the volume of damaged wood with use (m³/ha), P_x is the price per unit of measurement of the resource (€), R_x is the annual income per unit area, S is the reproductive stock per unit area (€), CF is the amount of CO₂ retained at the time of the fire (t/ha), PM is the price per fixed ton (€/t), IF is the annual increase in CO₂ retained (t/ha), RC is the income generated by fixing a ton of carbon in a year (€), R₁ is the average amount of soil lost the first year (t/ha), P₁ is the estimated price per ton (€), R₂ is the average amount of soil lost until recovery of the original cover (t/ha).

Spatial identification of different damage levels and net change in the value of resources

Determining losses in natural resources, both tangible and intangible, requires knowing the remaining value of the resources, i.e., the "net change in the value of the resources." This concept requires the incorporation of resource depreciation based on fire intensity level. Assigning the depreciation of each resource based on fire

intensity level is made on the basis of depreciation rates or percentage levels, given their greater simplicity and practical applicability.

In the case of the timber and firewood use resources, and under the framework of the FIREMAP, SINAMI and INFOCOPAS research projects, circular plots with a 10-m radius were taken for different plant typologies and degrees of damage in the following fires: Huetor (1993), Aznacollar (1995), Estepona (1995), Los Barrios (1997), Cazorla (2001,2005), Aldeaquemada (2004), Minas de Ríotinto (2004), Alajar (2006), Gaucin (2006), Obejo (2007), Orcera (2009) and Vértice Hill (2011). For the valuation of losses incurred by the hunting resource, information from Montfrague National Park and the Aldeaquemada and Minas de Ríotinto fires (Zamora and others 2010) was used in order to have not only spatial but also temporal analysis of the natural recovery of reproductive stock and, consequently, of the annual income generated by the hunting resource.

Depreciation levels of the carbon fixation and erosion control resources were estimated based on tree mortality and the consumption level of aerial biomass, from measurements of burned and unburned trees with similar dendrometric characteristics (fires of: Monte Catena, 2009, Obejo 2007, Cazorla 2001, 2005). Economic valuation of erosion damage, or conversion of lost biomass into monetary units, was determined based on the Obejo fire (2007) study, which analyzed the costs associated with the loss of different soil amounts (tons per hectare). In the case of biodiversity, damage valuation is based on the "surrogate value" applied by the Administration (recovery and/or conservation programs) or the value given by the population (contingent valuation). The values obtained for this resource include adjustments based on post-fire costs incurred by the pertinent authorities to prevent the escape and migration of species through the application of food supplementation, predator elimination and competition reduction measures (Molina 2008).

The depreciation rates of landscape assets are very difficult to validate. The aforementioned research projects estimate the depreciation rates for these assets by the technique of social preferences or valuation through indirect landscape perception techniques by pre- and post-fire comparison of a territory. Landscape use is affected to a greater extent than leisure and recreational activities. Large wildfires that occurred in Sierras de Cazorla, Segura y Las Villas Natural Park (place where the Catena Hill fires occurred in 2001, 2005 and 2009) provided a good database for quantitative estimates on the impact on landscape assets. It can thus be stated that the 2005 fire resulted in a 40% decrease in the number of tourists and paralyzed numerous business projects for remodeling and expanding recreational facilities.

Use of Geographic Information Systems (GIS) allows identification of plant typology and its economic valuation, as well as the availability of information about fire behavior. Based on this, the depreciation rate for each resource is estimated

individually. The integration of the two concepts provides the economic vulnerability of each resource present in the burned area. The economic valuation of damages is the sum of the vulnerabilities of the resources present in the burned area.

Results

Economic valuation of natural resources

The results of the Catena Hill fire showed the non-use resource as being the most important (217,865 €) (Table 2). Given the nature of the *P. pinaster* stands affected, and their longevity (over 100 years in some stands), the timber resource also attained a high value (194,093.17 €). The third most important resource was carbon fixation, given the large amount of aerial biomass in the forests affected (69,137.71 €).

Table 2—Economic valuation of “Catena Hill” resources

Resource	Valuation (€)	Representativeness (%)
<i>Timber</i>	194,093.17	29,35
<i>Firewood use</i>	60,771.17	9,19
<i>Hunting</i>	8,704.35	1,32
<i>Carbon fixation</i>	69,137.71	10,45
<i>Erosion control</i>	21,973	3,32
<i>Biodiversity</i>	6,820.79	1,03
<i>Landscape</i>	27,277	4,12
<i>Leisure and Recreation</i>	54,686	8,27
<i>Non-use resource</i>	217,865	32,94
TOTAL	661,328.19	100

The total value of the forest resources affected by the fire was 661,328.19 €, representing a value of 3,164.25 €/ha in terms of economic damage per unit area. Landscape assets (landscape, leisure and recreation and non-use resources) accounted for 45.33% of the value of the forests affected, followed by tangible resources (timber, firewood use and hunting) which accounted for 39.85%.

Classification of fire intensity level from average flame length

Determining the effects of potential fire behavior on the economic valuation of stocks has been done by identifying the average flame length for each pixel (directly related to the linear intensity of the advancing front). That information is obtained directly from the results provided by the VISUAL-CARDIN program in each of the pixels covered by fire spread. Four fire intensity levels were identified (Table 3):

- o Degree of damage I. It corresponds to Fire Intensity Level (FIL) VI or flame length greater than 12 m. Area severely affected. Continuous crown fire of great virulence and consumption of aerial material. The ground has been virtually denuded.
- o Degree of damage II. It corresponds to Fire Intensity Level (FIL) IV or flame length between 6-9 m. Moderate affect. Passive crown fire with some crown runs. The ground is left unprotected by clumps due to the intensity. There is almost total surface fuel consumption.
- o Degree of damage III. It corresponds to Fire Intensity Level (FIL) III or flame length between 3-6 m. Area moderately affected. Ground fire with consumption of surface material. The fire advances with the slope but not the wind. There are isolated scorched trees.
- o Degree of damage IV. It corresponds to Fire Intensity Level (FIL) II or flame length between 2-3 m. Area slightly affected. Ground fire with consumption of surface material. The fire moves backwards, without slope or wind in its favor.

Table 3—Representation of the different Degrees of Damage on “Catena Hill”

Degree of Damage	Píxels *	Area (ha)	Area (%)
I	398	25	12
II	946	59	28
III	356	22	11
IV	1644	103	49

* Cells of 25 x 25 meters, defined for all levels of information, based on resolutions of 250 and 500 meters.

Identification of net change in the value of the resources and the VISUAL-SEVEIF software flow line

From the experience gained in the large wildfires that occurred in Andalusia during the period 1993-2011 and the scientific results of the FIREMAP, SINAMI and INFOCOPAS research projects, the depreciation matrix was made (Rodríguez y Silva and others 2009), (Figure 2).

This matrix is made up of the set of percentage factors based on the fire intensity levels (kW/m) and the corresponding degree of damage, as indicated in the previous section, so that when applied to the initial socio-economic value, it provides both the losses caused by the wildfire and the residual economic value of vegetation unaffected by the fire.

NIF	Vtr	Vfwr	Vhr	Vcar	Verr	Vbir	Vlar	Vler	Vnonr
I	8,33%	5%	20%	10%	10%	20%	5%	2%	4%
II	16,65%	10%	45%	25%	25%	40%	25%	20%	19%
III	38,58%	20%	65%	45%	45%	60%	60%	55%	46%
IV	57,85%	45%	85%	65%	65%	80%	80%	65%	54%
V	82,79%	65%	95%	85%	85%	100%	90%	85%	69%
VI	89,41%	75%	100%	100%	100%	100%	100%	85%	69%

Figure 2—Depreciation matrix (“Vtr”, timber resource depreciation (Rodríguez y Silva *and others* 2012); “Vfwr”, firewood use depreciation; “Vhr”, hunting resource depreciation; “Vcar”; carbon resource depreciation; “Verr”, depreciation of erosion control; “Vbir”, depreciation of faunal biodiversity; “Vlar”, depreciation of landscape resource; “Vler”, depreciation of leisure and recreation resource; “Vnonr”, depreciation of non-use resource).

In the VISUAL-SEVEIF software architecture, the depreciation matrix has been integrated in order to provide automatically, and for each pixel concerned, the percentage reduction in the initial economic value as a result of the fire behavior developed in it.

The VISUAL-SEVEIF software flow line has been defined by the following sequence of calculation processes (Fig. 3):

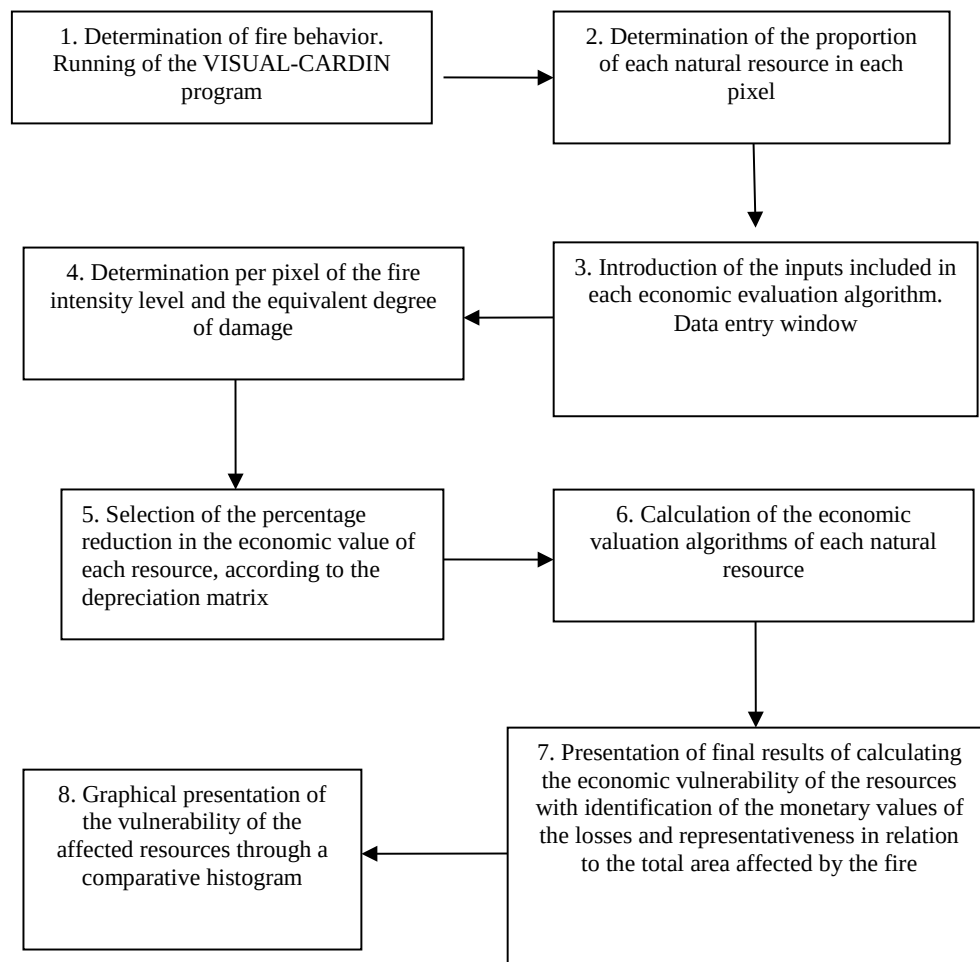


Figure 3—Flow line of the operational process corresponding to the VISUAL-SEVEIF computer program.

impact on burned areas (Molina 2008, Molina and others 2009). In this regard and as recommended by other authors (Borchet and others 2003, Vélez 2009, Rodríguez y Silva and González-Cabán 2010, Molina and others 2011), damage valuation should not ignore the multifunctionality of Mediterranean forests and reduce it to only timber resource losses.

Forest management in the study area (Sierras de Cazorla, Segura y Las Villas Natural Park) has lost the primary objective of yesteryear, namely timber production, and the secondary one as well, resin production. Forest management should be based on multifunctionality, with a high degree of emphasis on landscape conservation and use. Carbon fixation represents a high-potential resource in the quest for economic efficiency. In addition, wildfire occurrence not only means the loss of the fixation capacity of forests but also the sending of a large amount of emissions into the atmosphere. The use of the vulnerability criterion as a more advanced concept than

traditional valuation answers the need for a management tool that incorporates the incidence of the greatest Mediterranean disturbance, forest fires, in the prioritization of actions or development of risk indices (Rodríguez y Silva and others 2009). Classification of the monetary units into qualitative indices of the potential seriousness that the impact of a potential fire could have on an area facilitates the connection or integration of the socio-economic aspect in models aimed at determining the wildfire defense priorities for forest areas.

Conclusions

The recognition or valuation of forest ecosystems is essential for the spatiotemporal planning work of forest fire managers. The importance of having an evaluation model of socio-economic impacts encompasses a wide range of possibilities, facilitating prevention, valuation and post-fire restoration work and, consequently, decision-making.

References

- Andrews, P.** 1986. Behave: Fire Behavior Prediction and Fuel Modeling System. Burn Subsystem, part 1. USDA Forest Service. Intermountain Research Station Ogden, UT 84401. General Technical reports INT-194.
- Borchert, M., Johnson, M., Schreiner, D., Vander Wall, S.** 2003. Early postfire seed dispersal, seedling establishment and seedling mortality of *Pins coulteri* (D.Don) in central coastal California, USA. *Plant Ecology* 168(2), 207-220.
- Caballero, D. Martínez-Millán, J., Martos, J., Vignote, S.** 1994. Cardin 3.0. A model for forest fire spread and fire fighting simulation. II International Conference on Forest Fire Research. Proceedings. November 1994. Coimbra. Portugal.
- Constanza R., D'Arge, R., de Groot, R., Farber, S., Grasso, M., Hannon, B., Limburg, K., Naeem, S., O'Neill, R.V., Paruelo, J., Raskin, G.R., Sutton, P., Van der Belt, M.** 1997. The value of the world's ecosystem services and natural capital. *Nature* 387: 253-260.
- Martínez Millán, J.** 1990. Fire behaviour modelling research and practice. International Conference on Forest Fire Research. Proceedings. November 1990. Coimbra. Portugal.
- Martínez Millán, J., Vignote, S., Martos, J., Caballero, D.** 1991. Cardín, un sistema para la simulación de la propagación de incendios forestales. Ministerio de Agricultura, pesca y Alimentación. Instituto Nacional de Investigación y Tecnología Agraria y Alimentaria. Investigación Agraria. Sistemas y Recursos Forestales, vol.0-1991-separata nº:10. Madrid.

- Martínez Ruiz, E.** 2000. Manual de Valoración de Montes y Aprovechamientos Forestales. Ediciones Mundi-Prensa, Madrid.
- Molina, J.R.** 2008. Integración de herramientas para la modelización preventiva y socioeconómica del paisaje forestal frente a los incendios en relación con el cambio climático. Tesis Doctoral.
- Molina, J.R., Rodríguez y Silva, F., Herrera M.A., Zamora, R.** 2009. A simulation tool for socio-economic planning on forest fire suppression management. Libro Forest Fires: Detection, Suppression and Prevention. Nova Science Publishers. USA.
- Molina, J.R., Herrera, M.A., Zamora, R., Rodríguez y Silva, F., González-Cabán, A.** 2011. Economic losses to Iberian Swine production from forest fires. Forest Policy and Economics 13: 614-621.
- Piñol, J., Terradas, J., Lloret, F.** 1998. Climate Warming, Wildfire Hazard, and Wildfire Occurrence in Coastal Eastern Spain. Climatic Change 38(3): 1480-1573.
- Rodríguez y Silva, F.** 1999. A forest fire simulation tool for economic planning in fire suppression management models: an application of the Arcar-Cardin. Proceedings of the Symposium on Fire Economics, Planning and Policy: Bottom lines, USDA Forest Service. Pacific Southwest Research Station. General Technical Report PSW-GTR-173. San Diego California.
- Rodríguez y Silva, F., Molina, J.R., 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. Sevilla. (www.wildfire07.es).
- Rodríguez y Silva, F., Molina, J.R., Herrera, M.A., Zamora, R.** 2009. The impact of fire and the socioeconomic vulnerability of forest ecosystems: A methodological approach using remote sensing and geographical information systems. General Technical Report PSW-GTR-227. Pacific Southwest Research Station. Forest Service, U.S. Department of Agriculture; 151 - 168.
- Rodríguez y Silva, F., González-Cabán, A.** 2010. "SINAMI": a tool for the economic evaluation of forest fire management programs in Mediterranean ecosystems. International Journal of Wildland Fire 19: 927-936.
- Rodríguez y Silva, F., Molina, J.R.** 2010. Manual Técnico para la Modelización de la Combustibilidad asociada a los Ecosistemas forestales Mediterráneos. Departamento de Ingeniería Forestal. Universidad de Córdoba. Córdoba. España.
- Rodríguez y Silva, F., Molina, J.R., González-Cabán, A.; Herrera, M.A.** 2012. Economic vulnerability of timber resources to forest fires. Journal of Environmental Management 100: 16-21.
- Vélez, R.** 2009. La Defensa contra incendios forestales. Fundamentos y Experiencias. McGraw-Hill, Madrid.
- Zamora, R., Molina, J.R., Herrera, M.A., Rodríguez y Silva, F.** 2010. A model for wildfire prevention planning in game resources. Ecological Modeling 221: 19-26.

Fighting Forest Fires in Brazil¹

José Carlos Mendes de Moraes²

Abstract

Fire has been used in Brazil for many years, but the increased use of this tool, combined with natural events and the presence of large forest and agricultural areas, has led to a significant jump in the number of forest fires, most of them caused by accident. To optimize existing resources and to cope with growing demand, action levels were adopted according to the size and complexity of the incident and priorities for fighting forest fires were also set. As part of the attack readiness strategies, the Integrated Multi-agency Operational Coordination Centers (known as CIMANs in Brazil) were established in several Brazilian states, as well as the national CIMAN that involves the participation of the Ministry of the Environment, National Civil Defense, National Public Safety Force, the National Indian Foundation, the Brazilian Institute of the Environment, the Chico Mendes Institute for Biodiversity Conservation and fire departments. The main objective of the integration of response agencies is to better manage human and material resources available to fight forest fires, resulting in a reduction in response time between detection and initial attack.

Keywords: *forest fires, firefighting policies*

Introduction

Man's use of fire dates back to ancient times. Fire control was essential for the human species to embark on its journey towards civilization. Early man's first encounters with fire must have occurred naturally through observation of natural phenomena: lightning, oil seeps and volcanic activity (Moraes 2009).

Over time, man began to dominate the use of fire, providing a constant source of heat, light and protection against wild animals. Later on, man began using fire as an agropastoral tool and for transforming and processing materials.

Although accounts dating back as far as 32,200 B.C. of naturally-caused fires have been found, the appearance of man and his practice of using fire as a tool for clearing and occupying virgin land resulted in losses outweighing potential benefits,

¹ An abbreviated version of the paper was presented at the Fourth International Symposium on Fire Economics, Planning, and Policy: Climate Change and Wildfires, Nov 5-11, 2012, Mexico City, Mexico

² Environmental Manager, Technician Brazilian Institute of the Environment and Renewable Natural Resources, SCEN – Trecho 2 Ed. Sede del IBAMA – Bloque “C” – 70.818-900, www.ibama.gov.br, Brasil.

since the careless and/or poor use of fire causes an environmental impact of greater degree for society as a whole (Moráis 2011).

For the researcher Cornacchia (1996), fires caused by human action became more frequent than those caused by natural factors, such as lightning, thereby altering the natural fire regime. A survey by the researcher verified that fire periodically affects, and has done so since thousands of years ago, most of the world's biomes, enabling him to say that it influenced and still influences the evolution of biodiversity.

Historically, in Latin America, the use of fire as a tool has been mainly used to renew pasture or destroy tropical forests to open up new lands for agricultural and pastoral purposes (RIZINI 1976).

According to Ramos (1995), in a continent-sized country like Brazil, with one of the highest annual rates of biomass production, great diversity of vegetation and climate, and inhabited by a people with deeply-rooted cultural values, establishing a nationwide forest fire prevention and suppression program is no easy task, as it demands effort and a fairly long-term timeframe, mainly because it requires profound behavioral changes.

Changes began to be noticed in 2001 with the hiring of crews to prevent and fight forest fires in the Federal Conservation Units. In 2008, crews were also hired in critical municipalities, which were selected based on technical, social and environmental factors.

The social element is certainly a relevant factor for hiring crews. Being generally located far from major centers, with few employment opportunities, hiring crews for the six-month period coinciding with the dry season, that is, in the period between harvests when few agricultural activities are performed, has created new jobs in these regions, thus substantially contributing to income distribution and, consequently, strengthening the local economy.

Forest Fire Prevention and Suppression Crews

To contain forest fires in protected areas, the Brazilian Institute of the Environment and Renewable Natural Resources (IBAMA) developed a project for the creation of forest fire prevention and suppression crews in Federal Conservation Units. The project, initiated in 2001, showed a concern at the time with the maintenance of the Conservation Units (CUs) in every aspect, preserving not only the flora and fauna, but also protecting an entire gene pool because these areas probably contain species that have not yet been cataloged or are even unknown in the scientific realm (Morais, 2004).

The year 2008 marked the extension of this line of action in cases of environmental emergencies, especially related to wildfires. IBAMA began hiring crews in critical municipalities, including forest areas unprotected by law. The main motivation was the fact that a state of environmental emergency had been declared for 14 federal units, based on climatic conditions favorable to the occurrence of forest fires.

The selection of the municipalities involved technical criteria, taking into account the concentration of hot spots detected by reference satellites, made available by the National Institute for Space Research (INPE), and superimposed on forest remnants (F). A reference satellite is a satellite whose daily hot spot data are used to compose time series over the years, enabling analysis of trends in the numbers of hot spots for the same regions, in periods of interest (<http://www.inpe.br/queimadas/faq.php>). The reference satellites are NOAA -12 with night passages for detections until August 9, 2007 and Aqua UMD for evening passages from this date forward.

For fine adjustment of the data, the following criteria are also used: coverage information for protected areas) (Federal Conservation Units and State Integral Protection Units (IP), Indigenous Lands (IL) and Federal Conservation Units and State Sustainable Use (SU), Settlement Projects (SP) and Forest Remnants area (R).

Finally, an index was established, taking into account the percentage of each criterion in relation to the detection of hot spots in the state and the area of the state. Different weights were attributed for each index and the indexes were added. Lastly, 5 points were added for municipalities covered by the multi-year IBAMA programs to combat deforestation in the Amazon, Caatinga and Cerrado (PPCD), establishing a Priority Index (PI).

$PI = F \times 4 + R \times 3 + IP \times 3 + IT \times 2 + SU \times 1 + SP \times 1 + PPCD$	(1)

Recalling that the PI values obtained are used solely for comparing municipalities in the same state, it is not possible to extrapolate its application as an index to the national level.

With the aim of making a significant improvement in the quality of suppression efforts, local residents are selected, trained and hired on a temporary basis; most of them are farmers with deep knowledge of the region and with considerable skill at using hand tools.

In 2011, on an experimental basis, the *Tiro Quente* (Hot Shot) quick response crew was formed in Brasilia. The main objective of the crew is to prevent and fight wildfires in forest remnants, support protected areas and fire departments and mainly provide quick response to other units in the federation.

Specialized units also cover the states of Rio de Janeiro and Rondônia. Based on the region's road network and the proximity of Brazilian Air Force bases, these crews can be rapidly deployed to other states as well.

The specialized *Tiro Quente* crew is essential to the success of firefighting operations. With the implementation of the crews, it is possible to cover much of the country by land routes and completely by air deployments. In addition, the National Center for Preventing and Fighting Wildfires (PREVFOGO) gains agility in fighting wildfires, thereby minimizing the impacts caused by forest fires, reducing the emission of carbon dioxide to the atmosphere, and improving responses to forest fires.

The federal crews, even those installed in critical municipalities, see action throughout Brazil, based on established priorities and activation levels.

Crew Action Priorities

Considering the large number of fires and other demands relating to fire prevention, action priorities for crews established in critical municipalities were set.

The first priority is to fight wildfires in Protected Areas, including the following:

- a) Federal, state and municipal Integral Protection Conservation Units, established to ensure the maintenance of ecosystems free from alterations caused by man;
- b) Permanent Protection Areas, which include protected areas whether covered or not by native vegetation. They have the environmental function of preserving water resources, the landscape, geological stability and biodiversity, facilitating the gene flow of wildlife, protecting soil resources and ensuring the welfare of human populations (Forest Code 2012).
- c) In and around sustainable use CUs, where the environment is exploited but in a way that ensures the conservation of renewable environmental resources and ecological processes, maintaining biodiversity and other ecological attributes in a socially just and economically viable way. Prescribed burns are allowed in these areas (SNUC 2000).
- d) Legal Reserves, which are located in the interior of a rural property (Forest Code, 2012). They were established by the Forest Code in permanent preservation areas to provide sustainable use of natural resources, conservation and rehabilitation of ecological processes, biodiversity conservation and shelter and protection of native flora and fauna.
- e) Indigenous Lands, for which guidance and support are obtained from the National Indian Foundation (FUNAI) and local indigenous communities.

The second priority is to provide attack support in several areas, including the following:

- a) areas where populations live in a close relationship with the natural environment, being dependent on their natural resources for their sustenance and making use of them through activities with low environmental impact;
- b) areas designated for planned agrarian reform, characterized by an interdisciplinary and multi-sectoral approach, and integrated into territorial and regional development. The objective is to make rational use of physical spaces and natural resources and seek the implementation of sustainable living and production systems, all with a view to fulfilling the social function of land and to promoting economic, social and cultural development of rural workers and their families (INCRA 2012).
- c) public forests, natural or planted, located in the various Brazilian biomes, in properties under the control of the federal government, the states, the municipalities, the federal district or indirectly-administered entities.
- d) forest areas, in rural and urban properties, if there is no fire department in that location.

Priority 3 provides for, when requested and with the due authorization of the corresponding public agency, showing the appropriate techniques for conducting a controlled burn and controlling its implementation, if necessary. It also includes awareness-raising through environmental education, particularly in rural communities, in relation to forest fire prevention and suppression. Moreover, crews make rounds of their area and thus ward off potential arsonists. They may even perform the initial attack, thus preventing the fire from spreading.

When the crew is not carrying out any of the above tasks, it can perform socio-environmental actions such as decontaminating water sources, combating dengue fever, raising awareness among families in risk areas, and supporting anti-hunger and social equality campaigns, among others.

To publicize the actions of the IBAMA crews established in critical municipalities, a poster showing their priorities was created (Fig. 1).



Figure 1—Poster created to publicize the actions of the IBAMA crews established in critical municipalities.

Activation System

To promote both simple and complex firefighting, IBAMA puts, according to need, its structure at the disposal of these crews and coordinates with other bodies the necessary support. The activation of these resources occurs according to a predetermined sequence of actions. The activation chain, which functions without signed protocols between cooperating institutions, has operated precariously but efficiently thanks to the dedication of the technical staff recommended by the managers of the participating institutions.

To internalize and facilitate understanding, PREVFOGO adopted a tool for managing actions and resources relating to fighting wildfires, which established three activation levels.

At Level 1, the fire is considered small and can be extinguished with the crew's own resources or those of other institutions established within the city's limits. The crew boss coordinates all actions to extinguish the fire. The incident must be reported

to the state coordination office that monitors the event remotely. At the end of attack operations, the crew boss must file a fire report.

When the fire cannot be eradicated only with the crew's resources and those of its colleagues in the municipal area and requires the coordination of IBAMA's state resources and those of other institutions involved, it is given Level 2 status, where the PREVFOGO state coordinator, in order to supplement the resources already used in the incident, coordinates with a state-level body, enabling him/her to deploy closer crews, activate fire departments, request aircraft, etc.

By involving many human and material resources, it is necessary to establish a situation room, where one can quickly view all the available resources, and promote the Incident Command System (ICS).

At level 2, the state PREVFOGO coordination office must report the fire situation to the Operations and Attack Center at PREVFOGO headquarters, which takes over control of the fire and, at the end of the attack, a fire report must be drawn up.

At Level 3, the fire cannot be controlled with resources available up until then. The complexity of the operation requires the mobilization of resources held by national institutions, whether IBAMA or other cooperating agencies. The Operations and Attack Center becomes directly involved in the fire, coordinating human and material resources possessed by other states in the country to help fight the wildfire.

Due to the high costs of extended attack operations, it is essential to have efficient control over available resources such as flight hours, personnel involved, and vehicles used. To that end, the use of the Incident Command System (ICS) is recommended. Under it, the causes and origins of wildfires are investigated and an extended attack report is produced at the end of the event, detailing all activities carried out, human resources used, equipment used, costs incurred, flight hours, area reached, difficulties encountered, suggestions for improving the system and evaluation of prevention and control plans, if any.

To internalize action levels, staff developed a flowchart where the level of the event and its peculiarities, the activities to be carried out for each type of incident and the procedures to be performed can be quickly understood (Fig. 2).



Figure 2—Flowchart where the action levels, the level of the event and its peculiarities, the activities to be carried for each type of incident and the procedures to be performed can be quickly understood.

Largely due to level-three disasters, the Ministry of the Environment, through the National Program to Reduce the Use of Fire in Wildland Areas (PRONAFOGO), arranged for technicians and managers to use the ICS and together with PREVFOGO encouraged states to organize the Integrated Multi-agency Operational Coordination Centers (CIMANS).

Integrated Multi-agency Operational Coordination Center (CIMAN)

In 2010 in the State of Roraima, the Roraima Green Operation, an initiative of the Ministry of Environment and part of the action strategy of the National Fire Reduction and Replacement Program in Wildland Areas (PRONAFOG), was implemented. The planning, coordination and implementation of integrated actions

were developed from the demands from forward firefighting bases and the deliberations and decisions taken at the Integrated Multi-agency Operational Coordination Center (CIMAN/RR) (Roraima 2010).

The Center is composed of institutions responsible for fighting forest fires and environmental crime control. The CIMAN/RR consists of representatives of the Brazilian Institute of the Environment and Renewable Natural Resources (IBAMA), the Chico Mendes Institute for Biodiversity Conservation (ICMBio), State Civil Defense Coordination (CEDEC/RR), the Roraima Military Firefighters Corps (CBM/RR), the Federal District Military Firefighters Corps (CMB/DF), the Independent Environmental Monitoring Unit of the Military Police of the state of Roraima (PM/RR), and the Roraima State Foundation for the Environment, Science and Technology (FEMACT), among others, acting through joint coordination, respecting the autonomy and the legal powers of representative bodies, with the primary mission of monitoring risk areas susceptible to forest fires, detecting hot spots and activating response teams, identifying deforestation areas, and conducting monitoring activities according to the priorities established by the CIMAN/RR (Fig. 3).



Figure 3—Map of the state of Roraima with the logos of all agencies involved in forest fire management in the state.

The first CIMAN installed in Brazil aimed to promote, in a single situation room, information sharing on operations in process and to seek joint solutions among the organizations involved in it, according to the flowchart of the participating institutions (Fig. 4).

OPERAÇÃO RORAIMA VERDE

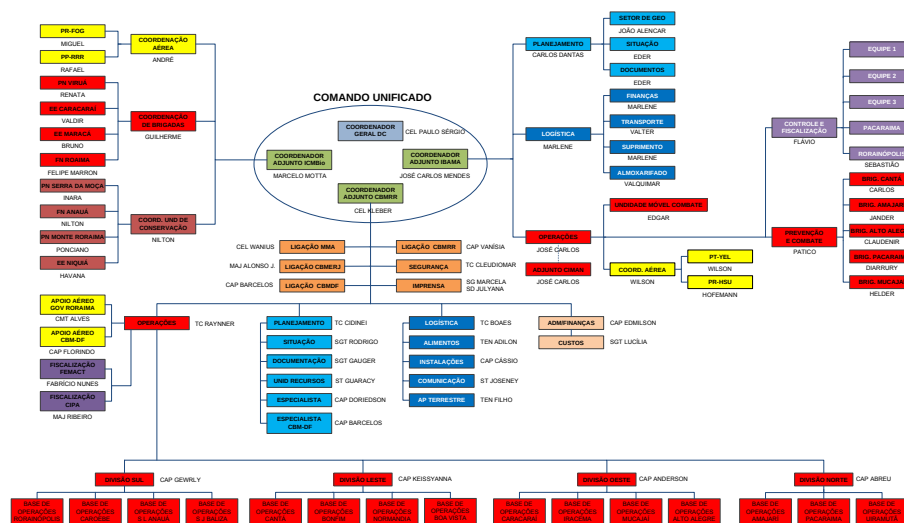


Figure 4—Roraima Verde program operational flowchart

Using some ICS tools, the results of the actions taken were evaluated in order to optimize human resources, the materials used and the strategies adopted. In daily meetings, participants developed Integrated Action Plans, which contain, among other things, guidelines, specific objectives for the operational period, activities required for each agency involved, as well as evaluation of actions taken (Fig. 4).

The ICS was developed in the 1970s, in response to a series of wildfires that virtually destroyed southwestern California. As a result, municipal, county, state and federal authorities joined forces to form the FIrefighting RESources of California Organized for Potential Emergencies, known by the acronym FIREScope³ (SCI 2011).

At the end of July 2010, a wave of large-scale wildfires occurred in central and northern Brazil. Until then, separate firefighting actions were carried out by public agencies belonging to different levels of government, each with its own working mode and according to its own operational capacity. In the first two weeks of August, the situation worsened, so the IBAMA president decided to create, albeit informally, the National CIMAN in Brasilia.

The situation room's executive group met daily at PREVFOGO headquarters until the end of September with PREVFOGO coordinating staff. Representatives of National Civil Defense, the National Public Security Force, the National Indian Foundation, the Fire Department and the Chico Mendes Institute for Biodiversity Conservation, among others, participated in the meetings. A total of 38 meetings were held (PREVFOGO 2010).

The year 2011 was a year with above average rainfall throughout the country, reducing the number of forest fires and thus necessitating only a few National CIMAN meetings.

Conclusion

Throughout Brazilian history, the use of fire has intensified and consequently there was a steady increase in forest fires which led to the need for public policies in this area, such as the important creation of the Integrated Multi-agency Operational Coordination Centers, known as CIMANs.

One of the programs that has made not only fighting fires viable but also the campaign to raise awareness of the need to use fire wisely was the creation of crews in regions of eminent risk and particularly those specialized in strategic points.

Prioritizing crew activities disciplines their services, giving importance and value to suppression operations. The operation system is making better use of available human and material resources, thereby reducing the response time in forest fires.

References

- Cornacchia, G. 1996.** Manejo de Fogo “Parque Nacional de Brasília – PNB. PREVFOGO/IBAMA. Brasília.
- Código Forestal. 2012.** Dispõe Sobre a Proteção da Vegetação Nativa. Ley Nº 12.651, de 25 de mayo de 2012. Brasília.
- INCRA. 2012.** Modalidade de Projetos de Assentamentos Criados Pelo Incra na Atualidade. socioambiental.org. Accedido en 2012 Junio 29. disponible en: http://www.socioambiental.org/banco_imagens/pdfs/DefinioTiposdeAssentamentoeCrditos.pdf.
- Morais, J.C.M. 2009.** Incêndios Florestais e Queimadas. In: Encontro Intercontinental Sobre la Naturaleza, Anuarios. Fortaleza.
- Morais, J.C.M. 2004.** Tecnologia de Combate aos Incêndios Florestais. Revista Floresta 34, P.211-216, Curitiba.
- PREVFOGO. 2010.** Relatório de Combate aos Incêndios 2010. Prevfogo, Ibama. Brasília,
- PREVFOGO. 2011.** Relatório de Combate aos Incêndios 2011. Prevfogo, Ibama. Brasília
- Ramos, P.C.M. 1995.** Sistema Nacional de Prevenção e Combate aos Incêndios Florestais. In: Fórum Nacional Sobre Incendios Forestales, Anuarios. IPEF, P. 29-38. Piracicaba.
- Roraima, 2010.** Relatório Operação Roraima 2010. Prevfogo, Superintendencia del Ibama. Boa Vista, RR
- Rizzini, C.T.T. 1976.** Tratado de fitogeografia do Brasil. Vol. 01. USP. São Paulo,.
- SCI, 2011.** Manual de Sistema de Comando de Incidentes – Cuerpo de Bomberos Militar del Distrito Federal – CBMDF. Brasília.

SNUC, 2000. Sistema de Unidades de Conservação da Natureza. Ley nº 9.985, de 18 de julio de 2000. Brasília.

Mega Wildfire in the World Biosphere Reserve (UNESCO), Torres del Paine National Park, Patagonia – Chile 2012: Work Experience In Extreme Behavior Conditions in the Context of Global Warming¹

René Cifuentes Medina²

Abstract

Mega wildfires are critical, high-impact events that cause severe environmental, economic and social damage, resulting, in turn, in high-cost suppression operations and the need for mutual support, phased use of resources and the coordinated efforts of civilian government agencies, the armed forces, private companies and the international community.

The mega forest fire that struck the Torres del Paine National Park and World Biosphere Reserve in the southern Magallanes region of Chile, in the period from December 2011 to February 2012, was caused by the negligent act of a tourist, in an area of difficult access by land and under extreme behavior conditions that made rapid access of ground attack resources even more difficult and made air attack impossible. Factors that influenced the event from the beginning were rapid rate of spread, high caloric intensity, resistance to control and long-distance emission of firebrands.

On the other hand, the effects of climate change and global warming are being felt and viewed worldwide as a real threat, generating perfect scenarios for the occurrence of fires of this kind. Thus, this fire serves as a concrete example worthy of analysis for its magnitude, the considerable resources and means used, the level of complexity in attack operations, the great logistical deployments that had to be implemented due to the remoteness and inaccessibility of the site, the complications that had to be overcome, its impact on tourism and the local economy, the extensive media coverage it received, and its considerable political impact. Hence the need to draw from this experience those factors that could be taken into account in the prevention or suppression of highly-complex future fires, in order to help reduce the substantial environmental, economic, social and political effects generated by such fires.

¹An abbreviated version of this paper was presented at the Fourth International Symposium on Fire Economics, Planning, and Policy: Climate Change and Wildfires; 5-11 November 2012, Mexico City, Mexico.

²Forestry Technician, Department Head, Fire Management, National Forest Corporation, Avenida Bulnes N° 0333, Punta Arenas, Chile. Rene.cifuentes@conaf.cl.

Keywords: climate change, economic impacts, mega-fires.

Fire as a disruptive agent at the regional level

In Chile, and around the world, forest fires are a problem that leaves no one feeling indifferent. In our country, 99% of all wildfires are anthropogenic. Statistics also show us that on average 5,500 such incidents occur each year, burning some 52,000 hectares of vegetation, with losses of approximately \$57 million US, corresponding to damages assessed on the market, such as wood, facilities, livestock and other assets, in addition to the social and environmental damage.

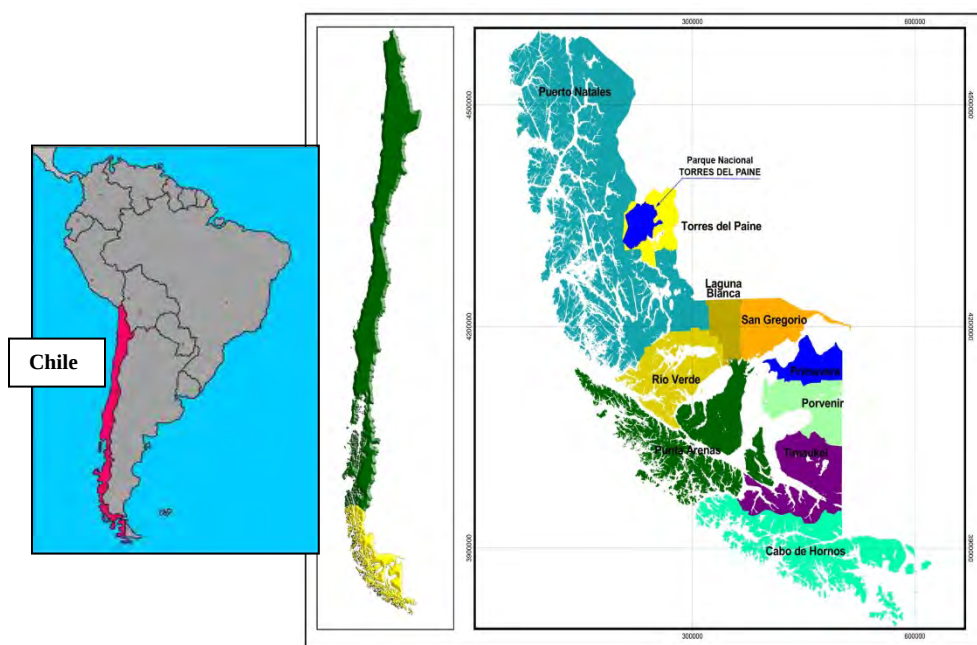


Figure 1— Location of Chile

History of fire in Torres del Paine

Torres del Paine Park, located in the extreme south of Chile, has such outstanding natural features that it is one of the most popular tourist attractions in the country, both for Chileans and foreigners (about 80% of all visitors are foreigners). It is one of Chile's most emblematic protected areas, as its approximately 242,000 hectares are home to a great variety of mountain scenery, glaciers and biological richness, which led to it being recognized as a World Biosphere Reserve by UNESCO, becoming the third most visited protected area in Chile (CONAF 2012). The increasing number of visitors to the Park (approx. 160,000 visitors annually) is having a negative effect on its natural resources, as manifested through different types of effects, among which

the one with the greatest impact is wildfires, which affect environmental quality and jeopardize the maintenance of the natural ecosystems and their sustainability.

For its physical and biological landscape, it is also a major economic asset for the region, but at the same time it also poses a major threat, as the high rate of visitors implies an increased risk of occurrence of ignition sources (Vidal and Reif 2011). Thus, in the period 1980-2012, there were 61 recorded fires, all caused by humans, affecting more than 48,000 hectares of protected area, including the great fires of 1985 and 2005 (Vidal and Reif 2011) that preceded the fire of 2011.

All the above reflects the uniqueness presented by the problem of forest fires in this region, since the environmental conditions, existing vegetation and a large number of mixed variables create conditions conducive to the spread of fire and which often make it difficult to combat them. In this way a small spot fire becomes a potential mega fire with disastrous consequences.

The last major fire broke out in the Park in late December 2011, continuing for about a month in its most active phase and burning a total of 17,606 hectares, of which 17,054 are within the Park's boundaries. Of the total area burned, an estimated 59.7% was Patagonian steppe communities dominated by grasses, 28.6% was scrub or shrubland, 9.7% was native forest and the remaining 1.9% was made up of other land uses.

Named the Olguin mega fire after the area where it started, it is considered one of the most devastating wildfires to have ever occurred in the history of the Park as a protected area. The magnitude of the Olguin fire stands out not only for the vast area burned, but also for the severity of the fire, which affected the vegetation and soils, and because a large section of the burned area (50%) was also consumed by the great fire that hit the park in 1985 (USNPS 2012). As a result, the destructive impact is stronger and ecosystem resilience in these sectors is lower, meaning that fire recurrence is recognized as a factor leading to progressive degradation of ecosystems in the long term (Zarin and others 2005).

Development of fire suppression operations

The fire spread quickly due to constant strong winds, abundant and dry organic fuel present throughout the park, area conservation efforts and a prolonged drought, resulting in a high rate of spread, high resistance to control and long-distance emission of firebrands leading to multiple spot fires.

The considerable resources and means required, the level of complexity involved in firefighting operations, the presence of extreme behavior factors, the great logistical deployments required due to the remoteness and inaccessibility of the site and the numerous complications that had to be solved, necessitated implementing

a complex extended attack structure, for which all material, technical and human elements in the Magallanes region were available through the local core civil protection system, the state civil protection system, and the mobilization of fire-fighting resources (CONAF and private fire crews) from central regions of the country under interregional mutual aid protocols, which were still insufficient. As a result, international cooperation was required and obtained by invoking mutual aid agreements and accepting offers of assistance from friendly countries.

The fire was finally extinguished on February 23, 2012, although mopping up and ash monitoring operations continued until March 2012.

Organization for complex extended attack (OOAAS)

Since the resources arrived on a staggered basis, the organization mounted also grew on a pace with the arrival of fire personnel, so much so that by as early as January 3, the OOAAS could be completed, in terms of what was essential for handling the emergency, all of which caused further serious logistical problems due to the long distances involved and the complexity of the supply line.

Table 1—*Resources used in the emergency.*

CONAF	GOVERNMENT	INTERNATIONAL
• Regional Core System • ORI Plan (Integrated Regional Operation) • PLANIMAG (Departmental Plan for Megafires)	• ACCEFOR (Operational Coordination Plan for Forest Emergencies) • Solidarity Plan, Joint Command Southern Armed Forces	• Agreement with the province of Santa Cruz, Argentina • Emergency mutual aid agreement with Argentina (ANPN) • Uruguay National Fire Brigade • Brazilian Ministry of the Environment (IBAMA)

Departmental Fire Management Operations Plan in the Magallanes Region (CONAF)

The CONAF fire management program in Magallanes covers the operation of four professional fire crews during the fire season, two of which are located in Torres del Paine National Park, one in the city of Punta Arenas, and the other in the city of Puerto Natales.

Integrated Regional Operations Plan (ORI Plan – CONAF)

The objective of the ORI Plan is to enable the Regional Directorate of the National Forest Corporation (CONAF) to make use of all available resources, whether material or human, to support Fire Management operations during an emergency through a regional-level extended attack organization, which has technical and administrative staff at its disposal for different tasks in the regional core extended attack structure in the early hours of the fire.

Departmental Plan for Megafires (PLANIMAG) CONAF

The plan provides for the mobilization of fire-fighting resources on an interregional support basis for megafires. It was implemented in stages beginning on December 28, 2011 and ending in April 2012 with the demobilization of all support resources, fire crews and technical staff from different regions of central Chile.

Operational Coordination Plan for Forest Emergencies (ACCEFOR Plan) of the National Emergency Management Agency's (ONEMI) Civil Protection System

The Civil Protection System's Operational Coordination Plan for Forest Emergencies (ACCEFOR) was enacted by Supreme Decree 156 in 2002. The plan establishes the organization, procedures and overall concept of how the member agencies of the Emergency Operations Committee (armed forces, fire departments, municipalities, civil defense, public works departments, etc.) should act in the event of forest emergencies when the local response established by CONAF is exceeded.

CONAF-Agrarian Council of the Province of Santa Cruz (CAP), Argentina Agreement to fight border wildfires

In force since 2003, it came about as a result of the need for concerted efforts to protect Patagonian ecosystems shared by the southern provinces of Chile and Argentina, where there are no natural barriers.

Argentina's National Fire Management Plan

The participation of fire crews operating under Argentina's National Fire Management Plan resulted from the need for more trained staff and the impossibility of sending more National System fire crews to the Region because of other major fires occurring at the same in the central regions. The request was made by invoking the agreement signed between Chile and Argentina for mutual assistance with personnel and equipment in the event of a disaster. Argentina responded quickly and

appropriately by sending fire crews attached to the country's southern National Parks.

Uruguay National Fire Brigade

The presence of Uruguayan fire crews was managed from the National Emergency Management Agency due to the need for specialized staff that was no longer possible to obtain from other central regions due to the existence of simultaneous fires and a red alert in those areas.

Brazilian Ministry of the Environment (IBAMA)

Its attendance was coordinated through the Fire Management Agency as a result of previous contacts, knowledge and training and seminar experiences involving officials of the two institutions.

Table 2—*Area burnt*

Land Use	Torres del Paine N.P.	Outside the Park	Total
Patagonian steppe/Grassland 	10.272,3	247,3	10.519,6
Scrub 	4738,6	304,7	5.043,3
Forests 	1.702,7	-	1.702,7
Other Uses	340,7	-	340,7
TOTAL	17.054,3	552,0	17.606,3

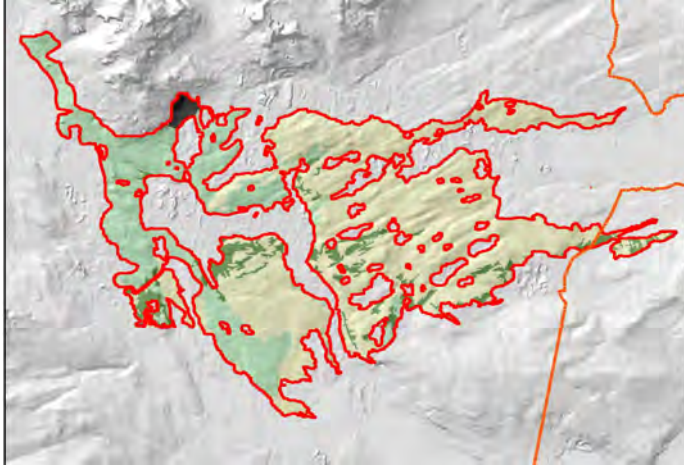
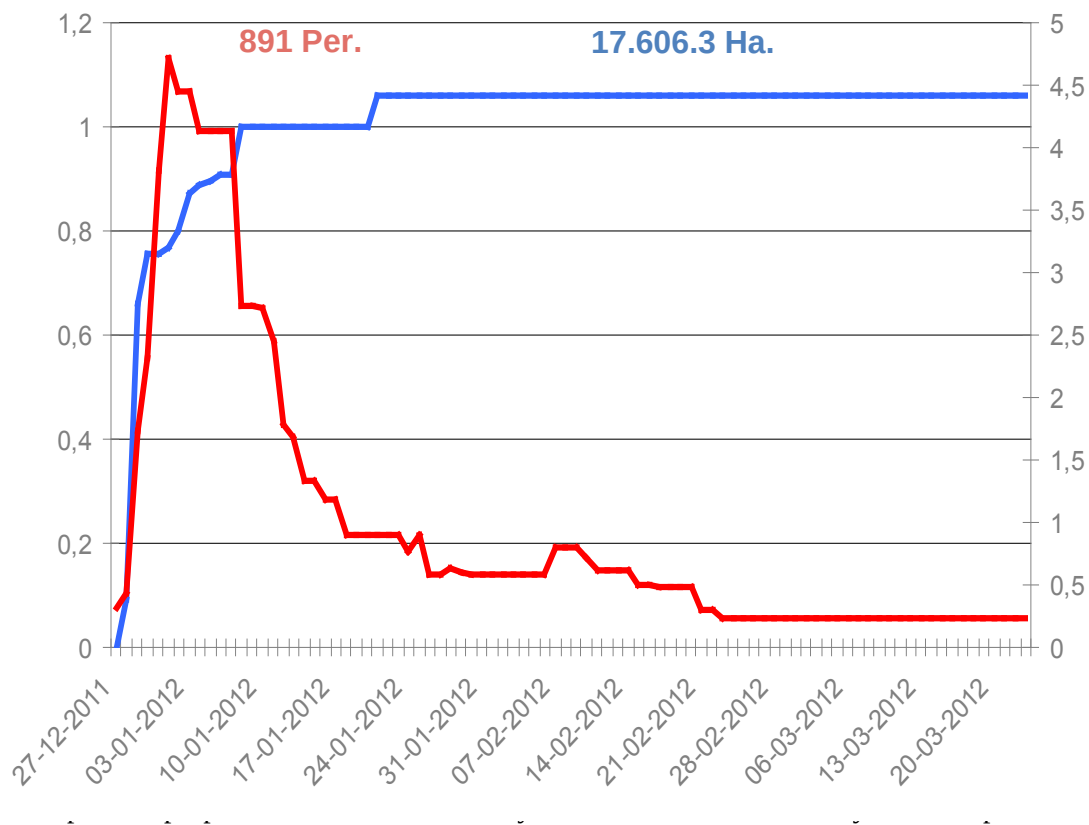


Figure 2— Torres del Paine fire perimeter

Graph 1— Personnel on fireline versus area affected



Fire severity based on the impact on plant communities

To assess the effects that this megafire had on the diversity of ecosystems, plants and animals, and to gather information that would allow proposing immediate measures and short- and medium-term recommendations for the recovery of affected systems, the Ministry of the Environment (MMA) formed a technical team composed of leading professionals and researchers from different national institutions and universities to develop a diagnostic report detailing the damage and impact on plant communities as the basis for a proposed plan to restore the affected ecosystems in the short, medium and long term.

In parallel, under an agreement between Chile's National Forest Corporation and the U.S. National Park Service, a team of researchers first conducted a field campaign and then prepared a comprehensive Post-fire Response Plan (USNPS 2012).

The effect of the fire on vegetation varied depending on the ecosystems and sectors affected. Figure 3 shows the degree of severity of the fire according to the Burned Area Emergency Response (BAER) report developed by the U.S. National Park Service (USNPS 2012).

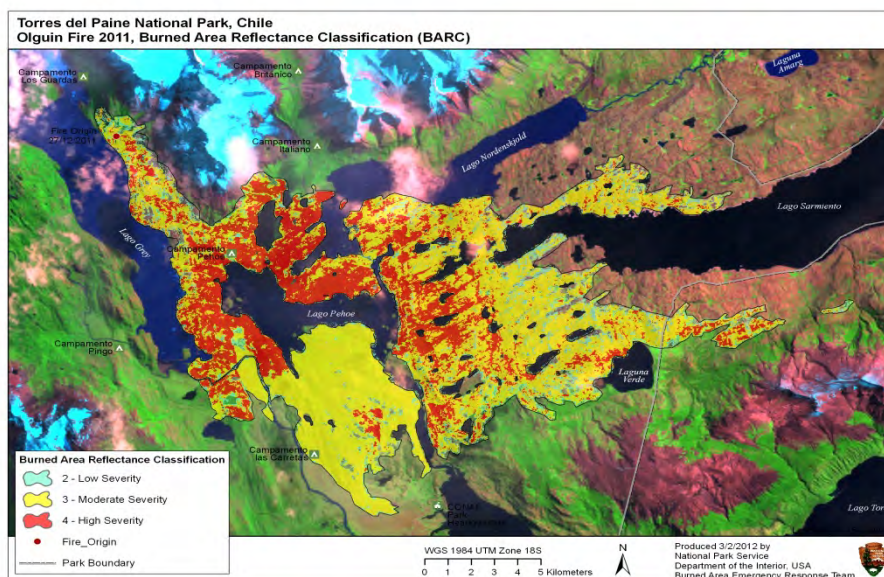


Figure 3— Map of the Torres del Paine fire showing the different degrees of severity during the fire.

Climatic variation in Magallanes

Wildfires are a widespread phenomenon in the world's terrestrial ecosystems, sensitive to global climate change that is creating more severe weather, longer

summer seasons and great fires, all of which has led to consensus among technical agencies such as the FAO and others as to the reality of global climate change.

In the Patagonian ecosystems of Chile and Argentina, wildfires are strongly influenced by climate variability. Years of increased fire activity are usually associated with dry winters and hot summers (Veblen and others 1999).

Warming of the climate system is unequivocal, as evidenced by observed global climate data (IPCC, 2007). For its part, Chile has been evaluated as a country vulnerable to climate change. Forecasts for the middle and end of the 21st century indicate a number of impacts on natural resources, because of the change in the water regime and temperature, as well as an increased incidence of extreme weather events.

The region comprising Magallanes and the Chilean Antarctica is the largest and southernmost of the country. It is located from 48° 36' to 56° 30' south latitude and between 66° 25' and 75° 40' west longitude. Its proximity to 60° latitude places it close to a belt of low-pressure or sub-polar cyclone systems, which means it is continually affected by westerly winds and frequent frontal systems. With a 132,297 km² mainland area and a 1,250,000 km² Antarctic area, it features an impressive geography of natural grasslands and forests, fjords, gulfs, canals, islands, archipelagos, and more than seven million hectares under the National System of Protected Areas of the State (SNASPE), corresponding to natural world tourist attractions (INE 2011a), including the Torres del Paine National Park and World Biosphere Reserve.

Regarding the current climate of Magallanes, based on a review of secondary information, it is possible to identify an upward temperature trend. This is consistent with global warming, calculated at 0.6 °C for the southern hemisphere in the last 130 years (IPCC 2007). This trend has also been detected in Antarctica, where it has increased by almost five times that figure, in a period of only 50 years. Regarding precipitation behavior generally, it remains stable; however, there are some significant specific trends, as seen on Evangelista Islet and Félix Bay, where there was a decrease in rainfall of 1,000 mm between 1900 and 1985 and 1,400 mm between 1915 and 1985, respectively (Endlicher and Santana 1988). According to CONAMA (2006), the evolution of precipitation in the south-central and southern part of the country since the mid 1970s has given way to a downward trend that has continued until now.

While it is true that there are no conclusive data that allow asserting in exact terms the increase in the average temperature during the summer in the Magallanes region, or changes in relation to wind strength and rainfall, it can be said that Magellan's climate is determined by topographic, oceanic and atmospheric factors. These elements contribute uncertainty to our knowledge of current climate behavior and also to projections associated with global climate change, which is, undoubtedly,

increasingly producing exceptional phenomena outside of historic patterns and/or ranges, as in the case of the water deficit, variation in wind strength and consecutive days of high temperature that shape complex scenarios that favor the occurrence of forest fires and extreme behavior with high rates of spread and resistance to control.

Conclusions

Due to particular regional conditions which limit the effectiveness of fighting wildfires, it is clear that it is only possible to achieve an effective response through proper planning based on an assessment of the occurrence and the losses caused by wildfires, by means of a proposal outlining prevention, prognosis and suppression measures that effectively control the initiation and spread of fire, which in the case of Torres del Paine, its special topography and forest fuels provide the perfect equation for fire risk, where the threat is determined by the increasingly significant increase in visitors and the vulnerability represented by the state and the condition of its forest fuels.

In this context, the linkage between human and natural systems, and their respective vulnerabilities, is particularly relevant. Adaptation involves **capacity building** in society to develop, evaluate and implement options as they are needed. The partnership between government, technical staff and beneficiaries is the key to achieving significant progress on climate change adaptation (Howden 2010), for which it is essential to educate society about this new scenario and improve public forest fire protection policies.

Finally, to fulfill the institutional mission "to contribute to national development through the sustainable management of forest ecosystems and the mitigation of climate change effects by promoting and monitoring forest-environmental legislation, protecting vegetation resources and managing the State's Protected Wilderness Areas, for present and future generations," it is essential that the management and public use of this emblematic Chilean National Park is designed and developed with a science that integrates and harmonizes the goals of conservation that justified its creation, with a regulated and sustainable use of its tourist attractions, generating capacities to adapt to new scenarios imposed by climate change.

References

- Ministerio de Agricultura – FAO. 2010.** Diagnóstico de la gestión del Riesgo Agroclimático, Chile
- Ministerio de Medio Ambiente. 2012.** Plan de restauración Ecológica del Parque Nacional Torres del Paine afectado por un incendio forestal 2011-2012, Chile

United States National Park Service. 2012. Burned Area Emergency Response Plan, USA.

Corporación Nacional Forestal Región de Magallanes y Antártica Chilena. 2012.
Documentos e informes técnicos sobre operaciones de combate del Incendio Olguín del
PN Torres del Paine, Chile.

Spatiotemporal Distribution Patterns of Forest Fires in Northern Mexico¹

Gustavo Pérez-Verdin², M. A. Márquez-Linares³, A. Cortes-Ortiz³, and M. Salmerón-Macias²

Abstract

Using the 2000-2011 CONAFOR databases, a spatiotemporal analysis of the occurrence of forest fires in Durango, one of the most affected States in Mexico, was conducted. The Moran's index was used to determine a spatial distribution pattern; also, an analysis of seasonal and temporal autocorrelation of the data collected was completed. The geographically weighted regression was applied to assess whether there is seasonality in the factors that influence their occurrence. The results indicate that forest fires are distributed in an aggregated manner and are not temporally correlated. It was found that precipitation, temperature, altitude, distance to roads and population severity index are non-stationary. The occurrence of fires is manifested according to population density and access roads, confirming the importance of socioeconomic factors in the distribution of these events. Low rainfall and high temperatures are climatic factors also greatly affecting fire occurrence.

Keywords: Autocorrelation, temperate forests, Durango, Mexico; Seasonality, Geographically Weighted Regression.

Introduction

In Mexico, most forest fires occur during spring and the occurrence period extends until vegetation, stimulated by the first rains, restarts its period of growth and development (Rodríguez-Trejo and Fulé, 2003; Alanís-Rodríguez *and others*, 2008). Fire occurrence depends on many climatic and topographic variables (precipitation, altitude, humidity, temperature, exposure, among others) which in turn depend on temporal variability (Drury and Veblen, 2008). Normally, wet years give rise to the formation of dense and rich vegetation that, eventually, is the ideal fuel for terrestrial wildfires of medium to relatively high intensity in the next dry year (Fulé and Covington, 1999). Similarly, areas facing north with high elevation have a lower risk

¹An abbreviated version of this paper was presented at the Fourth International Symposium on Policy, Planning, and Economics of Forest Fires: Climate Change and Forest Fires, November 5th to 11th, 2012, Mexico City, Mexico.

²Research Professor. National Polytechnic Institute. CIIDIR Durango. Durango, Dgo., Mexico, E-mail: guperezv@ipn.mx.

³Master Student. National Polytechnic Institute. CIIDIR Durango. Durango, Dgo., Mexico.

of the presence of fire, while those facing south and southwest are generally more susceptible to the presence of fire (Fulé and Covington, 1999).

Human activities are a very important factor that influences the occurrence of forest fires in many parts of Mexico (Avila *and others*, 2010). Many farmers use fire as the main tool to clear lands which are in turn used to grow commodities such as corn and beans or to promote pasture re-growth. Misuse of fire often generates the spread of large and severe fires that destroy not only wildlife but also affect directly the general population (Rodriguez-Trejo and Fulé, 2003). When fire is used repeatedly in the same areas, it generates a low accumulation of combustible material and gives rise to low intensity fires. In contrast, when present in large and scattered areas, and sporadically, there are great chances of generating moderate to high intensity fires, able to completely remove tree cover (Fulé and Covington, 1999).

The overall objective of this paper is to analyze the spatiotemporal distribution patterns of forest fires in the State of Durango during the 2000-2011 period. In particular, the study attempts to assess spatial autocorrelation and temporal seasonality, and to identify the most important variables that influence fire occurrence.

Methods

Study area

The study was conducted in the State of Durango's temperate-cold forests. Durango is located in the north of the country and has the largest pine and pine-oak forest reserves (Figure 1) and is also one of the areas most affected by wildfires (CONAFOR, 2012). It has a great topographical diversity, making it important to study the spatial variability of fires occurrence, and its territorial extent allows noticing the role of forest landowners in the prevention, control and suppression of forest fires. About 80% of the forest area belongs to *ejidos* (communal lands) and therefore its management depends heavily on the organization of these communities.

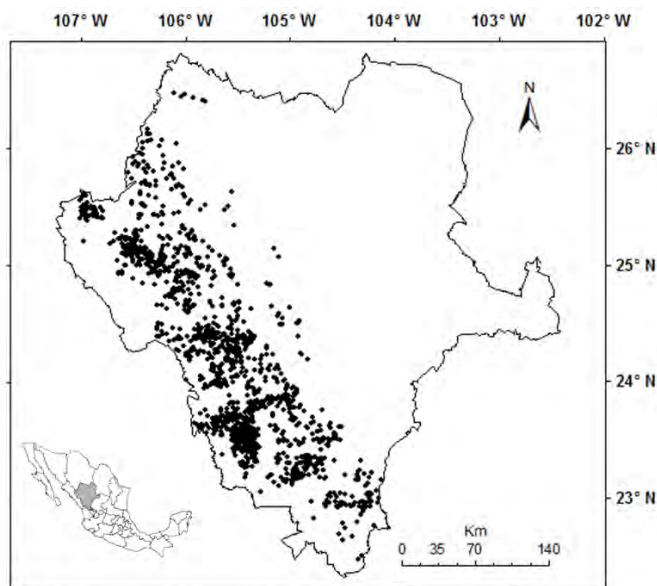


Figure 1—Location of Durango State, Mexico, and forest fires that occurred in the period 2000 to 2011.

Spatial analysis

The Moran's index (Moran, 1950) was used to estimate the spatial autocorrelation of forest fires in Durango. Autocorrelation is a measure of the distribution of a variable with itself through space (Wong and Lee, 2005); if the spatial distribution of that variable has a distinctive pattern (not random), it is said to be spatially autocorrelated. This Index may take values from -1 to 1, where negative values mean that the variable has a scattered distribution pattern and positive values have a concentrated distribution pattern. If the index is close to zero, then the variable is said to have a random distribution pattern (Wong and Lee, 2005). To test the null hypothesis of no autocorrelation, the empirical distribution is compared against a theoretical distribution, using a significance test comparing critical values at a certain level of reliability (Burt and Barber, 1996).

Temporal Analysis

Temporal analysis basically consisted of proving two properties of stochastic phenomena based on time series: seasonality and temporal autocorrelation. Temporary Seasonality is defined as those processes in which statistical moments (mean, variance, *etc.*) are not constant over time (Burt and Barber, 1996). To test this property, probability density functions of the variable of interest Y_t (*i.e.*, area affected by fire) were constructed for each year t . The temporal seasonality effect occurs if the

probability functions are the same for all years. That is, if the variance σ_t^2 and mean μ_t are constant for all years. In this case,

$$\sigma_t^2 = E(Y_t - \mu_t)^2 \text{ y } \mu_t = E(Y_t).$$

As in the case of spatial autocorrelation, whether there is a dependency among observations close in time was also analyzed. Temporal autocorrelation measures the dependence degree of a variable of interest Y at time t with itself at time $t + k$ (Burt and Barber, 1996), where k is the number of evaluation periods (known as lags) and can take different values. The autocorrelation for period $k = 1$, for example, means correlating variable Y_t with the same variable Y_{t+1} in which data have been shifted one time unit. The temporal autocorrelation ρ is then expressed as:

$$\rho(t, t + k) = \frac{E(Y_t - \mu_t)(Y_{t+k} - \mu_{t+k})}{\sigma_t \sigma_{t+k}} \quad [1]$$

Where σ is the standard deviation (the other terms are defined above). In this case, ρ also takes values from 1 to -1, where the positive value indicates a high correlation and the negative value indicates that the variable Y tends to oscillate with above average values immediately followed by below average values. When ρ tends to zero, it means that there is no correlation in the time period assessed k (Burt and Barber, 1996). If there is no autocorrelation, then it means that its magnitude appears randomly.

Factors affecting the magnitude of fires

The RGP model was used to estimate the magnitude of fires using the affected area (Sup) as a function of environmental, economic and topographical variables. The RGP model has the following expression (Fotheringham *and others*, 2002):

$$Sup(u, v)_i = \beta_0(u, v)_i + \sum_{i=1} \beta_i(u, v)_i X + \varepsilon(u, v)_i \quad [2]$$

Where term (u, v) indicates that the parameters β_0 and β_i (intercept and slope, respectively) should adjust in accordance to the location of the point (fire) i which has the coordinates u and v . This means that each point (fire) will have its own coefficients β_0 y β_i . The variable X denotes the set of factors that are related to the magnitude of the fire. The component $\varepsilon(u, v)$ represents the error associated with the point with the coordinates u and v . This model (known as Geographically Weighted Regression) assumes that the points are non-stationary and that, in this case, a fire's magnitude varies depending on its location.

Model fitting was done with the support of the parameters: determination coefficient, standard error, and a coefficient named Akaike Information Criterion (CIA, for its acronym in Spanish). A Gaussian type model was used where the bandwidth was automatically identified by an adaptive iteration (see RGP model details in Fotheringham *and others*, 2002; Harris *and others*, 2011). To test the null hypothesis of no seasonality of independent variables, a Monte Carlo test was used for comparing the observed variance of the estimated parameters of each variable against a dataset randomly taken. Probability values were estimated for each of the variables and a significance level of 0.05 was utilized. The data processing was done with the program GWR3.0 ®.

Sources of information and data

The National Forestry Commission (CONAFOR, for its acronym in Spanish) database (2000-2011 period) was utilized. In addition to fire location, it includes the dependent variables affected area and number of days required for suppression of the event. Independent variables were taken from other information sources. The National Geography Institute (INEGI) digital elevation model was used to obtain the altitude and exposure data. INEGI's thematic maps were also used to obtain information on vegetation, soils, roads and towns. Climatic variables, namely average monthly rainfall and temperature, were obtained from the National Weather Service database, according to the year of fire occurrence. The variable that identifies property types was obtained from the National Agrarian Registry. With the information gathered, it was possible to make changes to them or carry out cartographic analysis on them. For example, the population severity index (IGP, for its acronym in Spanish) was calculated, expressed as:

$$IGP = \sum_n^N \frac{P_n}{D_{in}^2}, \forall_n: D \leq 20 \text{ km} \quad [3]$$

Where P is total inhabitants in population center n , N the total number of towns, D is the distance (radius) from the fire i and town n , taken up to a 20 km radius of the fire. The IGP is a measure of the population's effect on fire occurrence. High levels (on this index) mean higher human pressure on the occurrence of fires. Table 1 shows the characteristics of the variables used in the study.

Table 1—Descriptive statistics in the analysis of the factors that affect the magnitude of forest fires in Durango, Mexico (Sample size = 1560).

Variable	Description	Average	Std. Dev.	Min	Max
<i>SUP</i>	Surface (Ha)	84.0	215.24	0	2600
<i>IGP</i>	Population severity index	15.0	17.83	0	76
<i>CAMINOS</i>	Distance to roads (Km)	1814	1870	0	13101
<i>LOCALID</i>	Distance to towns (Km)	3417	2228	10	11774
<i>PASTIZAL</i>	Distance to grassland areas (Km)	2819	2329	0	9983
<i>CULTIVOS</i>	Distance to crop areas (Km)	3556	2750	0	9997
<i>DEFOREST</i>	Distance to deforested areas (km)	6257	5053	0	28569
<i>PRECIP</i>	Rainfall (mm)	607	191	174	1233
<i>TEMP</i>	Temperature (°C)	16.0	1.83	12	28
<i>REGPROP</i>	Property regime (1: <i>ejidos</i> ; 2: private)	1.2	0.43	1	2
<i>PEND</i>	Slope (%)	11.5	9.6	0	52
<i>EXPO</i>	Exposure (degrees azimuths)	178	108	0	360
<i>ALTITUD</i>	Altitude (m. above sea level)	2437	301	753	3124

Results and discussion

Spatial analysis

Moran's index (MI) was applied to determine the existence of spatial autocorrelation of forest fires using their geographical coordinates *X* and *Y* (longitude and latitude), and in both cases the coefficient was positive with values of 0.88 and 0.74, respectively. The no autocorrelation null hypothesis test was rejected because the coefficient $Z(I_M)$ was 6.14 ($p < 0.001$) for *X* and 5.22 for *Y* ($p < 0.001$). This means that fires present an *aggregated* distribution pattern, with high concentrations near roads and population centers.

To analyze the critical areas for fire presence, an analysis of the “hot spots” in the area affected and the number of days required for suppression was performed. Figure 2 shows the “hot spots” or places with high impact by wildfires and those “cold spots” where the effect is smaller. There are between 5 and 6 “hot spots” in the entity and they are located in inaccessible locations distant from population centers. In contrast, the “cold spots” are located near the population centers of El Salto, Pueblo Nuevo and San Miguel de Cruces, San Dimas. It is important to mention that “cold spots” are located in areas where, at present, there is greater involvement by forest landowners. The San Miguel de Cruces area, municipality of San Dimas and El Salto, municipality of Pueblo Nuevo, are characterized by high social organization in which the participation of landowners and landholders, not only in fighting fires, but

in all restoration and management activities, is very positive. While it is true that there is a high frequency of fires, they are managed more efficiently, *i.e.*, in less time and with less surface area affected.

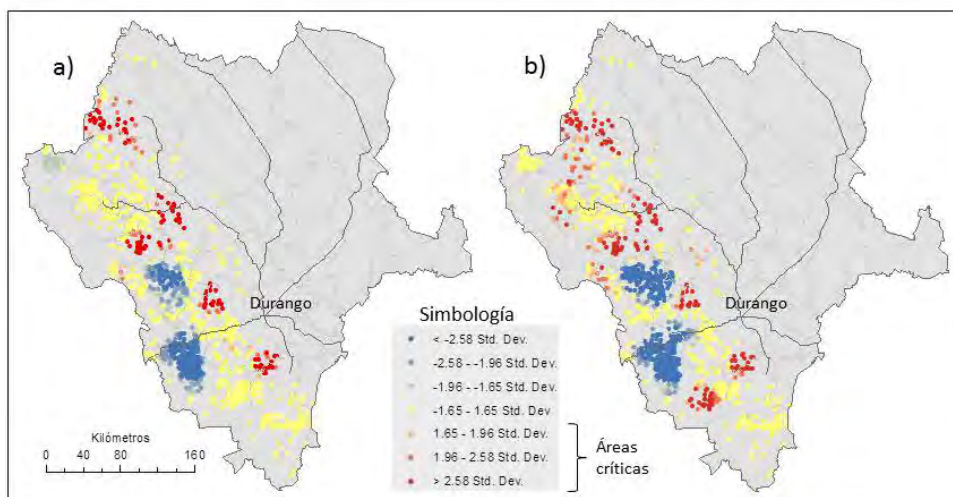


Figure 2- Critical Areas of forest fires in Durango. Red dots mean hot spots while blue ones are cold spots. Figure 2a) shows hot spots in area while Figure 2b) represents the number of days for suppression.

Temporal analysis

To evaluate temporal seasonality, probability density functions of the variable of interest were constructed (*i.e.*, area affected by fire) in each year. They estimated the average and variance, and analyzed variances' homogeneity using the Levene test. The results indicate that the most common probability density function was the Pearson Log-III, which is repeated in 5 of the 12 years comprising the study. However, the average and variance in each year are different. The Levene test and the one-way analysis of variance showed that both variance ($L = 18,012$, $p < 0.001$) and the average affected area ($F = 8995$, $p < 0.001$) respectively, are statistically different. The exception is observed in period 2004-2005 where the same probability density (log-Pearson III) was obtained. However, the *t*-test reveals that there are significant differences in the variances and averages of these two years. Therefore, the results show that, in the period under review, there is no homogeneity of variances in the information regarding area affected by forest fires and that this phenomenon is a non-stationary process. In other words, fire occurrence, expressed in this case as affected surface, occurs totally randomly in each year. This phenomenon is very similar to precipitation, which can bring in a very humid year (season), but the following one is very dry.

To observe temporal variations in more detail, the temporal autocorrelation coefficient was estimated, which measures the affected area dependence degree in time t with itself at time $t + k$. Several categories and time periods k were used. A coefficient was estimated daily, monthly and yearly, and in each category up to 10 periods (lags) were used to observe the consistency of results. The results indicate that in the daily correlation a coefficient that varies between 0.08 and 0.20 ($p < 0.05$) was found, indicating the existence of autocorrelation; however, this is very low. In the case of monthly and annual autocorrelations, despite having relatively high coefficients (0.33 to -0.77), this was not statistically significant in any of the periods ($p > 0.05$). The results indicate a slight daily autocorrelation, that is, the amount of surface burning in one day has a positive effect, motivated perhaps by daily weather conditions, on the amount of surface burning in the following day. However, this does not happen in the case of monthly and annual autocorrelations. In such cases, and in accordance with Levene's test, the (variable) affected area behaves randomly.

Geographically weighted regression (RPG)

Individual analysis of the parameter means of the RPG model factors that affect fire magnitude shows that distance to grassland areas, distance to crop areas, rainfall, slope and exposure are negative. The rest of the factors' parameters assume positive values (Table 2). This table shows that, based on the Monte Carlo test, in factors population gravity index (IGP), distance to roads (ROADS), precipitation (PRECIP), temperature (TEMP) and altitude (ALTITUD) the spatial seasonality hypothesis is rejected and it is concluded that these factors are significantly non-stationary in the study area. The property of no seasonality suggests that the magnitude of forest fires does not follow a consistent pattern of variability and is influenced by the fire's geographical position. For example, fires that are geographically closer to roads have a relatively lower affected area than those where the distance is greater. This may be because in the more remote areas, fire fighting and control is more difficult and therefore fires tend to affect more surface than in those areas where access is relatively easy. Such differences could not be detected by the overall model (RLS) in which it is assumed that the distance to roads has a constant effect on the affected surface. Fires' geographical position determines the influence degree of these factors over forest fires' magnitude.

Table 1—Ranges of the parameters of the factors on the local regression model (RGP) for the area affected by forest fires in Durango, Mexico.

Variable	Min	First quartile	Mean	Second quartile	Max	Monte Carlo test (<i>p</i> -value)
Intercept	-3209.9	-1612.4	-459.06	-31.697	800.56	0.06
IGP	-3.587	-0.379	-0.079	3.619	5.054	0.00***
CAMINOS	0.002	0.011	0.030	0.044	0.082	0.02*
LOCALID	0.004	0.010	0.015	0.024	0.034	0.30
PASTIZAL	-0.013	-0.005	-0.002	0.001	0.018	0.48
CULTIVOS	-0.014	-0.003	-0.001	0.002	0.008	0.32
DEFOREST	-0.011	-0.002	0.000	0.002	0.008	0.06
PRECIP	-0.365	-0.222	-0.184	-0.055	-0.024	0.02*
TEMP	-15.374	2.772	14.771	56.434	121.841	0.05*
REGPROP	-71.188	-3.483	7.907	18.228	36.430	0.64
PEND	-4.215	-2.268	-1.060	-0.562	0.002	0.35
EXPO	-0.183	-0.062	-0.018	0.028	0.239	0.80
ALTITUD	-0.173	0.008	0.094	0.327	0.647	0.05*

*** = significant at 0.1% level; ** = significant at 1%; * = significant at 5%.

The factors distance to paths (*CAMINOS*), distance to towns (*LOCALID*) and precipitation (*PRECIP*) show consistent signs; that is to say, they remain unchanged at their maximum, intermediate and minimum values. The first two are directly related, while *PRECIP* is inversely related to the magnitude of the fires. Avila and others, (2010) found the most important factors that influence fire occurrence are vegetation susceptibility to fire, intensity of land-use change and precipitation. For precipitation, a common factor in this study, they found that this factor has a direct influence on the number of fires. This is somewhat contradictory since high rainfall in a given year tends to reduce the number of fires and the amount of affected area that year.

The results for the RGP model confirm that the magnitude of the fires is strongly influenced not only by environmental factors (precipitation, temperature, altitude), but also by socioeconomic factors (population severity index, distance to roads and distance to towns). There is little that can be done to mitigate the effect of the first, but there is much that can be done to reduce the effect of the second group. While it is true that fires located near roads and towns are low magnitude, their constant and recurring frequency increases the opportunity cost and decreases the likelihood of addressing other priorities. Rodriguez-Trejo and Fulé (2003) discuss a number of measures that can be implemented to reduce the negative impact of fire. Their management proposals are divided into cases where fires are excessive, normal (appropriate) or insufficient.

Finally, to observe in detail the possible variations of the combined effect of all factors, an analysis of the predicted values and residuals of the local model (RGP) was performed. Using a geographic information system, a map to indicate the differences between the affected and predicted areas was built (Figure 3). Frequency analysis revealed that 84% of the residual value of all fires are located in the middle of the table, that is between -82 and 82 hectares (-0.5 to 0.5 standard deviations). This suggests that the differences between the values of the area observed and predicted by the local model are mostly concentrated around zero and that the model is generally acceptable. The average of the residuals equals -0.94 ha, while the median is equal to -12.3 ha.

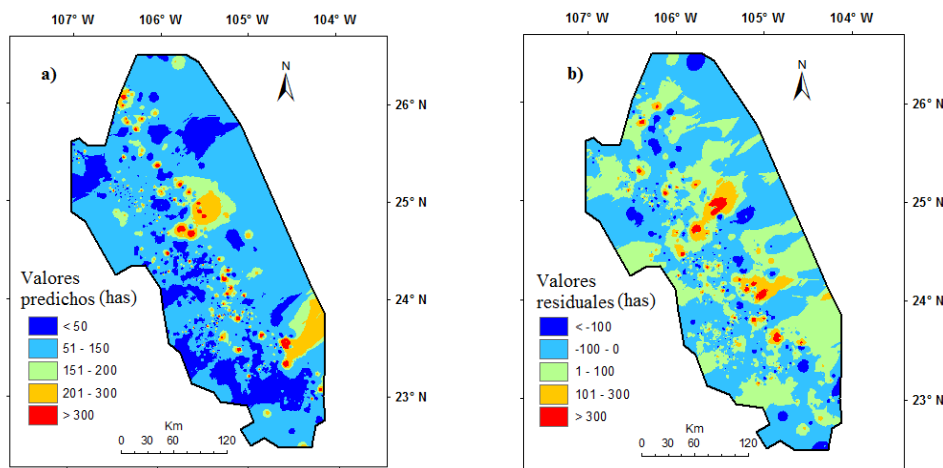


Figure 3—Spatial analysis of the RGP model results in Durango, Mexico. Figure 3a) shows predicted values while Figure 3b) shows the residuals.

Summary

According to the results, fires in the State of Durango are spatially distributed in an aggregated manner and are not temporarily stationary. The geographically weighted regression model is a suitable tool for the study of phenomena such as forest fires. This model, unlike the simple linear regression method, assigns a different weighting as observations increase their distance and become more dissimilar. It also helps to identify factors that have a constant or variable effect according to geographical location. The most important factors that influence fire magnitude can be classified as environmental (precipitation, temperature and altitude) and socioeconomic (distance to roads, distance to towns and population severity index). The population severity index (IGP), distance to roads (ROADS), precipitation (PRECIP), temperature (TEMP) and altitude (altitude) factors are not stationary in the study area nor in the time period analyzed. The geographical position of fire determines these factors'

influence over the magnitude of forest fires. The use of these statistical tools in studies analyzing stochastic variables is recommended.

Acknowledgments

This study was carried out with funding from Instituto Politécnico Nacional (National Polytechnic Institute), project SIP 20110943, CONACYT and the Comisión de Operación y Fomento de Actividades Académicas (Commission for the Conducting and Promotion of Academic Activities, known by the Spanish acronym COFAA-IPN). We thank the National Forestry Commission's Durango management staff and the National Meteorological Service's general coordination office for their help in collecting data.

References

- Alanís-Rodríguez E., Jiménez-Pérez J., Espinoza-Vizcarra D., Jurado-Ybarra E., Aguirre-Calderón O.A., González-Tagle M. A.** 2008. Evaluación del estrato arbóreo en un área restaurada post-incendio en el parque ecológico Chipinque, México. *Revista Chapingo. Serie Ciencias Forestales y del Ambiente* 14(2): 113-118
- Avila FD., Pompa GM., Antonio NX., Rodríguez TD., Vargas PE., Santillán PJ.** 2010b. Driving factors for forest fire occurrence in Durango State of Mexico: A geospatial perspective. *Chinese Geographical Science* 20(6): 491-497.
- Burt J.E., Barber G.M.** 1996. *Elementary statistics for geographers*. The Guilford Press: New York, NY.
- CONAFOR (Comisión Nacional Forestal).** 2012. Reporte nacional de incendios forestales. Publicación interna de trabajo. CONAFOR. Guadalajara, Mex. Disponible en <http://www.mexicoforestal.gob.mx/files/120427%20reporte%20nacional%20incendios.pdf> (Ultimo acceso Mayo 12, 2012).
- Drury, S.A., Veblen, T.T.** 2008. Spatial and temporal variability in fire occurrence within the Las Bayas forestry reserve, Durango, Mexico. *Plant Ecology* 197: 299–316.
- Fulé, P.Z., Covington W.W.** 1999. Fire regime changes in La Michilia Biosphere Reserve, Durango, Mexico. *Conservation Biology* 13(3): 640-652
- Fotheringham, A., Brunsdon, C., Charlton, M.** (2002). *Geographically weighted regression: The analysis of spatially varying relationships*. West Sussex, England: John Wiley & Sons, LTD.
- Harris P., Brundson C., Fotheringham A.S.** 2011. Links, comparisons and extensions of the geographically weighted regression model when used as a spatial predictor. *Stoch. Environ. Res. Risk. Assess.* 25: 123 – 138.
- Moran, P.A.P.** 1950. Notes on continuous stochastic phenomena. *Biometrika*, 37: 17–23.
- Rodríguez-Trejo, D.A., Fulé, P.Z.** 2003. Fire ecology of Mexican pines and fire management proposal. *International Journal of Wildlife Fire* 12:23-37.
- Wong W.S.D, Lee J.** 2005. *Statistical analysis of geographic information with ArcView GIS and ArcGIS*. John Wiley Inc. New York, NY.

Spatial Allocation of Market and Nonmarket Values in Wildland Fire Management: A Case Study¹

**John W. Benoit, Armando González-Cabán, Francis M. Fujioka,
Shyh-Chin Chen, José J. Sanchez²**

Abstract

We developed a methodology to evaluate the efficacy of fuel treatments by estimating their costs and potential costs/losses with and without treatments in the San Jacinto Ranger District of the San Bernardino National Forest, California. This district is a typical southern California forest complex containing a large amount of high-valued real estate. We chose four sites to represent different land use types – real estate, mixture of real estate and wilderness, recreation use and non-use. Within each site, we iteratively ran the FARSITE fire simulation model using different random starting locations and weather scenarios. Weather data for the simulations was extracted from both a remote automatic weather station data stream and a high-resolution weather model.

These simulations were repeated to incorporate simulated fire suppression and fuel treatments. We define heuristics for simulating suppression tactics based on actual fire line production rates. Fire suppression resources were simulated and incorporated into the fire spread simulations. We simulated fuel treatments by applying collected treatment data over the landscape and adjusting fuel models using ArcFuels, a GIS-based fuel management and risk assessment tool.

The economic value of each land-use type in the San Jacinto wilderness was estimated spatially using tax assessment data, recreation values, and water resource values. Costs of suppression and treatments were estimated from actual data.

Key Words: Decision-making, FARSITE, fire spread simulation, fuel treatments, GIS, Monte Carlo simulation, San Jacinto Wilderness.

¹ An abbreviated version of this paper was presented at the Fourth International Symposium on Fire Economics, Planning, and Policy: Climate Change and Wildfires, 5-11 Nov 2012, Mexico city, Mexico

²Computer Specialist, Research Economist, Emeritus Research Meteorologist, Meteorologist, Mathematical Statistician, respectively; USDA Forest Service, Pacific Southwest Research Station, 4955 Canyon Crest Drive, Riverside, CA 92507, USA; jbenoit@fs.fed.us, agonzalezcaban@fs.fed.us, fmfujioka@fs.fed.us, schen@fs.fed.us, jsanchez@fs.fed.us.

Introduction

Commonly asked questions in the fire community have to do with the risk, cost, and effectiveness of fuel treatments and fire suppression. However, quantifying such values is often difficult if not impossible. Many costly fire planning decisions are therefore based on 'gut' feelings. It would help planners to have better estimates of the costs and benefits of different strategies. In this study, we developed a methodology to provide such costs and benefits estimates.

The San Jacinto Ranger District (SJRD) in the San Bernardino National Forest lies amidst a well-populated region of southern California. It contains a mixture of wilderness and high-priced homes, and is a favorite spot for recreational activities. The threat of wildfires in this district is a serious concern, as there is great potential for destruction monetarily, environmentally, and in terms of life. For our study, we gathered several data layers for San Jacinto, including geographic, climatological, and economic data.

Economic data layer development

We estimated economic values spatially by examining three sources: real estate, recreational use, and water replacement cost. Real estate values were obtained by tax assessment data inflated to 2005 values. The majority of high-priced housing was in Idyllwild. Much of the surrounding area had little or no housing (Figure 1).

Recreational attractions included 128 km of hiking trails and an aerial tramway from the Palm Springs area that attracts 350,000 visitors annually. Two ranger stations and a state park office issue usage permits to visitors, which allows the annual visitation to be tracked and regulated. Recreational usage value was obtained from these permits. Finally, the value of water resources was estimated by considering the cost to replace water supplies that would be contaminated due to post-fire erosion. The three sources of economic value were then aggregated into a spatial data layer. The data layer estimated total economic values of every 30-meter square pixel in the SJRD



Figure 1—The San Jacinto Ranger District. The Idyllwild-Pine Cove community near the district's center accounts for most of its developed area. Source: Google Maps.

Batch fire simulations

We collected several geographic data layers for the district, such as a map of elevation values. A fuel model map was obtained from the California Department of Forestry and Fire Protection's FRAP website (FRAP 2007). This map identified the observed arrangement of fuel models in the SJRD in 2004. Fuel models are used in modeling fire behavior.

We chose four sites within the district to represent different land uses: Real Estate, Real Estate Edge, Recreation Only, and Non-Use. The Real Estate site represented high-valued properties and was centered on the town of Idyllwild. The Real Estate Edge site was located in an area consisting of approximately half real estate (Idyllwild) and half undeveloped wilderness. Two areas along the main highway through the San Jacinto district were selected to represent Recreation Only use. Finally, a generally inaccessible, non-utilized area was chosen that represented the Non-Use site. All sites have the same area of approximately 12.6 square kilometers (Figure 2).

Within each of the four sites, 100 x-y coordinate pairs were randomly and uniformly selected. These locations served as the simulated ignition points of fires for the fire model used. Additionally, 100 starting times were randomly selected without replacement for each site from June 1, 2005 to July 10, 2006, a period for which we had modeled 1km spacing, hourly gridded wind and weather data for the San Jacinto area using Meso-scale Spectral Model (MSM, Juang 2000). The simulation was done by forcing MSM with roughly 60km spacing operational analysis from National Centers for Environmental Prediction.

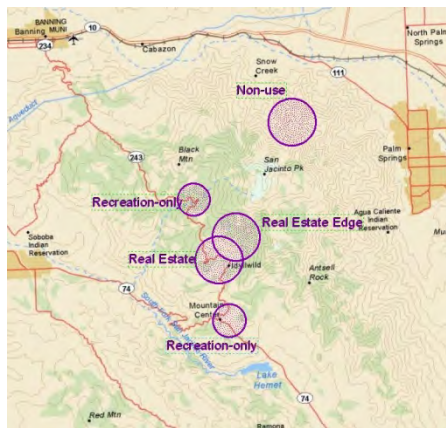


Figure 2—Locations of selected study sites in the San Jacinto Ranger District.

In addition, temperature, relative humidity and precipitation were used in the fire model as a single stream of hourly values representing the entire modeling domain. Data for these variables came from the Keenwild weather station located near Idyllwild, and was collected for the same period as that covered by the gridded RSM wind data.

Each unique combination of the randomly selected locations and starting times at each site defined the scenario for a single fire growth simulation. We used FARSITE version 4.1.0 fire area simulator to perform the simulation runs for these scenarios. FARSITE is a popular tool among fire managers in the United States for predicting both prescribed fire and wildfire behavior. It is typically run as a Microsoft Windows application, allowing the user to visualize predicted fire behavior given terrain, fuels, and weather as input parameters. Output can also include raster grid files of the arrival times, fire line intensities, flame lengths, and spread rates, as well as vector files of simulated fire perimeters (Finney 1998).

We created a command line version of the program that could be iteratively driven by a Perl script. The script used different input parameters for each run based on the random locations and starting times. Terrain and fuel conditions at and around each location, along with weather conditions, would determine the modeled fire behavior. We set a maximum of six hours simulation time on each run. Realistically there are fires that burn much longer than this time limit; however, the intent was to model *free-burning* fires without significant suppression activity taken.

A total of 40,000 attempted *free-burning* fire simulations were made (100 locations x 100 starting times x 4 sites). Each run produced an output grid of arrival time values over the same 30-meter cells that the input landscape data layers were divided into. The arrival time of each cell is the amount of time (in hours) that the fire took from the ignition point to each cell. All arrival time grids from each site's completed simulation runs were compiled into a summary grid, where cell values represented the total number of times they had positive arrival time values during the

runs. This summary grid could be interpreted as a two-dimensional histogram, indicating how often each cell was ‘burnt’ during the simulated fires. Estimated probabilities of burning were obtained by dividing the cell values by the number of successful runs. Multiplying this grid of probability values by the economic data layer produced a map of expected loss due to wildfire.

Fire suppression modeling

After the initial set of free-burning simulations, a second set was performed using the same random locations and times but including simulated fire suppression. We developed a system for suppression actions by predefining tactics as a set of rules to use in FARSITE. FARSITE allowed obstructions to fire growth to be specified, given point-to-point paths and rates or coverage lengths. We defined a set of firefighting resources for suppression actions, which emulated actual resources that could be available to a forest district (Table 1); and included production rates and costs. Resource attributes were taken from estimates given in resource allocation studies (Donovan and Rideout 2003, Wiitala 1999) and adjusted by the U.S. Consumer Price Index.

These fire simulations were allowed to run unrestricted for the first hour to model the time between which the fire ignites and fire suppression begins. After the initial hour, these simulations ran for only five hours in simulation time, and thus were six-hour simulations like the free-burning ones. As in the unsuppressed case, a total of 40,000 simulations were run. The modified driving script decided suppression tactics given the first hour perimeter (unsuppressed) of each fire. Costs of resources used during each simulation were included with the arrival time grid output. Another expected loss map was then produced using the same method as with the unsuppressed simulations.

Table 1—*Suppression resources modeled in fire simulations.*

Resource	Quantity	Cost
Type II Hand crew	2	Flat fee: \$1260.69 Per hour: \$ 160.96
Type I Hand crew - “Hotshots”	1	Flat fee: \$1600.01 Per hour: \$ 225.35
Engine - 600 gallon capacity	1	Flat fee: \$ 435.35 Per hour: \$ 76.56
Engine - 1000 gallon capacity	1	Flat fee: \$ 317.62 Per hour: \$ 76.56
Air tanker - 1200 gallon capacity	1	Per drop: \$9271.71
Air tanker - 200 gall	1	Per drop: \$5150.95

on capacity		
Helicopter - 375 gallon capacity	1	Per drop: \$1064.65
Helicopter - 1000 gallon capacity	1	Per drop: \$2839.06

Fuel treatment modeling

The costs and effectiveness of fuel treatments in the SJRD was of interest. We incorporated fuel treatment effects into our simulations by obtaining actual treatment information for SJRD for 2004 to 2010 (Region 5 – Geospatial Data 2012). These records included descriptions of treatment activities and costs. Most of the treatments occurred around Idyllwild or along the main highways through the forested region. A new fuel models map was built using ArcFuels that presented the effects of fuel treatments on the area (Vaillant and others 2012). We reran the unsuppressed fire simulations (40,000) using the modified fuels map and all original information. As before, we created an expected loss map based on these runs. To compute costs for the four study areas (Figure 3), it was necessary to assign the treatments to only one area each. This allowed treatment costs to be summed and used to represent total preventative costs for each study area.

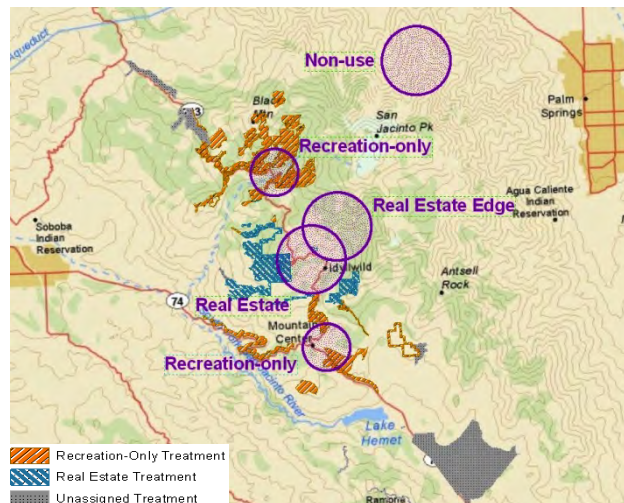


Figure 3—Fuel treatments applied to the San Jacinto Ranger District from 2004-2010. The Recreation Only and Real Estate study areas were assigned costs of nearby treatments. Costs for treatments far from the study sites were disregarded. The Real Estate Edge and Non-Use sites had no treatment costs since there were none in their proximity.

Combined modeling

Finally, we performed a set of suppressed fire simulation runs on the treated landscape. These runs were similar to the previous runs in all other aspects besides the use of treated fuels and suppression resources and rules. Output was again saved and processed to produce an expected loss map.

Results

We attempted a total of 160,000 simulation runs, but some problematic situations occurred¹. All FARSITE simulations were run deterministically – effects such as random spotting were disabled. Not having any random components in the fire model meant that perimeter differences could then be attributed solely to particular ignition points, weather scenarios, and to using or not using suppression or fuel treatments.

Figure 4 shows charts of the total simulated costs spent for protection, total burned area of successful runs, and losses due to damage. The Cost charts represent money spent on suppression resources, fuel treatments, or both. The Real Estate Edge and Non-Use sites had no treatment costs because none were applied in these areas. Also, the proximity of treatments applied to the Real Estate site resulted in differences in the Real Estate Edge treated versus untreated cases.

We computed loss from the developed economic data layer discussed earlier.

¹Because of space limitations these are not presented here, and are not considered in the results.

Loss was accumulated from the economic values of 'burned' pixels for all simulation runs for each of the four sites. Overall total loss values tended to be exceedingly large partly because of high-priced real estate (mainly in the Idyllwild area) loss included values.

Total area burned is the sum of the final (6-hour) perimeter sizes of the fire simulations for each case. As we expected, in most cases, area burned was reduced when simulated suppression efforts were applied. In suppressed cases for the Real Estate and Real Estate Edge sites, adding treatments appeared to actually *increase* loss and area burned (Table 3). This may indicate that fuel parameters are misspecified or that fuel maps used in the fire model are inaccurate. This phenomenon may also be due to the change of fuel types 'slowing down' the line production rate from simulated fire crews and thus allowing more escaped fires. More analysis will be needed to reveal cause of the increased burned area in the treated and suppressed cases. Additionally, for the unsuppressed cases of Real Estate and Real Estate Edge sites, areas burned decreased when treatments were applied, but losses *increased*. This may happen if a fuel type was changed to one that allowed fires to burn fewer but higher-valued pixels than before treatments – an undesirable effect.

Finally, there were two situations where adding suppression to fires on treated landscapes appeared to slightly increase loss (Recreation Only site) or area burned (Real Estate site). This likely occurred because simulated fire line is included in computed fire size for each run. If suppression efforts did not greatly alter the final perimeter size of a fire, it would appear that the fire was smaller without suppression intervention. This situation seemed to occur mainly with fires that remained relatively small at the end of the simulated six-hour time period.

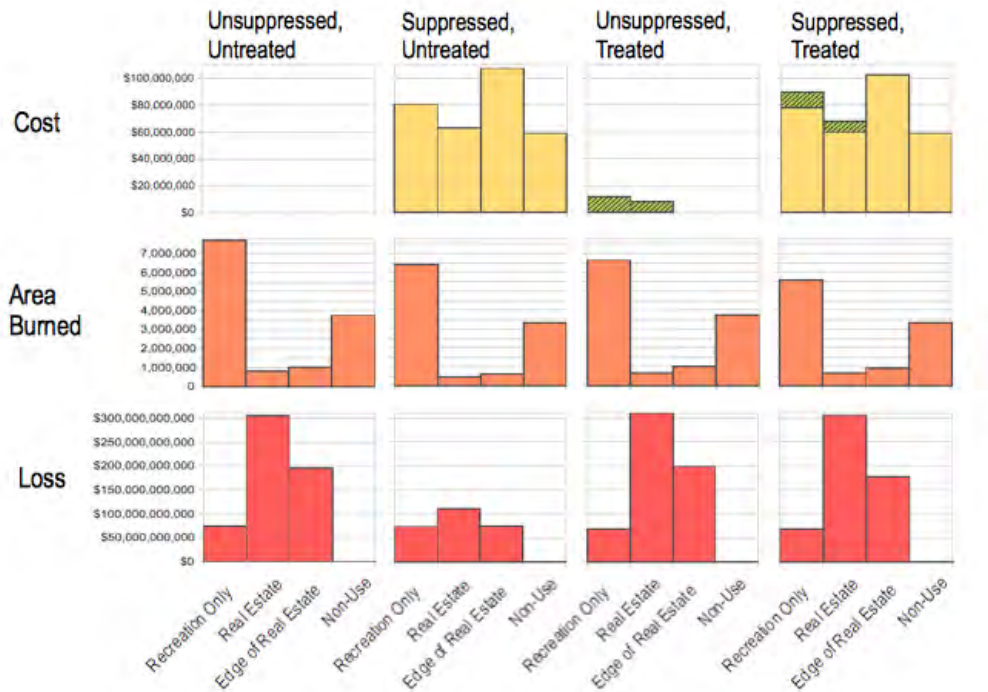


Figure 4—Charts of total protection cost, area burned, and loss for each of the four sites for the four cases. Note that the columns in the Suppressed, Treated case for Cost are simply the sums of the Suppressed, Untreated and Suppressed, Treated columns.

Of the four sites, Real Estate exhibited the lowest area burned values but highest loss in each of the four cases. The small fire sizes at this site may be the result of earlier fuel management practices for which the effects are reflected in the 'untreated' landscape used for the fire simulations. Potential damage by such fires would be great, as they would be occurring within the largest inhabited area within the district.

Table 3—Total sums of costs for protection, area burned, and losses for the four sites.

Site	Protection Cost	Area Burned (Ha)	Loss
Recreation Only			
Unsuppressed, Untreated	\$0	7,701,358	\$73,950,098,015
Suppressed, Untreated	\$80,346,991	6,399,367	\$73,690,421,333
Unsuppressed, Treated	\$11,646,751	6,646,165	\$68,161,910,849
Suppressed, Treated	\$89,278,608	5,598,839	\$68,281,014,079
Real Estate			
Unsuppressed, Untreated	\$0	823,324	\$304,332,752,013
Suppressed, Untreated	\$62,899,279	471,933	\$111,446,356,075
Unsuppressed, Treated	\$8,197,408	664,961	\$309,458,665,154
Suppressed, Treated	\$67,544,194	672,204	\$305,190,933,121
Real Estate Edge			
Unsuppressed, Untreated	\$0	1,026,896	\$195,790,547,680
Suppressed, Untreated	\$106,832,043	599,295	\$75,269,486,390
Unsuppressed, Treated	\$0	1,022,757	\$198,186,376,318
Suppressed, Treated	\$102,309,409	919,693	\$177,385,793,990
Non-Use			
Unsuppressed, Untreated	\$0	3,747,335	\$593,915
Suppressed, Untreated	\$58,755,176	3,317,480	\$528,227
Unsuppressed, Treated	\$0	3,747,335	\$593,915
Suppressed, Treated	\$58,755,176	3,317,480	\$528,227

Discussion

Results of running these nearly 160,000 fire simulations surprisingly showed minimum loss to occur when suppression was applied to a landscape that did not undergo treatment. This does not necessarily mean actual treatments did not have any beneficial effect. It is possible that the resulting treated fuels were misspecified, or that other factors were not taken into consideration. Suppression and treatments had less of an effect on area burned than we expected. The random placement and times of simulated fires may have produced unrealistic scenarios that were not accounted for when treatments were placed. Suppression heuristics could have been insufficient to completely stop the simulated fires. Run output will have to be more closely analyzed to find the source of the unexpected results.

The methodology we used is a framework to estimate cost, area burned, and damage due to fire under different protection scenarios. Adding a suppression heuristics component allowed us to include simulated firefighting effects. We were able to model the effects of fuel treatments on fire as well.

From the results presented here it is clear the potential for improvements in the methodology. The random ignition locations and starting times could have been selected using a more realistic distribution based on local fire history, thus reducing potential overrepresentation of simulated ignitions in particular seasons.

We implemented a version of FARSITE that employed an older set of fuel models used in the U.S. Forest Service. The system we used to determine fuel distribution after treatment required the use of a newer set of fuel models, which posed difficulty when trying to incorporate the treated fuels landscape in FARSITE. This created uncertainty and possible incorrect matches between the two sets. This version of FARSITE also only allowed for single streams of temperature, relative humidity, and precipitation values to represent weather in a large region, whereas we had modeled gridded weather data available to us. Only gridded wind values were allowed in our version. It would be advantageous to have the capability of using the other gridded weather fields rather than the single streams when modeling fires.

Improving the accuracy of the data layers we used would help produce more realistic fire simulations, suppression and treatment costs, and economic loss estimates. Work is currently underway to gather more accurate economic values for the district. This work involves surveying wilderness users to estimate nonmarket values of the region.

Fire suppression decisions could have been simulated in a number of ways, but the simplest was to define a set of heuristic rules on how resources should be deployed based on existing conditions matching real world tactics in deploying resources. Some improvement may be gained by correcting or redefining these rules, or by allowing suppression actions to be altered during the course of each fire simulation run. Such changes would likely make the simulated fire suppression decision-making component more realistic.

Results from this methodology must be interpreted carefully. The modeled behavior seen when adding or removing suppression and/or fuel treatments has not been empirically tested. Also, the spatial economic data layer we developed incorporated the nonmarket values of wilderness, water replacement costs, and real estate values. Putting too much emphasis on protecting mainly the highest value areas may lead to leaving a majority of less valued areas at a lower protection level. Since cost amounts of resources and treatments were rough estimates, the final computed monetary values may not be as accurate as would be desired. We intend to improve the accuracy of these input values in future studies.

References

- Anderson, H. E.** 1982. Aids to determining fuel models for estimating fire behavior. Gen. Tech. Rep. INT- 122. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 22 p.
- Broyles, George.** 2011. Fireline production rates. 1151 1805P. San Dimas, CA: U.S. Department of Agriculture, Forest Service, San Dimas Technology and Development Center. 23 p.
- Donovan, Geoffrey; Rideout, Douglas B.** 2003. An integer programming model to optimize resource allocation for wildfire containment. *Forest Science*. 49 (2) 331-335.
- Finney, Mark A.** 1998. *FARSITE: Fire Area Simulator—model development and evaluation*. Res. Pap. RMRS-RP-4, Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 47 p.
- FRAP – Fire and Resource Assessment Program.** 2007. California Department of Forestry and Fire Protection. Web. 22 April 2012 <<http://frap.fire.ca.gov/>>.
- Juang, H.-M. H.** 2000. The NCEP Mesoscale spectral model: A revised version of the nonhydrostatic regional spectral model. *Mon. Wea. Rev.* 128: 2329-2362.
- NWCG – National Wildfire Coordinating Group.** 2004a. Fireline Handbook. PMS 410-1, NFES 0065. Web. 24 April 2012. <<http://www.nwcg.gov/pms/pubs/410-1/410-1.pdf>>.
- NWCG – National Wildfire Coordinating Group.** 2004b. Interagency Air Tactical Group Supervisor's Guide. NFES 1393. Web. 26 April 2012. <<http://gacc.nifc.gov/eacc/library/Dispatch/aviation/ATGSguide.pdf>>.
- NWCG – National Wildfire Coordinating Group.** 2006. Incident Response Pocket Guide. PMS 461, NFES 1077.
- Region 5 – Geospatial Data.** 2005. USDA Forest Service. 31 August 2012. <<http://www.fs.usda.gov/detail/r5/landmanagement/gis?cid=STELPRDB5327833>>
- Scott, Joe H.; 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: US Department of Agriculture, Forest Service, Rocky Mountain Research Station. 72 p.
- Trethewey, Diane.** 2007. Development of an index for quick comparison of helicopter costs and benefits. *International Journal of Wildland Fire* 16(4): 444-449.
- USDA Forest Service.** 2009. Aviation Operations and Safety Plan. Pacific Southwest Region. <http://www.fs.fed.us/r5/fire/aviation/pdf/09_av_ops_safety_plan.pdf>.
- Vaillant, Nicole M.; Ager, Alan A.; Anderson, John; Miller, Lauren.** 2012. ArcFuels User Guide: for use with ArcGIS 9.X. Internal Report. Prineville, OR: US Department of Agriculture, Forest Service, Pacific Northwest Research Station, Western Wildland Environmental Threat Assessment Center. 247 p.
- Wiitala, Marc.** 1999. A dynamic programming approach to determining optimal forest wildfire initial attack responses. Symposium on Fire Economics, Planning, and Policy: Bottom Lines, April 5-9, 1999, San Diego, CA. Gen. Tech. Rep. PSW-GTR-173. Berkeley, CA: USDA Forest Service, Pacific Southwest Research Station; 115-123.

Shift in Fire-Ecosystems and Weather Changes¹

Bongani Finiza²

Abstract

During recent decades too much focus fell on fire suppression and fire engineering methods. Little attention has been given to understanding the shift in the changing fire weather resulting from the global change in weather patterns. Weather change have gradually changed the way vegetation cover respond to fire occurrence and brought about changes in fire behavior and intensity. In the past two decades there has been an increase in the occurrence of catastrophic fires, fire fighters has lost their lives in the line of duty, the environment was degraded and the livelihood of many people has been damaged or destroyed. Fire season also seems to extend beyond the normal fire season making it difficult to confirm the duration of fire season. According to observations and recent reports across the globe, it was revealed that most wildfires managed to escape while fire fighters perceived that they had them under control. Some fires that escaped also resulted as a result of shortage of water and other basic resources. It is time to transform firefighting techniques and devise new strategies that will enable fire managers to prevent and take control of out of control fires. This should lead to savings on suppression costs and allow better application of money earmarked for fire management. Efforts to offset the results of wild fires should be refocused by adjusting fire activities to synchronize with changes in weather and to deal more effectively with an altered vegetation cover. Water is a scare resource with significant impacts on some countries in Africa such as South Africa, Morocco and Kenya; there are also other countries which are becoming water stressed at an increasing rate. These countries include the United Kingdom, Cameroon and Nigeria. Dry and wet seasons are becoming longer in some regions, resulting in vegetation cover that is starting to adapt and change. These changes might vary from a drier flashier vegetation where plants adapted to survive in drier conditions become more dominant (usually woody weeds), to a denser vegetation cover with a higher fuel load in wetter areas.

Key words: Climate change, fire management, vegetation covers

Introduction

¹ An abbreviated version of the paper was presented at the Fourth International Symposium on Fire Economics, Planning, and Policy: Climate Change and Wildfires, November 5-11, 2012, Mexico City, Mexico.

² Forestry Student at Nelson Mandela Metropolitan University, George Campus in South Africa; Cell: (+27) 076 030 1350; Fax: (+27) 086 218 4033; Email: s210095784@live.nmmu.ac.za

The occurrences of catastrophic fires around the globe are starting to raise a serious concern. Global climate change has a significant influence in which way fires are behaving, spreading and occurring. Scientific report has shown that water availability will become a scarce resource (United Nations Global [UNGC] 2009). Vegetation cover is also impacted by climate change and forests are believed to be there ones which are going to be severely be impacted and there will be a shift in their ecosystem (Food and Agriculture Organization [FAO] 2012). Fire plays a significant role in maintains of biodiversity and ecosystem. Changing weather is altering fire benefits by altering favorable conditions to results in a high number of catastrophic fires which are resulting in loss of lives and environment destruction (Fried and others 2004). Climate change does not only have an impact on environmental factors but also has a significant impact on economy. To be able to obtain a quantified impact on economy, it is necessary to calculate the physical impact and convert it into its economic value (Tol 2009). The most important firefighting basic recourse; water is also badly impacted and some countries are facing water scarcity and thus other are facing water stress.

Weather changes and its significant impact

The change in weather patterns has resulted in change in vegetation and has a significant influence in the way wildfires are continuously occurring and the destruction they are causing. Ecosystems and biodiversity are changing and degrading to the extent of value loss. Some parts of South Africa will experiment a severe impact of climate change to an extent that some of the species will be lost through extinction (Stefik 2006). The ecosystem will shift and so thus the fire-ecosystems will change to certain degree. The distribution of flora and fauna is influenced by the environmental climatic patterns. These species are only occurring in areas which are rich in biodiversity, thus have different maintenance requirements and if there is a shift in weather patterns might lead to an extinction of some species (Stefik 2006). In the figure below, they illustrate the fire ignition sources and the possible future changes (Trollope 2012).

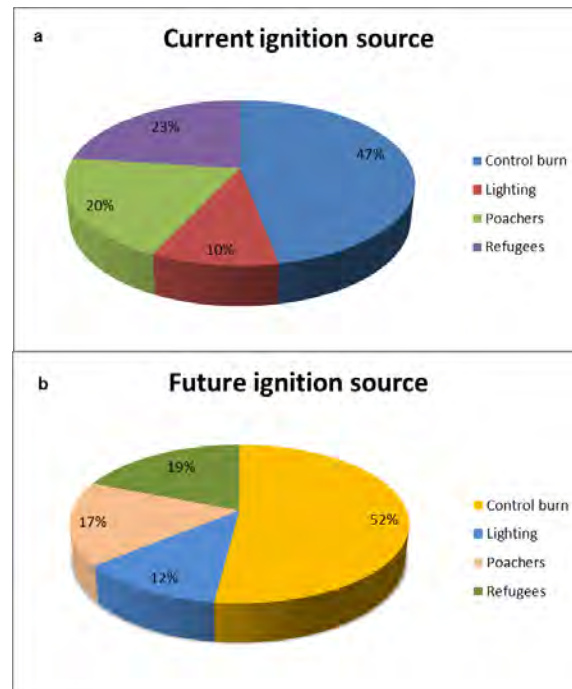


Figure 1—The ignition source assessment of Kruger National Park in South Africa (Trollope, 2012), 1a illustrate the current fire status while 1b illustrate future scenario

Changing response in South African biomes

The South African biomes are distributed according to weather patterns and climate variation. These biomes are not only distributed in manner of climatic characterization but also soil properties play a significant role. Favorable conditions for fire occurrence and spread are determined by weather and vegetation state (Thonicke 2010). Too much fire frequency and intensity results in short fire returns intervals and that might cause a severe damage to the ecological progress of the biome. South African biomes are expected to change and be compacted to the eastern part of the country, and it is expected that the western part will have an increase in acidity and there will be an introduction of a new biome up to northern certain parts (Stefik 2006). Figure 2 illustrates the present fire-ecosystems in South Africa and the predicted shift in the fire-ecosystems.

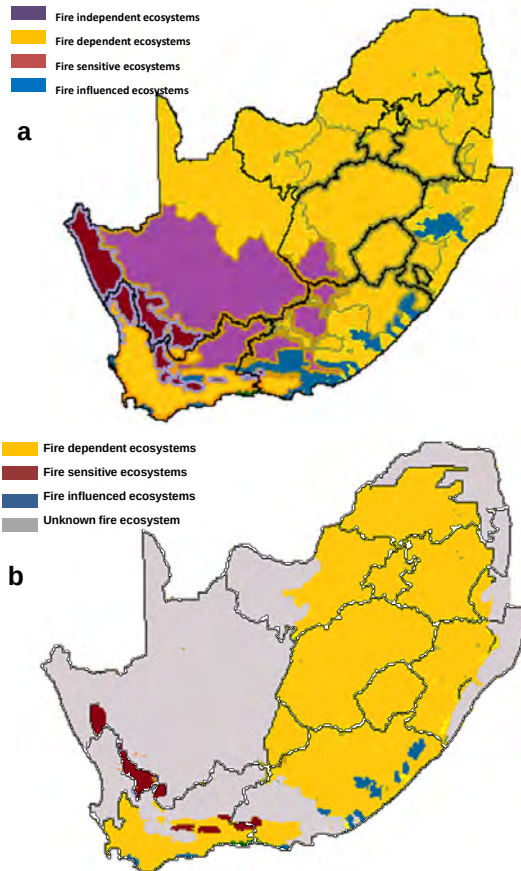


Figure 2—The current fire-ecosystems in South Africa and the predicted future changes due to the climate change (Turpie, 2003), 1a shows the current distribution of fire-ecosystem and 1b shows future change as a results of climate change

Grassland –

Fire is required in South African grassland biome to maintain its biodiversity and ecological functionality. The fire management system is recognized within South Africa, for domestic and wildlife management purpose (Trollope 2012). To maintain grass palatability, fire occurrence or application is required. Fire is perceived as a primary tool to manage rangelands to sustain the demand from wildlife and domestic livestock (Trollope 2012). Grasslands are situated in summer rainfall areas. Climate change has a potential of altering precipitation patterns and that may leads to less productivity of these areas and may significantly affects the botanical composition, ecological status and basal cover. The types of classes which will be affected are (Trollope 2012):

- Decreaser Species: the grass and herbaceous species which decrease when the area is under or overgrazed.
- Increaser I Species: grass and herbaceous species which increase when the area is under grazed.

- **Increaser II Species:** grass and herbaceous species which increase when the area is over grazed.

Savannah –

Savannah biome is believed to be affected by the climate change in areas around the equatorial belt and the forest biome is been replaced by savannah (Favier and others 2003). The vegetation behavior is not entirely driven by the climate change but also by the human burning activities. Natural forest expansion into savannah ecosystem is restricted by the use of fire, either too frequently or at highly intensity (Favier and others 2003).

Forest –

Present areas which contain forest biome are expected to shrink and some of commercial species are said to be not adaptive to such weather changes. The survival and growth of is influenced by climate condition, some of species are more adaptive than others and that might results in extinction of some species (FAO 2012). Forest behavior and respond to the changing weather is said to have an impact on species level not on forest level. The shift in the forest ecosystem is entirely influence by the adaptability of species to environmental change. It is also been perceived that most species have a tendencies of moving to the higher altitudes or higher latitudes (FAO 2012). Climate change does not only impact on forest tree species but also impact on non-timber forest plants and animals. Forest habitant is altered and becomes not favorable for the survival of other species especial those which does not easily or does not at all adapt to changes.

Fynbos –

The fynbos biome is one of the fire-dependent vegetation in South Africa to maintain its ecosystem and biodiversity. Fire occurrence or application stimulate seed germination and/or release from cone (de Ronde 2012), recently in South Africa there has been a series of worse fires in fynbos areas which to some extent manage to claim lives and damage to property (in press). The fynbos optimum fire rotation has been set at approximately 12 to 20 years and in drier areas range from 20 to 30 years. Human interventions have results to the reduced rotation to between 6 and 8 years (de Ronde 2012).

Karoo –

The succulent Karoo biome is believed that will also suffer the same faint as forest biome in terms of impact and loss of species, degradation of biodiversity (Hoffman

and others 2009). Some of the species are susceptible to drought (Hoffman and others 2009), which means as they dry up and die could results in the succulent Karoo to become fire adaptive vegetation.

Effectiveness of suppression methods

The present fire suppressing methods are becoming ineffective due to insufficient data on the shift response of vegetation cover. Vegetation response to climate change also influence the way in which will respond to fire in a manner that will facilitate the spreading effect and contribute to difficulties of fire suppression techniques (Midgley and others 2002). A number of challenges have arisen in fire suppression and fire fighters have lost their live in a line of duty. Most fires have managed to escape and cause a severe damage to the environment due to unforeseen change in basal cover.

Change in water quality and quantity

The number of escaped fires has started to increase in recent years and it has been said that most of these fires escape due to the shortage of water. Climate change will affect water in the following manner and will results in difficulties to proper control wildfires (UNGC 2009); increase water shortages, decrease natural water storage capacity from glacier/snow-caps melting, affects water supply capacity infrastructure, precipitation and flooding events will increase to extreme levels, and surface and groundwater will be contaminated due to sea-level rise.

Altered ecosystem –

Ecosystems are altered in terms of become more susceptible to fire and mortality rate is accelerated. The way in which vegetation respond to fire has start to shift to either long fire season or to catastrophic fires (de Ronde 2012). The impact will influence the change in physiology, productivity and growth, the distribution and abundance of species is also disturbed due to the shift of climate patterns (Midgley and others 2002). The figure below illustrates the present fire-ecosystems (GFI 2004); across the world and due to the impact of climate change, they are bound to shift as the natural vegetation cover will change in most parts of the world (FAO 2012).

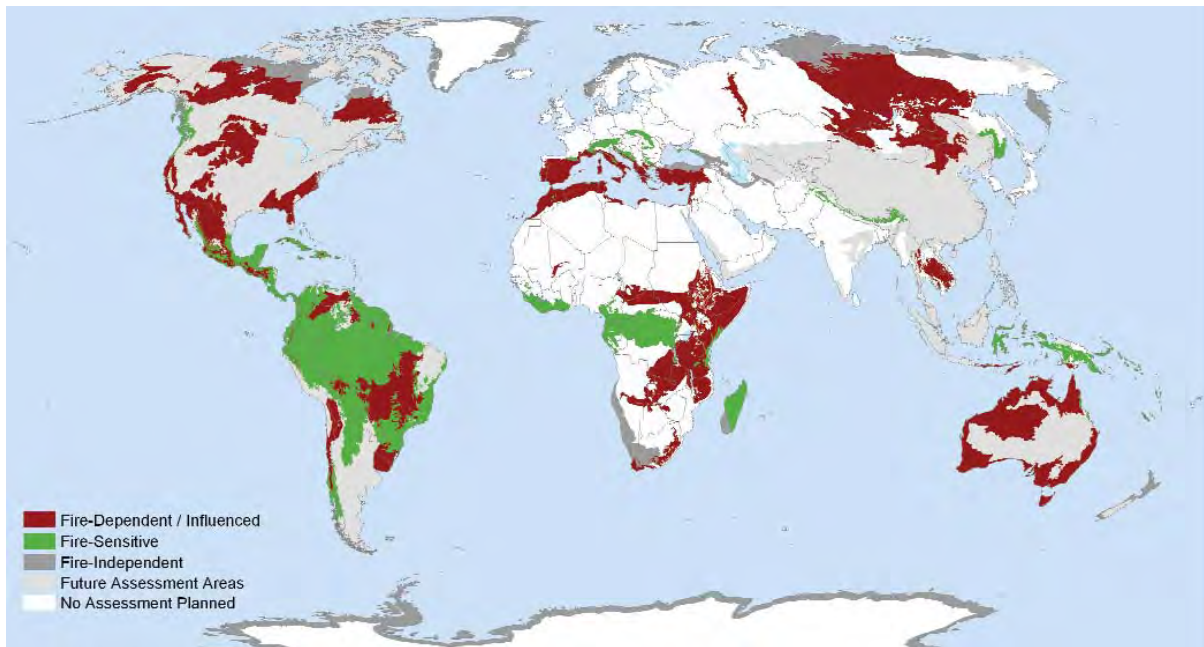


Figure 3—The classification of fire-ecosystems of the world (GFI, 2004)

Influence on fire regimes

In the past decade fires used to occur in fire-dependent and fire-influenced ecosystems, and thus there were playing a vital role in maintaining these ecosystems (GFI 2004). Fire occurrence and application is beneficial for the biodiversity and thus it is said that it can be destructive to plants and animals which are not adaptive to fire. Humans have become a source of ignition more than the natural occurrence of fire and such action has significant contribution to the negative impact of climate change (GFI 2004). Fire regimes started to shift from the normal fire occurrence time to either, occur early and/or extend beyond the normal season. The shift in the fire regimes can be seen as the current fire occurrence patterns compare to the natural patterns (GFI 2004).

Adaptation and improved suppression methods

Fire managers are not only required to understand the effect of climate change to fire, but to adjust fire activities to synchronize with the change in environmental conditions. The appropriate approach is to have an understanding with how much shift or alteration in environment has taken place and which might be suitable anchor techniques and methods to effectively deal with matter at hand. The adjustment of suppression methods and adaptation is not a sole responsibility of an individual company or organization, the appropriate adaptation methods are to be developed at a

national level down to regional level (Lebel and others 2012). Development of strategies in isolation by a particular sector might not be in line with other strategies which are developed to adapt and that might influence the acceleration of severe impact to the environment and an increase of catastrophic fires. Adapting to the climate change does not necessarily mean one has to use fire more often or not at all but to adjust to application methodology.

Manipulation of burning pattern

Fires are causing a serious damage to the environment and commercial forests. It is time for fire managers to devise or enhance firefighting strategies and tactics to control of fires to be able to restrict fires to areas that are supposed to burn and protect plantations. de Ronde (2012), has suggested that to avoid wildfire damages within the forest plantation, the fire manager will have to embark in prescribe burning within the compartment stands. The method is already been practiced in area with high number of wildfires and the problem with it is that it has negative impact on wood properties (de Ronde 2012); the significant impact on wood properties is still undertaken. Pool (2011), also recommends the practice of mulching as a form of fuel load management and according to his findings, mulching has a significant influence on fire behavior, intensity and rate of spread, (South African forester, in personal communication) argues that the method in some areas might present a number of problems, due to the fact that it results in difficulties to fight fires which are suspended on the ground as a result of compressed flammable gases.

Understanding adjacent vegetation

When it comes to fire management, in most cases the fire managers are only concern with preventing fire from spreading into the plantations and from within to beyond to the neighboring vegetation. The understanding of change in environmental response requires the studying of also the adjacent ecosystems and devise management strategies for both ecosystems. The importance of bring adjacent vegetation into picture is to avoid the repetition of severe damage which South Africa has gone through between 2007 and 2008, the loss of 25,000 hector in a single day due to extreme weather conditions (de Ronde 2012). Most wildfires start in adjacent vegetation into commercial plantation and these areas are mostly owned by communities, the ignition source is equivalent to the one of Kruger national park.

Integration of operations

The effect of climate change does not only affect fire suppression methods, it affects a number of operations and thus it is of utmost importance to have a mainstream adaptation planning in order to integrate operations and to also maintain the interconnection within the operations and environment (Lebel and others 2012). Operation integration should be adapted at a national level in order to have formality and to have operations systems which are interlinked.

Ultimate remunerations on economic dynamic

The forest companies are spending a lot of money and basic on fire suppression and the costs are relatively increasing due to the influence of climate change on vegetation. It is not a wise decision to spend more and/or less resources on fire engineering, thinking that will prevent and protect fires from destroying forest. With the understanding of an ecological biome value will result in taking necessary precaution steps and applying appropriate resources (Turpie 2003). To increase investment returns, it is of benefit to practice integrated management for both commercial and environmental conservation.

Conclusion

The evaluation of climate change impact on vegetation response to fire at this stage is hard to be quantified. Fire management has been a challenge at a global scale, the shift in vegetation response and adaptation to climate change has made management more difficult. In South Africa, prescribed burning practices are becoming dangerous due to the high number of escaped fires during the operation. The diversity of weather patterns is also making it difficult to devise a strategy which will be applicable at a national level. When it comes to management of fires, it is of utmost importance to take all affected factors into consideration in order to select an appropriate method which will be effective in bringing wildfires under control.

References

- de Ronde C. 2012.** White Paper on Vegetation Fires and Global Change. Current fire regimes, impacts and the likely changes - IX: Sub-Saharan Africa. Functional Role of Fire in *Fynbos* and Industrial timber plantations. 91-93p.
- Favier C, Chave J, Fabing A, Schwartz D and Dubois M.A. 2003.** Modelling forest-savanna mosaic dynamics in man-influenced environments: effects of fire, climate and soil heterogeneity. *Ecological Modelling* 171 (2004) 85-102
- Food and Agriculture Organization (FAO). 2012.** Forest Management and Climate Change: A Literature Review. Forests and Climate Change Working Paper 10:
- Fried J.S., Torn M.S. and Mills E. 2004.** The Impact of Climate Change on wildfire Severity: A Regional Forecast for Northern California:

- Global Fire Initiative (GFI). 2004.** Fire, Ecosystems and People: A Preliminary Assessment of Fire as a Global Conservation Issue. Ecosystems and People Living in a World of Fire
- Hoffmana M.T., Carricka P.J., Gillsona L. and West A.G. 2009.** Drought, climate change and vegetation response in the succulent karoo, South Africa. South African Journal of Science 105, January/February 2009
- Lebel L, Li L, Krittasudthacheewa C, Juntopas M, Vijitpan T, Uchiyama T, and Krawanchid D. 2012.** Mainstreaming climate change adaptation into development planning. Bangkok: Adaptation Knowledge Platform and Stockholm Environment Institute. 32 pp.
- Midgley G.F., Hannah L., Millar D., Rutherford M.C. and Powrie L.W. 2002.** Assessing the vulnerability of species richness to anthropogenic climate change in a biodiversity hotspot. Climate change and conservation special issue. Global Ecology & Biogeography (2002) 11, 445–451
- Pool C.F. 2011.** The Benefits of Mulching. SA Forestry Magazine. The Seventh Fire Management Symposium held in Pietermaritzburg.
- Stefik J. 2006.** The Effect of Global Warming on South African Ecosystem's. The Department of Meteorology, College of Earth and Mineral Sciences, The Pennsylvania State University, University Park, PA 16802
- Tol R.S.J., 2009.** The Economic Effects of Climate Change. Journal of Economic Perspectives—Volume 23, Number 2—Spring 2009—Pages 29–51
- Thonicke K., Spessa A., Prentice I.C., Harrison S.P., Dong L. and Carmona-Moreno C. 2010.** The influence of vegetation, fire spread and fire behaviour on biomass burning and trace gas emissions: results from a process-based model. Biogeosciences Discuss., 7, 697–743
- Trollope W.S.W. 2012.** White Paper on Vegetation Fires and Global Change. Current fire regimes, impacts and the likely changes - IX: Subsahara Africa. Functional Role of Fire in Subsaharan Savanna and Grassland Ecosystems. 83-89p.
- Turpie J.K. 2003.** The existence value of biodiversity in South Africa: how interest, experience, knowledge, income and perceived level of threat influence local willingness to pay. Ecological Economics 46 (2003) 199-216
- United Nations Global Compact (UNGC). 2009.** Climate Change and the Global Water Crisis: What Businesses Need to Know and Do: 01-09p

Recreational Use Management and Wildfires in Southern California: Using GIS and Visual Landscape Simulation Models for Economic Assessment¹

Daniel Moya², Armando González-Cabán³, José J. Sánchez³, and José de las Heras²

Abstract

Recent advances in fire behavior are conforming strategies for forest management in non-industrial private and public forests in the western United States. The strategy developed should include identifying the most cost-effective ways for allocating fire management budgets. In recreational areas, visitors' opinion should be included in forest planning decisions and surveys have been useful tools to collect this information. However, it is difficult to assess fire prior to occurrence, particularly in areas where fire regime varies due to climate change. We merged geographic information system (GIS) applications and visual landscape simulation models to obtain visual information about predicted scenarios including different forest management programs, climate change predictions and future wildland fire risk. In our study, we represent both, forested landscapes and individual stands, after forest management activity and wildfires in the short, medium and long term. Our goal was to determine how recreational values are related to preservation (or not) of different parts of the landscape and how it is affected by wildfires through time. We used an online survey to determine recreationists' willingness-to-pay (WTP) for non-fire programs in the San Jacinto Wilderness, San Bernardino National Forest in Southern California. The computer visualization is a useful tool to gauge visitors' preferences and consider it in land management planning, including potential actions or disturbances based on landscape modeling. This type of tool can be used by forest managers and stakeholders to support their decision to demonstrate and evaluate tradeoffs of pursuing alternative fire management strategies to promote a more sustainable future wildland fire management program and its appropriate role in public land management.

Keywords: *Fire-prone areas, forest management; non-market valuation*

¹ An abbreviated version of this paper was presented at the Fourth International Symposium on Fire Economics, Planning, and Policy: Climate Change and Wildfires, November 5-11, 2012, Mexico City, Mexico

² Assistant Professor and Professor, respectively, ETSI Agrónomos. Universidad Castilla-La Mancha. 02071 Albacete, Spain.; email: Daniel.Moya@uclm.es

³ Research Economist and Economist, respectively, USDA Forest Service, Pacific Southwest Research Station, Riverside, CA 92507; email: agonzalezcaban@fs.fed.us; jsanchez@fs.fed.us

Introduction

Wildland fire risk assessment and fuel management activities have become a major activity because an increasing area burned related to global change, mainly in Mediterranean areas (Flannigan and others 2000). USDA Forest Service (FS) in western US promotes tools to reduce the growing financial and ecological losses from catastrophic wildfires (Calkin and others 2011). Fuel treatment activities includes a wide range of operations in forest management, such as thinning, mechanical treatments (e.g., mastication) or prescribed burning to reduce fuel and break continuity (both horizontal and vertical), which aims to reduce the frequency of large wildfires (Finney and others 2006). However, including fuel management in forest planning is complex and needs applications to be tested with fire behavior modeling software in both a research and operational context (Calkin and others 2011).

Scientists are modeling many aspects of complex natural ecosystems simultaneously and linking it to fire behavior models using as input factors weather conditions (Flannigan and others 2000). In practice, simulation models examine the potential effectiveness and ecological impacts of fuel treatment program in a static scenario, such as ArcFuels that is an ArcGIS interface for fuel treatment planning and wildfire risk assessment (Ager and others 2011). It includes extensions to several models, such as Forest Vegetation Simulator (FVS), FARSITE, BehavePlus and Stand Visualization System (SVS). SVS contributes with a visual output, which generates graphics depicting stand conditions, representing information obtained for homogeneous polygon from the dataset.

Public expectations from federal land management have expanded in recent years. Operational application concerns a quantitative of social and ecological values, and the design of fuel treatment projects in terms of where, how much, and how to treat surface and canopy fuel to meet wildland fire management objectives (Zimmerman and others 2006). Forest managers should include the public acceptance of their management strategies including landscape appearance through time. Traditional methods have not always provided enough information to understand what happened, mainly to non-specialists such as some stake holders, politicians or general public (González-Cabán and others 2011).

The aim of our study was to enhance public communication. To achieve it, we linked the Arcfuels interface, SVS outputs and a visual simulation model (Envision, McGaughey 1997) to obtain visual simulations for predicted scenarios. We applied the system to a wildland area enclosed in San Bernardino National Forest to obtain different visual simulation including forest management, severity of a hypothetical fire in the current conditions and the natural regeneration in different scenarios for

the short-, medium- and long-term.

Methods

We selected a recreational area in the San Jacinto wilderness, San Jacinto Ranger District, San Bernardino National Forest and also part of California San Jacinto State park in southern California. The wilderness cover about 32,248 acres (13,055 ha), the altitudinal range varies from 6,000 to 10,000 feet (1,800-3,050 m) above sea level, and the climatic habitats goes from desert to alpine areas. Of the 16 trails crossing the recreational area we selected four of the most highly used for our work: Deer Springs, Devil's Slide, South Ridge and Pacific Crest Trail.

The wilderness and surroundings contains several recreational grounds, campgrounds, villages and housings (high wildland-urban interface area) and is crossed by hiking trails so the social and recreation usefulness is very important. The fire history in the area indicates that in the last century several wildfires burned at lower altitudinal areas surrounding the wilderness; however, for the last 100 years no fire have been evidenced (Figure 1). In the area, the time since the last fire have exceed the fire recurrence period because the fire exclusion policies, special weather conditions and different ecosystems (Wohlgemuth and others 2009). In addition, the fuel load in the wilderness is very high (Figure 1). Therefore, the wildfire risk and hazard in the area is high.

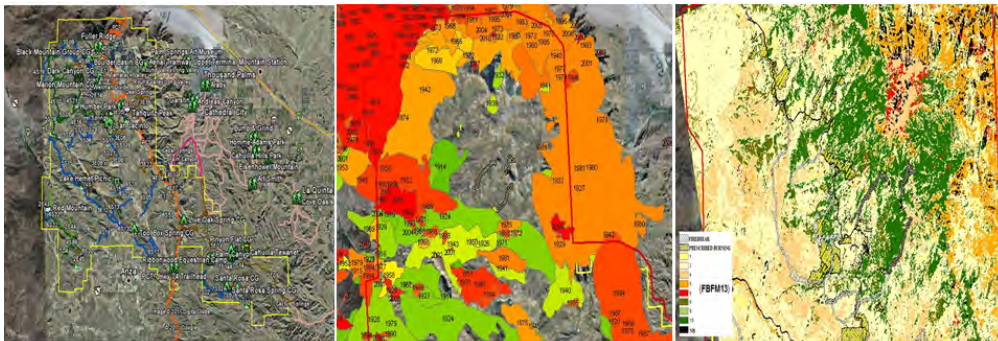


Figure 1— San Jacinto wilderness, located in the San Jacinto Ranger District in San Bernardino National Forest in southern California: high anthropic pressure (left), fire history (center) and fuel load (right).

According to the California wildlife habitat relationship system (2008), the predominant biotic communities in the study area are Sierran Mixed Conifer (Smc): Douglas Fir, Ponderosa pine, White Fir, Montane Chaparral (Mcp): Ceanothus Species, Manzanita Species, Bitter Cherry, Subalpine Conifer (SCN): Engelmann Spruce, Subalpine Fir, Mountain Hemlock, Montane Hardwood-Conifer (MHC): Ponderosa Pine, Incense Cedar, and California Black Oak.

We hiked the trails, digitalizing the routes using a DeLorme *PN-40 GPS*⁴ and converting to shape with *Topo USA* software. We recorded several images of the viewshed from different points and obtained several detailed images in three relevant locations: the trailhead, midway trail, and end of trail (highest elevation).

To include the fuel management and forest planning in the study we developed a viewshed analysis technique to link the spatial allocation, the natural development of the ecosystem, and the incidence of wildfires depending on silvicultural treatments preventing large and severe wildfires and the visual state as time passes. For the four trails selected viewshed we obtained their current conditions. After that, we assumed that a wildfire was going to burn the wilderness, but the incidence was dependent on fuel management treatments. Three different scenarios were examined: no treatment (*high severity* of fire), heavy silvicultural treatments (*low severity* fire) and a medium management (*medium severity* fire). In addition, we included time elapsed since the fire: burned in the *short-term* (0-5 years), burned in the *medium-term* (5-15 years) and burned in the *long-term* (more than 15 years). We obtained DEM (digital elevation model), a shape containing the fuel load in the area, general information of National Parks and forest management and vegetation information (USDA Forest Service Region 5 2011).

Using Arcfuels interface for ArcMaps v.9.1 (Ager and others 2011), we created a stand layer shape containing updated information of both abiotic (aspect, slope, elevation, etc.) and biotic (forest type, cover from above (CFA), size and tree density, wildlife habitat relationship (WHR), etc.) factors. In the next stage, we simulated the three selected fire classes (low, medium and high severity) for the summer 2011 and the natural regeneration for the three time intervals (short-, medium- and long-term). The outputs were recorded in a SVS format. The SVS files for each scenario were copied and loaded in Envision to create a different project for ten possible scenarios (control and three severities of fire in three different intervals), replicated for each location for the four trails. For each point, we adjusted and focused light and background parameters to the moment in which the viewshed was photographed in the trail. Using DEM and coordinates recorded, we created a viewpoint to obtain the same perspective as in the photograph. Vegetation was recreated using SVS stand look up table and surface grid were created to recreate the soil surface according the simulated scenario. A background was built using the real image, separating visual simulation below the horizon and inserting a picture of the sky (from the real conditions) above the horizon. The rendering options were optimized to obtain the visual output most similar to the recorded picture.

⁴ Citing brand name products does not constitute an endorsement by the USDA Forest Service.

Results

In this first phase of the research we obtained several visual images to be used in studies assessing nonmarket resources valuation. Conducting surveys in the San Jacinto Wilderness will allow us to replicate the experiment in other Mediterranean regions, such as southeastern Spain. Once the survey data is collected, it will provide information to determine recreation values including forest planning and fuel management under hypothetical fire scenarios (Table 1). It will also allow linking management, forest regeneration and recovering of recreation values.

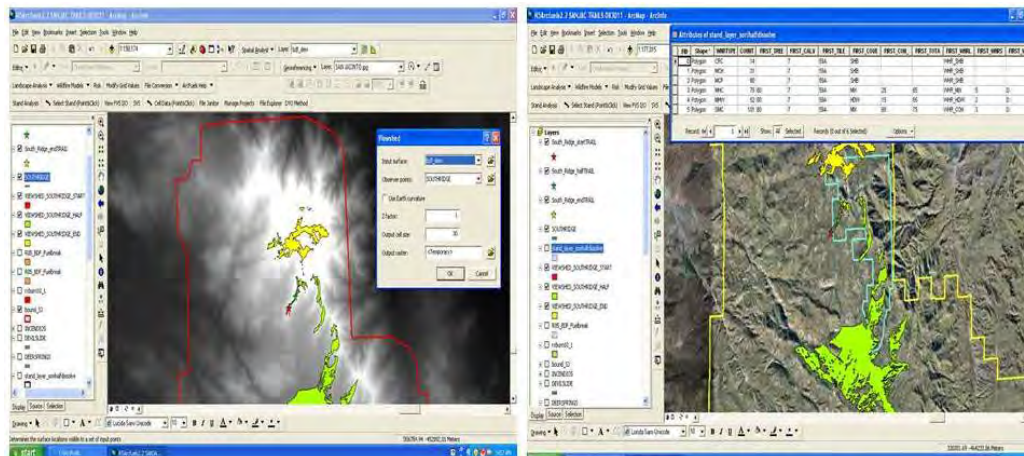


Figure 2—ArcFuels: ArcGIS interface for fuel treatment planning and wildfire risk assessment; creating basic information for the stand layer of studied area in San Jacinto wilderness, San Bernardino National Forest in southern California.

The fire scenarios developed will place recreationist on a particular trail, in a characteristic point and the viewshed would change depending on the fire severity and time since fire. Based on our experimental design, we obtained 108 images (Figure 3). The viewshed surface visible to a recreationist depends on where in the trail is; the highest elevation produces the greatest viewshed area. Four tree coverage losses (related to fire severity) were evaluated: less than 25%, 25-50%, 50-75% and 75%-100% in CFA (related to low, medium and high severity). The visualization outputs will help respondents understand the hypothetical fire scenarios as well as the landscapes preserved using resources derived from the wilderness permit fees invested in preservation efforts.

Discussion

Sustainable forest management should meet stand-level objectives while maintaining or enhancing the aesthetic and biological quality of a landscape. Englin and others (2001) found that there is an increase in visitation during recent fires, but then decreases for several years. Visualization tools provide feedbacks to design a stand

treatment, helping in the communication and understanding of future effects and possible scenarios in a landscape context.

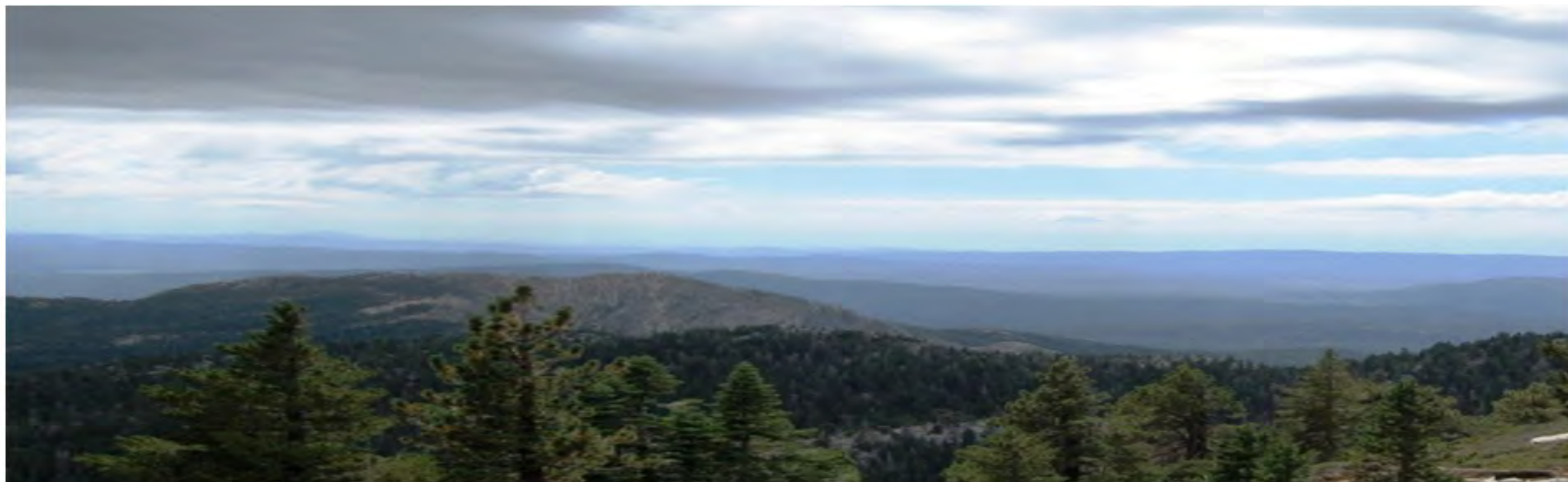




Figure 3— Visual simulations obtained for the Sky tram Trail to San Jacinto peak. The viewshed represented here was located in the midway trail point; we took a photo and recreated the same image as control (upper image). In addition, we recreated three fire severity fires (lower images) for an hypothetical wildfire occurring during the summer of 2011: low (top), medium (middle) and high (bottom).

The public acceptance of forest management activities are usually linked to the appearance of forested landscapes and individual stands, depending on the viewshed.

By using visualization tools, alternatives and disturbances can be simulated within a landscape context, which remains constant. Fire exclusion policies increases fuels, resulting in high-intensity and sometimes catastrophic large fires. Visualization can be used to communicate the high fire risk and show options for reducing the amount of fuel present, to decrease the impact of the disturbance. Depending on the accuracy of dataset, the output images can depict forest scenes that appear realistic. However, viewers must be able to distinguish rendered images from photographs, and presenters need to determine thoughtfully the appropriate level of realism for each application, thus preventing the risk of loss of credibility. It could help for identification of the most cost-effective ways for allocating fire management budgets, implementing the most appropriate management response to wildfires, including alternative science-based scenarios.

Table 1—Basic survey to be held. The header will be describing how in a fire-prone area, resources can be used for fire prevention. The respondent could be presented as randomly multiple choices for possible conditions facing in future scenarios depending on investments in fire prevention.

Viewshed destroyed	25-50%	50-75%	75-100%
Location	Trailhead (lowest elevation)	Midway Trail (medium elevation)	End (highest elevation)
Time elapsed since burn	Short term 0-5 years	Medium term: 5-15 years	Long term: >15 years
Wilderness Permit fee	\$25	\$20	\$15
RESPONDENT CHOOSE			

Summary

This study reported the opportunity given by landscape simulation model to improve forest management and the forest economic assessment, mainly in simulated scenarios. Computer-based landscape simulations have become a recognized tool for previewing the visual impacts of land use decisions if they are based in reliable models and predictions.

Acknowledgments

We thank the Spanish Ministry of Science and Education for their support by providing the Jose Castillejo mobility grant (JC2010-0224). We also thank the San Jacinto Ranger District staff, San Bernardino National Forest, for their help. Special thanks are given to Robert J. McGaughey (USDA FS Pacific Northwest Research Station) and Kenneth A. Wright (USDA Forest Service, Region 5).

References

- Ager, A.A.; Vaillant, N.M.; Finney, M.A.** 2011. Integrating Fire Behavior Models and Geospatial Analysis for Wildland Fire Risk Assessment and Fuel Management Planning. *Journal of Combustion*, Article ID 572452, 19 p.
- California Wildlife Habitat Relationships.** 2008. <http://www.dfg.ca.gov/biogeodata/cwhr>. Accessed 30 May 2011
- Calkin, D.E.; Thompson, M.P.** 2010. Barriers to Implementation of Risk Management for Federal Wildland Fire Management Agencies in the United States. In Viegas, D.X. (Ed.) *Proceedings of VI International Conference on Forest Fire Research*. Coimbra, Portugal.
- Costanza, R.; Voinov, A.** 2004. Landscape Simulation Modeling: A Spatially Explicit, Dynamic Approach. *Series: Modeling Dynamic Systems XIII*, 330 p.
- Finney, M.A.** 2005. The challenge of quantitative risk analysis for Wildland fire. *Forest Ecology and Management*. 211: 97-108.
- Finney, M.A.; Seli, R.C.; McHugh, C.W.; Ager, A.A.; Bahro, B.; Agee, J.K.** 2006. Simulation of long-term landscape level fuel treatment effects on large wildfires. In: Andrews, P.L., Butler, B.W. (eds) *Fuels Management-How to Measure Success: Conference Proceedings*. 28-30 March 2006; Portland, OR. USDA Forest Service, RMRS-P-41. 809 p. (Fort Collins, CO) p125-148.
- Flannigan, M.D.; Stocks, B.J.; Wotton, B.M.** 2000. Climate change and forest fires. *Science of the Total Environment* 262: 221–229.
- González-Cabán, A.; Sánchez, J.; Moya, D.** 2011. Developing tools to improve forest management in recreational and fire-prone areas in Southern California. In *Proceedings of MEDECOS XII: Linking Science to Resource Management. The International Mediterranean Ecosystems Conference*. September 6-9, 2011 – Los Angeles, California, United States.
- Baerenklau, K.A.; Gonzalez-Caban, A.; Paez, C.; Chavez, E.** 2010. Spatial allocation of forest recreation value. *Journal of Forest Economics* 16: 113–126.
- McGaughey, R.J.** 1997. Visualizing forest stand dynamics using the stand visualization system. In *Proceedings of the 1997 ACSM/ASPRS Annual Convention and Exposition*; April 7-10, 1997; Seattle, WA. Bethesda, MD: American Society of Photogrammetry and Remote Sensing. 4:248-257.
- McGaughey, R.J.** 2002. Creating visual simulations of fuel conditions predicted by the fire and fuels extension to the forest vegetation simulator. In: Crookston, N. L., Havis, R. N. (compilers) *Second Forest Vegetation Simulator Conference*. USDA Forest Service, Rocky Mountain Research Station, Fort Collins CO. RMRS-P-25. 208p.
- Rodríguez y Silva, F.; Molina Martínez, J.R.** 2007. Cartografía de modelos de combustible para la defensa contra incendios forestales. In *Proceedings of the 4th International Wildland Fire Conference*, Sevilla, Spain.
- USDA Forest Service Region 5.** 2011. USDA-Forest Service, Pacific Southwest Region, Remote Sensing Lab. Accessed 30 May 2001. <http://www.fs.fed.us/r5/rsl/clearinghouse/gis-download.shtml>.
- Wohlgeuth, P.M.; Beyers, J.L.; Hubbert, K.R.** 2009. Rehabilitation strategies after fire: the California, USA experience. In: Cerdá, A.; Robichaud, P.R. (eds). *Fire effects on soils and restoration strategies*. Enfield, NH: Science Publishers. pp. 511-536.

Zimmerman, D.E.; Akerelrea, C.; Smith, J.K.; O'Keefe, G.J. 2006. Communicating Forest Management Science and Practices through Visualized and Animated Media Approaches to Community Presentations. An Exploration and Assessment. *Science Communication* 27 (4): 514-539

Adaptive Management of Forest Fires in Periurban Areas in the Federal District, Brazil: A Case Study From the Urubu Valley Rural Community¹

Gabriel Constantino Zacharias² and Renata Marson Teixeira de Andrade³

Abstract

In a climate change scenario, where global warming increases the critical period of drought, the risk of wildfire is expected to increase. In the Federal District (DF) - Brazil, wildfire in periurban areas have economic, financial, environmental and public health significance, however it is poorly studied. Thus, one wonders if the DF is prepared to deal with the higher risk of wildfire in periurban areas as well as if a periurban community is able adapt to increasing risk of wildfire under climate change. This research presents a case study of the Urubu Valley Rural Community, located inside the Urubu Creek watershed, one of the largest rural community, more than 200 families, living only 10 km away from Brasilia-DF. We surveyed 40 families living in the Urubu Valley Rural Community, and measured their perception of environmental risk, in special wildfire risk, and adaptive and organizational capacity to cope with wildfire under climate change scenario. With this study, the community perceive that wildfire is high risk in many locations, in specially close to roads and public lands, and new real state development. This community perceives local nature very positively and values its environmental services (aesthetics, water supply, local climate and biodiversity); has great sense of belonging to the region and undertands the environmental risks they face under climate change. This perception has been attributed to the knowledge gained over the years due to local environmental activism: local environmental NGOs working in partnership with state and civil society organizations, such as environmental agency, universities and international NGOs dealing with climate change adaptation, led to the creation of a wide social network that supports the activities of wildfire prevention and combat in the Urubu Valley. The combination of risk perception, the capacity for mobilization and social networking were the key factors for implementing the first local

¹ An abbreviated version of the paper was presented at the fourth international symposium on fire economics, planning, and policy: climate change and wildfires, Nov 5-11, 2012, Mexico City, Mexico.

² Brazilian Institute of Environment and Renewable Natural Resources, gabrielzacharias@yahoo.com.br.

³ Professor at Universidade Católica de Brasília, renatamar2@gmail.com.

wildfire risk management under climate change scenario in the Rural Community in the Urubu Valley, the first a periurban community to implement a wildfire prevention plan in this region. Finally, to improve the local wildfire risk management of the Urubu Valley Rural Community and allow the implementation of these standards in other periurban communities throughout the Brasilia-DF, we used the ISO31000 risk management guidelines and the Firewise Communities USA program's experience. We hope that improved local wildfire risk management allow environmental managers in Brasilia DF to implement a local wildfire risk plan as part of an adaptation to climate change plan in many periurban communities in Brazil.

Key Words: environmental risk perception, firewise communities, wildfire risk.

Introduction

The Federal District (DF), Brazil, suffers every year with the forest fires in suburban areas. The National Institute for Space Research, since 2007 have been detected more than 1200 hotspots, and between 2010 and 2011 this number was approximately 800 foci in the Federal District, including Brasilia. And according to studies of climate change for the Cerrado region the trend is to increase the incidence of fires in the region with the increase in average temperature of the earth.

We chose to investigate forest fires in suburban areas because it has no such studies in Brazil, and also because periurban regions are home to communities that suffer from a lack of social and public services, depending heavily on aspects of the environment in terms of health, supply of electricity and housing (Sao Paulo 2004, p.19). In the DF, there are many inhabited periurban regions and constant threat of fire. We chose to study the Urubu Valley Rural Community, which is located in the watershed of Urubu creek, because of the historical social mobilization on participatory management of forest fires. This community has created an active social network, the Save the Urubu Valley Movement, supported by residents and local NGOs, in addition to a project to adapt to climate change, Aclimar Project, supported by HSBC Solidarity Institute, in partnership with the Catholic University of Brasilia and international NGOs such as WWF. This social network has organized a forest fires brigade, looking for support from the Federal and District governments to implement the Local Fire risk Prevention Plan.

This article focuses on a case study in an outlying area of the DF, and accesses the perception of environmental risk in a rural community, the process of environmental governance and social mobilization against forest fires, as forms of adaptive management to climate change. The Environmental Risk is expressed in this study by the combination of the consequences of an event and the probability of

its occurrence (Brazilian Association Of Technical Standards 2011, p. 01). To support the development activities of the rural community of the stream of the Urubu, this paper presents also recommendations from the local reality, the experience of the Firewise Communities Program American and ISO31000, which gives standard guidelines for risk management.

Methods

To study how the population of the Urubu Valley Rural Community organized an operating plan and a brigade for preventing and fighting forest fires, it was used bibliographic data collection, pre-existing studies and interviews with leaders the region.

The most important pre-existing studies used in this research was the Ecomapeamento Creek Watershed of the Urubu (Pedroso and Santos 2008), the Study of Perception of Environmental Risk and Climate Change in the Stream Watershed of the Urubu (Andrade and others 2011) and Operational Plan for Preventing and Fighting Forest Fire in the Urubu Valley Rural Community (Gouveia 2011).

Using these studies plus some open interviews with local leaders it was possible to understand the social context and the forest fire problem at the rural community and then compare this reality with the ISO31000 and the Firewise Program.

This comparison allow us to notice the similar points in this structures and the points it was necessary to improve in the reality of the rural community, in order to implement a risk management plan .

Results and Discussion

Urubu Valley Rural Community was able to create a social network which depend on individual engagement on environmental ethics and high mobilization capacity. According to Andrade and others (2011) there is among the community perception of high risk of fires in the region, and mobilization on firefighting and fire risk reduction was a priority.

Social mobilization in Urubu Valley Rural Community has emerged at various times from the 1980s, when an association was organized for the land tenureship process undergoing in the region, however environmental concerns became part of the agenda put by some individuals. Environmental problems, such as water scarcity, water contamination, waste disposal, deforestation, biodiversity loss, soil erosion, floods and fire were shared among some residents. A growing feeling of belonging

and stewardship for the region helped to boost nature preservation, agroforestry and agroecology initiatives and water management projects (Pedroso and Santos 2008).

This feeling of belonging comes from the perception of the residents who sees their home as a living watershed – “ecobacia”, as an area of many springs that feed in the Paranoá Lake, and has ecological corridors for many species, even though this region lies very close in the green belt of Brasília. Some of the most important features of local residents are (Pedroso and Santos 2008):

- Residence time 90% of the residents arrived since 1990
- Higher education 40%; 15% Basic
- Household income: 27% less than US \$ 933. 00 and 20% higher than US \$ 3420. 00
- Quality of life: good 65%, 10% bad
- Reasons to dwell in the region: 45% nature and 44% Leisure

The beautiful natural scenery - remnants of savannah, rivers, waterfalls, small mammals and birds - attracts people and boost in them the need to organize themselves to protect and preserve their environment. The Rural Community area is near to roads and areas of urban growth, as showed in Picture 1.



Picture 1— Location of Creek Watershed of the Urubu and its subdivisions.

Source: <http://www.ibram.df.gov.br/sites/400/406/00001637.pdf>

The Community has movements, associations and institutions created by the local population, to work on improving the quality of life. Among these institutions, the Instituto Salvia has been in the region since 1998, and developed the Aclimar Project - Planting Trees and Water Harvesting, in partnership with the Catholic University of Brasília. This project in particular has been important, among other things, for developing studies on Perception of Environmental Hazards and Climate Change in the Urubu Watershed for their baseline approach (Andrade et al 2011).

This study, using questionnaires, built the array of perceived environmental risks in the region, from the perception of the frequency of 22 environmental hazards, ranging from 1 (low frequency) to 4 (high frequency) and the perception of environmental impacts in the persons and property, ranked from 3 (least impact) to 9 (greatest impact), as Table 1 shows below.

Table 1—*Matrix of frequency, impact and risk classification of risk perception*

Frequency (F)	Impact (I)	Risk (F×I)	Classification of Risk
1 - 4	3 - 9	3-8	Negligible
		8-14	Tolerable
		14-28	High
		28-36	Critical

Source: Andrade and others (2011)

This study shows that Risk Perception of the residents on average consider bush and forest fire among the six high-level risks, as shown in Figure 1.

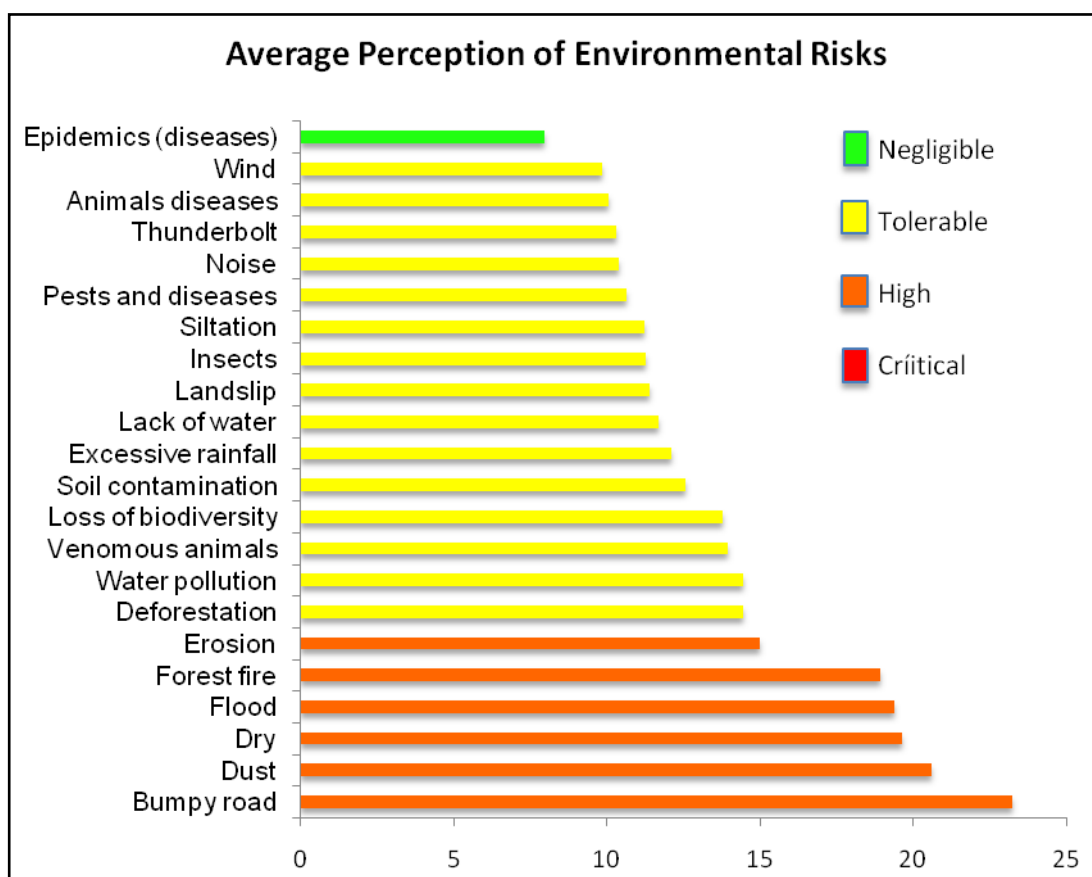


Figure 1—Perception of environmental risk rating for each of the 22 threats in the Urubu Valley Rural Community
Source: Andrade and others (2011)

In spite of the average of risk perception to forest fire been “high”, at some areas on the rural community this risk has been classified as “critical”, as show in Figure 2. These critical areas are near the urban growths areas.

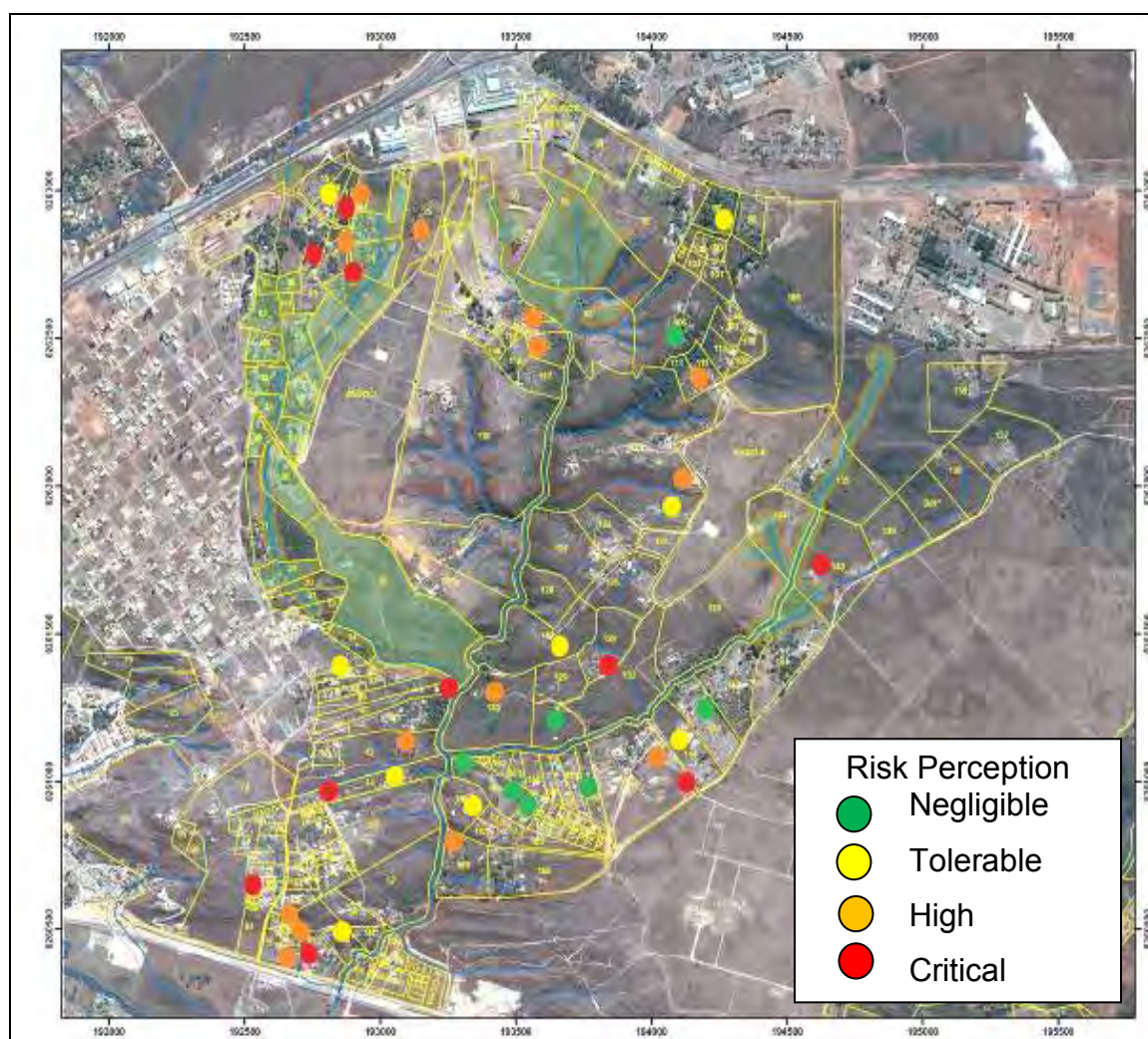


Figure 2—Spatialized perception of forest fire risk in the Urubu Valley Rural Community
Source: Andrade and others (2011)

The risk perception helps to understand how this community has been organized around the prevention of wildfires. So people began to act in a more organized in relation to forest fires lacked the 'how to', which came through the completion of a course Training Brigades for the Prevention and Combat of Forest Fires, prompted by local institutions with the National Center for Prevention and Combat of Forest Fires - Prevfogo the Brazilian Institute of Environment and Renewable Natural Resources - IBAMA.

This brigade was only possible because of the social network that works in the region, bringing together residents who have worked with forest fires, which are university researchers, as the Catholic University of Brasília, which work to protect

water sources and NGOs such as WWF and the Save the Urubu Valley Movement. This network has helped to build local fire hazard brigade capacity and performance, providing logistic means as transportation, media and storage of equipment and tools.

For the development of fire management plan for Urubu Valley Rural Community, this study made a comparison between local reality and the Firewise Communities program, based on the Technical Standard for the Environmental Risk Management ISO31000.

At this paper we show some of the most important correlation between the ISO31000 structure and the reality at the rural community and the Firewise Communities:

- **Mandate and commitment:** it is important to the rural community understand that, as at the Firewise Communities Program it is necessary to define who will be responsible for risk management and coordination of the whole process. At this point, the community is still failing.

- **Establishment of Policy Risk Management:** at the Firewise Program, the community holding meetings to establish how best to act in that region. At the Urubu Valley Community an Operating Plan was created to guide the creation of a policy of risk management more broadly, by a partnership between some institutes and a person how works with forest fire.

- **Responsibility:** it is necessary to the rural community formalize responsibilities for forest fires between the government and the community, as it is done at the Firewise Program.

- **Integration into organizational processes:** at the Firewise Program, technicians have previous knowledge in order to interact with the reality of the communities, seeking the best application of prevention techniques to the reality. The rural community has yet to discuss the integration of knowledge, the presence of the brigade and management in the homestead properties.

- **Reporting mechanisms and reporting internal and external publication:** The Community should encourage increased community participation in decision-making meetings and processes, and can improve their work proposing something like the "Best Practices - Communication Plan", from the Firewise Program.

- **Implementation of the framework for risk management:** the implementation depends on the entire structure created and local characteristics. The structure of risk management should be implemented in due time, allowing owners and institutions devote their efforts to this goal, including training sessions and information

Using the ISO31000 structure to implement an environmental risk management plan, after creates the entire framework, it is necessary to implement. During this stage, the most important is to define how to work with the risk, defining, identifying and the treatment necessary to success the risk protection.

As a part of the implementation, the ISO31000 proposes:

- **Defining risk criteria:** At the Firewise Program the criteria to measure risk are generally three: type of plant-based fuels, topography and slope of the frequency of climatic conditions conducive to forest fires. The Urubu Valley Rural Community needs to define the criteria to be used that could be: a risk matrix developed in this study, the accumulated data of hotspots and areas of significant interest to the community. Spatial data is needed, and maps of hotspots.

- **Identification of risks:** The Firewise Program provides the knowledge and materials needed to help people identify the main sources of risk to the community. The rural community could read these materials and a survey of people and institutions that work on the subject should be done to identify the main causes, origins and consequences of fires in the region.

- **Risk analysis:** At this stage the rural community should stipulate the frequency and severity of forest fire occurrence and identify which category this risk belongs, by risk matrix constructed in step Definition of Risk Criteria.

- **Risk assessment:** materials produced by the program to allow residents to know what the best action to avoid the risk of giving fire support to Urubu Valley Rural Community decision on treatment to be adopted. With categorized risks, should be compared with the initial context, to define what type of treatment will be given for each area. Should continue with the methodology adopted by the project acclimatize

- **Treatment of Risk:** Based on meetings, training and materials distributed, the community must deploy the appropriate treatments. The treatment given to the risk of fires in different areas should be defined individually, using the new knowledge and practices already employed in the region, as done by the project acclimatize.

- **Monitoring and review:** The program foresees the importance of monitoring its operation. This step should involve the actors participating in the Management Plan directly, including firefighters, owners and organizations to assess their functioning.

- **Records of the process of risk management:** communities are encouraged to report on the decision-making in an organized and standardized, which facilitates the registration of the management process. All activities of the brigade and the meetings on the issue of forest fires at the Urubu Valley Rural Community must be registered in order to be able to track the paths of decision making.

Conclusion

The perception of forest fire risk, the ability to mobilize and the social network helped to create and maintain the fire brigade at the Urubu Valley Rural Community.

However, it is necessary to recognize the responsibilities and to improve the knowledge about forest fire management to success at the community protection. A way to improve this knowledge is knowing others experiences like the Firewise Communities Program, their philosophy, materials and “way to act”.

The experience of Urubu Valley Rural Community is a successful example that the Government could use to protect all the periurban areas in the Federal District.

References

- Andrade, R.M.T.D., Delphino, R.M., dos Santos, M.J., Souza, M., Miccolis, A.** 2011. Study of Perception of Environmental Risk and Climate Change in the Stream Watershed of the Urubu, Brasilia – DF, 2011. XIV Encontro da Rede Luso-Brasileira de Estudos Ambientais. Recife.
- Brazilian Association of Technical Standards. NBR ISO 31000:2009.** 2011. Risk management - Principles and Guidelines. Rio de Janeiro: ABNT,
- Gouveia, G.P.** 2011. Operational Plan for Preventing and Fighting Forest Fire in the Urubu Valley Rural Community. Brasília: Movimento Salve o Urubu.
- Pedroso, M.D.S.C., Santos, V.J.D.** 2008. Ecomapeamento Creek Watershed of the Urubu. Brasilia: Seeding Education,. Under revision.
- São Paulo (State). Secretary of Environment..** 2004. Environmental Atlas of Sao Paulo - The green, the territory, the human being: Diagnosis and bases for the definition of public policies for the green areas in the city of São Paulo. São Paulo

Evaluation of the Flammability of Trees and Shrubs Used in the Implementation of Green Barriers in Southern Brazil¹

Antonio Carlos Batista², Daniela Biondi², Alexandre França Tetto², Rafaela de Assunção³, Andressa Tres³, Raquel Costa Chiao Travenisk³, and Bruna Kovalsyki³

Abstract

The purpose of green barriers, also known as green fuelbreaks, is to reduce the spread and intensity of fire, mainly by stopping it from spreading to the treetops, which facilitates fire control and suppression. A major difficulty in implementing green barriers is to identify suitable species for forming these structures. The aim of this study was to assess the flammability of some tree and shrub species used in urban forestry and along highways in Curitiba for use in green barriers in the rural-urban interface of cities in southern Brazil. To this end, fire behavior and flammability tests (epiradiator trials) were performed in the Forest Fire Laboratory at the Universidad Federal de Paraná on the following species: *Magnolia grandiflora* L., *Michelia champaca* L., *Jasminum mesnyi* Hance, *Casearia sylvestris* Sw. and *Viburnum odoratissimum* Ker Gawl. Test results showed that the species *J. mesnyi* is extremely flammable (FV = 5), *M. grandiflora* and *C. sylvestris* are highly flammable (FV = 4), and the species *V. odoratissimum* and *M. champaca* are moderately flammable (FV = 3) and low flammability, respectively.

Keywords: epiradiator, flammability, fire prevention.

Introduction

Establishing firebreak areas to prevent or reduce the spread of fire from one area to another is a very simple and effective preventative forestry technique, especially in large reforested areas with highly flammable species, such as conifers.

A firebreak is a barrier or a change from a highly flammable fuel to a less

¹An abbreviated version of this paper was presented at the Fourth International Symposium on Fire Economics, Planning, and Policy: Climate Change and Wildfires, November 5-11, 2012; Mexico City, Mexico.

²M.Sc, DSc. Professors Forestry Engineering Course at Universidade Federal do Paraná; Email: batistaufpr@ufpr.br, dbiondi@ufpr.br, yetto@ufpr.br respectively.

³Students Forestry Engineering Course at Universidade Federal do Paraná. rafa.assunc@gmail.com, dessatres@gmail.com, raqnisk@gmail.com, ybru_kovalsyki@hotmail.com, respectively.

flammable one. Firebreaks can be natural (a river or deciduous forest) or artificial (FPInnovations 2009). Manmade green barriers are strategically placed to protect the assets at risk and are generally wide or narrow strips in which dense or flammable vegetation is continuously changed for a cover with lower volume and / or low flammability (Green 1977). Plant material is always fuel, but not always flammable. Flammability varies by species and moisture content (Vélez 2000).

The objective of the green barrier is to reduce the spread and intensity of fire, mainly by stopping it from spreading to the treetops and thereby facilitating fire control and suppression. Tian and others (2007) find that green barriers play an important role in fuel management and landscape management systems.

In Brazil, green barriers, also known as "green fuelbreaks," are little known and little used in forest fire prevention, despite having been recommended for many years in forest fire prevention and suppression manuals (Batista and Soares 2008, Ribeiro and others 2007, Soares and Batista 2007).

One of the major difficulties in implementing green barriers is to identify suitable species for formation of these structures.

The aim of this study was to assess the flammability of some species of trees and shrubs used in urban forestry and along highways in Curitiba for use in green barriers in the urban-rural interface of cities in southern Brazil, through the method established by Valette (1990) and recognized by researchers from other world regions.

Methods

All laboratory and open area experiments required for carrying out the research were performed in the Forestry Department's Forest Fire Laboratory at the Universidad Federal de Paraná.

The species used in the experiments were selected based on the characteristics of tree and shrub species described by Biondi (2002), Lorenzi (1992), Lorenzi (1998), Lorenzi and Souza (2001), Lorenzi and others (2003) and on the methodology proposed by Biondi and Batista (2010). The species selected were:

- *Jasminum mesnyi* Hance, fam. Oleaceae: a perennial shrub with semi-herbaceous texture, scandent, native to China, with many long branches 2-3 m long, with dense and bright foliage, grown in full sun, preferably in high places to allow the formation of bending stems (Lorenzi and Souza 2001);

- *Michelia champaca* L, fam. Magnoliaceae: evergreen tree 7-10 m tall, native to India and the Himalayas, cylindrical stem with slightly fissured bark, with branches arranged to form a characteristic pyramidal canopy in juvenile stage,

simple alternate leaves, 10-18 cm long (Lorenzi and others 2003);

- *Casearia silvestris* SW, fam. Flacourtiaceae: tree 4-6 m high, persistent leaves, glabrous or rough and shiny on top, 6-12 cm long, is a hardy, perennial, heliophilous pioneer plant (Lorenzi 1992) and slow growing (Carvalho 2006);

- *Viburnum odoratissimum* Ker Gawl., fam. Magnoliaceae: evergreen tree, 5-7 m tall, native to India, China and Japan, stem with rough bark with lenticels, slow growing, very hardy and tolerant to adverse soil and climate conditions (Lorenzi and Souza 2003);

- *Magnolia grandiflora* L. , fam. Magnoliaceae: evergreen tree, 12-15 m tall, native to the United States, irregular stem with uneven bark, with vigorous branches forming pyramidal canopy in youth and open canopy in old age, has simple alternate leaves, clustered at the ends of branches, coriaceous, persistent, 6-12 cm long, is a slow growing and long-lived tree (Lorenzi and Souza 2003).

According to Biondi and Batista (2010), in order for species to be suitable for use in green barriers, their characteristics must meet certain requirements regarding low flammability to hinder the ignition and spread of fire. Thus, for example, the species should be hardier, with an oval or pyramidal canopy, which are the simplest shapes for uniting the canopies through a set spacing. It must have monopodic branching, which facilitates the canopies crossing one another and has fewer gaps in the canopy and on the stem. The leaves should have a fleshy, herbaceous or coriaceous texture, with smooth, shiny surfaces, and they should have high water content and be without villi, which favor ignition. The stem should have dead, even bark without peeling, as this helps protect the tree whereas detached bark provides more combustible material. The species must have moderate to rapid growth, in reference to the time it takes to form the barrier and the speed with which the species recovers from fire damage.

To perform the experiments, leaves and thin branches (< 0.7 cm in diameter) were collected from the tops of the preselected species. Then the material was placed in airtight plastic bags, weighed and identified in detail. It was then sent to the Forest Fire Laboratory, where moisture content was determined using standardized procedures. The moisture content of the material collected was determined by the following formula (Batista and Soares 2007):

$$U\% = ((WW - DW) / DW) \times 100 \quad (1)$$

where U% is the moisture content of the combustible material (in %), WW is weight (wet) of material at the time of collection, and DW is weight (dry) of material after drying in an oven at 75 °C for 48 hours.

The flammability tests were performed according to the methodology proposed by Petriccione and others (2006) y Petriccione (2006). An epiradiator delivering a 500W constant nominal power rating with a temperature of 250 °C was used. Each 1-gram sample in natural state was exposed to the epiradiator for 60 seconds, with 50 trials conducted for each species. Ignition potential was determined by the average time for combustion to occur after the material was exposed to the epiradiator (for longer than 60 seconds, the test is considered negative). Combustion period, that is, the time the flame remains visible, and flame length were also measured.

Flammability values were obtained from ignition potential (IP) and the mean time to ignition (MTI), based on Table 1 (Valette 1990).

Table 1—*Flammability values (Valette, 1990)*

PI MDI– s	< 25	25-38	39-48	42-44	45-47	48-50
>32,5	0	0	0	1	1	2
27,5 – 32,5	0	0	1	1	2	2
22,5 – 27,5	0	0	1	2	2	2
17,5 – 22,5	1	1	2	2	3	3
12,5 - 17,5	1	1	2	3	3	4
< 12,5	1	2	3	3	4	5

Legend: PI – ignition frequency (number of positive ignitions out of 50 attempts); MDI – mean time to ignition, in seconds; 0 = no flammability; 1 = low flammability; 2 = moderately flammable; 3 = flammable; 4 = highly flammable; 5 = extremely flammable

The comparison between the moisture content, time to ignition and combustion period means were performed using ANOVA and the Student-Newman-Keuls (SNK) comparison of means test.

Results

Table 2 shows the mean values of the flammability variables for the species studied. There was a large variation between the moisture content (U%) means of the species studied. *M. grandiflora* had the lowest value, while *M. champaca* showed the highest mean moisture content value of the material analyzed. The moisture content of live vegetation varies according to its developmental stage. The characteristics of leaf and branch structures also influence the moisture content of species. The moisture content of vegetation is one of the most important properties that control the flammability of living and dead fuels.

Table 2— Mean values of the flammability variables for the species studied.

Species	U%	MCP	FL	MTI	FV
<i>Viburnum odoratissimum</i>	163,1bc*	4,74 a	10,64 b	18,2	2
<i>Michelia champaca</i>	183,7 c	3,87 a	8,16 a	13,1	3
<i>Magnolia grandiflora</i>	116,8 a	7,44 b	25,22 d	12,5	4
<i>Caseariasilvestris</i>	164,5bc	5,32 a	13,46 c	15,7	4
<i>Jasminum mesnyi</i>	179,1 c	18,53 c	13,92 c	10,9	5

Legend: U% - moisture content of the material in %; MCP – mean combustion period, in seconds; MTI – mean time to ignition, in seconds; FL – flame length, in cm; FV – flammability value.

* Means followed by the same letter in a column do not differ according to the SNK test at 95% level of significance.

The combustion period means presented no great variation among the species tested. Only the species *J. mesnyi* stood out from the others, presenting a mean combustion period approximately 3 times greater than the other species.

The variable flame length (FL) showed a significant difference among most of the species studied. This variable reflects fire intensity, that is, the greater the flame spread, the greater the amount of energy released. The species *M. grandiflora* had the highest FL average and *Michelia champaca* the lowest.

The flammability (FV) of the species tested varied depending on the mean time to ignition (MTI) and its frequency (IP), according to Table 1.

The species with the lowest FV values also have the lowest MCP and FL values.

Discussion

According to the results in Table 2, *J. mesnyi* is the species with the highest level of flammability, i.e., it is extremely flammable, while *C. silvestris* and *M. grandiflora* are highly flammable. The species *Michelia champaca* and *Viburnum odoratissimum* had the lowest flammability values and based on the methodology described by Valette (1990), they were classified as flammable and moderately flammable, respectively.

The flammability of a plant depends on the type, tissue quality and water content in leaves and branches. Species having low moisture contents are expected to have greater flammability (Petriccione 2006). Contrary to such expectations, Figure 1 shows that there is no correlation between the moisture contents of the species and flammability.

Very similar results were found by Petriccione (2006) when evaluating the flammability of various plant species of Italy. While several researchers emphasize the influence of moisture on the flammability of vegetation (Delabrazze and Valette 1982, Soares and Batista 2007), the results of the analyzes performed in this study

did not verify that assertion. There is a need for more detailed studies on other relevant aspects related to flammability, like the presence of volatile organic compounds such as oils, resins and gums in plants, which were not investigated in this work.

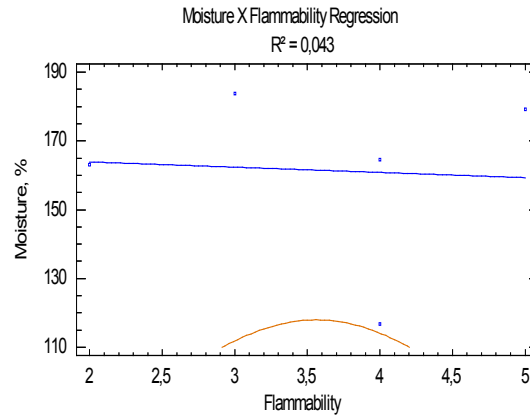


Figure 1—Correlation between the moisture content (%) of the leaves and branches of the species studied and flammability.

By contrast, significant correlations were obtained between other combustion parameters and moisture content, demonstrating the importance of moisture in the vegetation on fire ignition and spread, as seen in Figures 2 and 3.

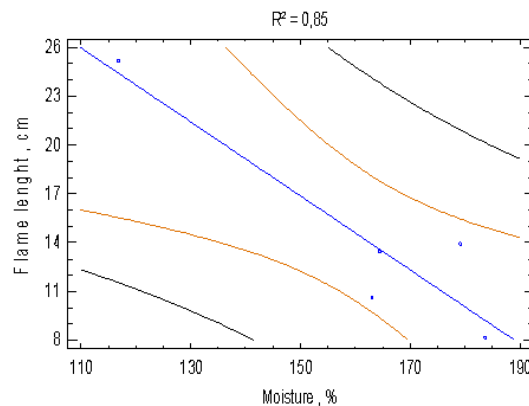


Figure 2—Influence of the moisture in vegetation on flame length (FL).

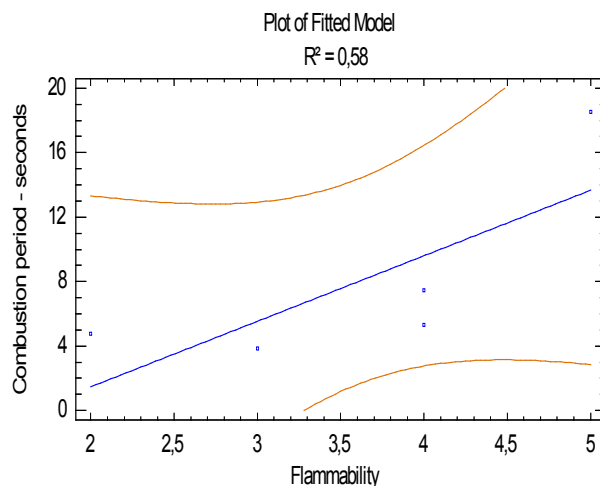


Figure 3—Influence of the moisture in vegetation on combustion (MCP)

Based on the results observed in these preliminary experiments, it can be concluded that the flammability of vegetation varies widely, depending not only on the moisture content but also on the chemical characteristics of the plant structure. These analyzes will be the subject of future research on the flammability issue. Another important conclusion obtained was the feasibility of using the method proposed by Valette (1990) for assessing the flammability of vegetation.

Summary

This paper describes an experiment conducted to investigate the flammability of trees and shrubs used in the establishment of green barriers in the rural-urban interface in the southern region of Brazil. A flammability assessment method which is widely used in several European countries and in the United States was employed. The species evaluated were: *Magnolia grandiflora* L., *Michelia champaca* L., *Jasminum mesnyi* Hance, *Casearia sylvestris* Sw. and *Viburnum odoratissimum* Ker

Gawl. The species *J. mesnyi* had the highest level of flammability, i.e., it is extremely flammable, while *C. silvestris* and *M. grandiflora* are highly flammable. The species *Michelia champaca* and *Viburnum odoratissimum* showed the lowest flammability values and based on the methodology described by Valette (1990), they were classified as flammable and moderately flammable, respectively.

References

- Batista, A. C.; Soares, R. V.** 2008. Silvicultura preventiva - uma alternativa para o controle de incêndios em reflorestamentos. In: I Encontro Brasileiro de Silvicultura, 2008, Curitiba - PR. Anais do Encontro Brasileiro de Silvicultura. Piracicaba: v. 1. p. 199-208.
- Biondi, D.** 2002. Seleção de espécies para o paisagismo rodoviário. Curitiba: FUPEF. Série Técnica. 11p.
- Biondi, D.; Batista, A. C.** 2010.. Ornamental plant species of Brazil and their potential use as fire breaks. In: VI International Conference on Forest Fire Research, 2010, Coimbra. Abstracts - VI International Conference on Forest Fire Research - CD-ROM. Coimbra - Portugal : ADAI/CEIF - Ed. Domingos X. Viegas, 2010. v. 1. p. 1-8.
- Carvalho, P. E. R.** 2006. Espécies arbóreas brasileiras. Brasília: Embrapa Informação Tecnológica; Colombo, PR: Embrapa Florestas; 627p.
- Delabraze, P.; Valette, J. C.** 1982. The Use of Fire in Silviculture. Symposium on Dynamics and Management of Mediterranean-type Ecosystems June 22-26, 1981, San Diego, California. Gen. Tech. Rep. PSW-58. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture.
- FPIInnovations, Wildland Fire Operations Research Group. Alberta, Canada.** 2009. Fuelbreak effectiveness: state of the knowledge. In: <http://fire.feric.ca/36532008/FuelBreakLiteratureSummary.pdf> (acesso em 20/07/2009).
- Green, L.R.** 1977. Fuelbreaks and other fuel modification for wildland fire control. USDA Agriculture Handbook, 499.
- Lorenzi, H.** 1992. Árvores brasileiras: manual de identificação e cultivo de plantas arbóreas nativas do Brasil. Nova Odessa: Plantarum; 315p.
- Lorenzi, H.** 1998. Árvores brasileiras: manual de identificação e cultivo de plantas arbóreas nativas do Brasil. Nova Odessa: Plantarum; v. 2. 376 p.
- Lorenzi, H.; Souza, H. M.** 2001. Plantas ornamentais no Brasil: arbustivas, herbáceas e trepadeiras. 3. ed. Nova Odessa: Instituto Plantarum; 1088 p.
- Lorenzi, H.; Souza, H. M.; Torres, M. A.; Bacher, L. B.** 2003. Árvores exóticas no Brasil: madeiras, ornamentais e aromáticas. Nova Odessa: Instituto Plantarum; 368 p.
- Petriccione, M.** 2006. Infiammabilità della lettiera di iverse specie vegetali di ambiente Mediterraneo. Università Degli Studi Di Napoli Federico II, Dipartimento di Biologia Strutturale e Funzionale, 48 p. (Tesi Di Dottorato In Biologia Applicata)

- Petriccione, M.; Moro, C.; Rutigliano, F. A.** 2006. Preliminary studies on litter flammability in Mediterranean regions. In: International Conference on Forest Fire Research, 5, Figueira da Foz, Portugal. Proceedings of... [S.I.: s.n.] 6p.
- Ribeiro, G. A.; Lima, G. S.; Oliveira, A. L. S.; Camargos, V. L.** 2007 (in press). Uso de vegetação como aceiro verde na redução da propagação de fogo sob linhas de transmissão. Revista CERES, UFV.
- Tian, X. R.; Shu, I. F.; Wang, M. Y.** 2007. Study on Eight Tree Species' Combustibility and Fuelbreak Effectiveness; In: IV International Wildland Fire Conference, 2007, Sevilla - España. Actas de La IV Conferencia Internacional sobre Incendios Forestales. Madrid - España: Organismo Autónomo de Parques Nacionales, Ministerio de Medio Ambiente, v. 1. p. 1-11.
- Valette J. C.** 1990. Inflammabilités des espèces forestières méditerranéennes. Rev. Forest. Fr. 42, 76-92.
- Vélez, R.** 2000. La defensa contra Incendios Forestales. Fundamentos y experiencias. Madrid: McGraw Hill.

A Community in the Wildland-Urban Interface¹

María Cecilia Ciampoli Halaman²

Abstract

Communities located in the wildland-urban interface undergo a process of transformation until they can guard against fires occurring in the area. This study analyzed this process for the Estación neighborhood in the city of Esquel, Chubut Province, Argentina. The analysis was performed by comparing the level of danger diagnosed for each neighborhood home in 2004 with that diagnosed using the same methodology in 2011. It also inquired about the behavior of neighbor residents in dealing with the problem of living in that area, analyzing the results of interviews conducted with them in 2011. It turned out that homes reduced their individual danger level in 72% of cases. However, the purpose of the neighbors was not to improve their situation with regard to interface fires but to refurbish their homes. So despite having reduced their fire danger, this community continues in the process of transformation towards prevention. To be considered a community prepared for fires in the wildland-urban interface, it is essential that its danger level is low as a consequence of the awareness of its people.

Keywords: Awareness, community, danger, interface, prevention.

Introduction

The landscape has been shaped by the presence of fire since time immemorial (Willis 1914, Raish 2005). However, it also recently began to respond to an interaction between natural phenomena and human activities (Farina, 2000; Forman, 1995). We can deduce from this current interaction that there is an implicit link between landscape and society, not only because society is affected by the landscape, but also because it participates in its modeling (Nogué 2007).

The need to defend the landscape against wildfires arose as a result of the interaction between natural phenomena and human activities (Tortorelli 1947).

¹ An abbreviated version of this paper was presented at the Fourth International Symposium on Fire Economics, Planning, and Policy: Climate Change and Wildfires, 5-11 November, 2012, Mexico City, Mexico.

² National Coordinator for Prevention and Information, National Fire Management Plan (PNMF), Ministry of the Environment and Sustainable Development Argentina. Ruta 259 km 4 Esquel Chubut Argentina. Email: cciampoli@ambiente.gob.ar.

Today this need is increasing for forest areas surrounding urban centers (Sonner 1994), where wildland-urban interface (WUI) fires occur, (Velez 2000). In the WUI, the frequency and threat of fires increase as the population growth rate increases (SDSyPA PNMF & BCFS 2002). However, the local population is usually not aware of the existing danger (Fariás2009).

Prevention is the key, and like any initiative it must be carefully planned to be successful (Chile Region VIII, CONAF 2006). In Argentina, a guide has been developed for the prevention of interface fires. Using this guide, the wildland-urban interface area called the Estación neighborhood, located in the city of Esquel in the Argentinean province of Chubut, was characterized in 2004.

To address the prevention of interface fires in the Estación neighborhood, in 2004 a diagnosis was made of the situation, as this is the first planning step. The diagnosis consisted of an assessment of the vulnerability of homes to fire using standard criteria.

At that same time (2004), the city of Esquel began making progress in terms of their building structures (Schulz 2012, p.c.), although it didn't for several years around the specific theme of interface fires (Epele 2012, p.c.). For this reason and at the initiative of the local fire service to resume the analysis of the problem (2011), it began to reassess the danger posed to the homes in the Estación neighborhood, considered a pilot area.

Se comienza a vislumbrar la iniciativa de la comunidad de Esquel, apuntando hacia la preparación contra los incendios que se producen en el área de interfaz urbano-forestal.

One is beginning to see evidence of the Esquel community initiative at work, as the area moves toward preventing fires from occurring in the wildland-urban interface area.

Objective

The objective of this study is to determine if a community is prepared for wildland-urban interface fires, by analyzing the transformation process of the Estación neighborhood.

Specific Objectives

1. To determine if there was a reduction in the fire danger level for homes in the selected interface area between 2004 and 2011.
2. To determine the behavior of area residents regarding the interface fire

danger.

Methodology

Study Area

Esquel is the central city in an area that extends into the western region of the province of Chubut, between 42° 54' and 43° lat. South, on the eastern fringe of the North Patagonian Mountain Range. The city has about 30,000 people within its area of influence. Economic activity is concentrated in three corporate organizations: the *Sociedad Rural* (Rural Society), the *Cámara de Comercio, Industria, Producción y Turismo* (the Chamber of Commerce, Industry, Manufacturing and Tourism) and the *Cámara de Prestadores de Servicios Turísticos* (Chamber of Tourism Service Providers). The city has four bank branches.

The region has a cold-temperate climate, with rain and snow during the winter months. Average annual rainfall in Esquel is 590 mm. Winds are generally classified as moderate to severe, with maximum wind speeds occurring in the spring and summer and prevailing winds from the west-southwest. In the Esquel area, the valleys are oriented northeast to southwest.

The municipal ejido, or common land, of the city of Esquel is located in a strip that constitutes an ecotone zone, a transition area between cold-temperate forests to the west in the Andes and the Patagonian steppe to the east.

Protection against wildfires in the Esquel region is the responsibility of specific fire management agencies: provincial, regional or national depending on the magnitude of the event. Among the most noteworthy are the Provincial Fire Management Service of Chubut (SPMF) and the National Fire Management Plan (PNMF) of Argentina.

Suppression of wildland-urban interface fires involves not only the pertinent forest fire agencies but also other related organizations. Their coordination has been arranged for Esquel and surrounding villages through interagency plans (Institutional Coordination Plan 2010-2011).

The Estación neighborhood containing the study area is one of the interface neighborhoods of the city of Esquel (Figure 1). The area itself consists of the seven closest blocks to the woodland surrounding the Estación neighborhood.

The topography of the neighborhood is very unique because it lies within the canyons belonging to Leonidas Alemán Hill. This location exposes the neighborhood to upward or downward airflows depending on the time of day (Dentoni and Muñoz 2001; APN unpublished), creating a powerful effect on fire behavior (Hirsch 1996).

Another fire danger factor for the neighborhood is the surrounding vegetation, specifically an approximately 24-h, city-owned stand of pines (*Pinus ponderosa* Douglas ex Laws) with high-density planting (CIEFAP 2001).



Figure 1—Aerial image of Estación neighborhood. Source: Sub-secretary of the Environment for the Municipality of Esquel 2004.

The neighborhood is classified as low-income residential (Esquel SEAS 2001). While most of the houses have basic services, namely electricity, water and gas, there are some exceptions. There are also troubled areas and ones occupied by illegal settlements bordering the neighborhood.

The buildings are mostly stable, with well-finished foundations and doors and windows. Durable materials and proper masonry characterize their construction. However, there are also some sub-standard homes and some that do not even have direct access from the street, making it necessary to cross a neighbor's property to access the dwelling in question.

The families generally consist of five or six members. Both parents work and most receive a state subsidy. The average monthly income is about \$ 3,000 (Argentine pesos, equivalent to about 500 euros), with most men working in construction and most women as housekeepers. State aid includes receiving assistance for food and heating.

Methods

1. The results of the danger assessment carried out on homes in the Estación neighborhood in 2004 were compared with those of the 2011 one. The comparison

was made to determine similarities or differences in the overall degree of danger between the two assessments (2004 and 2011) for each of the 53 homes, considering also the criteria by which that danger level was obtained. The criteria were also reclassified according to the difficulty in implementing them.

The procedure adopted for both assessments is detailed in the respective studies (Ciampoli Halaman 2004, 2011); it should be noted that it was proposed in the guide for interface fire prevention in Argentina (SDSyPA PNMF & BCFS 2002).

The criteria reclassified according to the degree of implementation difficulty are presented in the table below (see Table 1).

1. Simple measures: only require the owner's will to be done.
2. Medium measures: require some monetary investment in addition to the owner's effort.
3. Structural measures: require extensive restructuring to be implemented.

These recommendations were proposed for the Estación neighborhood among other areas of the province of Chubut.

Table 1—*Housing assessment, and simple, medium and structural measures with their respective recommendations.*

Measure	Criterion
Simple	roof cleaning
	stacked firewood and combustible material
	services
	protective home measures
Medium	conifer forest cover
	lot occupation
	access
	Special factors (Sprinklers, Extreme forest fuel load, Deficient home indication).
Structural	house location
	roofing material
	cladding material
	Special factors (Access, windows, bridge capacity).

2. The information gathered in 46 interviews with neighborhood residents in 2011 was analyzed in order to determine their behavior with respect to fire danger. The analysis consisted of identifying the survey questions pertaining to the subject in question and classifying their answers in percentage terms. The interview technique used was that of directly interviewing the neighbors on an individual basis (CONAF, 2006), supported by leaflets delivered to every neighbor interviewed (Ciámpoli Halaman 2011).

Results

1. A reduction in fire danger between 2004 and 2011 was determined for the homes in the interface area of the Estación neighborhood in Esquel, Chubut, Argentina. Of the 53 homes compared, 72% scored lower in 2011 than in 2004. Of these homes that decreased their danger level, 51% were classified in a lower category by one level than in the previous assessment.

Of the criteria evaluated:

Simple measures were generally followed: roofs were cleaned, firewood or combustible materials were moved away from homes or directly eliminated, and urban trees were pruned to avoid contact with power lines.

In terms of medium measures, some were improved and others not. Conifer forest cover decreased in value for all of the homes, since the stand was harvested in 2011, and lot occupation fell, as many of the substandard buildings that existed in 2004 were not found in 2011. It should be noted, however, that the access situation remained unchanged in virtually all cases.

Regarding structural measures, improvements were also found in some criteria but not in others: roofs were generally replaced with new ones made of better materials, the location of the homes in virtually all cases remained the same, and large windows facing the forest increased the danger of several homes.

2. An analysis of the interviews revealed that six questions specifically addressed the fire danger issue. Those questions are presented below along with the summarized results of the responses given by the 46 neighborhood residents interviewed, classified as a percentage.

1) Respondent's awareness of the fire danger in his/her living area

91% of respondents replied that they knew about the danger that exists in their area. It should be noted that of the remaining 9%, half had resided there for only a few months and the other half had also not lived there for a long time.

2) Possession of a vehicle for evacuation

73% of respondents answered negatively. It should be noted that of the 37%

who do have their own transport, the vast majority use it to travel to their workplace so if there is an evacuation it is quite possible that the vehicle will not be available for that purpose at the home.

3) Knowledge of the contact number in case of fire

78% claimed to know the number to call. It should be noted that in all cases respondents referred to the number of the volunteer fire department, so even if they detected a fire that started in the forest they would call the volunteer fire department.

4) Personal experience with the damage or effects caused by a forest fire, either on one's interests or property.

7% of respondents said they had been affected by fire during the time they had lived in the Estación neighborhood. This result is noteworthy because according to surveys, the average number of years that residents have been living in the Estación neighborhood is 14. Therefore, except for four isolated cases, the rest of the neighbors were there when the La Zeta Hill fire occurred that affected the Estación neighborhood stand on March 4, 2007. Figure 17: schematic of the fire that occurred on March 4, 2007 at La Zeta Hill.

5) Preventative measures taken by residents at their homes

76% said they had not taken any action. This result includes most of the respondents who said they had been affected by fire.

6) Carrying out of green garden waste burns

58% of respondents answered negatively. It should be noted that local residents know that the sanctioning authority for conducting burns is the institution to which the interviewers belong. Of the 42% that do perform waste burns, the vast majority said they have no other choice due to the lack of a collection service.

The responses of the interviewed neighbors were also linked with the households that decreased their danger level between assessments, finding that of the 38 households that decreased their individual danger, 56% of them have neighbors who said they had not taken any action in this regard.

Discussion

While 72% of households decreased their individual danger, there was no direct contribution to this reduction by their neighbors. Direct contribution in this case refers to actions planned and carried out for this purpose.

Regarding behavior, some peculiarities were detected. Namely, although most residents (over 90%) claimed to know they were living in a fire danger interface area, most (76%) did not take any preventive measures in this regard. This last figure includes more than half of the neighbors of the households that decreased their

danger level between assessments.

They said they had not been endangered by fire, even though most of them were already living there when the La Zeta fire that affected the Estación stand occurred there in 2007.

As for the few neighbors who did recall being threatened by the fire, most of them (67%) were part of the group that did not take any actions to reduce the danger to their homes.

Conclusions

While issues of a structural, environmental management and urban planning nature have evolved favorably in terms of reducing fire danger in the Estación neighborhood, residents show contradictions in their response to the problem. Therefore, this community continues in the process of transformation towards prevention.

One can thus see the dominance of the social aspect in structural issues and of environmental improvement works in the problem of fire in the wildland-urban interface, as no initiative can be sustained without the involvement of the residents themselves.

To be considered a community prepared for fires in the wildland-urban interface, it is essential that the danger level is low as a consequence of the awareness of its inhabitants.

References

- Administración de Parques Nacionales (APN). Delegación Regional Patagonia. Subprograma Ecología del Fuego.** Inédito. Protección de viviendas y estructuras en incendios mixtos y de interfase.
- Ciámpoli Halaman M.C. 2004.** Caracterización del Peligro de Incendio en la Interfase Urbano Forestal. Tesis de grado. Facultad Ingeniería Forestal. Universidad Nacional de la Patagonia San Juan Bosco. 49p.
- Ciámpoli Halaman M.C. 2011.** Hacia una Comunidad Prevenida ante el Peligro de Incendio Urbano Forestal. Tesis de Master en Medio Natural, Cambio Global y Sostenibilidad Socio Ecológica. Universidad Internacional de Andalucía. España. 101p.
- CIEFAP. Dirección de Medio Ambiente y Espacios Verdes – Municipalidad de Esquel. Universidad Nacional de la Patagonia San Juan Bosco Facultad de Ingeniería-Cátedra de Dasometría. 2001.** Inventario Forestal. Forestaciones Comunes Esquel. 47 p.
- Dentoni, M.C., Muñoz, M. 2001.** Glosario de Términos Relacionados con el Manejo del Fuego. Plan Nacional de Manejo del Fuego. Secretaría de Desarrollo Sustentable y Política Ambiental. Argentina. 28 p.

- Esquel Seas. 2001.** Plan participativo de desarrollo local, social, económico y ambientalmente sustentable: documento final. Esquel: Universidad Nacional de la Patagonia San Juan Bosco.
- Farias, M.C. 2009.** Report on fire culture in Argentina. Social representations of fire risk in an urban-forest interface – CIEFAP. Project Title FIRE PARADOX: An Innovative Approach of Integrated Wildland Fire Management Regulating the Wildfire Problem by the Wise Use of Fire: Solving the Fire Paradox. 33 p.
- Farina, A.2000.** The cultural landscape as a model for the integration of ecology and economics. *Bioscience*, n° 50(4), págs. 313-320.
- Forman, R.T.T. 1995:** Land Mosaics: The Ecology of Landscapes and Regions. Cambridge University Press, Cambridge, UK.
- Gobierno Regional y CONAF, VIII Región. 2006.** Manual del profesional que trabaja en prevención de incendios forestales. Gobierno de Chile. Ministerio de Agricultura. CONAF. 32 p
- Hirsch, K.G. 1996.** Canadian Forest Fire Behavior Prediction (FBP) System. User's guide. Canadian Forest Service. Northwest Region. Northern Forestry Centre. Canada. 122 p.
- Nogue, J., Eds. 2007.** La construcción social del paisaje. Editorial Biblioteca Nueva, SL. Madrid.
- Raish, C., González-Cabán A., Condie, C.J. 2005.** The importance of traditional fire use and management practices for contemporary land managers in the American Southwest. *Environmental Hazards* Published, by Elsevier Ltd.
- Secretaria de Desarrollo Sustentable y Política Ambiental. Plan Nacional de Manejo del Fuego, Argentina. Programa de Protección de Bosques, Ministerio Forestal de British Columbia, Canadá. Agencia Canadiense de Desarrollo Internacional. 2002.** Guía para la prevención de incendios de interfase en la República Argentina. Canadá. 72 p.
- Sonner, S. 1994.** Forest homes drawing fire. *The Spokesman-review*.
- Tortorelli, L.A. 1947.** Los Incendios de Bosques en la Argentina. Ministerio de Agricultura de la Nación. Dirección Forestal. Buenos Aires., Argentina. 231p
- Vélez, R. 2000.** La Defensa de los Incendios Forestales - Fundamentos y Experiencias. Ed. Mac Graw Hill. Madrid, España.
- Willis, B. 1914.** El Norte de la Patagonia. Comisión de Estudios Hidrológicos. Ministerio de Obras Públicas. República Argentina. Tomo 1, 500 p.

Fuel Load Modeling From Mensuration Attributes in Temperate Forests in Northern Mexico¹

Maricela Morales-Soto² and Marín Pompa-García³

Abstract

The study of fuels is an important factor in defining the vulnerability of ecosystems to forest fires. The aim of this study was to model a dead fuel load based on forest mensuration attributes from forest management inventories. A scatter plot analysis was performed and, from explanatory trends between the variables considered, correlation analysis was carried out using the stepwise method in SAS software. Results showed that leaf load, total volume and cutting intensity largely explain dead fuel load as the dependent variable. In addition to discussing the statistical benefits of the models studied, it is concluded that inventory data from management programs are an efficient and low-cost alternative for estimating forest fuel loads.

Keywords: inventories, forest fires, allometric relationships.

Introduction

All flammable plant material is considered forest fuel. Forest fuels are classified as living or dead; dead fuels are all biomass found on the ground; living fuels are comprised by herbaceous plants, shrubs and trees (Wong and Villers 2007). Dead fuels, in turn, are subdivided by weight into light or heavy fuels. They are also classified according to where they are found on a site: ground, surface or aerial fuels (Rentería and others 2005).

Forest fuel is one of the main elements involved in wildfire occurrence, and it is a very important factor to define the danger of forest fires, as the degree of danger is

¹ An abbreviated version of this paper was presented at the Fourth International Symposium on Fire Economics, Planning, and Policy: Climate Change and Wildfires, 5-11 November 2012, Mexico City, Mexico.

² Graduate Student in Conservation Sciences and Management of the Environment and Natural Resources; Email: marims1_@hotmail.com

² Profesor- investigador. Facultad de Ciencias Forestales (FCF). Universidad Juárez del Estado de Durango (UJED). Río Papaloapan y Blvd Durango s/n Col. Valle del Sur. Email: mpgarcia@ujed.mx

³ Professor and Researcher, School of Forestry Sciences, Universidad Juárez del Estado de Durango (UJED). Río Papaloapan y Blvd Durango s/n Col. Valle del Sur. Email: mpgarcia@ujed.mx

a function of the amount and type of fuel material present in each of the forest areas (Rentería and others 2005). It is known that fire intensity varies according to the fuel material. Therefore, it is essential to have updated dead forest fuel inventories. Planar intersections are one of the most common techniques; it was described by Brown in 1974, who mentions that this method can be applied to any type of forest. This technique consists of counting the intersections of woody plants in vertical planes. Based on this sampling the volume is estimated, and the weight is calculated based on the volume and the specific gravity of the woody plants.

Unfortunately, the drawback of this technique is that data must be taken *in situ*; therefore, it requires a considerable amount of time, effort and money. For this reason, the forest lands in which dead fuel quantification is carried out are few indeed. And of those that have some information available, since fuel loading is a dynamic process, after a certain time this information is out of date.

Stepwise regression is a method that facilitates relating variables with each other; this allows obtaining an equation to predict the value of the dependent variable once the values of the independent variable are known. This method is a useful, easy and fast tool to calculate dead fuels from living fuel information, and it can be used in all lands with forest inventory information, since the values for the dependent variables (dead fuel) and independent variables (mensuration data) are known.

The goal of this study is to estimate the dead fuel from living fuel information using allometric relationships, having as a hypothesis the existence of correlation between the dependent variable and the explanatory ones.

Materials and methods

Description of the study area

The selected study area is geographically located southwest of Durango State, Mexico. Its geographical coordinates are between 23° 07' and 23° 39' north latitude and 105° 12' and 105° 46' west longitude. It has a total area of 240,739 ha, with uneven topography in a system of plateaus associated with glens; its altitude ranges from 500 to 2,800 meters above sea level (m.a.s.l.). The soils were caused by weathering of igneous rocks. The main land uses are agriculture, livestock and forestry (Meraz 1998). Most ecosystems are common property, although some are privately owned. The climates are: C(w2), temperate, sub humid, summer rains from 5 to 10.2 percent annually; (A)C(w2), semi warm, temperate sub humid, summer

rainfall from 5 to 10.2 percent annually; Cb'(w2), temperate, semi cold with fresh long summer, sub humid, summer rainfall from 5 to 10.2 percent annually; Aw1, sub humid warm, summer rainfall from 5 to 10.2 percent annually; C(w2), temperate, sub humid, summer rainfall from 5 to 10.2 percent annually (Pompa 2012), (Figure 1).

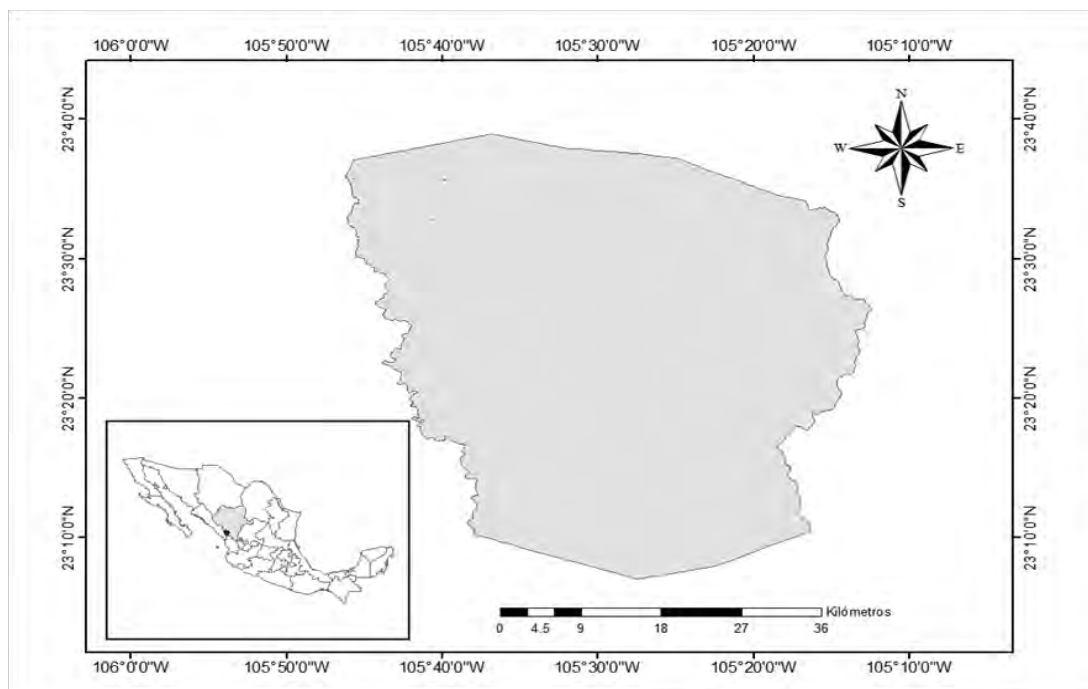


Figure 1 – *Ejido Pueblo Nuevo, Durango, Mexico.*

Methodology

First, the following mensuration data was collected: leaf litter load (Mg/ha^{-1}); light, medium and heavy woody fuels (Mg/ha^{-1}); slope (percent); average *Pinus* height (m); average removal (m^3); oak and pine squared diameter (cm); pine and oak cutting intensities (percent); oak, conifers and leafy tree percentages; physical stocks of each species (number of individuals); total IMA and productivity level of the stands obtained from the forest management inventory of Ejido Pueblo Nuevo, Durango. Using this information, a scatter plot analysis for dead fuel material was performed using each one of the living fuel variables, in which trends with a greater relationship to the dead fuel load were identified. Once the variables with greater contribution were identified, they were processed using the stepwise method in SAS

software in order to analyze the spatial relationships of the dependent variable (dead fuel) with the independent variables (living fuel).

The models used to estimate the dead fuel load were as follows (Table 1):

Table 1 - Models used to estimate the fuel load

Model
(1) $L = \beta_1 * S + \beta_2 * H + \beta_3 * R + \beta_4 * SD + \beta_5 * PCI + \beta_6 * ACI$
(2) $T = \beta_1 * L + \beta_2 * QSD$
(3) $SWF = \beta_1 * L + \beta_2 * QCI$
(4) $WHFL = \beta_1 * PSD$
(5) $SWF = \beta_1 * TOC + \beta_2 * QSD$
(6) $c3 = \beta_1 * TOC + \beta_2 * QSD$
(7) $c2 = \beta_1 * TOC + \beta_2 * QSD$
(8) $c1 = \beta_1 * QSD$

where $\beta_1, \beta_2, \beta_3, \beta_4, \beta_5, \beta_6$ are regression parameters, L is leaf litter load (Mg/ha^{-1}), S is slope (%), H is average Pinus height (m), R is average removal (m^3), QSD is *Quercus* squared diameter (cm), PCI is *Pinus* cutting intensities (%), ACI is average *Pinus* cutting intensities (%), T is total load (Mg/ha^{-1}), SWF is sum of light, medium and heavy wood fuel load (Mg/ha^{-1}), QCI is *Quercus* cutting intensities (%), WHFL is woody heavy fuels load (Mg/ha^{-1}), PSD is *Pinus* squared diameter (cm), TOC is total of other conifers (number of individuals), and C1, C2, C3 are categories of woody fuel loads with 1, 10 and 100 h of TR, respectively (Mg/ha^{-1}).

The criteria used to evaluate the model is based on a numerical analysis that compares three statistical parameters commonly used in forestry: 1) bias ($\bar{E}$), which evaluates the model deviation with respect to the values observed; 2) the root mean square error (RMSE), which analyzes the accuracy of the estimates, and 3) adjusted coefficient of determination (R^2_{adj}), representing the portion of variance explained by the model, taking into account the number of its parameters. Their expressions are:

Bias:

$$\bar{E} = \sum_{i=1}^n (y_i - \hat{y}_i) / n \quad (1)$$

Root mean square error:

$$RMSE = \sqrt{\sum_{i=1}^n (y_i - \hat{y}_i)^2 / (n - p)} \quad (2)$$

Adjusted coefficient of determination:

$$R_{adj}^2 = 1 - (n - 1) \cdot \sum_{i=1}^n (y_i - \hat{y}_i)^2 / (n - p) \cdot \sum_{i=1}^n (y_i - \bar{y})^2 \quad (3)$$

Where: y_i , $\hat{y}_i$ and $\bar{y}$ are the observed, estimated and average values of the dependent variable, respectively; n is the total number of observations used to adjust the model and p is the model's number of parameters.

Results and discussion

According to the fit statistics values obtained by using the stepwise method, the independent variables that mostly explain the influence of dead fuel loads are: pine and oak cutting intensities; total actual stocks of pine, oak and other leafy trees and leaf litter depth (Table 2).

Table 2 – Estimated dead fuel models from living fuels

Model	Parameters	Estimate	Standard error	Adjusted parameters	
				RMSE	R_{adj}^2
(1)	β_1	-0.084	0.018	4.363	0.761
$L = \beta_1 * S + \beta_2 * H + \beta_3 * R + \beta_4 * SD + \beta_5 * PCI + \beta_6 * ACI$	β_2	0.377	0.071		
	β_3	31.250	5.375		
	β_4	0.162	0.027		
	β_5	-0.066	0.015		
	β_6	-2.149	0.393		
(2) $T = \beta_1 * L + \beta_2 * QSD$	β_1	1.053	0.173	15.635	0.683
	β_2	0.413	0.044		
(3) $SWF = \beta_1 * L + \beta_2 * QCI$	β_1	1.120	0.128	17.100	0.371
	β_2	0.104	0.027		
(4) $WHFL = \beta_1 * PSD$	β_1	0.308	0.026	14.818	0.269
(5) $SWF = \beta_1 * TOC + \beta_2 * QSD$	β_1	0.106	0.018	5.729	0.554
	β_2	0.149	0.009		
(6) $c3 = \beta_1 * TOC + \beta_2 * QSD$	β_1	0.052	0.009	2.847	0.520

	β_2	0.068	0.004		
(7) $c2=\beta_1*TOC+\beta_2*QSD$	β_1	0.052	0.009	2.847	0.520
	β_2	0.068	0.004		
(8) $c1=\beta_1*QSD$	β_1	0.013	0.0008	0.595	0.380

In Table 2, the results show standard errors close to zero and reliable R^2 values, which indicates that there is a good correlation between the dependent and independent variables. It is important to mention that although some models (2, 3, 4, 5, 6, 7 and 8) have fewer parameters they are equally reliable as the models with more of them. As it can be seen in models 1 and 2, although they differ in number of estimated parameters, the calculated variable is the same and the final results are similar.

Quantity of leaf litter in model 1 shows standard errors close to zero and the fit statistics value is $R^2= 0.761$ indicating that there is a good correlation between leaf litter and the dependent variables. In model 2 the total fuel load also shows standard errors close to zero, with an $R^2= 0.683$. The results indicate that both models yield statistically reliable data even when they differ in the number of estimated parameters.

On the other hand, the models show that the main factors for the concentration of forest fuels are a function of the waste generated during cutting and total actual stocks, as outlined in the work by Rentería and others, 2005.

According to the obtained results, the cutting intensity, total actual stocks and leaf litter depth variables can be reliably used in calculating fuel load, although its classification is difficult in terms of dimensions (light, medium and heavy) and the place where it was found (ground, surface or aerial). For Flores and Omi (2003), their estimation is a useful strategy to identify areas with a higher susceptibility to forest fire occurrence, and is thus very useful to direct prevention, control and attack strategies. This is coincident with Estrada and Angeles (2007), who mentioned that the values obtained during any assessment of forest fuels, can serve as a basis for mapping forest fire risk by combining with other parameters. Additionally, with this method it is not necessary to carry out an inventory of forest fuels that requires time, effort and funding. Fuel data can be updated while updating the forest inventory.

Conclusion

Dead fuel load can be calculated from living fuels by using statistical techniques supported by mensuration data correlation. In this study, the variables that best

explained the models were: cutting intensity, total actual stocks and leaf litter depth. It was determined that this correlation method is a fast, reliable and efficient technique since the dependent variables are taken from existing inventory data. Additionally, it can be a useful tool in modeling fire danger, regimes and fire management strategies.

Acknowledgements

We thank the Ejido Pueblo Nuevo for providing information for this preparation of this paper. We are also grateful to Dr. Dante A. Rodriguez for his comments and suggestions on the original manuscript.

References

- Brown, James. 1974.** *Handbook for inventorying downed woody material*. USDA Forest Service. General Technical Report INT – 16. Utah, USA. 24 p.
- Estrada, Israel; Ángeles, Efraín R. 2007.** Evaluación de combustibles forestales en el parque nacional El Chico Hidalgo Sevilla España Wildfire. 1-19 p.
- Flores, José G.; Omi, Philip N. 2003.** Mapping forest fuels for spatial fire behavior simulation using geomatic strategies. Agrociencia. Colegio de postgraduados. 37(001): 65-72.
- Meraz, Rufino. 1998.** Programa de manejo forestal ciclo de corta 1997-2007. Servicio Técnicos Forestales del Ejido Forestal Pueblo Nuevo. 215 p.
- Pompa, Marin. 2012.** Sistema de información geográfica de los ecosistemas de Durango. Disponible en <http://www.ujed.mx/sigeed/Inicio.aspx>. Consultado el 17 de febrero de 2012.
- Rentería, J B.; Treviño E.J.; Návar, J de J.; Aguirre, O.A.; Cantú, I. 2005.** Caracterización de combustibles leñosos en el Ejido Pueblo Nuevo, Durango. Revista Chapingo. Universidad autónoma chapingo 11(001): 51-56.
- Wong, Julio C.; Villers, Maria L. 2007.** Evaluación de combustibles y su disponibilidad en incendios forestales: un estudio en el parque nacional la Malinche. Universidad Nacional Autónoma

Methodological Approach for Assessing the Economic Impact of Forest Fires Using MODIS Remote Sensing Images¹

Francisco Rodríguez y Silva¹, Juan Ramón Molina Martínez², and Miguel Castillo Soto²

Abstract

Assessing areas affected by forest fires requires comprehensive studies covering a wide range of analyzes. From an economic standpoint, assessing the affected area in monetary terms is crucial. Determining the degree of loss in the value of natural resources, both those of a tangible and intangible nature, enables knowing the residual value remaining after a fire, i.e., it enables determining the “net change in the value of the resources.” While the importance of economic analysis in the planning process for different post-fire rehabilitation actions is indisputable, determining the net change in the value of natural resources becomes complex when the size of the affected area makes gathering the information unfeasible, partly because of the costs involved in obtaining the information and partly because of the time that will elapse before the final assessment is available. Once the set of algorithms that allow the initial assessment and the corresponding depreciation of existing resources due to fire impact have been obtained, the assessment can be made immediately with the help of a geographic information system and the corresponding “fire impact depreciation matrix.” The ability to incorporate satellite image processing into economic damage assessment allows identifying with greater precision the delimitation of the affected areas based on the “normalized vegetation index.” Analysis and interpretation of MODIS images, combined with the energy intensity emitted by the spread of fire, can be integrated into econometric models in order to obtain, in a geo-referenced manner, the economic value per hectare resulting from wildfire damage. This paper details the methodology followed and the results obtained and validated in a series of wildfires that occurred in different geographic areas.

¹ An abbreviated version of this paper was presented at the Fourth International Symposium on Fire Economics, Planning, and Policy: Climate Change and Wildfires; 5-11 November 2012, Mexico City, Mexico.

² Professor and Director, Forest Fire Management Laboratory; Forestry Department. School of Agricultural Engineering and Forestry. University of Cordoba, Leonardo da Vinci Building. Rabanales Campus. 14071, Cordoba, Spain. E-mail: ir1rosif@uco.es.

² Professor, Forest Fire Management Laboratory. Department of Forest Resources Management. Faculty of Forest Sciences. University of Chile. Santiago, Chile.

Keywords: vegetation indices, depreciation ratio, economic vulnerability

Introduction

Forest fires are one of the biggest environmental problems (Moyano and Jimenez 2005). Although fire has been used since ancient times in agricultural plowing and pasture creation for the purpose of livestock use (Kenneth, 1962), socio-economic changes have led to an abandonment of traditional uses. This neglect results in a greater accumulation of scrub (Perez 1990, Rodriguez y Silva and Molina 2010), which, along with the accentuation of climate conditions (Piñol and others 1998), has led to an increase in virulence of forest fires, and consequently an increase in fire damage to natural resources and the surrounding environment.

The valuations of natural resources tend to underestimate the real value of the forest (Constanza and others 1997). Unlike traditional economic activity, the forest environment is characterized by the extraordinary relevance of externalities that involve harm or benefits of considerable magnitude to others. From a socioeconomic perspective, it is necessary to express all the natural resources in monetary terms. The assessment of damages caused by forest fires requires the individualized study of each of the resources (tangible and intangible) and their net value change in relation to fire severity and ecosystem resilience (Molina and others 2009).

The recognition and valuation of natural resources is essential for the spatiotemporal planning of preventive work and post-fire restoration (Molina 2008). Incorporating the concept of vulnerability extends the study beyond an economic valuation, integrating two concepts, the value of the resource and fire behavior. The integration of both concepts is done using a matrix of depreciation ratios based on flame intensity, called "depreciation matrix" (Molina and others 2011, Rodriguez y Silva and others 2012).

Numerous studies have shown the potential of remote sensing in the field of forest fires (Chuvienco and others 2005). The incorporation of satellite imagery to the economic evaluation provides, in a novel way, a tool of undoubted interest to accurately identify the area affected by fire. The advantage of using MODIS satellite imagery lies in the availability of virtually real-time information at zero cost. The difference between the value of the vegetation indices before and after flames have passed through the area can be integrated in a geo-referenced manner with the energy intensity emitted by flames, obtaining indirectly the economic losses per unit area (Rodriguez y Silva and others 2009).

The socioeconomic vulnerability model was made by configuring a mathematical algorithm associated with a Geographic Information System (GIS)

facilitating the development of spatiotemporal tracking cartography, at both the individual resource level and the integrated ecosystem vulnerability level. The automation of the calculation and management using GIS is being conducted under the project INFOCOPAS (RTA2009-00153-C03-03) funded by the National Institute for Agricultural Research (INIA, for its acronym in Spanish), to achieve in a versatile manner a geo-referenced understanding of the forest system vulnerability to wildfires, at virtually real time.

Methodology

The economic evaluation of the damage caused after the presence of flames (by MODIS images) has been carried out for 5 campaign fires in Andalusia: *Aldeaquemada* (2004), *Minas de Rio Tinto* (2004), *Alajar* (2006), *Cerro Catena* (2009) and *Cerro Vértice* (2011). This fire group provides a wide range of forest ecosystems and damage levels. The economic impact assessment of a large forest fire requires the following phases of analysis and development:

- a) Economic valuation of natural resources
- b) Spatial identification of different damage levels.
- c) Identification of the net value change in the resources
- d) Economic valuation of fire damages.

Economic valuation of natural resources

Economic valuation of natural resources must incorporate three types of resources: tangible resources, environmental services and landscape assets. The valuation of tangible resources includes timber and non-timber products. The methodological approach for assessing the impact on the timber resource is based on an algorithm that integrates the assessment tools, including the natural and artificial origin of woodland (Rodríguez y Silva and others 2012). The valuation of non-timber resources is based on expressions of the Assessment Manual of Losses and Environmental Impact Estimation for Forest Fires (Martínez Ruiz 2000). The assessment of the impact on the hunting resource will be performed through the adjustment proposed in Zamora and others 2010.

The valuation of environmental services includes three resources: carbon fixation, erosion control and faunal biodiversity. The assessment of carbon sequestration includes both the amount fixed at the time of the fire and the amount unfixed from that time, and thus requires the volume with bark, aerial biomass and annual increase (Table 1). The quantity of carbon corresponding to dry biomass was estimated at 50%. The erosion control will be expressed in lost economic profit

based on the potential amount of ground lost per surface unit. The expression used for the assessment (Table 1) includes an addend in respect to losses incurred during the first rains (bare soil) and a second addend that includes progressive soil losses until recovery of vegetation with similar protection to the one burned (Molina and others 2009). The faunal biodiversity or unique species valuation is completed via the cost of the species recovery program, or if no specific program is available, through the contingent valuation method (Molina 2008).

Spatial identification of the different damage levels

As an example, this paper discusses the methodological implementation for the *Cerro Catena* fire, which destroyed more than 200 hectares, mainly *Pinus pinaster* forest with semi-dense undergrowth dominated by *Rosmarinus officinalis* and *Juniperus oxycedrus*. The topography is steep with a height of 960-1200 meters above sea level, thus favoring the virulent spread of fire. The fire occurred under meteorological influence characterized by a temperature of 26 °C, relative humidity of 16% and a wind speed of 12.5 km/h.

The spatial identification of the different damage levels was performed using MODIS images (Terra and Aqua) for a previous date (September 6) as well as for a post-fire date (September 22). For both dates the images were acquired from the United States Geological Service's LP DAAC Server (https://lpdaac.usgs.gov/get_data/data_pool), which is administered by NASA. Preparing the images required the transformation of Sinusoidal Datum (original images) to the European Datum 1950 Zone 30N system, making the overlapping of the images with the fire perimeter in vector format.

Table 1—Mathematical formulations used for economic valuation

Resource	Formula	Resource status	Source
Timber	$V_{\text{mad}} = (1,7 * E * B) / (E + 0,85 * B)$	Mature and immature	Rodríguez y Silva and others 2012
	$E = C_0 * p [i^e + g(i^e - 1)] + A * (i^e - 1)$	Immature	
	$E = (C_0/z * t [i^e + g(i^e - 1)] + (C_0/z) * 0,5 * (i^e - 1)$	Immature	
	$E = [P * V - P_1 * V_1] + P * V [(i^{(T-e)} - 1) / (i^{(T-e)})]$	Mature	
	$B = [(V * P * 1,025^n) / 1,04^n] * [1 - (1,025 / 1,04)^e] * [1 + X * h * p]$	Immature	
	$B = V * h * t [R * P + (1 - R) * P_1]$	Mature	Martínez 2000; Molina and others 2011;
Use of firewood	$V_{\text{leñas}} = P_x * R_x * [((1+i)^n - 1) / (i * (1+i)^n)]$	Mature	

Hunting	$V_{cin} = P_x * R_x * [(1+i)^n - 1] / (i * (1+i)^n) + S$	Hunting reserve	Zamora and others 2010;
Carbonsequestration	$V_{carb} = CF * PM + IF * PM * RC * [((1+i)^{T-e} - 1) / (i * (1+i)^{T-e})]$	Forest stand	Molina 2008;
Erosion control	$V_{eros} = R_1 * P_1 + R_2 * P_2 [(1+i)^n - 1] / (i * (1+i)^n)$	-	Molina and others 2009
Faunal Biodiversity; landscape; Leisure and recreation; Non-use	$V_{biod/pai/oci/nouso} = R_x * [((1+i)^n - 1) / (i * (1+i)^n)]$	Presence of particular species	Molina 2008

Where "E" is the timber valuation based on the traditional Spanish approach (€/ha.), "B" is the timber assessment adapted from the American model (€/ha.), "Co" is the cost of replanting a hectare of land (€/ha.), "p" is the percentage of the stand affected by fire, "i" is the annual interest rate, "g" is the annuity depending on the rotation of the species, "A" is the value of one hectare of land without trees (€/ha.), "e" is the estimated age of the stand at the time of the fire, "V" is the timber volume expressed in m³/ha., "P" is the price of one m³ of felled wood (€), "n" is the number of years until the hypothetical felling season, "X" is the mortality coefficient dependent on the severity of the flames, "h" is the percentage of the species in the canopy, "z" is the cost reduction of restocking based on the self-healing phenomenon as a function of the rotation, "P₁" is the price of the damaged wood with commercial use (€/m³), "V₁" is the volume of damaged wood with utilization (m³/ha.), "Px" is the price per measurement unit of the resource (€), "Rx" is the annual income per surface area, "S" is the breedingstock per surface unit (€), "CF" is the amount of CO₂ trapped at the time of the fire (t/ha.), "PM" is the price per fixed ton (€/t), "IF" is the annual increase of CO₂ retained (t/ha.) "RC" is the income generated by fixing a ton of carbon in a year (€), "R₁" is the amount of soil medium lost the first year (t/ha.), "P₁" is the estimated price for a ton (€), "R₂" is the amount of soil medium lost until the recovery of the original cover (t/ha.).

Subsequently, the bands needed for spatial analysis were identified. Both for the Terra and Aqua platforms, the reflectivities of the bands used are located in the spectrum of 620-670nm (red) for band 1, and 841-876nm (near infrared) for band 2. In the case of images with a resolution of 500 meters, the band 7 used ranged from 210-215nm. Geo-referencing and adjusting of the final fire perimeter was performed with ArcGIS© software, keeping a 150-meter tolerance buffer in order to include the effect of the proximity to the burned area. An adjustment in the size of the cells was performed in order to harmonize bands 1.2 and 7 for the calculation of the vegetation indices. To obtain more detail in the graph showing the results, "cells" of 0.0625 ha

(25x25 meters) were defined.

The vegetation indices used were the NDVI, NBR, DNBR and RdNBR. The calculation of these indices based on MODIS requires mid-infrared (band 7) and near infrared (band 2). MODIS band 7 was used for its intrinsic ability to represent fuel moisture. Below are the various indices formulations:

$$\rho_{i,NIR} + \rho_{i,R}$$

$$\rho_{i,WIR} + \rho_{i,NIR}$$

Where $\rho_{i,NIR}$ is the reflectivity of pixel i in the near infrared band and $\rho_{i,R}$ is the reflectivity of the pixel i in the red band.

In both indices the value range oscillates between -1 and 1. The degree of damage of each "cell" was estimated by the differences in the values of vegetation indices, before and after the fire:

$$D\text{-}NDVI = NDVI_{\text{pre-fire}} - NDVI_{\text{post-fire}}$$

$$DNBR = NBR_{\text{pre-fire}} - NBR_{\text{post-fire}}$$

A third indicator was considered for the study, and corresponds to a normalization of the NBR, with the purpose of eliminating the existent correlation between the result of the ratio and the NBR pre-fire value. To do that, the following adjustment was made to the images:

$$RdNBR = \frac{DNBR}{\sqrt{Abs(NBR_{\text{pre-fire}}/1000)}}$$

Identification of the net value change in the resources

The determination of losses in natural resources, both tangibles and intangibles, requires knowing the remaining resource value, *i.e.* the "net value change in the resources." This concept requires the incorporation of resource depreciation based on the level of fire intensity. The allocation of the depreciation of each resource according to the level of fire intensity is made on the basis of depreciation ratios or percentage levels, given its simplicity and practical applicability.

In the case of the timber resource and firewood use, and under the framework of research projects FIREMAP, SINAMI and INFOCOPAS, circular plots of 10 m radius were taken for different plant types and damage levels in the following fires: *Huetor* (1993), *Aznacollar* (1995), *Estepona* (1995), *Los Barrios*

(1997), Cazorla (2001; 2005), Aldequemada (2004), Minas de Rio Tinto (2004), Alajar (2006), Gaucín (2006), Obejo (2007), Orcera (2009) and Cerro Vértice (2011). For the valuation of hunting resource losses, information from *Monfragüe National Park* was used, as well as from the *Aldequemada* and *Minas de Rio Tinto* fires (Zamora and others, 2010), in order to have not only a spatial analysis but also a temporal one of the natural recovery of the breeding stock, and consequently, of the annual revenues generated by the resource.

Depreciation levels of carbon fixation resources and erosion control were estimated based on tree mortality and on the consumption level of biomass in *Cerro Catena*, from measurements in burned and unburned trees with similar mensuration characteristics. Economic valuation of erosive damage, or conversion of lost biomass to monetary units, was determined based on the study of the *Obejo* fire (2007), which analyzed the costs associated with the loss of different soil amounts (tons per hectare). In the case of biodiversity, damage assessment is carried out based on the "subrogated value" (recovery and/or conservation programs) of the government or on the value given by the population (CVM). The values obtained for this resource include adjustments based on post-fire costs invested by the responsible authorities, to prevent the escape and migration of species through food supplementation measures, predator elimination and competition reduction (Molina 2008).

The depreciation ratios of landscape assets are very complicated to validate. The above-mentioned research projects estimate depreciation ratios for these goods by the technique of social preferences or by indirect assessment techniques of landscape perception by comparison between pre and post burned land. Landscape use is affected to a greater extent than the leisure and recreational activities. Large forest fires occurred in *Parque Natural Sierras de Cazorla, Segura y Las Villas* (location where the *Cerro Catena* fire occurred). They provided a good basis for quantitative approaches to the impact on landscape assets. This indicates that the fire of 2005 resulted in a 40% decline in the number of tourists and the temporary stoppage of numerous business projects for the renovation and expansion of recreational facilities.

Economic valuation of fire damages

The use of Geographic Information Systems (GIS) allows the identification of vegetation typology and its economic value, and the availability of information about fire behavior. The depreciation rate is estimated individually for each resource based on this behavior. The integration of both concepts provides the economic vulnerability of each resource present in the burned area. Economic valuation of

damages is the sum of the vulnerabilities of the resources in the burned area.

Results

Economic valuation of natural resources

The analytical results of the *Cerro Catena* fire indicated the non-use resource as the most important (€ 217, 865) (Table 2). Given the natural character of the *Pinus pinaster* stands affected, and their longevity (over 100 years in some stands), the timber resource also reached a high value (€ 194,093.17). The third resource in order of importance was carbon fixation, given the large amount of aerial biomass in the forests affected (€ 69,137.71).

Table 2—*Economic valuation of resources in "Cerro Catena"*

Resource	Valuation(€)	Representativeness (%)
<i>Timber</i>	194.093,17	29,35
<i>Use of firewood</i>	60.771,17	9,19
<i>Hunting</i>	8.704,35	1,32
<i>Carbon fixation</i>	69.137,71	10,45
<i>Erosion control</i>	21.973	3,32
<i>Biodiversity</i>	6.820,79	1,03
<i>Landscape</i>	27.277	4,12
<i>Leisure and Recreation</i>	54.686	8,27
<i>Non-use</i>	217.865	32,94
TOTAL	661.328,19	100

The total value of the forest resources affected by the fire was € 661,328.19, representing in terms of economic impact per surface unit a value of € 3,164.25 / ha. The landscape assets (landscape, leisure and recreation and non-use) accounted for 45.33% of the value of forests affected, followed by tangible resources (timber, use of firewood and hunting) which accounted for 39.85%.

Economic valuation of natural resources

A reconstruction of the fire potential behavior was performed *in situ*, identifying for each pixel the average flame length (directly related to the intensity of the linear advancing front). Four levels of fire intensity were identified (Table 3):

- o Damage degree I. Corresponds to a level of fire intensity (NIF) VI or flame length exceeding 12 meters. Very affected area. Continuous crown-fire,

highly virulent, and airborne material consumption. The soil has been virtually denuded.

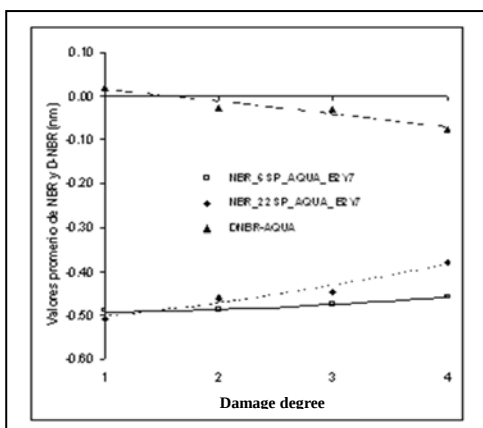
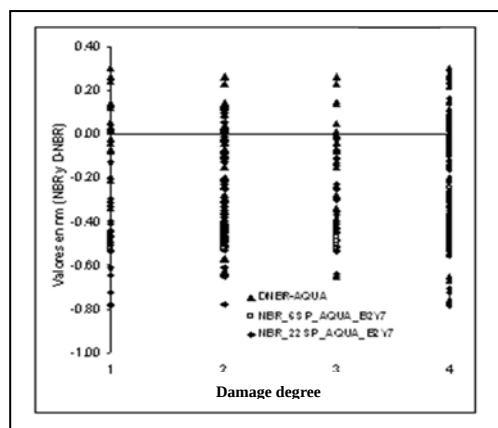
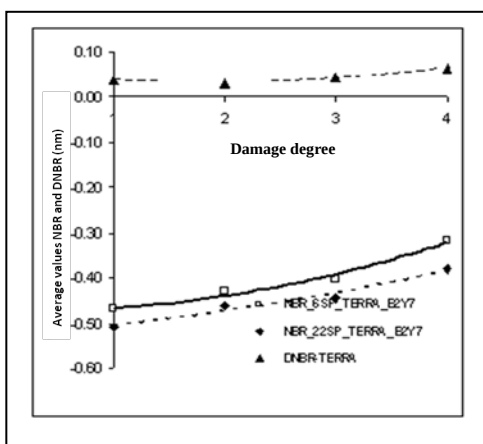
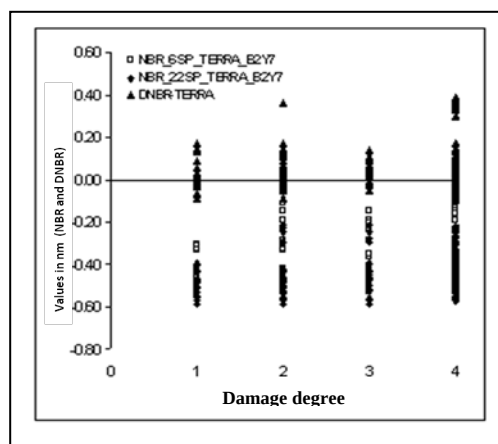
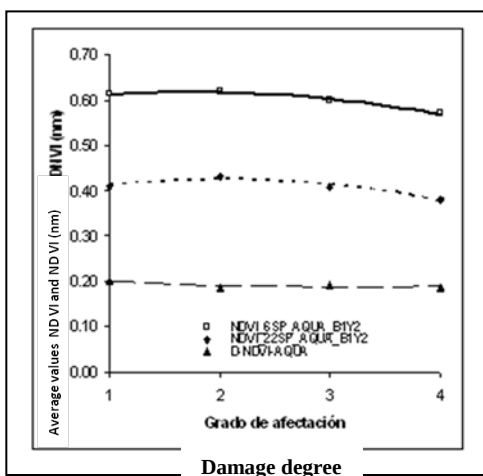
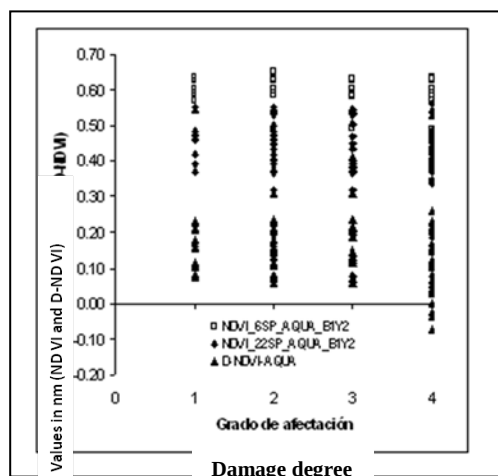
- o Damage degree II. Corresponds to a level of fire intensity (NIF) IV or flame length between 6 and 9 meters. Area affected to a moderate extent. Passive crown fire with some crown running. The soil is unprotected by clumps based on the intensity; there is practically a total consumption of superficial fuel.
- o Damage degree III. Corresponds to a level of fire intensity (NIF) III or flame length between 3 and 6 m. Moderately affected area. Surface fire with surface material consumption. The fire progresses in accordance to the slope but not downwind. There are isolated torched trees.
- o Damage degree IV. Corresponds to a level of fire intensity (NIF) II or flame length between 2 and 3 meters. Slightly affected area. Surface fire with surface material consumption. The fire diminishes, without advantageous slope or wind conditions.

Table 3—Representation of damage degrees in “Cerro Catena”

Damage degree	Pixels*	Area (ha.)	Area (%)
I	398	25	12
II	946	59	28
III	356	22	11
IV	1644	103	49

* Cells of 25 x 25 m., defined for all information levels, from resolutions of 250 and 500 m.

After the analysis, the observed behavior of the indices NDVI, NBR, DNBR, and RdNBR, regarding the identification of the four levels of fire intensity (Figure 1), was heterogeneous. In general, better results were obtained with the NBR compared to those for the NDVI, since it allowed better discrimination and contrast of the post fire severity. The indicator RdNBR allowed eliminating existent correlation between the result of the ratio and the NBRpre-fire value.



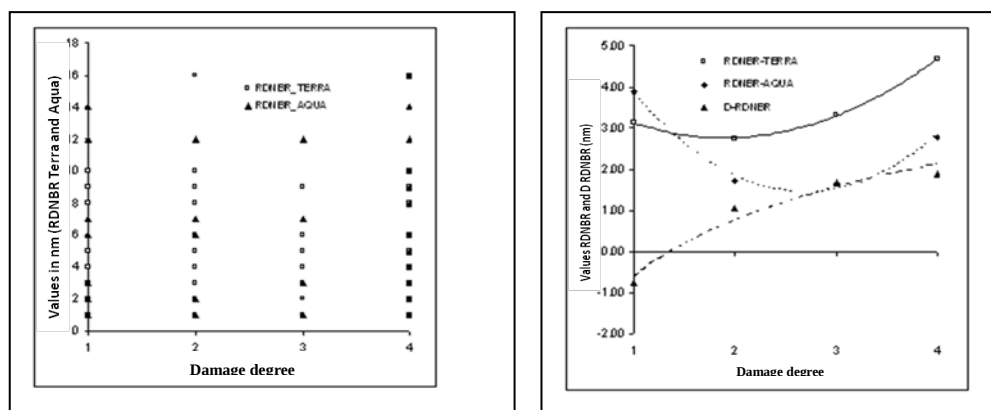


Figure 1—Values of the different indices for September 6 and 22 (left); averages for both measurements (right).

Identification of the net value change in the resources

From the experience gained in large forest fires that occurred in Andalusia during the period 1993-2011 and the scientific results of the research projects FIREMAP, SINAMI and INFOCOPAS, a depreciation matrix was developed (Figure 2).

This matrix was adjusted with the vegetation index of greatest correlation, as in other studies (Rodríguez y Silva and others 2009), in order to find an equation for each resource that provides the depreciation rate such that, applied to the initial socio-economic value, it provides both losses caused by wildfire and the residual economic value of vegetation unaffected by fire. Table 4 shows the models obtained for each resource:

NIF	Vrm	Vrle	Vrci	Vrca	Vrer	Vrbi	Vrpa	Vroc	Vrno
I	8,33%	5%	20%	10%	10%	20%	5%	2%	4%
II	16,65%	10%	45%	25%	25%	40%	25%	20%	19%
III	38,58%	20%	65%	45%	45%	60%	60%	55%	46%
IV	57,85%	45%	85%	65%	65%	80%	80%	65%	54%
V	82,79%	65%	95%	85%	85%	100%	90%	85%	69%
VI	89,41%	75%	100%	100%	100%	100%	100%	85%	69%

Figure 2—Depreciation Matrix ("Vrm" timber resource depreciation (*Rodríguez y Silva and others*,2012); "Vrle" firewood use depreciation; "Vrci" hunting resource depreciation; "Vrca" carbon resource depreciation; "Vrer" erosion control depreciation; "Vrbi" faunal biodiversity depreciation; "Vrpa" depreciation of the landscape resource; "Vroc" depreciation of leisure and recreational resource, "Vrno" depreciation of non-use resource).

Table 4— Correlation models between the rate of depreciation of each resource and RDNBR

Resource	Model	R ² (%)
Timber	$y = -11,219x^2 - 13,105x + 85,746$	97,95
Use of firewood	$y = -10,178x^2 - 13,066x + 69,997$	99,81
Hunting	$y = -14,244x^2 - 3,3187x + 105,54$	97,88
Carbon fixing	$y = -10,027x^2 - 15,545x + 93,826$	98,62
Erosion control	$y = -10,027x^2 - 15,545x + 93,826$	98,62
Biodiversity	$y = -13,19x^2 - 6,3753x + 102,61$	98,11
Landscape	$y = -19,406x^2 - 3,2702x + 108,36$	93,39
Leisure and recreation	$y = -14,846x^2 - 4,1257x + 90,027$	87,29
Non-use	$y = -11,673x^2 - 2,8962x + 73,225$	87,43

"y" is the depreciation ratio (%) and "x" the vegetation index value RDNBR

Economic valuation of fire damages

Economic vulnerability in case of the *Monte Catena* fire was high, estimated at € 262,687.99, which corresponds to a unit value in relation to the affected area of € 1,256.88 / ha. Of this amount, the impact of the fire on landscape assets (landscape, leisure, and recreation and non-use) accounted for 45.08% of the total damages caused by the wildfire. Meanwhile, the impact on tangible resources (timber resource, use of firewood and hunting) accounted for only 37.11% of the economic damages.

Table 5—*Economic vulnerability of resources in "Cerro Catena"*

Resource	Valuation (€)	Representativeness (%)
Timber	75.270,43	28,65
Use of firewood	16.788,16	6,39
Hunting	5.427,43	2,07
Carbon fixing	32.679,01	12,44
Erosion control	10.052,00	3,83
Biodiversity	4.042,37	1,54
Landscape	13.792,25	5,25
Leisure and recreation	22.933,50	8,73
Non-use	81.702,84	31,10
TOTAL	262.687,99	100

Discussion

Comprehensive assessments of damages caused by wildfires shed surprising results. Not in vain, the tangible resources represent only a portion of total economic impacts on burned areas (Molina 2008, Molina and others 2009). In case of the "Cerro Catena" fire, its strategic location within a natural park with a large influx of tourists bestows great importance on the landscape assets. Although the forest does not possess leisure and recreational infrastructure, this does not imply ignoring the possibility of future use, that is, it has a non-use value. In this regard and as suggested by other authors (Borchert and others 2003, Velez 2009, Rodriguez y Silva and González-Cabán 2010, Molina and others 2011), the assessment of damages should not pass over the multifunctionality of Mediterranean forests and reduce it to only timber resource losses.

Forest management in the study area has lost yesteryear's primary objective (timber production) and its secondary one (resin production). Its management must be based on multifunctionality, with high emphasis placed on preservation and starting with the use of the landscape. Carbon fixing represents a resource with great potential in the pursuit of economic efficiency. In addition, the occurrence of a wildfire not only means the loss of the fixation capacity of the forests, but also a

large amount of emissions. Using vulnerability criterion rather than valuation answers the need for a management tool that incorporates the incidence of the major Mediterranean disturbance, forest fires, in prioritizing actions or creating risk indices (Rodríguez y Silva and others 2009). The classification of currency units in qualitative indices of the potential severity that the impact of a potential fire could cause in an area facilitates connecting or integrating the socioeconomic aspect with other parameters or factors, to the creation of an overall risk and/or danger index (Chuvienco and others 2010).

Identifying the damage level or fire intensity with satellite imagery supported by a field inventory facilitates the extrapolation of the field information to the entire area burned. In this sense, MODIS, due to its free to access download platform, frequency, and effectiveness, is presented as an effective means of support. As other studies have shown (Chuvienco and others 2005), the normalized vegetation index is not presented as the best identifier of the burned area. However, the results achieved via the RdNBR allow obtaining regression equations with high statistical reliability, providing the losses caused by the forest fire based on depreciation ratios (Rodríguez y Silva and others 2009). The differences found in the depreciation ratio of various resources (Molina 2008, Molina and others 2009, 2011; Zamora and others 2010, Rodríguez y Silva and others 2012) determine the need to obtain an equation per resource.

Conclusions

The recognition or valuation of forest ecosystems is essential for spatiotemporal planning conducted by wildfire managers. The importance of having a socioeconomic impact evaluation model addresses a wide range of possibilities, facilitating prevention, evaluation and post-fire restoration work, and consequently, the decision making processes.

The increasing demand for thematic mapping by government agencies with management responsibilities implies the need to develop tools and products based on remote sensing and geographic information systems. Given current economic constraints, the use of a geo-referenced tool with free regular updates (MODIS) allows the inclusion of changes, improvements and temporal or spatial adaptations according to the needs of wildfire managers.

References

- Borchert, M.; Johnson, M.; Schreiner, D.; Vander Wall, S.** 2003. Early postfire seed dispersal, seedling establishment and seedling mortality of *Pins coulteri* (D.Don) in central coastal California, USA. *PlantEcology* 168(2): 207-220.
- Chuvieco, E.; Aguado, I.; Yebra, M.; Nieto, H.; Salas, J.; Martín, P.; Villar, L.; Martínez, J.; Martín, S.; Ibarra, P.; De La Riva, J.; Baeza, J.; Rodríguez y Silva, F.; Molina, J.R.; Herrera, M.A.; Zamora, R.** 2010. Development a framework for risk assessment using remote sensing and geographic information system. *Ecological Modeling* 221: 46-58.
- Chuvieco, E.; Ventura, M.; Martín, P.; Gómez, I.** 2005. Assessment of multitemporal compositing techniques of MODIS and AVHRR images for Burneo land mapping. *Remote Sensing of Environment* 94: 450-462.
- Constanza, R.; D'Arge, R.; de Groot, R.; Farber, S.; Grasso, M.; Hannon, B.; Limburg, K.; Naeem, S.; O'Neill, R.V.; Paruelo, J.; Raskin, G.R.; Sutton, P.; Van der Belt, M.** 1997. The value of the world's ecosystem services and natural capital. *Nature* 387: 253-260.
- Kenneth, O.** 1962. On man's use of fire, with comments on tool making and hunting. Social life of early man. Wenner-Gren foundation for anthropological research, New York.
- Martínez, Ruiz E.** 2000. Manual de Valoración de Montes y Aprovechamientos Forestales. Ediciones Mundi-Prensa, Madrid.
- Molina, J.R.; Herrera, M.A.; Zamora R.; Rodríguez y Silva, F.; González-Cabán, A.** 2011. Economic losses to Iberian Swine production from forest fires. *Forest Policy and Economics* 13: 614-621.
- Molina, J.R.; Rodríguez y Silva, F.; Herrera, M.A.; Zamora, R.** 2009. A simulation tool for socio-economic planning on forest fire suppression management. Libro Forest Fires: Detection, Supresión and Prevention. Nova Science Publishers. USA.
- Molina, J.R.** 2008. Integración de herramientas para la modelización preventiva y socioeconómica del paisaje forestal frente a los incendios en relación con el cambio climático. Tesis Doctoral.
- Moyano, E.; Jiménez, M.** 2005. Los andaluces y el medio ambiente. Consejería de Medio Ambiente. Junta de Andalucía.
- Pérez, M.R.** 1990. Development of Mediterranean agriculture: an ecological approach. *Landscape Urban Planning* 18: 211-220.
- Piñol, J.; Terradas, J.; Lloret, F.** 1998. Climate Warming, Wildfire Hazard, and Wildfire Occurrence in Coastal Eastern Spain. *ClimaticChange* 38(3): 1480-1573.
- Rodríguez y Silva, F.; Molina, J.R.; González-Cabán, A.; Herrera, M.A.** 2012. Economic vulnerability of timber resources to forest fires. *Journal of Environmental Management* 100: 16-21.
- Rodríguez y Silva, F.; Molina, J.R.; González-Cabán, A.** 2010. "SINAMI": a tool for the economic evaluation of forest fire management programs in Mediterranean ecosystems. *International Journal of Wildland Fire* 19: 927-936.
- Rodríguez y Silva, F.; Molina, J.R.** 2010. Manual Técnico para la Modelización de la Combustibilidad asociada a los Ecosistemas forestales Mediterráneos. Departamento de Ingeniería Forestal. Universidad de Córdoba. Córdoba. España.
- Rodríguez y Silva, F.; Molina, J.R.; Herrera, M.A.; Zamora, R.** 2009. The impact of fire and the socioeconomic vulnerability of forest ecosystems: A methodological approach using remote sensing and geographical information systems. Genral Technical Report PSW-GTR-227. Pacific Southwest Research Station. Forest Service, U.S. Department of Agriculture; 151 - 168.
- Vélez, R.** 2009. La Defensa contra incendios forestales. Fundamentos y Experiencias. McGraw-Hill, Madrid.
- Zamora, R.; Molina, J.R.; Herrera, M.A.; Rodríguez y Silva, F.** 2010. A model for wildfire prevention planning in game resources. *Ecological Modeling* 221: 19-26.

Assessment of Post-Fire Forest Structural Diversity Using Neighborhood Parameter in the Sierra Madre Oriental, Mexico¹

Diana Yemilet Avila Flores², Marco Aurelio González Tagle²,
Javier Jiménez Pérez², Oscar Aguirre Calderón², and Eduardo
Treviño Garza²

Abstract

The objective of this research was to characterize the spatial structure patterns of a *Pinus hartwegii* forest in the Sierra Madre Oriental, affected by a fire in 1998. Sampling was stratified by fire severity. A total of three fire severity classes (low, medium and high) were defined. Three sample plots of 40m x 40m were established for each severity. Variables obtained for all trees with a diameter at breast height (DBH) ≥ 5 cm in each plot were: DBH (cm) to 1.30 m, height (m), special location by recording the azimuth (°) and distance (m) from the center of the plot to each tree. A total of three index groups were employed to describe the structure: “aggregation” (W_i and D_i), “dominance” (U_i) and dimensional size (TD_i and TH_i). The variance analysis showed significant differences ($p > 0.001$) for dasometric parameter among low severities with respect to medium and high severities; this last two severities did not showed significant differences between them. Structural characterization results suggest that by increasing the fires severity degree, the aggregation degree increases, and the dimensional differentiation and dominance decrease as the severity degree increases.

Keywords: fire regimes, forest fire severity, spatial variation

Introduction

Fire is one of the most widespread natural disturbances in forest ecosystems (Perry and others 2008; Bekker and Taylor, 2010), which is presented as a natural disturbance factor (Omi, 2005). Almost all terrestrial ecosystems have a fire regime,

¹ Una versión abreviada de este trabajo fue presentada en el Cuarto Simposio Internacional sobre Políticas, Planificación y Economía de Incendios Forestales: Cambio Climático e Incendios Forestales, noviembre 5-11, 2012, Ciudad de México, México

²Departamento de Silvicultura, Facultad de Ciencias Forestales. Universidad Autónoma de Nuevo León. Ctra. Nal., km 145, 67700, Linares, Nuevo León, México. diesel_dyaf@hotmail.com.

ie, a fire history that has shaped or affected the structure and composition of species within that ecosystem. The presence of natural disturbances in forest ecosystems, such as fire, causes changes in its structure, which is reflected in the spatial distribution of trees (Gill and others 1999). These changes in the distribution of individuals cause that patterns and the spatial variation of the stand structure generate significant effects on the succession of forest ecosystems at the stand scale (Yu and others 2009).

In this context, research has shown that the fire effect on some forest ecosystems have undergone dramatic changes in its structure. Some authors report that the structural diversity at stand level is the result of fire severity and processes that operate at the stand scale during the absence of fire. The great variability generated in the structure of the stand contributes, in some cases, to the increase of the post-fire regeneration, also consider as fire effects (Lecomte and others 2006, Lampainen and others 2004, González and others 2008). In recent decades, we have developed different indices to assess forest structure, which include the set of indices developed by Gadow and Hui (2002), which measure small-scale variations in the position of trees, species and its dimensions based on neighborhood criteria. However, the application of these indices has focused primarily on assessing the effects of forest management, with minimal application to evaluate the fire effects on the forest structure. Therefore, the aim of this study was to characterize the spatial distribution of *Pinus hartwegii*, in three stands affected by different fire severity degrees during the summer of 1998, on the Potosí hill.

Methods

The present study was conducted on the Potosí hill, which is part of the Sierra Madre Oriental and is located within the municipality of Galeana, to the south of the state of Nuevo León, between 24°50'35'' and 24°53'16'' North and 100°13'12'' and 100°15'12'' West (Figure1). It reaches an altitude of 3700 meters above the sea, which ranks it as the highest peak in northern Mexico (INEGI 1986). During the dry season of 1997-1998 under the weather conditions attributed to the phenomenon of "El Niño", a large forest fire occurred in this area; this conflagration significantly affected coniferous forests on the hill (Lozano 2006).

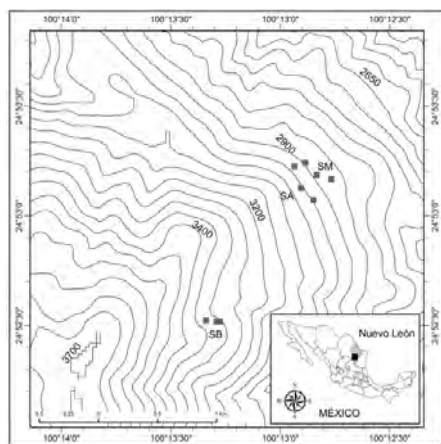


Figure 1—sampling site location in the study area. SB=low severity. SM=medium severity. SA=high severity.

Methodology

A total of three *Pinus hartwegii* stands with three different fire severity degrees (low, medium and high) each were selected. The classification made by Treviño and others (2000), who evaluated the areas burned in the south of Nuevo León by analyzing two Landsat TM satellite imagery and obtaining fire severity classes (this information was validated in the field), was taken as base to determine the severities. A total of nine sampling plots of 40 m x 40 m (three severities x three stands/severities) were established. For each plot, and only for those individuals with a diameter at breast height (DBH) ≥ 5 cm, the following dasometric variables were obtained: diameter to 1.30 m (cm), height (m), distance (m) and azimuth ($^{\circ}$) to each tree with respect to the center of the plot.

To describe the structure we used a set of indices to characterize the following stand parameters: "aggregation", which describes how trees are spread on the field, and "differentiation degree", which quantifies the differences in size of trees within the stand (Gadow and others 2001). The structural sampling method of five trees was the basis for the development of indices (Hui and Hu 2001), sampling developed to assess the structural attributes (size, species and the regularity of their positions) of the trees forming a forest stand (Gadow and others 2001, Aguirre and others 2003). Group determination was conducted using the program Winkelmass version 1.0.0 (2002), developed by researchers at the University of Göttingen, Germany. The index set used are shown below:

Table 1—Indices used for determining the structural groups evaluated.

indices	Where:
Gadow Uniformity Index W_i	n = number of neighboring trees considered; $W_{ij} = 1$ when j -th angle α between two next neighboring trees is less or equal to the standard angel α , otherwise it takes a value of 0. W_i can take values from 0 to 1, where a value close to zero represents regularity conditions, values close to 0.5 show a tendency to randomness and those close to 1 show clustering conditions
Distance index D_i	Where: d_{ij} = i -th tree distance to its j -th neighbor, n = number of neighbors considered, $\bar{d}_i$ = plot average distance i and N = number of structural groups determined by the Winkelmass program. The average distance of each severity were distributed in ten distance classes comprising ranges of 2 meters: class 1: $0 < D_i \leq 2$ m; class 2: $2 \text{ m} < D_i \leq 4$ m;....; class 9: $16 \text{ m} < D_i \leq 18$ m; class 10: $18 \text{ m} < 20$ D_i .
Dominance index U_i	Where $0 \leq U_i \leq 1$ and v_j is equal to 1 if the tree j is less than the reference tree i and 0 if not.
Diameter differentiation Index (TD_i) and Height differentiation Index (TH_i).	Where $TD(i)$ and $TH(i)$ = Diameter differentiation and plot height differentiation i ; n = number of neighbors considered; N = number of measured trees; d_{min} , d_{max} , h_{min} and h_{max} = are the maximum and minimum diamter and height between i and each of its neighbors

Results

Table 2 shows the dasometric parameters by severity. This characterization results indicate that the three severities recorded low densities, showing a decrease as the fire severity increases. The same situation occurred in the case of basal area and diameter parameters. However, in the case of the variable height, high severity showed a height average higher than the average severity.

Table 2—Dasometric characteristics of the *Pinus hartwegii* stands in the different classes of severity studied on the Potosí hill. PHb=low severity, PHm=medium severity, PHa=high severity. $\pm$ Standard deviation. Equal letters in each column indicate no statistically significant differences between severities. *parameters weighted in accordance with the basal area.

Severity	Density (N/Ha)	Basal area (m ² /Ha)	*Diameter (cm)	*Heigh (m)
PHb	185 $\pm$ 9.55	21.33 $\pm$ 0.51 ^a	38.30 $\pm$ 1.03 ^a	20.07 $\pm$ 1.57 ^a
PHm	183 $\pm$ 20.09	14.45 $\pm$ 1.02 ^b	31.76 $\pm$ 2.06 ^b	14.89 $\pm$ 0.82 ^b
PHa	150 $\pm$ 37.50	11.21 $\pm$ 5.35 ^b	30.46 $\pm$ 6.83 ^b	16.36 $\pm$ 2.26 ^b

Spatial distribution

Mean values of the Gadow Uniformity Index were $W_i = 0.528, 0.550$ and 0.594 for low, medium and high severity, respectively. Hui and Gadow (2002), state that values less than 0.475 suggest a regular distribution and those over 0.517 had an irregular distribution with tendency to cluster. Consistent with this, the values of obtained for the three severities in this paper indicate an uneven distribution with a tendency to cluster. Severities showed the following values for the distances index D_i : low severity with a

Fire-dependent ecosystems are characterized by presenting species that resist the passage of fire with adaptations that have acquired over time. Some of these adaptations are showed by *Pinus hartwegii* (Rodríguez 2008). Thus, dasometric characteristics and spatial distribution of *Pinus hartwegii* found in this study are consistent with those reported by some studies on fire ecology for this species. These studies refer to the ecological factor ‘fire’ as an important promoter of regeneration, because it facilitates the establishment of the species, which is favored by the conditions created by the fire disturbance, by opening up spaces in the understory, which favors the conditions for the establishment of new individuals (Rodríguez, 2008). The results obtained by the differentiation index and dominance index for diameter and height variables show that in high severity is where the greatest contrast of dimensions occurs. In addition, there is a rising trend of the aggregation and dimension differentiation as the fire severity increases, which consequently generates that dominance values decrease as the severity increases (Figure 2). These results are consistent with those reported by several related studies (Lecomte and others 2006, González and others 2008, Yu and others 2009 Bekker and Taylor 2010), who refer to dimensional heterogeneity conditions as fire impact effect on coniferous forests.

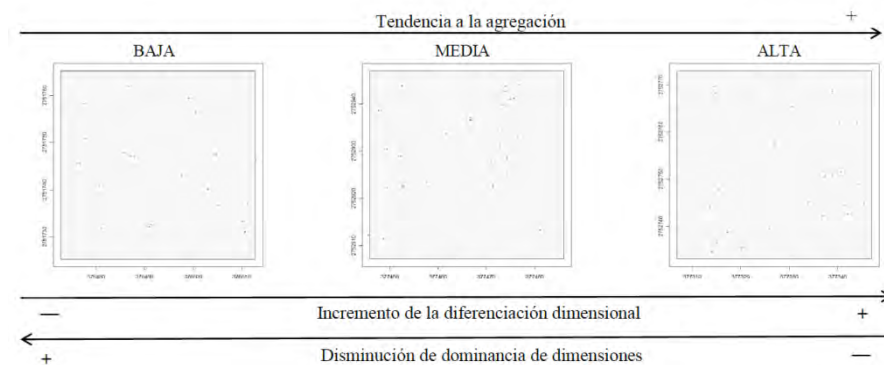


Figure 2—Spatial distribution by severity of the *Pinus hartwegii* individuals in the study area (the Potosí hill).

Furthermore, it is worth mentioning that the use of such indices in Mexico has been mostly aimed at assessing the impact of silvicultural treatments on forest ecosystem structures (Corral and others 2005), having a lower use with an ecological approach or to determine the influence of the fire disturbance on the forest structural characteristics (González and others 2008).

Conclusions

The results obtained indicate that when the severity degree of the fire increases, the degree of aggregation of trees and dimensional differentiation also increase. However, the degree of dominance in dimensions decreases as the severity fire degree increases.

Summary

The objective of this research was to characterize the pattern of spatial structure of a *Pinus hartwegii* forest in the Sierra Madre Oriental, affected by a fire in 1998. Sampling was stratified by fire severity. Three fire severity classes were defined (low, medium and high). Three sample plots of 40m x 40m were established for each severity. The variables obtained for all trees with a diameter at breast height (DBH) ≥ 5 cm in each plot were: DBH to 1.30 m (cm), height (m), spatial location by recording the azimuth ($^{\circ}$) and distance (m) from center of the plot to each tree. To describe the stand structure three groups of indices were employed: “contagion” and “distances” (W_i and D_i), “dominance” (U_i), and “size differentiation” (TD_i and TH_i) for DBH and height respectively. An analysis of variance was performed to detect differences between dasometric parameters by fire severity. Statistical analysis shows significant differences ($p > 0.001$) in the parameters such as basal area, diameter, and height, along the low, medium, and high fire severities. The characterization of the *Pinus hartwegii* spatial structure suggests that, with increasing degree of fire severity, the stands showed an increase on the aggregation index, however, the dimensional differentiation and dominance indices decreases as the fire severity increases.

References

- Bekker M. F., Taylor A. H. 2010.** Fire disturbance, forest structure, and stand dynamics in montane forests of the southern Cascades, Thousand Lakes Wilderness, California, USA. *Écoscience* 17 (1):59-72.
- Corral R. J. J., Aguirre C. O.A., Jiménez P. J., Corral R. S., 2005.** Un análisis del efecto del aprovechamiento forestal sobre la diversidad estructural en el bosque mesófilo de montaña «El Cielo», Tamaulipas, México. *Invest Agrar: Sist Recur For* 14(2): 217-228.
- Gadow K. von., Real P., Álvarez G.J. 2001.** Modelización del crecimiento y la evolución de los bosques. *UIFRO World Series*. Vol. 12, 242 pp.
- Gadow K.von., Hui G. Y., 2002.** Characterising forest spatial structure and diversity. In: Bjoerk, L. (Ed.), *Proceedings of the IUFRO International workshop ‘Sustainable forestry in temperate regions’*, Lund, Sweden, pp. 20–30.

- Gadow, K. von., Sánchez O. S., Álvarez G. J.G., 2007.** Estructura y Crecimiento del Bosque. 287 pp.
- Gill M., Woinarski J., York A., 1999.** Australia's biodiversity responses to fire. Biodiversity Technical Report No. 1, Environment Australia.
- González T, M. A., Schwendemann, L., Jiménez P, J. y Schulz, R. 2008.** Forest structure and woody plant species composition along a fire chronosequence in mixed pine-oak forest in the Sierra Madre Oriental, Northeast Mexico, Forest Ecology and Management 256: 161-167.
- Hui G.Y., Hu Y.B., 2001.** Measuring species spatial segregation in mixed forest. For Res 14(1):23-27.
- Hui G.Y., Gadow K. von. 2002.** Das Winkelmaß. Herteilung des Optimalen Standarwinkels. Allgemeine Forst u Jagdzeitung 10, 173-177.
- Instituto Nacional de Estadística, Geografía e Informática (INEGI). 1986.** Síntesis Geográfica del Estado de Nuevo León. México.
- Lampainen, J., Kuuluvainen, T., Wallenius, T.H., Karjalainen, L., Vanha-Majamaa, I. 2004.** Long-term forest structure and regeneration after wildfire in Russian Karelia. Journal of Vegetation Science 15: 245-256.
- Lecomte N., Simard M., Bergeron Y. 2006.** Effects of fire severity and initial tree composition on stand structural development in the coniferous boreal forest of northwestern Québec, Canada. Écoscience 13(2): 152-163.
- Lozano, F. 2006.** Los incendios en Nuevo León, México, durante el verano de 1998. Laboratorio de Sistemas de Información Georeferenciada. Centro de Calidad Ambiental, ITESM Campus Monterrey. En línea: <http://albers.mty.itesm.mx/proyectos/incendios/indexincendios.html#potosí>. Consultado Agosto 2010.
- Omi P.N., 2005.** Forest Fires: a reference handbook. ABC-CLIO, Inc. Santa Barbara, California. 345 pp.
- Perry D. A., Oren R., Hart S. C. 2008.** Disturbance in forest ecosystems. In: forest ecosystems. Ed. The Johns Hopkins University Press. Baltimore, Maryland, E.U.A. pp. 86-117.
- Rodríguez T. D.A. 2008.** Fire Regimes, fire ecology and fire management in Mexico. A Journal of the Human Environment 37(7):548-556.
- Yu H., Wiegand T., Yang X., Ci L. 2009.** The impact of fire density-dependent mortality on the spatial patterns of a pine forest in the Hulun Buir sandland, Inner Mongolia, China. Forest Ecology and Management 257: 2098-2017.
- Yocom L.L., Fulé P.Z., Brown P.M., Cerano J.N., Villanueva D. J., Falk D.A., Cornejo O. E. 2010.** El Niño–Southern Oscillation effect on a fire regime in northeastern Mexico has changed over time. Ecology 91(6):1660-1671.

Land Suitability for Establishing Rainwater Harvesting Systems for Fighting Wildfires¹

José María León Villalobos², Manuel Anaya Garduño¹, Enrique Ojeda Trejo¹, Dante Arturo Rodríguez Trejo³, José Luis Oropeza Mota¹, and Jorge Luis García Rodríguez⁴

Abstract

Rainwater harvesting systems (RHSs) can be used to improve the efficiency of helicopter fire-fighting operations. To this end, RHSs need to be strategically located in areas with high wildfire occurrence to maximize their usefulness. In this study, spatial analysis was carried out to determine suitable sites for establishing RHSs intended for air attack operations in three municipalities (Chalco, Ixtapaluca and Tlalmanalco) located in the eastern part of the state of Mexico, Mexico. Five variables were used for site selection: wind speed, distance to roads, runoff, evaporation and wildfire density. Each variable was graded by consulting experts and multi-criteria decision analysis was performed to integrate them on a map. Potential RHS sites that met most of the criteria established are in the north and south of the study area. The method used in this study to identify suitable sites for establishing RHSs is a useful tool. Expert knowledge and field visits would also be helpful in selecting the best RHS site and design, in order to reduce costs and environmental impacts.

Keywords: curve number, multi-criteria analysis, wildfire fighting.

Introduction

Mexico, like other countries, has been impacted by the increasing occurrence of forest fires and mega-fires, exacerbated by the effects of global climate change. On average 10,521 fires occur in Mexico each year, affecting some 292,701 ha (Rodríguez *and others*, 2000). PROBOSQUE, a pro-forest alliance in the State of Mexico, has identified the Itza-Popo region in the state as being at high risk for wildfires and, in particular, the municipalities of Chalco, Ixtapaluca and Tlalmanalco in number and area affected. To cope with the fire season, among other activities, air

¹ An abbreviated version of this paper was presented at the Fourth International Symposium on Fire Economics, Planning, and Policy: Climate Change and Wildfires, November 5-11; Mexico City, Mexico.

² Graduate College, Campus Montecillo; Email: jomalevi@yahoo.com.mx

³ Forest Science Department, Autonomous University of Chapingo.

⁴ Forest soils monitoring and inventorying Division, Mexico National Forestry Commission (CONAFOR in Spanish).

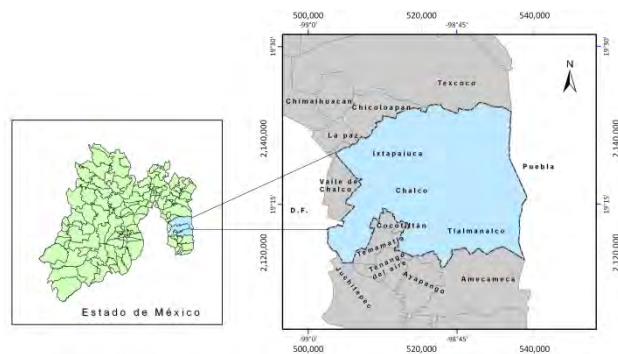
attack operations are conducted, but their efficiency is limited by the lack of nearby water sources.

Rainwater harvesting systems (RHS), which describe all methods to concentrate, store and collect rainwater runoff (De Winnaar and others 2007), are renowned for their versatility to solve water shortage problems, although their location may depend on many factors, so geographic information systems (GIS) are used to address this complexity (Mbilinyi and others 2007). Numerous studies have been undertaken to determine suitable RHS sites: Sekar and Randhir (2007) designed a spatial method to identify suitable rainwater harvesting sites based on groundwater recharge potentials; Mohtar and others (2006) presented a GIS-based system to locate suitable water harvesting reservoirs in a local watershed.

The objectives of this study are: a) the selection and geographic treatment by GIS of the variables that affect the location of suitable RHS sites and b) the weighting and integration of these variables using a participatory hierarchical process and a multi-criteria method.

Methods

The study area is located in the east of the state of Mexico, comprising the municipalities of Chalco, Tlamanalco and Ixtapaluca (Figure 1) and covering an area of 70,668.09 ha.



Figure—1 Study area location.

According to Escamilla and others (2010), the air operations officer for Mexico's national forestry commission (CONAFOR)⁵ and related studies (Weerasinghe and others 2010), the most important variables in water loading and RHS functionality in air control of wildfires are as follows : a) wind speed, b) fire density c) proximity to roads, d) visibility (fog), e) air temperature, f) altitude; g) surface runoff, h) slopes and i) evaporation. After a detailed analysis of the information, the variables visibility, air temperature, slope and altitude were

discarded, while the remaining ones were processed in the GIS, generating the following maps:

- a) Wind speed: eight AWS (automated weather stations) were geographically referenced in ArcGIS 9.2; the arithmetic means of the winds in the fire season (December to July) were obtained and the IDW (Inverse Distance Weighting) interpolation method was used. The map was reclassified according to the Beaufort scale.
- b) Fire density: the map was generated from 456 records in the study area for the 2005- 2010 period, using the ArcGis 9.2 point density module (Vilar del Hoyo 2007).
- c) Proximity of roads: the roads were digitized on SPOT 5 images and the Euclidean distance module in ArcGIS 9.2 was applied to generate vertical distances in meters.
- d) Surface runoff: it was calculated with the curve number (CN) method used by the USDA Soil Conservation Service (SCS); the rainfall information required in the calculation was obtained in two steps: 1) for each weather station, the length of records needed to ensure the data mean had a probability of 90% was determined, and 2) the rain distribution function values were adjusted to calculate the return period to 1.1 years and ensure a 90% probability in the precipitation range (Campos 1998).

The hydrologic group was assigned to each soil unit according to USDA SCS tables and vegetation cover, updated to 2010, was classified by its hydrological condition; both were superimposed on the ArcView 3.2 program and assigned the corresponding NC for antecedent moisture type II, 12.7 - 38.1 mm, (Ramakrishnan and others 2009). Surface runoff was multiplied by the cell surface (900 m²) to obtain the result in cubic meters.

- e) Evaporation: for calculating it, the average annual values were interpolated by the IDW method in Arc GIS 9.2.

To develop the land suitability map, maps of the fire density, surface runoff, evaporation, wind speed and distance to roads variables were reclassified into four categories, then each category was prioritized according to the expert and its weighting values immediately indicated; they were obtained from the method of addition and reciprocal (SEMARNAT - INE 2006): 0.33, 0.27, 0.20, 0.13 and 0.07, respectively. The maps were integrated by weighted linear combination (Bojórquez-Tapia and others 2003). The suitability map was standardized on a scale of 0 to 10.

Results

Maps were prepared in Arc Gis 9.2 for the five selected variables:

a) Wind speed: the most severe were found in higher altitude areas in the northeast, and the lowest in the lower areas in the southwest. The optimal class chosen for establishing RHSs was 29 to 49 km h⁻¹ (Table 1).

Table 1—Classes, areas and prioritization of the wind speed variable

Variable	Prioritization	Classes	Area	Surface area occupied
		km/h	ha	%
Wind speed	1	75 - 117	28 269.53	40.00
	2	62 – 74	8200.26	11.60
	3	50 – 61	13 832.61	19.57
	4	29 - 49	20 365.70	28.82
			70 668	100

b) Distance to roads: the study area presented, in a little over 94% of its area, distances from 0 to 1000 m that were selected as optimal (Table 2).

Table 2—Classes, areas and prioritization of the variable distance to roads

Variable	Prioritization	Classes	Area	On the Ground Distribution
		m	ha	%
Distance to roads	1	2000 - 2500	453.15	0.64
	2	1500 - 2000	786.96	1.11
	3	1000 - 1500	2348.46	3.32
	4	0 - 1000	67 078.62	94.92
			70 668	100

c) Surface runoff: the highest volumes (415-667 m³) were identified south of Tlalmanalco and was selected as optimal (Table 3); by contrast, to the north, in Ixtapaluca, the lowest inputs were located (163-280 m³).

Table 3—Classes, areas and prioritization of the variable surface runoff

Variable	Prioritization	Classes	Area	On the Ground Distribution
Surface runoff		m3	ha	%
	1	163 - 280	1836.24	2.60
	2	280 - 402	41 958.08	59.45
	3	402- 415	15 346.02	21.74
	4	415 – 667	11 432.91	16.20
			70 668	100

d) Evaporation: values between 1080 and 1968 mm were found as the annual average (Table 4). Class 1080 - 1302 mm was selected as the optimum.

Table 4— Classes, area and prioritization of the variable evaporation

Variable	Prioritization	Classes	Area	On the Ground Distribution
Evaporation		mm	ha	%
	1	1745 - 1968	13 390.56	18.95
	2	1524 - 1745	12 738.51	18.03
	3	1302 - 1524	11 103.03	15.71
	4	1080 - 1302	33 437.79	47.32
			70 668	100

d) Fire density: there were from 0 to 3.3 fires km⁻² and densities of 2.4 to 3.3 were selected as optimal (Table 5).

Table 5— Classes, areas and prioritization of the variable fire density

Variable	Prioritization	Classes	Area	On the Ground Distribution
Fire density		fires km-2	ha	%
	1	0-0.8	55 193.72	78.10
	2	0.8-1.6	6949.52	9.83
	3	1.6-2.4	5484.25	7.76
	4	2.4-3.3	3043.71	4.31
			70 668	100

The maximum land suitability for RHSs intended for the control of forest fires was located to the northeast, in Ixtapaluca, and the south in Tlalmanalco (Figure 4). Most of the area, 30.49%, was placed in category five (Table 6).

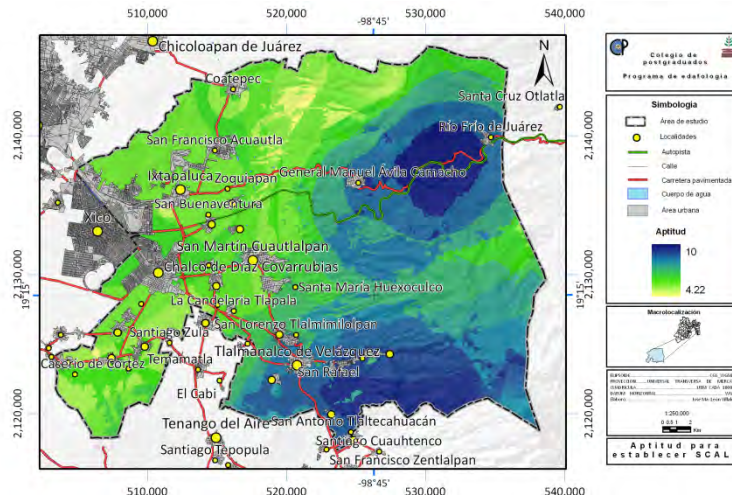


Figure 4—Land suitability for RHSs for forest fire control

Table 6—Area of each suitability category found in the study area

Suitability scale	Area	On the Ground Distribution
	(ha)	(%)
4	939.51	1.33
5	21 512.43	30.49
6	13 579.11	19.24
7	14 383.71	20.39
8	14 229.45	20.17
9	5829.93	8.26
10	85.86	0.12
	70 668	100%

Discussion

Other researchers with a similar approach rely on the analysis of two variables: a) surface runoff (Gutpa and others 1997) and b) slopes (Mbilyini and others 2007), simplifying the selection criteria, as observed by Ramakrishnan and others (2009).

Although for most studies the slope variable is important, it was discarded from the model because of its low weight value. By contrast, Gutpa and others (1997) indicate that slope is a key variable due to its influence on the amount of runoff; however, this claim has limited validity on a regional scale as is the case in this study. Elevation was also eliminated from the model because air fire control has been performed successfully at altitudes over 4,000 m.

Surface runoff presented great variability, 163-667 m³, on the map; for example, the northeast showed high curve numbers (70, 73 and 86) and significant runoff

volumes (415-667 m³), which were related to regosol soils and 600 mm of rainfall annually.

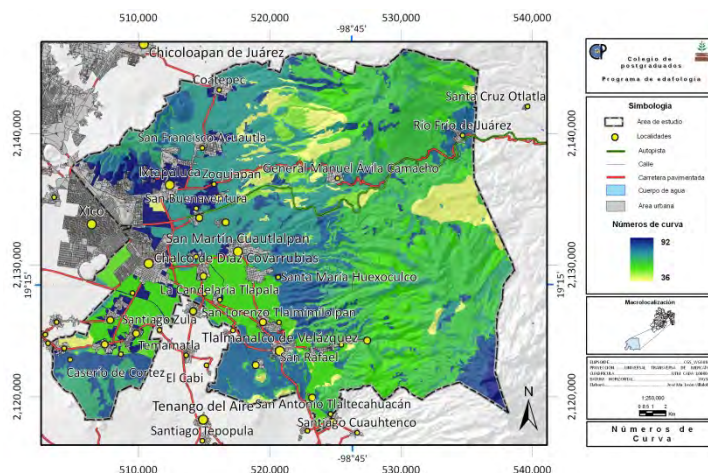


Figure 3—Curve number per unit of soil and vegetation type

This was also observed by Sekar and others (2007) in a similar study, where soil types and their infiltration capacity directly affected the curve number values and subsequent runoff values.

Distances to RHSs intended for agricultural use have been set at between 1000 and 2000 m (De Winnaar and others 2007); by contrast, this proposal requires greater proximity to roads. The optimal class kept a positive relationship with high suitability due to the adequacy of the road network in the fire areas. Furthermore, sites found to be suitable for RHSs intended for forest fire control respond, on one hand, to the weighting values of each variable, and on the other, to the optimum classes of each one, as is the case with the fire density, runoff and evaporation variables, which define the suitable sites in the north area. This was also observed by Weerasinghe and others (2010), whose potential RHS sites depended on the weight values and the optimum classes of each variable. Instead, there was a negative relationship with the wind speed variable in the north area, which is consistent with the observations of Simiu (1978), who stated that the records of wind under 10 do not produce accurate results.

Although you may consider other factors of social, economic and environmental, they can be validated in the establishment of RHS site according to terrain and layout of the structure (De Winnaar and others 2007, Sekar and Randhir 2007, Ramakrishnan and others 2009).

Summary

This research evaluated the territorial capacity in three municipalities in the eastern part of the state of Mexico, RHS intended to establish air control of wildfires, combining variables affecting the water loading of the helicopter and the same RHS by multicriteria evaluation in GIS, finding good skills in over 28% of the study area, in two areas: north, in Ixtapaluca, and south in Tlalmanalco. Variables responded mostly with a positive, except for wind speed. Identified fitness provides a useful framework for making decisions, which will have to add economic and social elements to decide on the type of structure (design) that is more affordable and cause the least environmental impact.

References

- Bojórquez – Tapia, L.A. L.; Bower, P.; Castilleja, G.; Sánchez-Colón, S.; Hernández, M.; Calvert, W.; Díaz, S.; Gómez-Priego, P.; Alcantar, G.; Melgarejo, D.; Solares, M.; Gutiérrez L.; M. Juárez. 2003.** Mapping expert knowledge: redesigning the monarch butterfly biosphere reserve. *Conservation Biology*. 17 (2): 367-379.
- Campos, A.D.F. 1998.** Procesos del ciclo hidrológico. Universidad Autónoma de San Luis Potosí. San Luis Potosí, México. 556 p.
- De Winnaar, G.; Jewitt, G.P. W.; Horan, M. 2007.** A GIS-based approach for identifying potential runoff harvesting sites in the Thukela River basin, South Africa. *Physics and Chemistry of the Earth, Parts A/B/C*. 32 (3): 1058-1067.
- Escamilla, G.; Pérez P.J.; Valenzuela P.L. 2010.** La brigada de helitanque y los procedimientos de trabajo con helicópteros. Corporación Nacional Forestal. Santiago de Chile, Chile. 52 p.
- Gutpa, K. K.; Deelstra, J.; Sharma, K. D. 1997.** Estimation of water harvesting potential for a semiarid area using GIS and remote sensing. (242). http://iahs.info/redbooks/a242/iahs_242_0053.pdf (22 de febrero de 2012).
- Mbilinyi, B.P.; Tumbo, S.D.; Mahoo H.F.; Mkiramwinyi, F.O. 2007.** GIS - based decision support system for identifying potential sites for rainwater harvesting. *Physics and Chemistry of the Earth, Parts A/B/C*. 32 (16):1074-1081.
- Mohtar, H.R., Zhai, T.; Choi, J.Y.; Adrian, B.; Ouessar, M.; Abdelli, F.; Bernard, E. 2006.** Web - based GIS - Hydrologic Modeling for Siting Water Harvesting Reservoirs (ISCO2006). [http://www.vulgarisation.net/isco2006/1/T1-MohtarWeb%20Based%20GIS%20Hydrologi-cal % 20Modeling-USA.pdf](http://www.vulgarisation.net/isco2006/1/T1-MohtarWeb%20Based%20GIS%20Hydrologi-cal%20Modeling-USA.pdf) (19 de enero de 2012).
- Promotora de Bosques del Estado de México (PROBOSQUE). 2011.** Probosque en alerta durante la temporada de estiaje (6). http://www.forestalxxi.com/index.php?option=comcontent&view=article&id=243:probosque-en-alerta-durante-la-temporada-de-estiaje&catid=76:probo_osque&Itemid=70 (20 de enero de 2012).
- Ramakrishnan, D.; Bandyopadhyay, A; Kusuma, K. 2009.** SCS - CN and GIS - based approach for identifying potential water harvesting sites in the Kali Watershed, Mahi River Basin, India. *Journal of Earth System Science*. 118 (4):355-368.
- Rodríguez, T.D.A.; Rodríguez, A.M.; Sánchez, F.F. 2000.** Educación e incendios forestales. Editorial Mundi-Prensa. México, D.F. 201 p.

- Sekar, I.; Randhir, T.O. 2007.** Spatial assessment of conjunctive water harvesting potential in watershed systems. *Journal of Hydrology*. 334 (2):39-52.
- Simiu, E. 1978.** Wind effects on structures: an introduction to wind engineering. John Willey and Sons. New York, E.U. 589 p.
- Vilar del Hoyo. 2007.** Análisis comparativo de diferentes métodos para la obtención de modelos de riesgo humano de incendios forestales. Análisis comparativo de diferentes métodos para la obtención de modelos de riesgo humano de incendios forestales (1). http://www.geogra.uah.es/firemap/pdf/VilardelHoyo_et_al_SPAIN.pdf (20 de enero de 2012).
- Weerasinghe, H.; Schneider, U.; Löw, A. 2010.** Water harvest and storage location optimization model using GIS and remote sensing (1). [http://balwois.com/balwois/administration/full paper/ffp-1653.pdf](http://balwois.com/balwois/administration/full%20paper/ffp-1653.pdf) (5 de febrero de 2012).

Culture of Fire and Environmental Education in Wildfire-Prone Areas: Current Situation in Spain¹

Clara Quesada-Fernández² and Daniel Quesada-Fernández³

Abstract

The *culture of fire* in the context of climate change has become a complicated relationship between people and natural areas. The interaction between people and fire is not a new issue. The use of fire by humans in most aspects of life, especially in rural areas, together with rapid and haphazard growth of structures in wildfire-prone areas, has led to the owners and residents living there being less involved due to an urban conception of natural and forest areas. At the same time, rural areas have been decreasing and their populations aging due to migration to cities. Although the authorities responsible for forestry and civil protection, both at the national and regional-local levels, have implemented various wildfire prevention strategies in these areas, they have discovered that these are insufficient to curb the problem which is increasing with time. For this reason it has been concluded that the public should move from being part of the problem to being an active part of the solution. Furthermore, human behavior is largely unpredictable, especially in emergency situations, such as those in wildland-urban interface areas, which increases the risk value in these areas. Thus, through environmental and forestry education activities, as well as those in emergencies, it is possible to carry out information, training and awareness-raising efforts about the problem. This paper provides a summary of some of the examples of the current situation in Spain in wildfire-prone areas in a wildland-urban interface situation and outlines what future recommendations and measures could be adopted to protect property and life and contribute to safer firefighting work.

¹ An abbreviated version of this paper was presented at the Fourth International Symposium on Fire Economics, Planning, and Policy: Climate Change and Wildfires, November 5-11, 2012, Mexico City, Mexico.

² Forest Engineer, MSc Forest Fire Management, MSc Civil Protection and Emergency Management (claraquesada@gmail.com)

³ Professor, Faculty of Education, Departament of Social and Experimental Science Teaching, Universidad de Córdoba (Córdoba, España) (danielquesadafernandez@gmail.com)

Keywords: climate change, human behavior, evacuation, wildfire suppression, wildland-urban interface, forestry policy, prevention, risk

Introduction

The *culture of fire* in the context of climate change has become a complicated relationship between people and natural areas. The interaction between people and fire is not a new issue. The use of fire by humans in most aspects of life, especially in rural areas, together with rapid and haphazard growth of structures in wildfire-prone areas, has led to the owners and residents living there being less involved due to an urban conception of natural and forest areas. At the same time, rural areas have been decreasing and their populations aging due to migration to cities. Wildfires are an endemic problem in the countries of the Mediterranean basin. The latest overall statistics indicate that the area affected in recent years has remained the same or increased slightly. But in the summer of 2012, a dramatic increase occurred in Spain. The total number of acres burned quadrupled over the last decade and the size of the average fire has doubled in some areas over the previous year. The quantification of hectares affected that used to be evaluated in the hundreds has now become thousands or, in the most extreme cases, tens of thousands.

All Spanish regions are being affected by environmental problems and public safety, public health and civil protection emergencies directly or indirectly. Many areas are experiencing their worst disasters in recent decades (Valdemaqueda, province of Madrid; Coín, province of Málaga) or even in their history (Castrocontrigo, province of León; Cortes de Pallás and Andilla, province of Valencia; La Gomera Island, province of Tenerife) by area affected and assets threatened and affected but mainly by the tragic consequences on people's lives. Many of the affected area are located near population centers, most of them wildland-urban or wildland-rural interface areas.

The overall situation

The Spanish forest area is very important both overall and in each of the Autonomous Communities-Regions (Table 1) and presents interesting economic values both in tangible and intangible values, from the point of view of production, recreational and environmental aspects.

In many regions there are major depopulation problems, as many of the inhabitants of rural villages have migrated to urban centers. The exponential growth of many of these centers, coupled with the concentration of inhabitants and the proximity of the rural and forest environment, facilitates the occasional outing to

these natural areas by those seeking tranquility and relaxation. Life in the cities and towns with high population densities (Table 2), often with exaggerated and incompatible values for the citizenry itself, has become somewhat uncomfortable and therefore residents need to periodically distance themselves from these built-up areas. However, these people do not have the same environmental awareness as in the past since their conception of the rural and forest environment is from the point of view of people in an urban environment.

Table 1— *Main features of the forest area from information contained in the National Forest Inventory (IFN3 and IFN4) and the Forest Map of Spain (MFE50 and MFE25).*

Autonomous Community (Region)	Treed area (ha)	Treeless area (ha)	Total forest area (ha)
Aragon	1,543.465	1,071.868	2,615.333
Canaries	132.142	434.276	566.418
Cantabria	213.718	148.396	362.114
Castile-La Mancha	2,708.098	889.462	3,597.561
Castile and León	2,944.948	1,870.336	4,815.284
Catalonia	1,606.236	330.720	1,936.956
Andalusia	2,922.691	1,544.446	4,467.137
Community of Madrid	258.106	163.225	421.330
Chartered Community of Navarre ⁽¹⁾	435.003	159.389	594.392
Valencian Community	747.821	519.216	1,267.036
Extremadura	1,897.506	830.353	2,727.859
Galicia ⁽¹⁾	1,429.775	610.947	2,040.722
Balearic Islands	173.126	44.371	217.496
La Rioja	165.812	135.381	301.193
Basque Country	397.306	98.696	496.002
Principality of Asturias	441.946	323.983	765.929
Region of Murcia	301.708	185.669	487.377
Ceuta and Melilla ⁽³⁾	n.d. ⁽²⁾	n.d. ⁽²⁾	n.d. ⁽²⁾
Total	18,319.405	9,360.734	27,680.139

(1) CCAA with MFE25 figures. (2) n.d. = no data available. Source: Statistical Yearbook of Forestry 2009 of the Ministry of the Environment and Rural and Marine Affairs of Spain (MAGRAMA). (3) Autonomous Cities.

This attempt to escape from urban areas materializes on numerous occasions in homes, established legally or illegally, built in the forest in the urban mode but without following zoning and safety rules. Most of these zones constitute the wildland-urban and rural-urban interface areas that cause major problems.

Table 2— *Characterization of the regional area and population in Spain.*

Autonomous Community (Region)	Population (2011⁽¹⁾)	% total population	Area (km²)	% total area	Population density (hab/km²)
Andalusia	8,424.102	17,85	87.591	17,32	96,18
Aragon	1,346.293	2,85	47.719	9,44	28,21
Principality of Asturias	1,081.487	2,29	10.604	2,10	101,99
Balearic Islands	1,113.114	2,36	4.992	0,99	222,98
Canaries	2,126.769	4,51	7.447	1,47	285,59
Cantabria	593.121	1,26	5.321	1,05	111,47
Castile-La Mancha	2,115.334	4,48	79.463	15,71	26,62
Castile and León	2,558.463	5,42	94.223	18,63	27,15
Catalonia	7,539.618	15,98	32.114	6,35	234,78
Valencian Community	5,117.190	10,84	23.255	4,60	220,05
Extremadura	1,109.367	2,35	41.634	8,23	26,65
Galicia	2,795.422	5,92	29.574	5,85	94,52
Community of Madrid	6,489.680	13,75	8.028	1,59	808,38
Region of Murcia	1,470.069	3,12	11.313	2,24	129,95
Chartered Community of Navarre	642.051	1,36	10.391	2,05	61,79
Basque Country	2,184.606	4,63	7.234	1,43	301,99
La Rioja	322.955	0,68	5.045	1,00	64,01
Ceuta ⁽²⁾	82.376	0,175	19	0,004	4335,58
Melilla ⁽²⁾	78.476	0,166	13	0,003	6036,62
Total	47,190.493	100	505.980	100,06	93,27

(1) Reference date January 1, 2011. Source: Population data from the National Statistics Institute (INE), regional area data from the National Geographic Institute (IGN) 2012. (2) Autonomous Cities.

On the other hand, the implementation of forest rehabilitation policies in areas degraded by forest fires and/or other causes combined, paradoxically, with the lack of management in these and other areas have led to the accumulation of biomass in our forests. According to data from the Third National Forest Inventory (IFN3), conducted from 1997–2007, and the first data available for some provinces from the start of the Fourth National Forest Inventory (IFN4), treed forest areas have increased while those of sparse and scattered forests and treeless forests have decreased.

Consequently, available forest biomass, in both older and younger trees, has increased in value.

At the same time the population that once made use of this biomass has aged and can no longer carry out this work, while younger people find that the social, energy and economic remuneration for these activities isn't adequate and therefore they either reduce or abandon them.

Although the authorities responsible for forestry and civil protection, both at the national and regional-local levels, have implemented various wildfire prevention strategies in these areas, they have discovered that these are insufficient to curb the problem which is increasing with time.

Forest fire prevention

Forest fire prevention is an essential element in the fight against wildfires and in carrying out policy planning, resource allocation, organization of mechanisms and in the implementation and achievement of results. This is a long-term task in terms of the desired effects, in terms of both forest timeframes and attitudinal change in people.

General prevention

Forest fire prevention has traditionally been seen as an activity involving medium or large scale forestry actions consisting of reforestation, through seeding or planting, and cleaning and repairing forest roads. Actions such as forest hydrologic restorations were later incorporated. In many areas, primarily in rural communities, it was not considered essential to perform any other type of task because the use of biomass and the management of the land through the so-called *culture of fire* made it unnecessary. The population was involved in its environment, its use, its exploitation and, above all, in its conservation. However, the change in social uses was compromising this maintenance as well as the involvement of the population.

Need for prevention and social participation

In addition to taking standard intervention actions in rural areas, their populations must also be taken into account. These inhabitants of the forest and rural environment, the aging population or the new urbanites, need to be involved in the development, improvement and conservation of the environment. To do this, changing attitudes and mentalities to raise awareness that the environment is not what it was in the previous generation, nor is it of the urban type, also requires a long-term process involving residents living in the area.

In working with the users of the forest area, it is possible to carry out preventive

proposals, communicating what they are (information task) and their purpose (training task) before performing them (either by themselves or helped administratively and in carrying them out). Knowing the environment and the risks involved helps to take measures to prevent them from occurring.

An added aspect is the proliferation of areas where forest and urban areas are close to one another and overlap, resulting in wildland-urban interface areas. The result of intended forest use of the land by the urban population or the urban-minded is a series of additional problems and increased risk in these areas, both for users and for emergency personnel who come there in the event there services are required.

Although the authorities responsible for forestry and civil protection, both at the national and regional-local levels, have implemented various wildfire prevention strategies in these areas, they have discovered that these are insufficient to curb the problem which is increasing with time. For this reason it has been concluded that the public should move from being part of the problem to being an active part of the solution.

The main elements in reducing fire risk in wildland-urban interface areas are: management of vegetation and other fuels, measures on buildings and actions on road and defense infrastructure, active and passive, and on homes. Suitably protected infrastructure contributes significantly to the safety of residents and firefighters alike and facilitates a rapid response to wildfires. Unprotected buildings, whose owners have not taken preventive measures, may cease to be a priority in the activities of civil protection teams. The collaboration of owners is necessary to ensure the defense of buildings in interface areas. These aspects can be achieved through awareness-raising, educational and sensitization activities.

A general approach aimed at the general public allows the dissemination of fire prevention messages and information on appropriate forest use through institutional outreach and promotional campaigns by organizing conferences, seminars and courses and putting out publications with a general focus in the region or in more specific environments, such as the urban, residential and rural ones. Given that this system is aimed at the general public, real participation should be given to civil society with collaboration in local prevention plans and outsourcing of services through technical assistance and hiring. Other measures that have been used to great effect in other areas include the use of volunteerism as an educational method and the integration of disadvantaged groups.

A school-level approach must take into account that it is targeted at a young audience with great perception skills and the ability to learn new concepts. Information campaigns in this approach occur through contact with students with activities designed to raise awareness among children through educational events at schools and forest excursions. As a reinforcement measure, it is important to put out

publications and take advantage of the benefits and ease offered by new technologies and the current adaptation to them that schools have. Education is the appropriate tool to promote social and behavioral changes, so targeting forest fire prevention campaigns at the school population is seen as an especially important issue to take into account in the planning phase.

In another proposed approach, that of the local level, the geographical framework in which the information campaign takes place is different. The proximity of residents who may feel the problem is closer when they are given specific examples and details from their own area should be taken advantage of. The customized information, advice, verbal deterrence, awareness-raising and personalized education that can be provided in these cases are all important.

Study cases

The Regional Administrations of the Autonomous Communities and the General Administration through the Ministry of Agriculture, Food and the Environment are conducting information campaigns to inform the public about the implications of the misuse of fire and the risk of forest fires that can lead to wildfires causing serious ecological and economic losses. In the case of the wildland-urban interface areas, the very important task of awareness-raising is being performed. There are numerous examples of tragic events that occurred in 2012 involving people living in wildland-urban and rural-urban interface areas.

The Ministry of Agriculture, Food and the Environment conducts statewide campaigns, influencing the rural population in many areas (Vélez, 2007) through the work performed since 1998 by the Integrated Forest Fire Prevention Teams (EPRIF). These teams consist of technical and operational personnel who act in areas where fires caused by human activities have a greater incidence. At the urban and general level, it also develops other awareness-raising and sensitization campaigns such as the school campaigns.

At the regional level throughout the year 2011, the practical application of tasks resulting from the *Pyrosudoe* project study of the *culture of fire* in residents/owners in wildland-urban interface areas was developed. This project, which falls within the Interreg IV program of the European Union's Seventh Framework Programme for Research (FP7), involved the collaboration of specialists in forest fire prevention from the participating partners, France (Aquitaine, Languedoc-Roussillon), Portugal (Algarve) and Spain (Andalusia, Aragon, Balearic Islands), and provided for the implementation of measures to reduce the risk of wildfires in forests near wildland-urban interface areas.

In this sense, briefings were held with municipal officials to convey the concern of the Regional Administration in this regard. It is the municipalities, at the local

level, which should be responsible for self-protection plans in their territory, and it is the citizens thereof who should be involved in this process and who should demand their creation and, especially, their eventual implementation. The municipalities participating as pilot study areas hosted these initiatives with interest and concrete actions are now being carried out in some of them.

In Andalusia some information sessions were held with municipal officials, citizens and anyone else involved in land management, both public and private. In this regard, officials from urbanized areas, architectural and design firms and forest plant suppliers attended. At the technical level, other training sessions were held that were attended by the heads of the Regional Government responsible for forest fire prevention and suppression (INFOCA Plan), as well as those responsible for Civil Protection agencies.

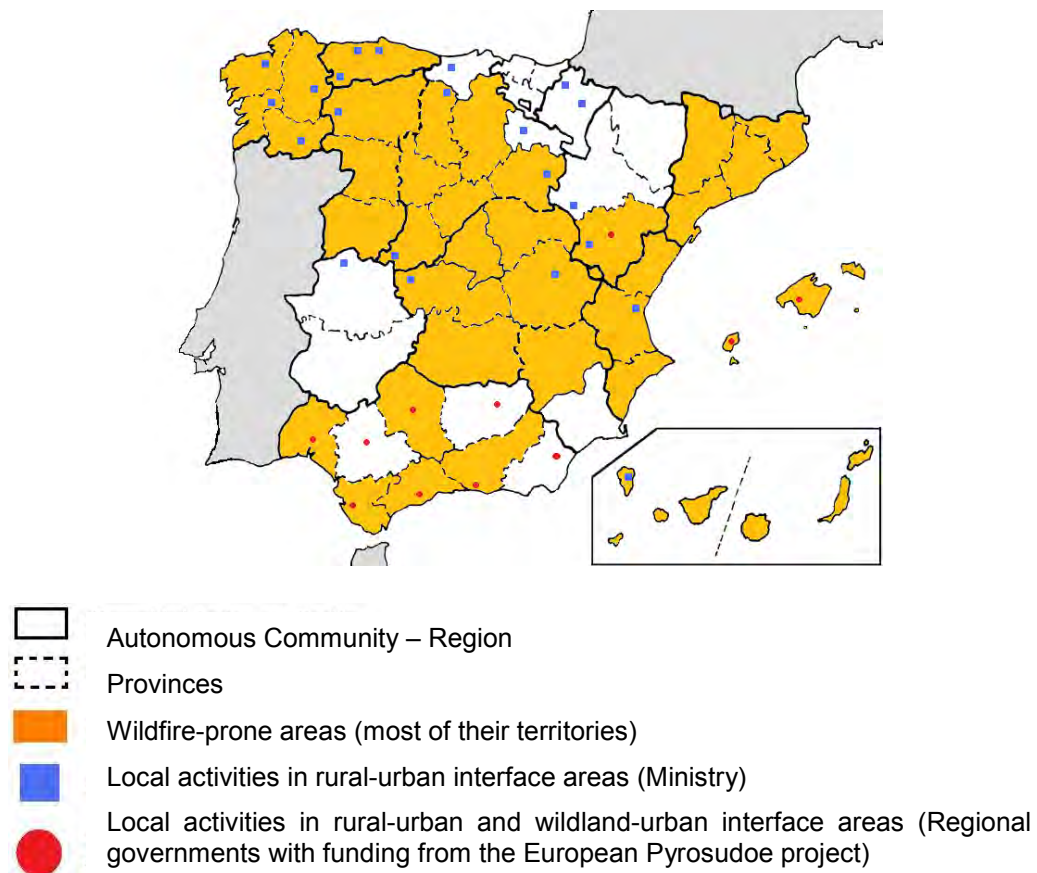


Figure 1: Examples of public information programs conducted in wildfire-prone areas. Source: Quesada, D., 2011 & 2012.

On the Balearic Islands, meetings were held with forest owners and managers. Several informational handouts were issued on the subject. It is worth noting the added difficulty of information tasks in this community due to the importance of foreign tourism and the presence of owners and residents from other European countries.

In both cases it was concluded that the people living in the population centers of the wildland-urban interface areas and bordering areas tend to have loyalty to the municipality with the personal decision not to change their place of residence. However, this circumstance does not imply the perception or experience of the risk of forest fires.

Similarly, the Regional and Local Administration should also work so that Forestry and Environmental Agencies and officials responsible for natural areas with environmental protection categories join interests and reconcile wills in an attempt to raise awareness about the problem through meetings with naturalist groups, farmers, livestock farmers and hunters.

In the case of the Balearic Islands, there is little tradition of using silviculture and forest management on private and public properties as a tool for prevention through stand improvement. Thus, the need arises to demonstrate adaptive forestry through carrying out work aimed at mitigating impacts. Therefore, it is essential to develop a previous planning task to identify risks, vulnerable areas and guidelines to reduce this vulnerability.

The characteristics of the wildfire risk areas in the wildland-urban interface suggest that it is not possible to separate the forest environment from the inhabitants living in it and that they have great heterogeneity in the perception of that risk.

The overall risk of natural phenomenon perceived by citizens is primarily focused on the risk of wildfires as a weather risk. The population does not perceive that there is a higher risk because of being in populated areas in the forest environment because they do not see the wildland-urban interface areas as such. That is, they perceive wildfires as being caused by human action but also to a large extent as an unpredictable natural phenomenon. However, in certain areas there are many people who acknowledge the significance of the wildfire risk in the wildland-urban interface as they have suffered the consequences of fire and consider it a personal risk. In this regard there have been numerous examples over the last several years, many of them in 2010, 2011 and 2012, both in the Balearic Islands and Andalusia with thousands of acres burned and thousands of residents evacuated as a preventative measure in the affected areas. In the Balearic Islands, the wildfires include, among others, those that occurred on the island of Ibiza: Benirràs, in 2010; Cala Longa and Morna-Sant Joan de Labritja, in 2011 and on the island of Mallorca: Santa Margalida and Artà in 2011; Capdepera, in 2012. In Andalusia, wildfires that

can be cited as examples are those that occurred in the provinces of Almería (Mojácar, 2010 and Bédar, in 2012), Málaga (Manilva, in 2011 and Ojén, in 2012), and Granada (Lanjarón, in 2012).

Moreover, much of the public often does not have a clear idea, or does not even consider, whether state logistics in the field of forest fires presents the degree of suitability required. There is a belief that increased investment in resources implies risk reduction in the wildland-urban interface with better results in terms of fewer fires and acres burned. At the same time, the population perceives that forest fire prevention is much less expensive than management of forest areas and that the existing obstacles in risk prevention are not of an economic or technological nature but rather of a political-organizational one. In this regard, legislative initiatives aimed at preventing risk are well-received and hence the need to involve the private owner and to shift the share of responsibility that corresponds to the individual. The Administration and the institutions that should be involved in the management of forest fire risk in the wildland-urban interface correspond to the municipalities through the tasks of prevention, management and intervention.

In parallel, plans call for the project's results to be publicized in order to raise awareness among forest landowners and the general public of the need for this type of forest management and adaptation.

Conclusions

Despite the degree of awareness and increasing sensitization in society about the negative impacts associated with forest fires, it is necessary to intensify efforts and perform new tasks in order to give residents living in the wildland-urban interface areas greater knowledge, show them the risks involving forest fires that can be found and enable them to be able to consider these risks in their entirety. In this sense, it would be necessary to carry out studies leading to knowledge of risk perception on the part of the population, and then, based on these results, conduct an educational and awareness-raising campaign followed by monitoring and control.

Research into the causes of forest fires will allow determining the extent of the problem in each area and sociological research will allow analyzing the social attitude to forest systems. These aspects should allow for feedback at all times on public awareness through correction elements.

To create awareness of risk in the population and of the proper use of fire in forest areas, the public should be educated to raise awareness in the field of forest fire prevention. The information must be provided at various levels depending on the population involved and it must be taken into account that there are various channels for the dissemination of information and that the recipients thereof are in

heterogeneous groups of perception. Information campaigns are a useful tool for the prevention of forest fires in areas where their causality has a markedly anthropic origin. The ultimate goal, however, remains the same. The identified pathway begins at the general level, passes through the schools and ends up at the local level.

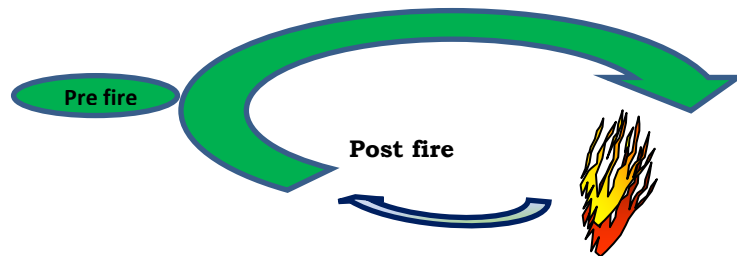


Figure 2— Desirable general efforts applied to the wildfire process from the standpoint of prevention. Source: Quesada, D, 2012.

Summary

Environmental education campaigns on the culture of wildfire risk in the wildland-urban interface provide data on local and sectorial problems essential for the planning of any policy on forest fire prevention. They also allow attaining a high level of social participation and joint responsibility to address this problem, while establishing a closer manager-managed relationship. In this regard, legislative initiatives aimed at preventing risk are well-received and hence the need to involve the private owner and to shift the share of responsibility that corresponds to the individual. The Administration and the institutions that should be involved in the management of wildfire risk in the wildland-urban interface correspond to the municipalities through the tasks of prevention, management and intervention.

References

- Absher, J.; Kyle, G.** 2007. An overview of risk and trust as precursors to defensible space actions by wildland-urban interface residents.
- Allen, J.B.; Ferrand, J.** 1999. Environmental locus of control, sympathy, and proenvironmental behaviour: a test of Geller's actively caring hypothesis. *Environment and Behavior*, 31(3): 338–353.
- Caballero, D.; Quesada-Fernández, C.** 2010. Caracterización del Riesgo por Incendio Forestal en la Interfaz Urbano-Forestal de la Comunidad Autónoma de Islas Baleares. Govern de les Illes Balears. Direcció General de Medi Forestal i Protecció d'Espècies.
- Caballero, D.; Quesada-Fernández, C.** 2010. Estudio y diagnosis del riesgo por incendio forestal en la interfaz urbano-forestal en la Comunidad de Madrid. Gobierno de Madrid. Consejería de Presidencia, Justicia e Interior.
- Caballero, D.; Quesada-Fernández, C.** 2010. Estudio y diagnosis preliminar del riesgo por incendio forestal en la interfaz urbano-forestal en la Comunidad Autónoma Valenciana. VAERSA.
- Caballero, D.; Quesada-Fernández, C.** 2011. Caracterización del riesgo por incendio forestal en la interfaz urbano-forestal en la Comunidad Autónoma de Andalucía - Zona costera de Málaga y Granada. Junta de Andalucía, Consejería de Medio Ambiente.
- Cvetkovich, G.T.; Winter, P.L.** 2008. The experience of community residents in a fire-prone ecosystem: a case study of the San Bernardino National Forest. Res. Pap. PSW-RP-257. Albany, CA: Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture.
- Kollmuss, A.; Agyeman, J.** 2002. Mind the Gap: why do people act environmentally and what are the barriers to pro-environmental behavior? *Environmental Education Research*, 8 (3).
- Molina-García, Y.** 2006. La participación comunitaria en la prevención y combate de incendios forestales: estrategias que la promueven. *Revista For. Lat* 40:107-123.
- Mueller, J.M.; Loomis, J.B.; González-Cabán, A.** 2008. 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 California.
- Rodríguez-Trejo, D. A.; Rodríguez-Aguilar, M.; Fernández-Sánchez, F.** 2001. Educación e incendios forestales. Mundi Prensa. Madrid.
- Quesada-Fernández, C.; Caballero, D.** 2011. Caracterización de la interfaz urbano forestal y propuesta de medidas preventivas contra incendios forestales en los municipios de Córdoba y Almodóvar del Río. Junta de Andalucía, Consejería de Medio Ambiente.
- Quesada-Fernández, C.; Quesada-Fernández, D.** 2011. Improving educational aspects as a way to prevent fire risk in fire prone communities in Spain. In Duce, P.; Spano, D. Proceedings of the ICFBR 2011, International Conference on Fire Behaviour and Risk. Alghero. Italy. EDES Sassari. Italy.
- Quesada-Fernández, C.; Quesada-Fernández, D.** 2012. Improving educational aspects as a way to prevent fire risk in fire prone communities. Cases of study in Spain. In: Spano, D.; Bacciu, V.; Salis, M.; Sirca, C. Modelling fire behaviour and risk. Sassari. 218-223.
- Vélez, R.** 2000. Actuación sobre las causas de origen humano. Persuasión, conciliación y sanción. Legislación preventiva. In: Vélez, R, coordinator. La defensa contra incendios forestales. Fundamentos y experiencias. McGraw-Hill, Madrid. 13.1-13.6 y 13.18–13.28,

- Vélez, R.** 2002. Forest fire prevention with a target: The rural people. In: Viegas, D, editor. Proceedings of the IV International Conference on Forest Fire Research. Luso, Portugal.
- Vélez, R.** 2007. Experiences in Spain of community based fire management. In: Proceedings of the IV International Wildland Fire Conference, Sevilla, 2007.
- Vélez, R.** 2008. Forest Fires in the Mediterranean Basin. In: González-Cabán, A, coordinator. Proceedings of the III Symposium on Fire Economics. Carolina, Puerto Rico, 2008.
- Villalba Ondurria, D.; Martín Pinto, P.** 2004. La educación como herramienta fundamental en la prevención de incendios forestales. Tabanque, 18. 189-20

Fire Risk in the Road Landscape Patterns of the State of Paraná, Brazil – Planning Grants for the Wildland-Urban Interface¹

Daniela Biondi², Antonio Carlos Batista³, and Angeline Martini⁴

Abstract

Urban growth worldwide has generated great concern in the planning of the different environments belonging to the wildland-urban interface. One of the problems that arise is the landscape treatment given to roads, which must not only comply with aesthetic and ecological principles, but also be functional, adding functions relating to forest fire prevention and control. The components for proper road functioning, such as slopes, right of ways, medians, signs, bridges and service stations, need appropriate landscape treatments to not only improve and conserve the site, but also to provide both comfort and safety to drivers and passengers. The relationship of these structures with the environment and road users requires incorporating fire-resistance characteristics into the layout, composition and selection of the plant species used.

The Highways Department of the state of Paraná, Brazil recommends 22 standards that define the function of the sites and the characteristics of the vegetation to be established. In none of these standards is forest fire risk taken into account. To contribute to road landscaping, the aim of this study was to analyze the fire risks of these landscape patterns so as to enrich them with less flammable species to inhibit and / or impede the spread of fire. In a detailed analysis of the recommended standards, it was found that in 50% of these standards, fire risk is one of the basic factors for the selection of species used. According to this research, road landscape standards that present the highest fire risks are: bus stops, service stations, property boundaries, industrial zones, native vegetation, degraded areas, green barriers (shelterbelts), slopes and central medians. We conclude that forest fire

¹ An abbreviated version of this paper was presented at the Fourth International Symposium on Fire Economics, Planning, and Policy: Climate Change and Wildfires, 5-11 November 2012, Mexico City, Mexico.

² M.Sc, DSc. Professor Forestry Engineering Course, Federal University of Paraná. Email: dbiondi@ufpr.br.

³ M.Sc, DSc. Professor Forestry Engineering Course, Federal University of Paraná. Email: batistaufpr@ufpr.br.

⁴ Forest Engineer, Graduate Student, Engineering Course, Federal University of Paraná. Email: martini.angeline@gmail.com.

risk assessment in road landscape planning should be an essential tool to reduce damage caused by fire in the wildland-urban interface areas of Paraná, Brazil.

Keywords: road landscaping, landscape, fire prevention.

Introduction

The destruction of homes and loss of life due to fires in wildland-urban interface (WUI) areas are capturing headlines in various parts of the world (Gill and Stephens 2009). Wildland-urban interface areas are defined as physical spaces where vegetation and buildings coexist in an environment conducive to fires (Ribeiro and others 2010). Radeloff and others (2005) complement the concept of WUI by saying it is an area of conflict between humans and the environment, exemplified by, among other things, the destruction of homes by wildfires, habitat fragmentation, introduction of exotic species and the loss of biodiversity.

Ribeiro and others (2010), in diagnosing fires in WUI areas of Portugal, found that forest fires in these areas are a growing problem not only in Portugal, but around the world, where the increase in the frequency and danger of fires tends to coexist with the presence of human settlements.

WUI areas are of great concern in terms of fire management and risk assessment (Lampin-Maillet and others 2011).

The term fire risk refers to the potential for a fire to start and spread in an area (Soares and Batista 2007). According to Jappiot and others (2009), fire risk is the result of a combination of risk due to the probability of ignition (i), the probability of fire spread across the landscape (ii) and vulnerability expressed as the potential damage to vegetation, houses and other buildings, mainly because of the intensity of the fire.

Most studies of southern Europe indicate that the fire ignition sources are located around the interface between human activities and forested areas. Approximately 50% of fire ignition sources are located on the sides of roads (including all road categories). These ignition sources are varied: cigarettes, car accidents, cars without spark arrestors and power lines. They can produce different forms of ignition: cigarette butts, flames (fires, accidents) or sparking (power lines, motors, automobiles), which emit variable energy and thus display differential ability to ignite vegetation (Curt and Delcros 2007).

The vegetation along roads is usually divided into zones that are organized as a series of lines located on the sides of the road until reaching the adjacent natural vegetation or wildlife area. This organization depends on local environmental conditions and the structural components of the road corridor (hard shoulder,

travelled surface, declivity). The spatial patterning of these structural components and the vegetation play an important role in fire ignition and spread (Curt and Delcros 2010).

Related to the above, one of the issues that arises is the road landscaping treatment, which should not only comply with aesthetic and ecological principles, but also functional principles, including functions for the control of forest fires. Road landscaping refers to all activities carried out on the sides of roads or highways, promoting their integration into the landscape and combining the principles of ecological, cultural and aesthetic conservation (Biondi 2002).

In a practical and applied vision, Goetze (2000) lists the following goals for road landscaping: integrate the landscape to the environment, at the same time mitigating the effects of its implementation; reduce maintenance costs through the use of appropriate vegetation; contribute to road safety; create rest areas for road users; assist in road maintenance and enrich roadsides with native vegetation; contribute to the development of tourism in the region and generate savings in road maintenance by using vegetation that preserves its structure.

In Brazil, road landscaping is still in its early stages. Although the country has 8,514,876,599 km², over 60% of freight transport is via national highways. In addition, 17.9 million cars circulate on Brazil's roads and highways, plus 3.087 million light commercial vehicles, 1.17 million trucks and approximately 258,000 buses. According to the National Department of Transport Infrastructure, the country has just over 1.7 million kilometers of roads, of which only 10% are paved, or approximately 172,897 km, of which 57,211 km are federal roads (33%), 94,753 km are state roads (55%) and 20,914 km are local roads (12%). Regarding road maintenance, 80% of the paving is over ten years old (Brazil 2012).

In order to contribute to road landscaping, this work aims to analyze the fire risk of road landscape patterns and look for measures and techniques to implement that hinder fire ignition and spread in wildland-urban interface areas in Paraná, Brazil.

Methods

This research on fire risk in road landscaping was carried out for the roads of Paraná, Brazil (Figure 1).

The Department of Highways of Paraná, Brazil recommends 22 road landscaping patterns or standards (Goetzke 2000). They are:

1. Narrow Roadside Pattern (< 25 m) – linearly arranged vegetation, varying the species in groups of 5 individuals
2. Wide Roadside Pattern (> 25 m) – arranged as islands;
3. Fuel Station Pattern – creeping and shrub vegetation with lush flowering

or attractive foliage to mark the entry landscape;

4. Terraces Pattern – light vegetation able to survive the lack of water and soil fertility, and that covers most of the ground surface;
5. Fill Pattern – vegetation that contributes to drainage and ensures its stability, and can be shrubs (next to parking), grass (base of the fill) and trees (at the end);
6. Return Pattern – low-lying vegetation that indicates the returns;
7. Pattern for Industrial Areas – lush flowering vegetation to highlight these areas;
8. Pattern for Existing Tree Vegetation: floriferous herbaceous vegetation that complements the local tree vegetation;
9. Pattern for Commercial Stores on Side Streets: annual vegetation planted in flowerpots to visually set off these stores;
10. Road Sign Pattern – vegetation that serves as a backdrop for road signs;
11. Bridge Pattern – vegetation to indicate bridges;
12. Degraded Areas Pattern: rustic vegetation, able to survive in arid environments, with interesting landscaping;
13. Green Barrier Pattern: big trees to hide degraded areas;
14. Conduit (gutter) Pattern - vegetation that serves as a filter for slope runoff;
15. Intersection Pattern: vegetation (trees and shrubs) that serves as a stimulus to reduce speed;
16. Horizontal Curve Pattern / Living defenses – vegetation (trees and shrubs) used for long-distance signaling;
17. Cut Slope Stability Pattern – vegetation (grass, scandent bushes and creepers) to protect the slope against erosion;
18. Crosswalk Pattern – small bushes that provide stimulus lines to reduce speed and mark off the crosswalk;
19. Central Median Pattern with Light Barrier – easy-maintenance bush and grass cover that serves as a barrier against light;
20. Central Median Pattern without Light Barrier: low-maintenance creeping vegetation (low grasses);
21. Bus Stop Pattern – arboreal vegetation able to offer shade and wind shelter;
22. Anti-erosion Pattern – erosion-resistant vegetation, to ensure the stability of drain outlet (Figure 2a and 2b).

The relationship of road landscape patterns to fire risk is based on factors associated with fire ignition and spread, such as vegetation (lifestyles, flammability, seasonality), relief, microclimate, design and layout of vertical and horizontal road

structure, vehicular traffic intensity, type of neighborhood or land use, and human presence.

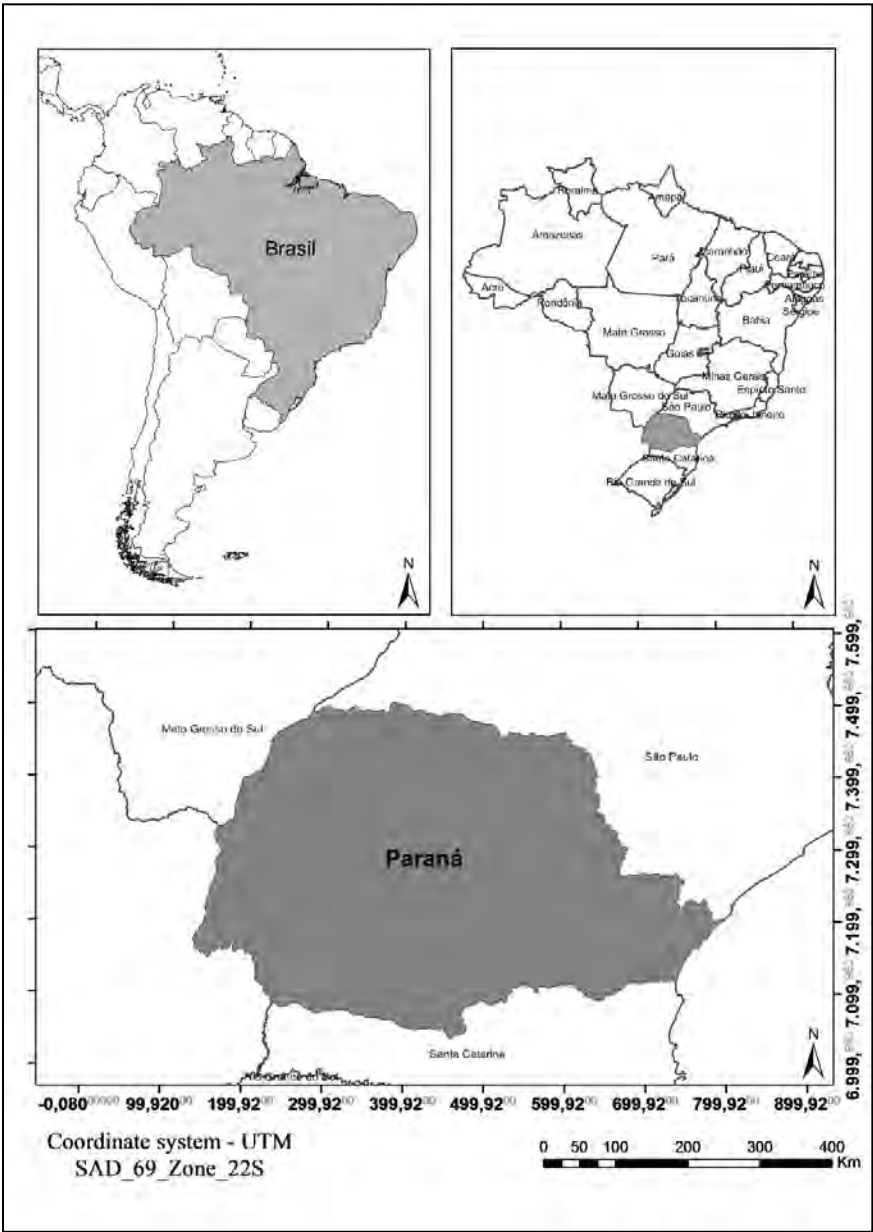


Figure 1—Study area location.

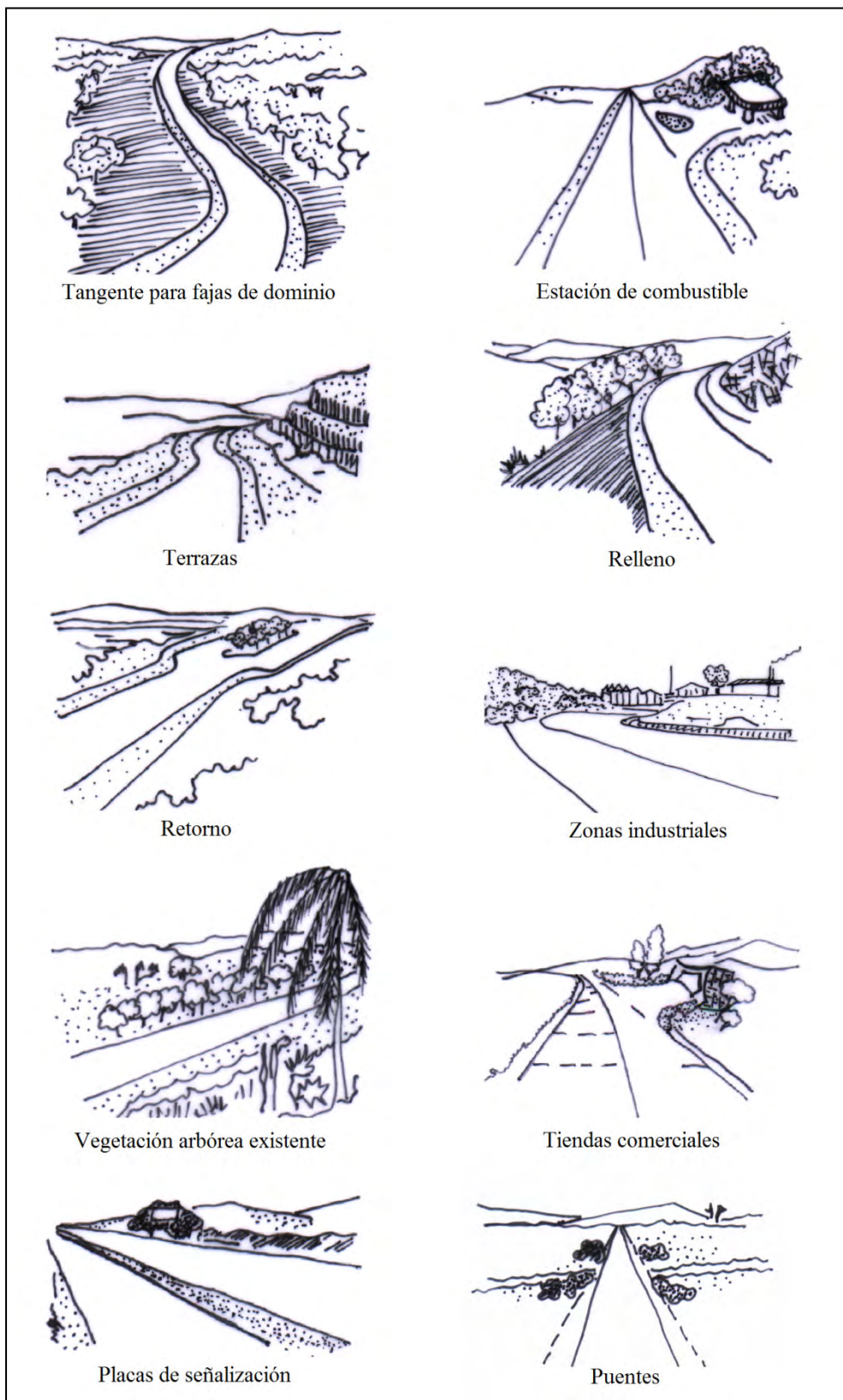


Figure 2a—Road landscape patterns (based on Dória, 1973 and Göetzke, 2000).

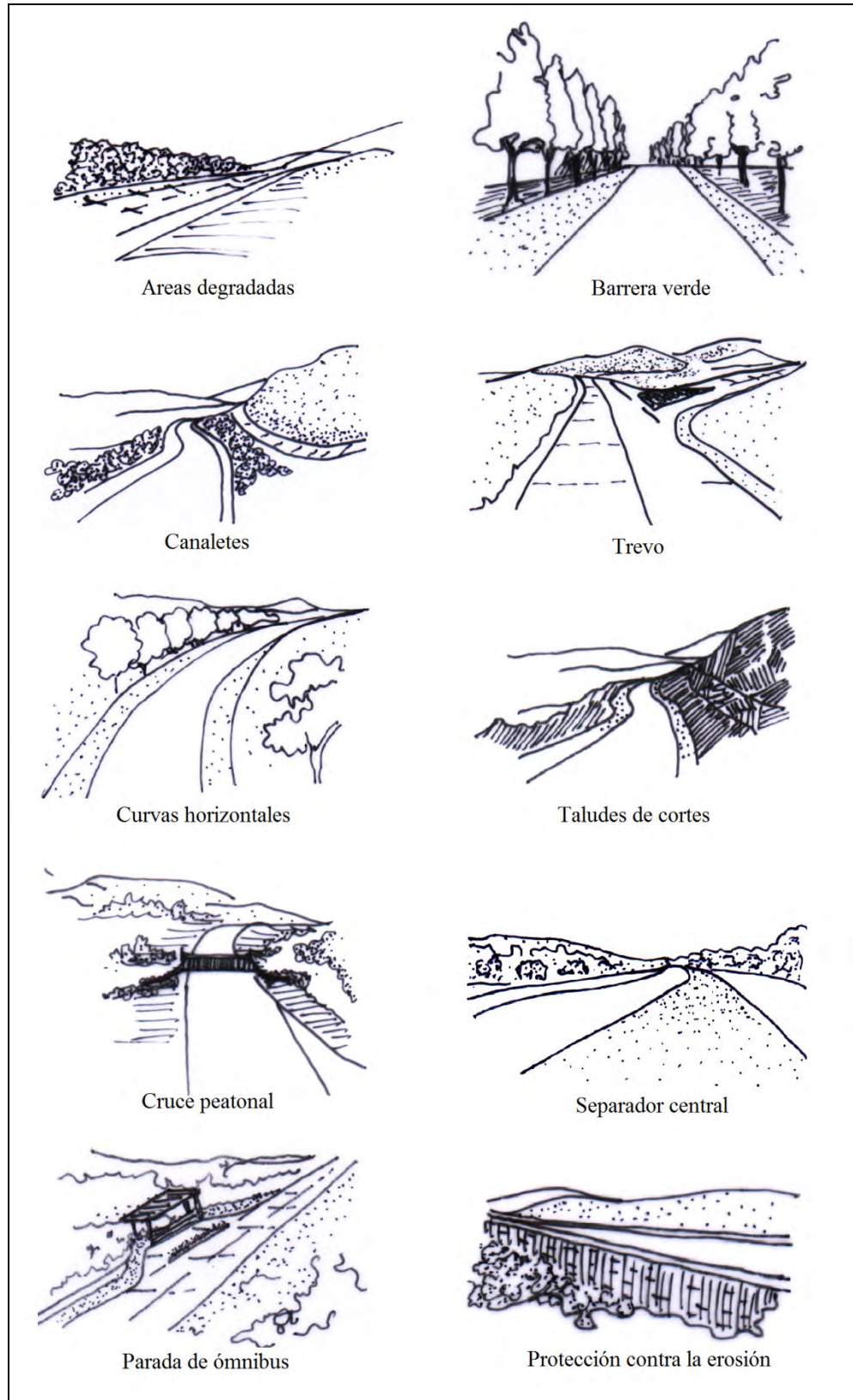


Figura 2b—Road landscape patterns (based on Dória, 1973 and Göetzke, 2000).

Results

The results of the fire risk analysis of 22 road landscape patterns are shown in Table 1. As can be seen, 54.5% (12) have a high risk of forest fires, 27.3% (6) have a low risk and 18.2% (4) have a medium risk.

Table 1-*Analysis of fire risk in 22 road landscape patterns.*

Road landscape pattern	Risk		
	H	M	L
Wide roadside pattern (<25 m)	x		
Narrow roadside pattern (>25 m)	x		
Fuel station	x		
Terraces		x	
Fill		x	
Return			X
Industrial areas	x		
Existing arboreal vegetation	x		
Commercial stores on side streets	x		
Road signs			X
Bridges			X
Degraded areas	x		
Green barrier	x		
Conduits (gutters)		x	
Intersections			X
Horizontal curves / living defenses		x	
Cut slope stability	x		
Crosswalk			X
Central meridian with light barrier	x		
Central meridian without light barrier	x		
Bus stop	x		
Anti-erosion			X

LEGEND: H = high; M = medium; L = low.

Discussion

Characterization of high fire risk

Road landscape patterns considered to have a high fire risk presented on their boundaries a type of neighborhood that provides a constant threat due to the presence

of ignition sources in land management activities on farm, livestock and forestry properties, as in the case of areas tangent to wide or narrow road right-of-ways.

The “Fuel Station,” “Stores on Side Streets” and “Bus Stop” patterns are considered highway service facilities. According to Biondi (2002), service facilities include all the necessary services for the comfort and safety of road users, such as checkpoints, fuel stations, restaurants, stores and others. These structures should be framed by the accompanying landscape. The high fire risk for these patterns is not associated with the landscaping of the facilities, but with the constant presence of man (anthropism), vehicular traffic intensity, flammable materials such as fuel (gasoline, diesel and ethanol), electrical appliances and equipment (refrigerators, air conditioners, fans, stoves, etc.) subject to accidents that can start fires, and the generation of waste or garbage (cigarette butts, paper, plastic, cardboard and wood) that can increase the amount of combustible material.

In the "Industrial Areas" pattern, regardless of the type of production, this site and its surroundings add many factors that increase susceptibility to fires, such as human activities, vehicular traffic intensity and flammable materials.

The risk of fire in the "Existing Arboreal Vegetation" and "Green Barrier" patterns depends on the characteristics of their constituent species. The degree of risk is associated with the species (flammability), composition (mix of species) and design (spacing or grouping form).

In the "Degraded Areas" pattern, the risk is higher because normally in these places, because of the various previous uses of the land (mining, agriculture use or forestry), there are residues which may contribute to both fire ignition and spread.

The "Cut Slope Stability" pattern poses a high fire risk not only for the use of flammable species, but mainly because of the relief that can favor the spread of fire.

As for the “Central Meridian with or without a Light Barrier” pattern, the fire risk is linked to the flammability of the species used and especially the design, which usually consists of a single species arranged in a continuous horizontal and vertical manner. Thus, the site presents easily-ignited combustible material, depending on the season, along with its continuous distribution favors the spread of fire.

Characterization of medium fire risk

The "Terraces" pattern refers to structures linked to the continuous ramps on the slopes that serve to prevent surface water runoff to the road platform (CATI, 2012). For this pattern in Paraná, light vegetation able to survive the severe lack of water and soil fertility, and which covers most of the ground surface, is recommended. The medium fire risk of this pattern is mainly due to the fact that the structure is vertically

interrupted and to the use of creeping vegetation (little combustible material) in the horizontal area.

The "fill" pattern is defined as road sections which, in order to be constructed, require the accumulation of materials obtained from cuts or elsewhere (CATI, 2012), giving the area extreme soil moisture conditions. For this reason the landscape treatment usually recommended is vegetation that contributes to drainage and ensures stability, and it can be shrubs (beside the road), grass (base of the fill) and trees (at the end). Due to the mixture of vegetation (herbaceous, shrub and tree), this pattern has a medium forest fire risk.

The "Horizontal Curves / Living Defenses" pattern presents a medium fire risk because the landscaping (tree and shrub insertion) cannot occupy both sides of the road so as not to impair driver visibility.

The medium fire risk for the "Conduit (gutter)" pattern can be associated with both the flammability of the vegetation that serves as a filter for the water that runs off the slopes and the continuous arrangement of vegetation that accompanies the conduit.

Characterization of low fire risk

The low fire risk of the "Return," "Intersection" and "Crosswalk" patterns is due to the greater amount of permeable area surrounding these patterns, isolating the vegetation or combustible material.

For the "Road Signs," "Bridges" and "Anti-erosion" patterns, although the vegetation characteristic is important, the discontinuous landscaping arrangement reduces fire risk.

Conclusions

We conclude that the risk analysis performed made it possible to discriminate between road landscape patterns based on factors associated with fire ignition and spread.

It is also concluded that forest fire risk assessment in road landscape planning should be an essential tool to reduce fire damage in the wildland-urban interface areas of Paraná, Brazil.

From the characterization of the level of fire risk, it is possible to plan the selection and composition of less flammable species since it is not possible to change the essential structure of the road pattern.

Given the impossibility of changing road patterns, due to their functionality, from the characterization of the level of fire risk it is possible to plan the selection

and composition of less flammable species and impede the spread of fire.

Summary

This study analyzed forest fire risk in the road landscape patterns used in the state of Paraná, located in southern Brazil. Analyses were based on factors associated with fire ignition and spread, such as vegetation, relief, microclimate, structure design and layout of vertical and horizontal road structure, vehicular traffic intensity, type of neighborhood or land use and human presence. The results indicated that 54.5% (12) of the landscape patterns have a high forest fire risk, 27.3% (6) a low risk and 18.2% (4) a medium risk.

Acknowledgement

We wish to thank Dr. Marcos P. R. Rodríguez for his help in reviewing the Spanish version of this text.

References

- Biondi, D. 2002.** Seleção de species para o paisagismo rodoviário. Curitiba: FUPEF Séria Técnica 01/02. 24 p.
- Brasil. 2012.** Disponible en: <www.brasilazul.com.br/rodovias.asp>. Acesso em 08 de junho de 2012.
- CATI. 2012.** Disponible en: http://www.cati.sp.gov.br/Cati/tecnologias/manejo_conservacao_solo/EspecificacoesTecnicasdeServico-AnexoI.pdf. Acesso em 08 de junho de 2012.
- Curt, T.; Delcros, P. 2010.** Managing road corridors to limit fire hazard. A simulation approach in southern France. *Ecological Engineering* 36(2010) 457-465.
- Curt, T.; Delcros, P. 2012.** Simulating fire ignition and initial propagation at road-forest interfaces. Disponible en: <http://www.fire.uni-freiburg.de/sevilla-2007/contributions/doc/cd/SESIONES_TEMATICAS/ST3/Curt_Delcros_FRANCIA.pdf>. Acesso en: 15/06/2012.
- Dória, R.A. 1973.** Como plantar árvores e arbustos nas estradas de rodagem. Rio de Janeiro: Departamento Nacional de Estradas e Rodagens. 23p.
- Gill, A. M.; Stephens, S. L. 2009.** Scientific and social challenges for the management of fire-prone wildland–urban interfaces. *Environ. Res. Lett.* 4 (2009) p. 1-10, doi:10.1088/1748-9326/4/3/034014.
- Göetze, S. 2000.** Paisagismo Rodoviário. In: Governo do Estado do Paraná – Secretaria de Transportes. Manual de Instruções Ambientais para Obras Rodoviárias. Curitiba, DER/UFPR/FUPEF:2000. P 179-222.
- Jappiot, M., Gonzales-Olabarria, J.R., Lampin-Maillet, C., Borgniet, L. 2009.** Assessing wildfire risk in time and space. In: Birot, Yves (Ed.), *Living with Wildfires: What Science can Tell Us? A Contribution to the Science-policy Dialogue*, p.41–47.

- Lampin-Maillet, C.; Long-Fournel, M.; Ganteaume, A.; Jappiot, M.; Ferrier, J.P. 2011.** Land cover analysis in wildland–urban interfaces according to wildfire risk: A case study in the South of France. *Forest Ecology and Management* 261 (2011) 2200–2213
- Radeloff, V. C.; Hammer, R. C.; Stewart, I.; Fried, J. S.; Holcomb, S. S.; Mckeefry, J. F. 2005.** The wildland–urban interface in the United States. *Ecological Applications*, 15(3), pp. 799–805.
- Ribeiro, L. M.; Viegas, D. X.; Caballero, D. 2010.** Wildland Urban Interface - a diagnostic analysis for Portugal. Abstractcs - VI International Conference on Forest Fire Research - CD-ROM. Coimbra - Portugal : ADAI/CEIF - Ed. Domingos X. Viegas, 2010. v. 1. p. 1-11.
- Soares, R. V.; Batista, A. C. 2007.** Incêndios Florestais: controle, efeitos e uso do fogo. Ronaldo Viana Soares e Antonio Carlos Batista Ed. Curitiba. 264p.

Advances in Integrated Fire Management in Central Mexico

Dante Arturo Rodríguez Trejo¹ and Arturo Cruz Reyes²

Abstract

This paper reports on the research and operational results of efforts made by some rural communities, the National Forestry Commission (CONAFOR), the Universidad Autónoma Chapingo (UACH) and other organizations to achieve integrated fire management in central Mexico. The research includes the latest results obtained by UACH's Ajusco Project on the subject, in both fire-maintained and fire-sensitive ecosystems. Operationally, the paper reports on the holding of workshops, meetings and prescribed burns oriented towards this type of fire management in Mexico City and the states of Mexico, Puebla and Tlaxcala, organized with producers by CONAFOR and UACH. It is a joint effort involving farmers, government organizations at the federal and state levels, and a teaching and research institution. It seeks to contribute to this management alternative, through the merger of the ecological use of fire, its judicious and low-impact use by rural communities, and the prevention and fighting of forest fires, promoting all kinds of positive impacts and reducing the negative ones.

Introduction

Despite its small area of almost 150,000 ha, Mexico City, also known as the Federal District, is a federal entity with the biggest human population in the country. The largest number of fires also occurs there. In fact, it is not uncommon to have more than 1,000 fires per year. However, most are small, as the National Forest Commission (a federal government agency) and the Natural Resources Commission (an agency of the Mexico City government) have the human resources, materials and specialized equipment to perform fire management tasks. Over 40 % of the causes are agricultural. Farmers burn open grasslands or in the forest to promote the emergence of new sprouts, called "pelillo" in Mexico, which they use to supplement the diet of their animals during the dry season. Escapes from the burning of crop residues, used to clear the ground, fertilize it with ashes and reduce potential pests, are also part of such agricultural causes. About 25 % of the causes include bonfires

¹ Professor-Researcher, Forestry Department, Universidad Autónoma Chapingo, Chapingo, Edo. de Méx., C.P. 56230, MÉXICO. Tel. 5959521500 x 5468. Email: dantearturo@yahoo.com

² Forest Engineer, Head of the Forest Fire Department in Mexico City, National Forest Commission. Progreso 5, Col del Carmen Coyoacán, Coyoacán, Distrito Federal, C.P. 04100, MÉXICO. Tel. 5555540612. Email: acruz@conafor.gob.mx

and still-lit matches and cigarette butts tossed onto the ground by passers-by and fieldworkers (CONAFOR, 2012; CORENA, 2012).

Rural areas in the southern part of Mexico City cover almost 89,000 ha, and include some 50,000 ha with forest vegetation. The latter includes both fire-maintained and fire-sensitive and -influenced vegetation. The first group includes pine forests, oak forests, matorrales (shrublands) and zacatonales, while in the second group a few patches of cloud forest and sacred fir forest can be mentioned. The latter is considered moderately adapted to fire by recent research.

The forests in the south of Mexico City, which are in wildland-urban interface areas, provide many environmental services to the city, such as control of dust clouds, water and carbon capture, recreation and leisure sites and ecotourism, among others.

As is the case elsewhere in the country and in many parts of the world, a large number of fires in this area are linked to agricultural causes, which are based on poverty and the needs of rural people, but also on a lack of information. But they are also superimposed on extensive ecosystems requiring fire to stay healthy, such as those mentioned; moreover, the smoke produced from fires further contaminates what is already one of the most polluted cities in the world.

It has also been estimated that climate change, globally and in Mexico, is expanding dry areas and thus resulting in increased fire hazard. This, coupled with a still far-off solution to poverty, lets us see near-future, medium-term and long-term scenarios of more forest fires, which must be managed from their social and ecological components, in addition to preventing and fighting fires that will remain an important part of management efforts.

The above is the challenge facing fire management in Mexico City and the country as a whole, which will only be properly met when fire is used for ecological, management and conservation purposes in ecosystems that need it, and when people who use fire in the traditional way minimize escapes, follow the existing regulations and stop conducting uncontrolled burns, so that the positive effects of fire are maximized and the negative ones (such as air pollution and erosion) minimized. All this should be promoted and validated by research carried out by universities and research centers, which have also taken a very active role in Mexico. This is called integrated fire management.

In the year 2000, the University of Chapingo initiated the Ajusco Project, which is focused on fire ecology, integrated fire management and restoration of burned areas. The project's goals, in addition to those set forth in the previous paragraph, are to promote fire research, increase the number of postgraduate students delving into the subject, train more people in the area of forest fires, provide feedback to courses with the information generated and participate in national and international

workshops and conferences, such as this one, to disseminate the results. The aim of this paper is to give a summary overview of what has been achieved so far by the project and its impact.

Work regions and partnerships

Although the project team started its research in the cold-temperate area of central Mexico, it is now also at work in tropical and semi-arid areas. In total the project team has worked or is working in Mexico City and 11 states of the country: State of Mexico, Tlaxcala, Hidalgo, Puebla, Guerrero, Oaxaca, Chiapas, Quintana Roo, Campeche, Sonora and Coahuila.

In various forms, it has worked with international institutions and organizations such as: the University of Arizona, Northern Arizona University, the University of Colorado, the U.S. Forest Service, the Fire Sciences Laboratory in Missoula, Montana, Natural Resources Canada, the Nature Conservancy, the University of Lleida, Spain and the University of Jaén, Spain. Nationally, partnerships have been formed with CONAFOR, CONAFOR-Mexico City, CORENA, CONAFOR-Puebla, Colegio de Postgraduados, Universidad Autónoma de Guerrero, Universidad Autónoma de Hidalgo, and CONANP. Some of the contributions made by the project are cited below. The references correspond to members of the work team.

Including professors' work, theses, articles derived from both and published in international or national journals, books, book chapters and presentations at events, from regional to international, there have been more than 60 publications. Some more are in progress and several of those already published are mentioned below.

Contributions to the ecological component of IFM

Basic information

In this regard the work team has contributed, along with other organizations, including the federal government, to the acceptance of the ecological role of fire in the regulatory and operational areas of fire management in the country. This has been promoted through conferences, work meetings, workshops, scientific papers and presentations at workshops. In this particular area, the public has been farmers, children, middle school to graduate students, fire management operational and regulatory staff, professors and researchers. It has also helped to determine the level of relationship between fire and the various types of vegetation in the country.

Mexico is the country with the highest number of species of pine (47 taxa) and oak (167 species) worldwide (Farjon and Styles, 1998; Zavala, 2007), and its forests

cover large areas. Through adaptations to fire such as thick bark, grass stage, regeneration in burned areas, rapid growth, recovery of crown foliage that was dried or scorched, most Mexican pine species show adaptations to fire. Among the pines with the most adaptations to this ecological factor and that have wide distribution are: *Pinus hartwegii*, *P. montezumae*, *P. patula*, *P. greggii*, *P. oocarpa*, and *P. michoacan*, among others. The least adapted include the pinyon group, such as *P. cembroides* (Rodríguez and Fulé, 2003) (Figure 1). Regarding oaks, of 73 species analyzed and reviewed, the majority also showed adaptations to fire. Morphological indications that reveal such adaptations in different species include: resprouting capacity, thick crust, regeneration in burned sites, small nut and deciduous habit. In general, oaks in cloud forests and tropical forests (except those forming savannas) are fire-sensitive, for example *Q. insignis*. Among the tree species adapted to fire in Mexico are: *Quercus rugosa*, *Q. crassifolia*, *Q. crassipes*, *Q. magnoliifolia*, *Q. hypoleucoides* and *Q. arizonica*. Shrubs include: *Q. frutex*, *Q. repanda*, *P. potosina* and *Q. microphylla*, among many others (Rodríguez and Myers, 2010).

Fire-sensitive ecosystems have also been evaluated, such as the tropical forests of the Selva El Ocote Biosphere Reserve, Chiapas, after 23,000 ha were affected by fires in 1998. Seven years after the fires, the number of tree species and their diversity based on the Simpson index (D), in samples from different conditions studied, was: unburned forest (45 species, D=0.96), areas only burned in 1998 (27, D=0.86), areas burned in 1998 and restored with direct seeding (13, D=0.73), others burned in 1998 that were restored but were burned again in 2003 (10, D=0.58), and others burned in 1998 and 2003 (13, D=0.69). The control area presents a slight gradation in the values of importance among the abundant species in the unburned area. On the other hand, a few species, typical of savannah, dominate the lower richness present in the affected areas (Maldonado and others, 2009). Sacred fir (*Abies religiosa*) forest, the type of climax vegetation in the temperate areas of the entity, has been considered as moderately adapted to fire. Prone to crown fires in dry years, such as 1998 and 2011, one of these fires affected 200 ha in the community of Topilejo, Mexico City, in 2011. A 73.1% mortality rate was determined, and logistic models were used to estimate the probability of tree mortality. Structure variables, namely height ($p < 0.0001$), diameter at breast height ($p = 0.028$), crown length ($p < 0.0001$) and height to the base of the crown ($p > 0.0001$), explained, with an inverse relationship, the mortality. By contrast, a direct relationship was found with the severity variables: fatal height ($p < 0.0001$) and crown scorch percent ($p < 0.0001$) (Temiño and others, in process) (Figure 2).

The avifauna of burned areas was studied in a *Quercus crassifolia* forest in Chignahuapan, Puebla. This research found that a hummingbird, *Hylocharis leucotis*, prefers severely burned areas where it finds the species *Bouvardia ternifolia*, which

has a tubular flower where the nectar is obtained (Ponce *and others*, 2011). A general proposal for fire regimes and fire ecology for Mexican vegetation was also developed (Rodríguez, 2008).



Figure 1—Stand of *P. hartwegii*, in central Mexico, where low intensity and severity prescribed burning was conducted seven months earlier. Photo by Dante A. Rodríguez Trejo (2006).



Figure 2—Effects of a crown fire in central Mexico on sacred fir (*Abies religiosa*) forests six months later. Photo by Dante A. Rodríguez Trejo (2011).

Applications

In this case, besides better understanding the fire ecology in species and regions of interest, the strategy is to have applications and guidelines that are useful when performing prescribed burns and that help to maximize the beneficial effects and minimize the negative impacts of fire. For example, Rodríguez *and others* (2007) point out from logistic models that low-intensity prescribed burns (early morning, against the wind and slope), conducted no later than mid-season, cause virtually no mortality in *P. hartwegii* saplings, while an intense burn (afternoon, and with the wind and slope), which simulates a fire, eliminates more than 80 % of individuals. In probabilistic terms, at lower diameter at breast height (DBH), all treatments have a greater probability of mortality, but this is much more pronounced in the late-season treatments conducted at high intensity (with the slope and wind, with burning in the afternoon) and in dense stands. For example, a tree with a 10-cm DBH has a < 1 % probability of mortality if a prescribed burn is carried out in mid-season, in the morning and at low intensity (against slope and wind) in open stands. By contrast, a

tree of the same diameter burned with the intense treatment, in dense stands and in May will have a 50 % probability of mortality. These results are considered to be applicable to most temperate-cold climate pines in the country. The resulting model was:

$$P = 1 / (1 + \exp - (-2.3145 + 2.2619X_1 + 2.00528X_2 + 2.0343X_3 - 0.4119X_4))$$

Where: X_1 is time of year (0=March, 1=May), X_2 =intensity (0=low, 1=high), X_3 =density (0=low, 1=high), X_4 =DBH (cm).

P. hartwegii is fire resistant, but *Q. crassifolia* is tolerant. For the latter species, in areas burnt with high severity, Juárez *and others* (2012) suggest that the probability of mortality for the above-ground part of an oak also with 10-cm DBH is 30 %. However, the probability for the entire individual (including the root) is only 5 %, as it is able to resprout. According to these authors, the probability of resprouting increases with lethal height (since by affecting buds containing auxins these phytohormones are eliminated and with them the inhibition to activate basal buds) and decreases with the diameter of the trees (the juveniles are more vigorous). On the other hand, according to Temiño *and others* (in process), for the species moderately adapted to fire, *Abies religiosa*, in an area affected by a crown fire 6 months before, a tree with a 10-cm DBH has an 80 % probability of mortality.

As part of the ecological responses in pine forests, there is greater species richness and diversity in the understory. Hernández and Rodríguez (2008), Espinosa *and others* (2008) and Islas (in press) show that one year after burning that richness increases by approximately 40 %, compared with the control, reaches 60 % by the end of the second year and falls to an additional 50 % by the end of the third. Another contribution lies in the estimation of total load (TL) or the load of certain types of forest fuels, e.g. woody fuels, from models using explanatory variables of the stand structure, such as basal area (BA), as proposed by Rodríguez *and others* (2009):

$$TL = 2.462 + 9.5553 \ln BA$$

Applications in the fire prevention and suppression component of IFM

Studies carried out in this regard include that of Carrillo *and others* (2011) and those of UACH-CONAFOR (2008) and Rodríguez *and others* (2011) on the impact and fire hazard resulting from Hurricane Dean. In the first, fire hazard areas were identified in the state of Puebla, as detailed in the following section. In the last two,

fuel loads felled by Hurricane Dean in 2007 and their spatial distribution were determined, along with hazard areas requiring priority attention based on fuel loads and distance to agricultural areas.

Another study conducted by UACH-CONAFOR (2011) establishes that, given the particular characteristics of Mexico City in terms of fire, which combine the same rural pressure found elsewhere in the country with the pressure of Mexico City, by not fighting fires, almost 58,000 wooded hectares of the federal entity would be affected by fire each year.

Contributions to the social component of IFM

Human dimensions and fire

For Puebla, Carrillo *and others* (2012) modeled the effect of both environmental (precipitation and exposure) and anthropogenic (number of branch roads and proximity to rural communities) variables, which influence the probability of fire in the entity. In this case, there tends to be more fires in areas with higher rainfall (where more fuels accumulate) on southern exposures (drier), in areas with many branch roads and few communities.

Derived from a project undertaken by CONAFOR-UACH (2007), Rodríguez *and others* (2008) refer to an inverse relationship between various forest fire parameters and the human development index, and also a direct relationship with: surface area disturbed by man, number of farmers subsidized in the spring-summer cycle for agricultural production, and maximum wind speed.

Applications in the social component of IFM

In this case the intent is to: A) disseminate the information generated so that it reaches the rural communities and is useful to them, B) contribute to the application of controlled burns in order to achieve effects similar to those demonstrated experimentally, and C) maximize the benefits derived from fire and contrast the negative effects of prescribed burns and wildfires. With regard to the latter, the aim is to discourage the indiscriminate use of fire and promote its correct rural use in communities where there is no empirical knowledge of this type. To this end, some efforts have been made with rural communities, with farmers or community fire brigade members, such as:

Workshop on fire and prescribed burns with ejidatarios in Chignahuapan, Pue., 2000, sponsored by the Technical Forest Services of Sierra Norte de Puebla.

Training Workshop on forest fires with Puebla state firefighters in

Huauchinango, Pue., in 2001, sponsored by INIFAP.

Training Workshop on forest fires with Puebla state firefighters in Chignahuapan, Pue., in 2003, sponsored by CONAFOR-Puebla and Puebla's Ministry of Environment.

Intoductory workshop on IFM in Villas de Santa Clara, Talxcala, 2009, sponsored by CONAFOR.

Participation in meeting on research and community experiences in the Tlalpan borough, sponsored by CORENA, Mexico City government, in 2012.

In this component, Chavarría (2009) and Ortiz (2009) analyzed grazing practices in central Mexico, the yield and carrying capacity of grassland in *P. hartwegii* forests and the precise objectives of fire use by livestock farmers.

In the workshops mentioned above and others, some of the available information has been disseminated in the form of lectures and practices, with feedback from farmers. One recent effort was to conduct an extensive prescribed burn on land with a high incidence of fire, which is summarized in the sub-section entitled "Application of prescribed burns towards IFM."

Establishment of demonstration areas

As a result of research or workshops, several demonstration areas have been established. They have been visited by farmers, students and researchers, who were able to see the benefits of prescribed burns. In most of them, there is continuing research on fire ecology and medium-term fire effects. The following list of demonstration areas includes information on their location, size and year of establishment (Figures 3 and 4):

Chignahuapan, Pue. (1 ha, 2000)

Ajusco National Park, Mexico City (4 plots, each with 1 ha, 2002)

Ajusco National Park, Mexico City (4 plots, each with 1 ha, 2006)

Villas de Santa Clara, Tlaxcala (1 ha, 2009).

Ajusco, Mexico City (12 ha, 2012).

Efforts in other forums

In order to disseminate the project's advances, information has been presented at events like World Fire 2003, 2007 and 2011 in Sydney (Australia), Seville (Spain) and Sun City (South Africa), respectively, and at the 4th International Fire Ecology and Management Congress in Savannah, Georgia (USA, 2009). See, for example, Rodríguez (2010, 2011).



Figure 3—Prescribed burn carried out with ejidatarios in Chignahuapan, Pue. Photo by Dante A. Rodríguez Trejo 2000.



Figure 4—Prescribed burn conducted with communities in Villas de Santa Clara, Taxcala. Photo by Dante A. Rodríguez Trejo, 2009.

The project has also been involved with The Nature Conservancy (TNC) in various workshops held in Central America between 2002 and 2006 and focused on fire ecology and integrated fire management, as well as with CONAFOR (several Forest Expos, state events), CORENA (events in Mexico City), and other government organizations, NGOs, and universities (UNAM, Universidad Autónoma de Guerrero, Universidad Autónoma de Puebla, Universidad de Hidalgo).

Application of prescribed burns towards IFM

Prescribed burns carried out in workshops are intended to promote integrated fire management. Next, a prescribed burn, the last and largest conducted by the project in central Mexico, is detailed. This prescribed burn, oriented to IFM, was held at a site belonging to a community, with its permission and the participation of firefighters belonging to it. An area with a high incidence of forest fires, as well as difficult terrain, was chosen. Such difficulties lie in areas with abundant hills, which imply uneven terrain. At the site, almost all year winds blow from different directions throughout the day and with different speeds, tending to increase as the day progresses. Fuels are mainly grasses, but with young trees in patches in different areas. Adult trees (*Pinus hartwegii*) are present at medium to low density.

The prescribed 12-ha burn was directed and conducted by CONAFOR and UACH staff. The objectives were:

- Reduce forest fuels to abate the fire hazard and protect young trees from fire.
- Produce forage for the livestock of herders, who often start fires in the area without causing significant damage to the trees.
- Contribute to maintaining wildlife habitat and the fulfillment of the ecological role of forest.
- Find a synergy with farmers to burn at low intensity and gradually discourage the generation of forest fires.
- Obtain, on a large scale, experimentally determined benefits, such as: minimum mortality of trees, including juveniles, little damage to tree crowns, promotion of understory species diversity and reduction of forest fuels.

In March and April 2012, the experimental prescribed burn was carried out in two stages, with the participation of 30 firefighters at different times. The first stage was to burn a wide 2-ha band, located on a very steep slope and towards which winds often blow. It served as a safe area to treat the rest of the site. The second stage was the extensive burn.

The topographic and wind variation make it infeasible to apply a traditional technique, because the fire would eventually find a favorable wind and/or upslope on which it would develop more intensely, negatively affecting the young trees and, to some extent, also the adult trees.

For this reason an adaptation between chevron and backing fire techniques was made, since the fire was begun in a slightly irregular strip, starting on the ridgeline of the hills, in order to treat the latter always against the slope and with or against the wind, or perpendicular therewith, according to the case. Before the fire began to climb other slopes, burning began on the next line starting from the next ridgeline, so that it was roughly working on lines. Over most of the site, it was possible to have low intensity and severity.

In accordance with the prescription, it was generally possible to burn with flame lengths of 0.5 to 1 m, particularly around the perimeter of the site. In some small interior sectors flame length was greater. In such cases the burning of fuels in the direction of the fire's advance was done earlier to reduce the intensity. The advance by lines from the ridgeline was always maintained (Figures 5-8).



Figure 5—Prescribed burn in progress in Ajusco, Mexico City. Photo by Dante A. Rodríguez Trejo, 2011.



Figure 6—Prescribed burn in progress. Photo by A. Rodríguez Trejo, 2011.



Figure 7—Completed prescribed burn. Photo by Dante A. Rodríguez Trejo, 2011.



Figure 8—The prescribed burn area (left half of photo) 6 months later. Photo by Dante A. Rodríguez Trejo, 2011.



Figure 9—The work crew. Photo by Dante A. Rodríguez Trejo, 2012.

Today the area is monitored in terms of research (for example, studying the effect of the fire on height growth and resprouting in young trees) and its use by members of the community (qualitatively). It also serves as a demonstration area and, in the future, more prescribed burns are planned to help reduce fires and maximize various types of fire benefits in these forests that need them as an ecological factor. These forests are heavily used by the inhabitants of these rural areas, where due to the influence of city dwellers (tossed cigarette butts, bonfires) fires are also produced. All of the above is within the context of Mexico City, one of the biggest and most polluted cities in the world, and which requires the services of these forests.

Conclusions

The project has been one of the efforts that have helped increase information about fire ecology and fire use in the country, and one of the pioneering initiatives in integrated fire management. The strategy of thesis research has proven to be effective and contributes to the training of more professionals in the field of forest fires. The challenge is to continue contributing in this direction, but with new topics, while continuing to contribute to the social component.

References

- Bonilla P., E., Rodríguez T., D. A., Borja de la Rosa, A., Cántora G., C., Santillán P., J.** Dinámica de combustibles en rodales de encino-pino de Chignahuapan, Puebla. *Revista Mexicana de Ciencias Forestales* (aceptado).
- Carrillo G., R. L., Rodríguez T., D. A., Tchikoué, H., A. I. Monterroso R., Santillán P., J.** 2012. Análisis espacial de peligro de incendios forestales en Puebla, México. *Interciencia* 37(9): 678-683.
- Chavarría Sánchez, M. R.** 2009. Quema prescrita en bosque de *Pinus hartwegii* y su impacto en el potencial forrajero como aporte al manejo integral del fuego. Tesis Maestría en Ciencias. Programa de Posgrado, DICIFO, UACH. Chapingo, Edo. de Méx. 82 p.
- CONAFOR (Comisión Nacional Forestal).** 2012. Reporte de incendios forestales. URL : <http://www.conafor.gob.mx/portal/>
- Contreras Moctezuma, J., Rodríguez Trejo, D. A., Retama Hernández, A. y Sánchez Rodríguez, J. de J.** 2003. Humo de incendios forestales en bosques de *Pinus hartwegii*. *Agrociencia* 37(3): 309-316.
- CORENA (Comisión de Recursos Naturales).** 2012. Reporte de incendios forestales. Inédito.
- Espinoza M., A., Rodríguez Trejo, D. A. y Zamudio S., J. F.** 2008. Sinecología del sotobosque de *Pinus hartwegii* dos y tres años después de quemas prescritas. *Agrociencia* 42(6): 717-730.
- Farjon, A., Styles, B. T.** 1997. *Pinus* (Pinaceae). Flora Neotropica. Monograph. 75. New York Botanical Garden. New York. 291 p.
- González Rosales, A. y Rodríguez Trejo, D. A.** 2004. Efecto del chamuscado de copa en el crecimiento en diámetro de *Pinus hartwegii*. *Agrociencia* 38(5): 537-544.
- Islas M. G. E., Rodríguez Trejo, D. A., Martínez H., P. A.** Diversidad del sotobosque y radiación solar en un bosque de *Pinus hartwegii* con quema prescrita. *Revista Mexicana de Ciencias Forestales* (aceptado).
- Juárez Martínez, A. y Rodríguez Trejo, D. A.** 2003. Efecto de los incendios forestales en la regeneración natural de *Pinus oocarpa* var. *ochoterenae* Martínez. *Revista Chapingo. Serie Ciencias Forestales y del Ambiente* 9(2): 125-130.
- Juárez B., J. E., Rodríguez T., D. A., Myers, R. L.** Fire tolerance of trees in in oak-pine forest at Chignahuapan, Puebla, Mexico. 2012. *International Journal of Wildland Fire* 21(7): 873-881.
- Maldonado Méndez, M. de L., Rodríguez Trejo, D. A., Guízar Nolasco, E., Velázquez Martínez, J., Náñez Jiménez, S.** 2009. Reducción en la riqueza de especies arbóreas por incendios en la Reserva de la Biosfera Selva El Ocote, Chiapas. *Ciencia Forestal en México* 34(106): 127-148.
- Martínez Hernández, H. C. y Rodríguez Trejo, D. A.** 2008. Species diversity after prescribed burns at different intensities and seasons in a high altitude *Pinus hartwegii* forest. *Interciencia* 33(5): 337-344.
- Myers, R. L., Rodríguez Trejo, D. A.** 2009. Fire in tropical pines. In Cochrane, M. (ed.). *Tropical fire ecology: Climate change, land use and ecosystem dynamics*. Springer-Praxis. Heidelberg, Germany. pp. 557-605.
- Neri Pérez, A. C., Rodríguez Trejo, D. A., Contreras Aguado, R.** 2009. Inflamabilidad de combustibles forestales en las selvas de Calakmul, Campeche. *Universidad y Ciencia* 25(2): 1-12.

- Ortiz Contla, H.** 2009. Análisis del manejo tradicional de pastizales con fuego en el Ajusco. Tesis Maestría en Ciencias. Programa de Posgrado, DICIFO, UACH. Chapingo, Edo. de Méx.
- Ortiz Rodríguez, J. N., Rodríguez Trejo, D. A.** 2008. Supervivencia y crecimiento de una plantación de *Pinus hartwegii* en áreas quemadas. Revista Chapingo, Serie Ciencias Forestales y del Ambiente XIV(2): 89-95.
- Ortega Baranda, V. y Rodríguez Trejo, D. A.** 2007. Supervivencia y crecimiento iniciales y concentración de nutrimentos de *Pinus hartwegii* Lindl. plantado en localidades quemadas. Revista Chapingo, Serie Ciencias Forestales y del Ambiente 13 (2): 115-124.
- Ponce C., L., P., Aguilar V., B. C., Rodríguez T., D. A., López P., E., Santillán P., J.** Influencia del fuego en la riqueza y diversidad de aves en un bosque de encino-pino de Chignahuapan, Puebla. 2012. Revista Mexicana de Ciencias Forestales 3(10): 65-76.
- Ramírez Contreras, A.; Rodríguez Trejo, D. A.** 2009. Plantas nodriza en la reforestación con *Pinus hartwegii* Lindl. Revista Chapingo, Serie Ciencias Forestales y del Ambiente 15(1): 43-48.
- Rodríguez Trejo, D. A.** 1996. Incendios forestales. Mundi Prensa-UACH-INIFAP. México, D. F. 630 p.
- Rodríguez Trejo, D. A.** 2001. Ecología del fuego en el ecosistema de *Pinus hartwegii* Lindl. Revista Chapingo. Serie Ciencias Forestales y del Ambiente 7(2): 145-151.
- Rodríguez Trejo, D. A.** 2002. Efecto del fuego en el crecimiento en diámetro de *Eucalyptus camaldulensis* Dehnh. Revista Chapingo. Serie Ciencias Forestales y del Ambiente VIII(1): 71-74.
- Rodríguez Trejo, D. A.** 2004. Investigación en manejo integral del fuego. Forestal XXI. 7(1): 45-46.
- Rodríguez Trejo, D. A.** 2005. Nuevos horizontes en el manejo del fuego. México Forestal 19 (Revista Electrónica). 3 p.
- URL: <http://www.mexicoforestal.gob.mx/editorial.php?id=23&laPublicacion=20>
- Rodríguez Trejo, D. A.** 2006. Ecología del fuego en bosques de coníferas. En: Flores G., G., Rodríguez Trejo, D. A., Estrada, O.; Sánchez Zárraga, F. (Coords.). Impacto ambiental de incendios forestales. Instituto Nacional de Investigaciones Forestales y Agropecuarias, Mundi Prensa, Colegio de Posgraduados. China. pp. 103-119.
- Rodríguez Trejo, D. A.** 2007. Manejo integral de incendios forestales. El proyecto Ajusco, un ejemplo. Extensión al Campo 1(3): 41-45.
- Rodríguez Trejo, D. A.** 2007. Fuego. En: Cibrián Tovar, D. and others Enfermedades forestales en México. UACH, CONAFOR, USDA FS, CFS, NRC, COFAN. pp. 42-50.
- Rodríguez Trejo, D. A.** 2008. Fire ecology, fire regimes and fire management in Mexico. Ambio 37(7-8): 548-556.
- Rodríguez Trejo, D. A.** 2012. Génesis de los incendios forestales. Revista Chapingo. Serie Ciencias Forestales y del Ambiente 18(3): 357-373.
- Rodríguez Trejo, D. A.** 2009. El fuego y sus efectos en los árboles. En: Flores G., G. (Coord.). Impacto ambiental de incendios forestales. Instituto Nacional de Investigaciones Forestales y Agropecuarias, Mundi Prensa, Colegio de Posgraduados. China. pp. 103-119.
- Rodríguez Trejo, D. A.** 2011. ¿Qué investigación es necesaria para restaurar los bosques de clima templado-frío de México? Seminario: Necesidades de investigación para la restauración de bosques de México. Congreso Mundial de Restauración Ecológica. Agosto de 2011. Mérida, Yucatán.

- Rodríguez Trejo, D. A.** 2011. Panelista en el “Seminario Internacional sobre Evaluación de Políticas Públicas Forestales” (Panel Incendios Forestales). México, D. F. CONAFOR, ITTO, PHUMA, SEMARNAT. 4 y 5 de agosto de 2011.
- Rodríguez-Trejo, D. A., Myers, R. L.** 2010. Using characteristics of oaks as guides to restoring fire regimes in Mexican pine-oak and oak forests. *Ecological Restoration* 28(3): 304-323.
- Rodríguez Trejo, D. A., Rodríguez A., M., Fernández S., F. y Pyne, S. J.** 2000. Educación e incendios forestales. Mundi Prensa. México, D. F. 201 p.
- Rodríguez Trejo, D. A., Martínez Hernández, H. C. y Ortega Baranda, V.** 2004. Ecología del fuego en el ecosistema de *Pinus hartwegii*. En: Villers R., L. y López B., J. (eds.). Incendios forestales y sus efectos en el ambiente. UNAM. México, D. F. pp. 107-124.
- Rodríguez Trejo, D., A., Santillán Pérez, J., Tchikoué Maga, H.** 2006. El perfil del combatiente de incendios forestales en México. *Revista Chapingo, Serie Ciencias Forestales y del Ambiente* 12(1): 79-86.
- Rodríguez Trejo, D. A., Castro Solís, U. B., Zepeda Bautista, E. M. A., Carr, R. J.** 2007. First year survival of *Pinus hartwegii* Lindl. in burned areas in different times. *International Journal of Wildland Fire* 16: 54-62.
- Rodríguez Trejo, D. A., Tchikoué Maga, H., Santillán Pérez, J.** 2007. Emisiones contaminantes durante la temporada 2003 de incendios forestales en México. *Revista Chapingo, Serie Ciencias Forestales y del Ambiente* 13 (1): 33-40.
- Rodríguez Trejo, D. A., Ramírez M., H., Tchikoué, H., Santillán P., J.** 2008. Factores que inciden en la siniestralidad de los incendios forestales *Ciencia Forestal en México* 33(104): 37-58.
- Rodríguez Trejo, D. A., Rodríguez Aguilar, M., Villanueva Morales, A. y Bonilla Padilla, E.** 2010. Forest structure indicators as estimators of forest fuels load in an oak-pine forest. In: Viegas, Domingo Xavier (ed.). Abstracts of the VI International Conference on Forest Fire Research. 15-18 November 2010. Publicado por Associacao para o Desenvolvimento da Aerodinamica Industrial (ADAI) , Centro de Estudos sobre Incendios Florestais (CEIF). Coimbra Portugal. P. 45.
- Rodríguez Trejo, D. A., P. A. Martínez Hernández, H. Ortiz Contla, M. R. Chavarría Sánchez, F. Hernández Santiago.** 2011. The present status of fire ecology, traditional use of fire and fire management in Mexico and Central America. *Fire Ecology* 7(1): 40-56.
- Rodríguez Trejo, D. A., Hernández S., F., Juárez B., J. E., Ortiz C., H., Chavarría S., M. R., Martínez H., P. A., Pérez M., J., A. Vázquez A.** 2011. Wildfire 2011. Sun City, South Africa, May 9-13, 2011.
- Rodríguez-Trejo, D. A., Tchikoué, H., Cántora-González, C., Contreras-Aguado, R., de la Rosa-Vázquez, A.** 2011. Combustibles forestales, peligro de incendio y áreas prioritarias de protección en las zonas afectadas por el Huracán Dean. *Agrociencia* 45: 593-608.
- Rodríguez Trejo, D. A., Martínez, A., Mendoza B., C., García, F., Herrera, C. y Rafael de J., A.** 2012. Microsites and seedling quality in restoration. *Acta Botanica Gallica* 159(3): 299-301.
- Schilisky, A., Waugh, J., González, P., González, M., Manta, M., Santoso, H., Alvarado, E., Nuruddin, A. A., Rodríguez Trejo, D. A., Swaty, R., Schmidt, D., Kaufmann, M., Myers, R., Alentar, A., Kearns, F., Jonson, D., Smith, J., Zollner, D., Fulks, W.** 2007. Fire, ecosystems and people: Threats and strategies for global biodiversity conservation. TNC. GFI Technical Report 2007-02. Arlington, VA. 20 p.

- Sosa Pérez, G. y Rodríguez Trejo, D. A.** 2003. Efecto de la calidad de planta en la supervivencia de *Pinus patula* en un área quemada. Revista Chapingo. Serie Ciencias Forestales y del Ambiente 9(1): 35-43.
- Temño, S., Rodríguez T., D. A., Molina, D., Fulé, P. Z., Ryan, K.** Modelación de la mortalidad inicial de *Abies religiosa* en un incendios de copas en México. (en proceso).
- UACH-CONAFOR (Universidad Autónoma Chapingo-Comisión Nacional Forestal).** 2008. Programa de prevención y combate de incendios forestales y manejo del fuego en las áreas afectadas por el Huracán Dean en las áreas tropicales del sureste de México. UACH, CONAFOR. Inédito.
- UACH-CONAFOR (Universidad Autónoma Chapingo-Comisión Nacional Forestal).** 2011. Evaluación complementaria del ejercicio del programa E013, prevención y combate de incendios forestales, ejercicios fiscales 2008-2010. UACH, CONAFOR. Imédito.
- Vera Vilchis, V. y Rodríguez Trejo, D. A.** 2007. Supervivencia e incremento en altura de *Pinus hartwegii* a dos años de quemas prescritas e incendios experimentales. Agrociencia 41: 219-230.
- Zavala Ch., F.** 2007. Guía de los encinos de la Sierra de Tepotzotlán, México. Universidad Autónoma Chapingo. Chapingo, Edo. de México.

Management Adaptation to Fires in the Wildland-Urban Risk Areas in Spain¹

Gema Herrero-Corral²

Abstract

Forest fires not only cause damage to ecosystems but also result in major socio-economic losses and in the worst cases loss of human life. Specifically, the incidence of fires in the overlapping areas between building structures and forest vegetation (wildland-urban interface, WUI) generates highly-complex emergencies due to the presence of people and goods. During the last decade in Spain, the occurrence of such fire events has led to the concept of wildland-urban interface which has been included, at least implicitly, in all regional forest fire management policies and which, in certain cases, has had a specific policy development.

This paper advocates establishing a WUI typology based on the elements and processes that make up these areas with the aim of adapting a fire management strategy tailored to the specific characteristics and needs of each one. On the other hand, it recognizes the need for an integrated response to this problem that encompasses different fields (forest and fire policy, civil protection, spatial planning) and different fire management phases (forecasting, prevention, suppression).

Keywords: adaptation, forest fire, planning tools, wildland-urban interface, management, legislation, Madrid, risk.

Introduction

During the last several decades in Spain, there has been a significant growth in urban areas, first occupying farmland zones near population settlements and later on more distant forest areas. This process has enhanced the emergence of WUI areas. From 1987 to 2000, WUI areas increased by an estimated 6.8% and by 2.16% between 2000 and 2006, reaching 412,687 hectares of WUI³ (Herrero 2011).

¹ An abbreviated version of this paper was presented at the Fourth International Symposium on Fire Economics, Planning, and Policy: Climate Change and Wildfires, 5-11 November 2012, Mexico City, Mexico.

² Research Engineer. INRA. Department of Forest Ecology, Meadows and Aquatic Environments URFM. Domaine Saint Paul, Site Agroparc F-84914 Avignon, France. Email: gema.herrero-corral@avignon.inra.fr.

³ From the land cover cartography of the project: CORINE Land Cover 2006 (National Geographic Institute).

Its configuration has occurred coincidentally with a series of socioeconomic and political changes that have aggravated the forest fire problem. Processes of rural depopulation, land abandonment or reduction of traditional forest use have led to forest ecosystems becoming more dangerous structures with high combustibility, increasing the associated fire hazard. Additionally, increased recreational use of forest areas and the lack of adequate policies governing fire use in forest environments have helped create areas with a high wildfire risk (Vélez 2009). In this context, the rapid expansion of urbanization on forest vegetation spaces has contributed to generating new conflict scenarios where wildfires become true civil protection emergencies (Montiel and Smith 2010).

The historical incidence of forest fires in Spain is a recurring fact every summer (MARM 2009). However, the incidence and severity vary in each area and as such should receive special treatment. Similarly, the influence of the WUI distribution pattern on forest fire risk is not the same in all areas. Certain territory characteristics, related to forest cover and settlement system, influence not only the space occupied by the interface area, but also their evolutionary dynamics and characteristics associated with the forest fires risk.

The possibility of programming a true management adaptation of the WUI spaces to physical and social conditions that create the problem in each regional context requires a thorough knowledge of these areas to previously assess the situation and management needs. Assuming that the fire risk depends not only on the WUI presence, but also on its type and the characteristics of the territory in which it is located, this paper focuses on characterizing and establishing WUI situations as a useful tool for wildfire risk management planning adapted to the specific needs of each WUI type.

In this work, the specific objectives to be achieved are: (i) assess the degree of integration of the WUI concept as a forest fire risk area in the legislation and planning instruments in the Spanish context, (ii) define, delineate and characterize wildland-urban areas, addressing the territorial specificities that the phenomenon acquires to establish a typology and characterization that allows better forest fire management planning.

Study area and method

The study area is located in the western area of the Madrid community⁴. Its features make it an area of great interest for WUI studies as wildfire risk territories. On one hand, it concentrates a large area of forest areas that border heavily-urbanized areas on the city's boundaries.

⁴ 40° 50' 00'' N, 3° 51' 15'' W; 40° 30' 00'' N, 4° 11' 15'' W

In addition, the dynamics of urban growth on forest areas and the abandonment of farming activities have promoted the formation of WUI areas (a 37% increase from 1987-2000). By 2005, 23% of the Madrid WUI areas were concentrated in just over 9% of the total regional area (Herrero 2011). Furthermore, the area had an increase in its number of fires between 1989 and 2007, with humans in 99% of the cases being the ignition cause. Lastly, 22.3% of the fires occurred near built-up areas and, on several occasions, there were civil protection incidents (evacuations, damage to structures, power outages and road obstructions, personal injury).

During the last few decades, European research on forest fires and, specifically, population risk, has been very active, forming a well-structured research group highly experienced in the subject (Biro 2009). The ability to use this research as a basis for future strategies and policies on the subject has encouraged the scientific community to recognize the importance of considering political aspects, and to incorporate them as objectives within their research lines in order to produce useful scientific results to support political decision making (Agudo and Montiel 2009).

This approach to WUI areas in the forest fire context through the diagnosis and assessment of legal and policy instruments is a first step towards proposing new management approaches. In this analysis, there is a combination of qualitative and quantitative methodologies to study WUI areas spaces relative to forest fire risk in the Spanish context.

First, the regulatory and planning context of forest fires in Spain is presented, in order to place the management of WUI areas relative to this type of risk, from the collection of policy and planning documents related to forest fire management and its subsequent critical analysis. To do this, the management of WUI areas in relation to forest fires depends to a large extent on the legal, institutional and political framework in which it is supported (Simorangkir and others 2003).

In Spain, political and administrative decentralization establishes the separation of powers between the State and the Autonomous Communities (CCAA), leaving forest fire management and policy development responsibilities at the autonomous level and the responsibility to approve basic legislation at the state level (Fernández-Espinar 1991). Therefore, the diagnosis of the regulatory situation starts from documents approved at the national and regional levels.

Another aspect that determines fire risk management in WUI areas is related to the multisectoriality of the topic addressed by the various policies involved in forest fire management. Civil protection policy aims to protect life and property in emergencies, with fires being a type of risk that requires the development of special plans. In Forest Policy, fires are considered a threat to forest systems; their respective planning and legislation usually include a chapter devoted to wildfires with general measures. In a complementary way, in most cases, a legal and specific wildfire

planning framework, which sets out concrete prevention and suppression actions, has been developed, and delves into the risk management associated with buildings in the forest environment.

Along with fire sectoral policies, it is necessary to consider other spatial policies with a great influence on the issue. Specifically, spatial and urban planning policies have the ability to influence land-use organization and regulate their occupation conditions. Thus, by adopting the "precautionary principle" in spatial planning, it is possible to minimize the potential consequences of forest fires on civilians (Buxton and others 2011).

The next step is establishing *WUI situations* from the study of the structural elements that make up the territory and identifying the dynamics that determine their evolution under the Regional Geographic Analysis approach (Herrero and others 2012). For this purpose, the spatial analysis method for the delineation and characterization of WUI areas using Geographic Information Systems (GIS) has been applied. The process begins with mapping the WUI areas and subsequently characterizing them from the integration of different WUI types in the territorial context in which they are located. Thus, useful information is obtained for forest fire management planning (Fig. 1).

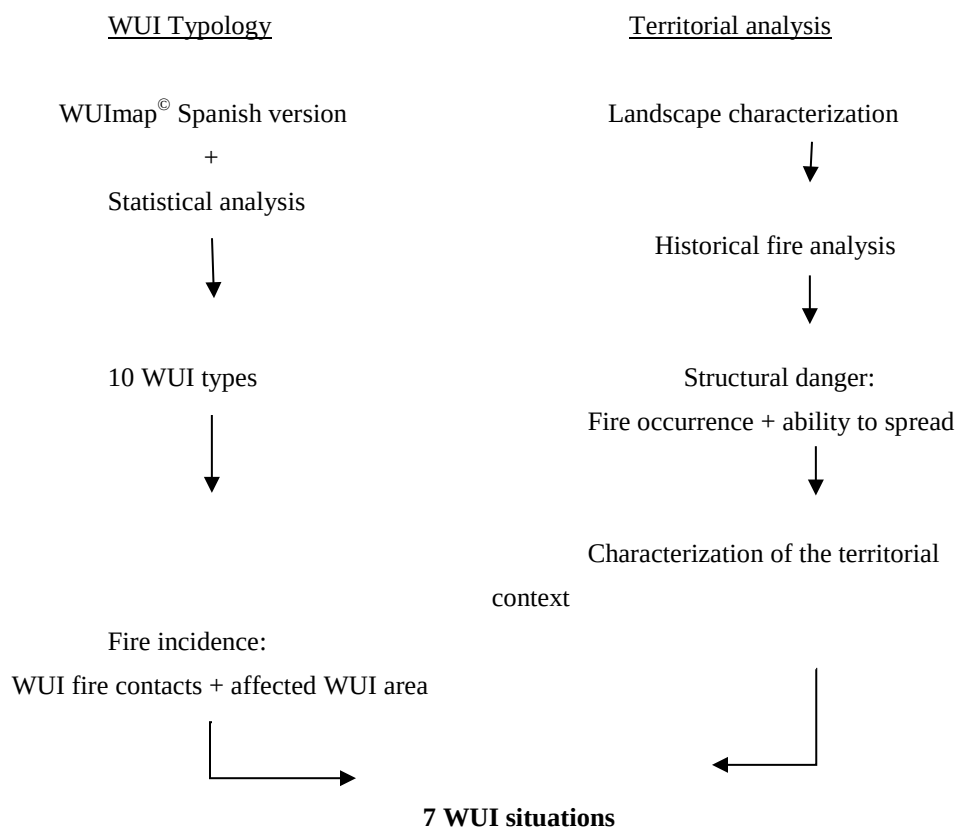


Figure 1—Process for WUI classification and characterization

Cartography of wildland-urban interface types

WUI areas have been mapped and classified based on the configuration of the buildings and the structure of the adjacent vegetation (Lampin-Maillet and others 2010). Spatial calculations were made with WUImap[©] software (Lampin-Maillet and Bouillon 2011) developed by Cemagref/Irstea Research Institute. To use WUImap[©] in the Spanish territorial context, it was necessary to make a number of changes to the software that have resulted in WUImap[©] Spanish (2010).

For calculation purposes, WUI is considered the area corresponding to a 100-m buffer around all those buildings located in a forest area or inside the forest influence area. This influence area is set at 400m from forest stands (Herrero 2011). The WUI areas are classified by integrating the information on the settlement type (isolated buildings, group of buildings, developments and cities) and the horizontal structure of forest vegetation from the aggregation index⁵ (*high*= structure with a strong aggregation degree and high vegetation continuity; *medium*= shows certain forest vegetation dispersion; *low*= no forest vegetation or no aggregation).

By using K-means cluster analysis, it was possible to classify each of the WUI entities into ten types⁶. Subsequently, the incidence of forest fires during the 2002-2008 period in WUIs is studied from the number of fire contacts and the burnt interface area, enabling the identification of the WUI types most affected by fire.

Territory characterization according to fire risk

The *regional context*⁷ in which WUIs are located plays a key role in managing fire risk. In many cases, forest fire occurrence and fire behavior depend on the structure of the landscape that results in a particular organization of land covers and uses (Mermoz and others 2005; Lloret and others 2002; Turner and Romme 1994). Furthermore, landscape arrangements have a big influence on residential settlement patterns because of the structure of the rural parcel which underlies this process, resulting in mixed urban/ agricultural parcels that evolve into WUIs. Moreover, the landscape character in which they are inserted provides information on the foreseeable dynamics in land use and vegetation evolution (especially natural regeneration processes) that is of great interest in evaluating the change in risk levels

⁵ The vegetation aggregation index was calculated with FRAGSTATS software © (McGarigal, 2002).

⁶ Type 1. Dispersed habitat with high vegetation continuity; Type 2. Dispersed habitat with medium vegetation continuity; Type 3. Dispersed habitat with large dispersion or without forest vegetation presence; Type 4. Group of buildings with high vegetation continuity; Type 5. Grouping of buildings with medium vegetation continuity; Type 6. Group of buildings with large dispersion or without forest vegetation presence; Type 7. Developments with high vegetation continuity; Type 8. Developments with medium vegetation continuity; Type 9. Developments with large dispersion or without forest vegetation presence; Type 10. Urban core in contact or proximity to forest vegetation.

⁷ From Zipperer (2005), the regional context refers to the WUI location in the landscape and its immediate environment.

(Galiana and others 2007). Thus, the study of landscape structure and composition is useful for analyzing land use and resulting changes in the landscape with impact on fire occurrence and its ability to spread (Romero-Calcerrada and Martínez 2004).

The Landscape Character Assessment Methodology of the Countryside Agency and Scottish Natural Heritage (2002) consists of the establishment of a hierarchical typology of units and landscape type in order to identify regions with homogeneous characteristics related to relief, forest vegetation, land uses and dynamics of the territories where WUIs are located. This information is critical for the adoption of prevention and suppression strategies based on forest fire risk (Galiana-Martin, Herrero and Solana 2011).

The landscape characterization in terms of fire risk that this work develops comes from the general definition of *Risk = Hazard x Vulnerability* (Camia and others 2006). It focuses on the danger, which is defined as the probability of a fire being produced (occurrence) and spreading over the territory (intensity) (Blanchi and others 2002). Its calculation is based on variables that can be considered static in the long term, such as topography or vegetation type (San-Miguel-Ayanz and others 2003).

The characterization of different types of landscapes based on the wildfire structural danger (fig. 2) correlates the fuel and slope characteristics with the landscape type to assess its ability to spread; and, on the other hand, it links forest fire occurrence to certain landscapes with specific characteristics. Thus, WUI typologies defined above are contextualized in a particular landscape that has an associated fire hazard degree.

Fire structural danger

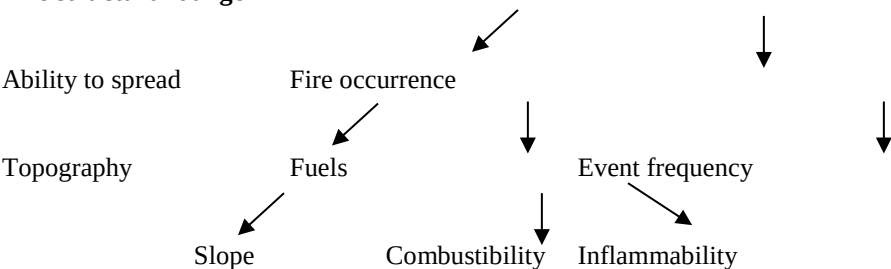


Figure 1—Components for the fire structural hazard calculation

WUI situations for forest fire management planning

This last stage contextualizes the different WUI types in the landscape where they are located in order to identify WUI situations. The term “*situation*” derives from the

scenario concept but does not refer to a prediction or a forecast (Hernández & Wider, 2006). This study defines "situation" as a theoretical description of reality, based on what is observed, to anticipate management needs (Caballero and others 2007, Castellnou and others 2009). Thus, this classification is a useful tool in forest fire prevention and suppression planning.

In this case, the seven most representative WUI *situations* in the study area have been identified from the inclusion of a specific interface type – set from the building model and adjacent vegetation structure – in a specific spatial context, shaped by landscape, structural and dynamic elements. From the in-depth analysis of the seven examples, management strategies and action proposals adapted to each *situation* are proposed.

Political and legal context

The first legal reference on record where the presence of buildings in a forest environment is recognized as a big fire risk is the specific national forest fire legislation (Act 81/1968 and its regulations 1972) which includes "preventive rules to be observed in (...) homes, buildings and industrial facilities located in the forest area". Later on, from Civil Protection policy, the "*Basic Guideline for Emergency Civil Protection Planning for Wildfires*" (1993) was approved; this document is a planning tool targeted specifically to the defense of "businesses, isolated villages, housing developments, campsites, *etc.*, that are located in fire risk areas". From this point, CCAAs began to develop general regulations for forest fire management that collect specific prevention and protection measures for WUI areas. More recently, state Forest Law 43/2003 also encourages the WUI concept in its forest fire management chapter.

Incorporation of WUI areas by political instruments for forest fire management is proposed for two reasons: as a vulnerable area where it is necessary to develop measures for the protection of people and assets through actions aimed at fuel reduction and the building of defense infrastructure; but also, as potential fire-generating territories where it is necessary to adopt measures to prevent ignition and possible fire spread towards nearby forests by regulating activities and fire use.

Fire hazard management of WUI areas develops preferentially from specific fire regulations and Civil Protection planning while forest law, in most cases, acts only as an auxiliary. There are different models for the organization of autonomous forest fire planning. The regions that keep a separation between the specific forest fire policy that addresses prevention and self-protection measures for the population, and the Civil Protection that focuses on the establishment of response protocols and functional organization at the time of emergency. On the other hand, there are the

autonomous communities, the CCAAs, where prevention and emergency management in WUI areas are included in the same planning document.

The articulation and development of regulatory and planning instruments may be (i) *hierarchical*, with the approval of regulations or plans at different levels subject to a hierarchically higher regulation and following a "cascade" organization, as in civil protection, or (ii) *Horizontal Sectorial*, where specific legislation influences the approval of regulations in others; for example, autonomous forest fire legislation recognizes the need to adopt self-protection plans that are set in the context of Civil Protection.

Integrated forest fire risk management associated with WUI areas requires an approach towards spatial planning policies. This connection occurs, on one hand, with the incorporation of criteria developed in the field of urban planning by forest fire regulations; for example, the design and material conditions for public protection and safety that are incorporated in the Building Code (2006) for buildings on forest land. On the other hand, urban planning includes preventive measures established by the sectorial regulations to reduce the risk of forest fires and the damage that might result in the interface areas (for example, the obligation to draft protection plans or the implementation of preventive measures in newly constructed buildings). Some urban regulations already integrate these precepts but it is still difficult to determine if they comprise a purely indicative function or will have truly binding effects.

In general, treatment of forest fires and, specifically, the interface areas are not developed in the spatial planning policies, where land use and urban planning are included, with all the potential that sectoral policies demand. The main opportunity for urban planning resides in avoiding the development of land with high wildfire risk. The existence of this risk must be established prior to the adoption of urban plans by mapping or writing reports by the pertinent sectoral agency. However, there is a lack of adequate zoning and forest fire risk mapping because in their preparation spatial planning is not considered as an end user.

In general, all autonomous wildfire regulations include the fire risk associated with the presence of urbanized areas located next to the forest environment and the need to address its management. However, advances in this area have followed a different pace depending on the importance given to this issue in each CCAA (Herrero 2009). Only in some CCAAs does the identification of WUI areas and their forest fire management attempt to adapt to the problematic and territorial specificities of the region⁸; this indicates the need to typify WUIs to adapt their management.

⁸ Cataluña focuses on developments without immediate continuity with the urban and located within 500 m of forest land, while Extremadura prioritizes villages' environments.

WUI situations

Seven WUI situations were identified in the study area (Figure 3): (I) exempt developments in the foothill meadows, (II) the foothill escarpment developments, (iii) developments on forest hills and slopes, (IV) urban edge in contact with forest vegetation; (V) scattered habitat in the foothill meadows; (VI) dispersed habitat in mountain forest; (VII) group of buildings in the foothills.

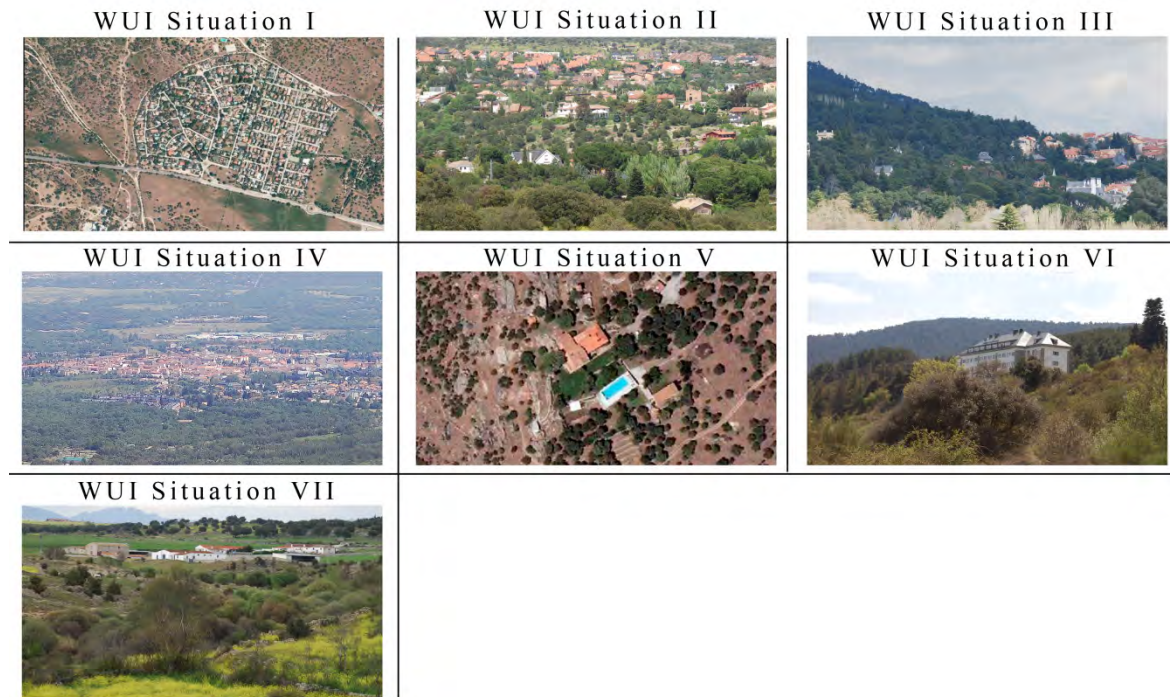


Figure 3—WUI situations in the study area

For each situation there is a card with the information gathered about: settlement name and municipality, aerial photograph, distribution area of equivalent situations, WUI type, morphological characteristics (building distribution, roads and perimeter), topography and vegetation, considerations in relation to wildfire risk based on physical variables and fire occurrence in the past. It also includes information on urban planning (where the new growth will occur, on what kind of ground cover and of what building type) to infer its evolution in the future. Furthermore, the legislation on protected natural areas that could affect buildings located in natural surroundings is taken into account. Also, the existence of forest fire prevention and emergency plans are collected. Lastly, the degree of adoption of specific fire management measures grouped into fuel reduction actions, information to the residents and the existence of other defense infrastructures is evaluated. All the information is embodied in proposed recommendations for their forest fire management approach.

The availability of regulations that govern basic measures to minimize the fire risk in interface areas is essential as a basis for effective management. However, the implementation of actions that have been approved generically is not always useful or feasible in some cases. For example, management needs in a development located in a mountain forest are often different from those of an isolated house in a foothill meadow. Not only because of the structural differences of both settlement types, but also because of the situation that they occupy in the territory and the characteristics of their environment.

In this regard, it is appropriate to have common guidelines, notwithstanding the need to assess the specific characteristics and needs of each territory in order to adapt and establish suitable measures in each case. The classification of WUI areas in Situations provides managers with information on the spatial organization of the territory, given that the interfaces grouped under the same Situation share similar characteristics and that common actions can be implemented to manage fire risk.

Conclusions

The approach to forest fire management should be based on a global and territorial approach to the problem where there is a link between fire and territorial policies, with the main objective of incorporating the structural causes of the fires with a population condition. In addition, complementary to the specific treatment that WUIs receive from the various policies involved, this type of area should be incorporated as a transversal element that is taken into account in the adoption of strategies that have an impact on the territory to facilitate the necessary coordination between the various sectors. This is to ensure consistency between the different policy objectives aimed at avoiding negative impacts; in this case, they materialize in a higher incidence of forest fires and increased loss and damage in habited areas.

Managing forest fire risk in WUI areas requires a comprehensive approach consisting of proper planning based on three stages: forecasting, prevention and suppression. Zoning and urban planning policies play a key role in preventing the proliferation of new interface areas, or at least minimizing their vulnerability. Its main contribution is the ability to predict and warn about the formation of possible risk situations. Through proper land-use zoning aimed at avoiding urban developments in high risk areas and the adoption of a safe settlement model can mitigate wildfire risk. Overall forest and specific forest fire policies address prevention actions aimed at preventing fire occurrence in existing buildings that are located close to forest environments. Additionally, the development of regulations and planning tools with objectives focused on suppression and emergency management is addressed by civil protection policy that establishes protocols for

action and self-protection at the time of the fire.

Shortcomings have been identified regarding policy instruments aimed at avoiding these risk situations. Such aspects must be addressed by territorial policies with influence on urban development and forest management. As earlier indicated, the possibility of integrating the issues associated with WUI areas in these policies requires, on one hand, having a joint vision of the area to be managed, considering the different uses to make them compatible and, on the other hand, to achieve greater integration with fire sectoral policies. In any case, it is important to distinguish between the existence of regulations on the subject, their development through planning instruments and their effective implementation through concrete actions that ultimately enable forest fire management in WUI areas.

Regarding the planning of forest fire management in interface areas, the use of WUI Situations is proposed as a useful tool, based on the theoretical description of reality, which enables anticipating management needs. As for the consideration of WUI area characteristics in isolation, the analysis of the WUI Situations also integrates relevant territorial information in order to propose a wildfire risk management approach adapted to specific conditions and applicable to similar scenarios. Drafting of planning instruments for fire risk management should take into account the existence of this variability in order to propose a different treatment that responds to the characteristics and needs of each situation.

Acknowledgements

The results presented here are from the doctoral thesis "Wildland-urban interfaces as fire risk areas: analysis and regional characterization in Spain" defended in the Department of Geography at the Autonomous University of Madrid. We are grateful to FIRE PARADOX project FP6-018505. Document available at: www.interfazurbanoforestal.com.

References

- Agudo, J.; Montiel, C. 2009.** Basis to start the process for a proposal of a new legislation at EU level. [Unpublished] Integrated project Fire Paradox, D7.1-1.3. 45p.
- Biro, Y. 2009.** Living with wildfires: what science can tell us. EFI Discussion Paper 15. Finland: European Forest Institute. 82 p.
- Blanchi, R., Jappiot, M., Alexandrian, D. 2002.** Forest fire risk assessment and cartography. A methodological approach. In D. X. Viegas (Ed.), IV International conference on forest fire research and wildland fire safety. Coimbra, Portugal, 16-20 November 2002.
- Buxton, M.; Haynes, R.; Mercer, D.; Butt, A. 2011.** Vulnerability to Bushfire Risk at Melbourne's Urban Fringe: The Failure of Regulatory Land Use Planning. *Geographical Research* (49). Pp. 1-12.

- Caballero, D., Beltrán, I., Velasco, A. 2007.** Forest fires and wildland-urban interface in Spain: types and risk distribution. En: IV Conferencia Internacional sobre Incendios Forestales. Sevilla: 13-17 Mayo, 2007.
- Camia, A., Guglielmet, E., Bovio, G., Deshayes, M., Lampin, C., Salas, J., Martínez J; Molina D; Carrega, P; Fox, D; Berolo, W; Sabaté, S; Vayreda, J; Martín, P; Martínez, J; Conese, C; Bonora, L; Karteris, M; Mallinis, G; Sergiopoulos, I; Gitis, I. 2006.** Wildland fire danger and hazards: A state of the art (80 pp.) Unpublished report. EUFIRELAB project. [On line]. www.eufirelab.org.
- Castellnou, M., Pagés, J., Miralles, M., Piqué, M. 2009.** Tipificación de los incendios forestales de Cataluña. Elaboración del mapa de incendios de diseño como herramienta para la gestión forestal. Paper presented at the 5º Congreso Forestal Español, Ávila, 21-25 Septiembre.
- Countryside Agency and Scottish Natural Heritage. 2002.** Landscape Character Assessment. Wetherby: Countryside Agency and Scottish Natural Heritage; 96 p.
- Fernández-Espinar, L. 1991.** La legislación forestal en el Estado de las Autonomías. Revista de estudios Agro-Sociales (158). Pp. 107-129.
- Galiana, L.; Herrero, G.; Solana, J. 2007.** Caracterización y clasificación de Interfaces Urbano- Forestales mediante análisis paisajístico. El ejemplo de Sierra Calderona (Comunidad Valenciana, España). En: IV Conferencia Internacional sobre Incendios Forestales. Sevilla: 13-17 Mayo, 2007.
- Galiana-Martin, L., Herrero, G., Solana, J. 2011.** A wildland-urban interface typology for forest fire risk management in Mediterranean areas. Landscape Research, 36, 151-171.
- Hernández-Jimenez, V.; Wider, N. 2006.** Running experiments with the Madrid Simulation Model. [Informe inédito] Time-Geographical approaches to Emergence and Sustainable Societies (TiGrESS) project. 24 p.
- Herrero, G. 2009.** Assessment of the Growing Importance of Wildland-Urban Interfaces in Fire Risk Management: WUI Regional Patterns in Spain. En: González, A. (coord). Proceedings of the III International Symposium on Fire Economics, Planning and Policy: Common Problems and Approaches. Puerto Rico: 29 Abril- 2 Mayo, 2008. Pp. 238-248.
- Herrero, G. 2011.** Wildland-urban interfaces as fire prone areas in Spain: Regional analysis and characterization (p. 546). Director: Galiana, L. Universidad Autónoma de Madrid. Dep. Geografía www.interfazurbanoforestal.com
- Herrero-Corral, G., Jappiot, M.; Bouillon, C.; Long-Fournel, M. 2012.** Application of a geographical assessment method for the characterization of wildland-urban interfaces in the context of wildfire prevention: A case study in western Madrid. Applied Geography (35). Pp. 60-70
- Lampin-Maillet, C., Bouillon, C. 2011.** WUImap: a software tool for mapping wildland-urban interfaces in Mediterranean European context. Journal of Environmental Science and Engineering, 5, 631-642

- Lampin-Maillet, C., Jappiot, M., Long, M., Bouillon, C., Morge, D., Ferrier, J. P. 2010.** Mapping wildland-urban interfaces at large scales integrating housing density and vegetation aggregation for fire prevention in the South of France. *Journal of Environmental Management*, 91, 732-741
- Lloret, F., Calvo, E., Pons, X., Díaz-Delgado, R. 2002.** Wildfires and landscape patterns in the eastern Iberian Peninsula. *Landscape Ecology*, 17, 745-759.
- Mermoz, M., Kitzberger, T., Veblen, T. T. 2005.** Landscape influences on occurrence and spread of wildfires in Patagonian forests and shrublands. *Ecology*, 86 (10), 2705-2715.
- Ministerio de Medio Ambiente y Medio Rural y Marino. 2009.** Los incendios forestales en España. 156p.
- Montiel, C.; Herrero, G. 2010.** An overview of policies and practices related to fire ignitions at the European Union level. En: Sande, J.; Rego, F.; Fernandes, P.; Rigolot, E. (eds). *Towards Integrated Fire Management. Outcomes of the European Project Fire Paradox*. Finland: European Forest Institute. Pp. 35-46.
- Romero-Calcerrada, R.; Martínez, J. 2004.** Nuevas técnicas para el estudio de los cambios en la ocupación del territorio: aplicación en la ZEPA Encinares de los ríos Alberche y Cofio (Comunidad de Madrid)". En: Conesa et al (ed). *Territorio y Medio Ambiente: Métodos cuantitativos y técnicas de información geográfica*. Murcia: Universidad de Murcia. Pp.329-342.
- San-Miguel-Ayanz, J., Carlson, J. D., Alexander, M., Tolhurst, K., Morgan, G., Sneeuwjagt, R., Dudfield, M. 2003.** Current methods to assess fire danger potential. En: E. Chuvieco (Ed.), *Wildland fire danger estimation and mapping: The role of remote sensing data*. Singapore: World Scientific Publishing. Pp. 24-34.
- Simorangkir, D.; Moore, P.; Haase, N.; Moore, P. (Ed). 2003.** Fires, laws and regulations – Towards best practices for legal aspects of fire. *Project Fire Fight South East Asia* (IUCN and WWF). 68p.
- Turner, M.; Romme, W. 1994.** Landscape dynamics in crown fire ecosystems. *Landscape ecology* (9). Pp. 59-77.
- Vélez, R. 2009.** Los factores causantes: las fuerzas y cambios sociales y económicos. En: Birot, Y. (ed.). *Convivir con los incendios forestales: lo que nos revela la ciencia*. Finland: EFI Discussion Paper (15). Pp. 23–27.
- Zipperer, W. C. 2005.** Ecological assessment and planning in the wildland-urban interface: a landscape perspective. In S. W. Vince, M. L. Duryea, E. A. Macie, & L. A. Hermansen (Eds.), *Forests at the wildland-urban interface: Conservation and management*. Boca Raton: CRC Press. Pp. 161-174.

Villaflores: Municipal Forest Fire Management Model¹

Pedro Martínez Muñoz² and Carlos Alberto Velázquez Sanabria³

Abstract

As provided for in the General Law on Sustainable Forestry Development, the Municipality of Villaflores has worked on a continuous basis since 2002 to reduce the damage caused by forest fires as part of its working agenda, in conjunction with Federal and State agencies and NGOs. The work plan has the following phases: a) **Inter-agency coordination**: participation of governmental agencies and NGOs; b) **Pre-suppression**: actions enabling the preparedness of resources (human, material and financial), highlighted by the establishment and operation of a Municipal Forest Fire Control Center; c) **Prevention**: actions to increase the participation of the general population; d) **Inter-municipal linking**: strategy to foster backup, validation and support among different municipal departments; e) **Detection and Suppression**: fire discovery and notification of staff responsible, who are dispatched under the principles of **initial attack**; f) **Social Participation**: aimed at **critical communities**, involving small farmers, children, youth and women, and also the participation of farmer organizations (UPROSIVI) and civil organizations (BIOMASA, FMCN, AMBIO, CBMM); and h) **Education and Training**: capacity building at the community and technical level, in order to have personnel qualified, skilled and trained in the subject area.

So far efforts have yielded the following results: 1) Decrease in the area affected per year, **from an average of 7,000 hectares between 1995-2001 to an average of 751 hectares**; 2) Empowerment in the subject by civil society, through UPROSIVI; 3) Training of 52 technicians and specialists and 105 community firefighters; 4) Resource allocation for alternative production and environmental projects; 6) Network of 30 community fire brigades in support of the program; 7) Development of a Municipal Forest Fire Information System; and 8) 74% contribution in days/man participation in prevention and suppression activities.

Keywords: Forest law, fire program, social participation.

¹ An abbreviated version of this paper was presented at the Fourth International Symposium on Fire Economics, Planning, and Policy: Climate Change and Wildfires; 5-11 November, 2012, Mexico City, City.

² Forestry Technician Ranger and wildfire consultant to the Villa Flores Municipality, Chiapas, Mexico; email: pmtz@hotmail.com.

³ Agronomist Engineer and Technical Consultant to UPROSIVI, and representative of BIOMASA; email: biomasa_ac@hotmail.com.

Introduction

When we think of improving service to forest fires, it is essential to have the participation of civil society, so we have to use what is mentioned in the General Law for Sustainable Forest Development, which lays down rules for carrying out actions related with fire management, involving the public administration offices of the three levels of government and society in general. Also, more specifically, the Mexico Official Policy (Norma Oficial Mexicana [NOM-015-SEMARNAT/SAGARPA] 2007) also provides the technical specifications of the methods of fire use in forest and agricultural lands, in order to prevent and reduce forest fires. In addition, on October 29, 2008, the Sustainable Forest Development Act was published for the State of Chiapas, in which are given powers and duties to the municipalities of the state for the implementation of actions related to the Integrated Fire Management. Considering the above legal framework, and before the phenomenon of climate change as the main process affecting safety and welfare of society and environment, the institutions, both governmental and nongovernmental, must commit to develop actions that contribute to the protection, conservation, restoration and sustainable use of natural resources of Mexico, particularly the forests, as an urgent action, considering that they are generating ecosystems of goods and environmental services on which we depend as humans. Taking in account what has previously described, the Villaflores Municipality, Chiapas, made the decision to develop actions to help reduce the environmental problems associated with the occurrence of forest fires since 2002 in an uninterrupted way, as part of its work agenda which attends permanently.

Legal Framework of Forest Fires

The division of responsibilities in preventing and fighting forest fires for the Federation, the States, the Municipalities and the owners of forest resources, is mentioned in various legal instruments in our country, as the General Law for Sustainable Forest Development (LGDFS-Spanish acronym) in the Articles 12 Fraction XVI, 13 Fraction XIV and XV, 15 Fraction XI, 123 and 124; Law for Sustainable Rural Development in the Articles 19 and 20; General Law for the Ecological Balance and Environment Protection (LGEEPA); as well as the Official Mexican Standard 015 SEMARNAT-SAGARPA/2007 which regulates the use of fire in agricultural and forest lands. These instruments also refer to decentralization of resources, functions and obligations, as well as social participation.

These legal mandates, identifies three aspects that make PPCIF of Mexico, which are listed below:

A) Federation

- ☐ SEMARNAT
- ☐ CONAFOR
- ☐ CONANP
- ☐ SAGARPA
- ☐ SEGOB - CIVIL PROTECTION
- ☐ Other federal support offices
 - B) Governments of States and Municipalities
 - C) Owners and/or landholders of forest lands.

The Article 123 of the LGDFS states that to CONAFOR corresponds to coordinate actions of prevention and specialized fighting of forest fires, as well as to promote assistance from other departments and agencies of the Federal Public Administration (APF), of the states and municipalities in terms of the distribution of responsibilities (mentioned in Articles 12, 13, and 15 of the LGDFS) and of agreements and treatments signed.

For a long time, there has been the perception that the initial attack is the responsibility of the Federal Government, however the LGDFS is clear by giving landowners and landholders of forest land and preferably forestlands, as well as municipal and state governments, the attribution of the initial attack of wildfires and to CONAFOR the attribution to support these levels of government and landowners, through extended attack or specialized firefighting.

Service at National Level

The National Program for Forest Fire Protection (PNPCIF-Spanish acronym) has a history that goes back beyond the decades of the 50's – 60's, through which it has evolved according to prevailing circumstances and conditions. The program has been staying at the ex-Ministry of Agriculture and Livestock (SAG-1946), Ministry of Agriculture and Water Resources (SARH-1976), the Secretariat of Environment, Natural Resources and Fisheries (SEMARNAP-1994), the Ministry of Environment and Natural Resources (SEMARNAT-2000), and now at the National Forestry Commission (established in 2001, although the Program for Forest Fire Protection was transferred from SEMARNAT to CONAFOR in 2002). During all these transfers and department changes, the PNPCIF has been subject to evolution and development, motivated by different program managers.

Historically, the PNPCIF is one of the most advanced in the field in Latin America, so that in many cases it has provided technical support to other countries in the region, including Guatemala, Paraguay, Belize, Costa Rica, etc. It is considered a

strong program in Latin American, but not as developed as in countries such as U.S., Australia, Spain and Canada.

Service at State Level

It is in December 1994, when the Ministry of Environment, Natural Resources and Fisheries (SEMARNAP) transferred to the State, the authority in forestry and the service responsibility to wildfires. In October 2008, the Sustainable Forest Development Act is published for the State of Chiapas, which specifies that the State designates the Department of the Rural Field (Secretaría del Campo, in Spanish), as the institution responsible for coordinating, supervising and implementing actions to prevent, fight and control the wildfires in the state, asking for participation from federal, state and municipal governments, as well as NGOs and society in general.

Although, the State Government has channeled additional budgets and has invested in the training of the technical personnel, operational and administrative infrastructure of the State is still limited to fully assume responsibility stated in the Act, so that the responsibility for the coordination of protective actions against forest fires is still shared with the federation. Derived from this inter-institutional coordination, in recent years, Chiapas has not occupied, nationally, the top in terms of areas affected by forest fires. The operational organization for the service of forest fires has been given by working along with the State Center for Forest Fire Control (CECIF-Spanish acronym) and Regional Centers for Forest Fires (CRIF-Spanish acronym), with the participation of representatives of the agencies involved in this issue at State level, and 25 municipalities have been determined critical by fire incidence and hazard.

With this scheme of work, there have been great advances in the state, consider it as one of the most developed states in forest fire protection nationwide. In Chiapas, a strong coordination has been established among units of the three levels of government, NGOs and civil society, development of local capacities in specialized areas of forest fires; specialized equipment, among other things.

Experience of the Villaflores Municipality:

The Municipality of Villaflores (Figure 1) has an area of 1, 232.10 km², of which has a forest area of over 70, 000 ha, consisting of woodlands, forests and secondary vegetation in various strategic areas such as the Reserve of the Biosphere "La Sepultura", the Forest Reserve "The Frailescana", the Cerro Nambiyigua, the Cerro Brujo, among others, which are constantly threatened and affected by forest fires. In the period 1995-2001, the Municipality of Villaflores was affected by forest fires in

51.926 ha, which represented 41% of total problems of the Frailesca region. The above figures indicate that during the mentioned period, the Municipality of Villaflores was the most affected by forest fires in the State of Chiapas. The Biosphere Reserve "La Sepultura" (REBISE) and the Protected Area of Natural Resources "La Frailesca" (APRN La Frailesca) are located in part of its territory, where there are diverse ecosystems such as the Tropical Montane Cloud Forest (endanger species), pine forest, high and semi-evergreen forests, among others.

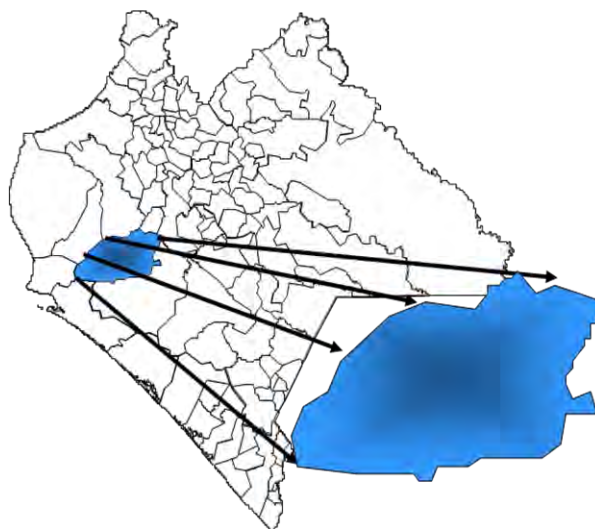


Figure 1—Location of the Municipality of Villaflores.

The forest fire problem that occurs in the Municipality of Villaflores is due to excessive use of fire in agricultural activities, it is to be understood that this region is considered the "breadbasket of the state of Chiapas", for its high yields in corn that has been obtained, but, lately, there have been other causes for fire occurrences such as lightning strikes, smokers, hunters and trash burning. In the past 15 years, the municipality of Villaflores has been placed between the first places affected by forest fires and incidence, which has brought, side effects of this phenomenon, among them the loss of vegetative cover, erosion and mudslides, mostly in the upper part of the mountain area.

In the Municipality of Villaflores until 2001, service to forest fires was traditionally a task for the Federation together with the State Government, along with the Honorable Municipal Council which preferentially supported with logistics resources without a defined initiative in this area. The Municipal Program for Forest Fire Protection starts in 2002 which has been the basic premise of protecting natural resources through participation and strengthening of local capacities, and the promotion of productive alternatives for the use of fire. After ten years the results of

this program have been constant and obvious as it has reduced the affected area of 3,851 hectares in the year 2001 to 168 h affected in the last critical season (2012), as well as a technical team of specialists has been consolidated, an effective interagency coordination has been developed, and these activities have been empowered by a community organization (UPROSIVI) with developers and community brigades with the "initial attack" strategy of 2005, with which a municipal model of service to forest fires and Integrated Fire Management has been established.

Due to the success of the firefighting strategy in the municipality, another problem has been developed which is the accumulation of combustible material available to burn in the forests that conjugated with existing steep topographic conditions and extreme weather (such as those presented in the critical period), can cause rapid fire spreading of large magnitude. To solve this problem, the Municipal Information System for Forest Fire Management was developed, first phase, where different activities are posed to help us to improve decision-making in fire management and, especially, to predict fire behavior when wildfires occur or prescribed burns are conducted (as an effective way to manage fuels), this is as a supplement to the fire prevention strategy of the existing Municipal Program, in addition to the Management Plans of the Biosphere Reserve La Sepultura (REBISE) and the Protection Area of Natural Resources (APRN) La Frailescana, for reducing the risk and disruption of forest fires that impact severely on this municipality. This strategy was based on the realization of a diagnosis of the perception of fire, mainly focused on two aspects, the historical (causes and effects of fires in the area, ignition sources and frequency, efficiency indicators, burn seasons, records of burning schedules, surface size, etc.), and social (problems, the relationship of fires with activities, resources and management of ANP, linking problems with other institutions and organizations involved in the management and conservation actions, etc.).

Phases Of The Fire Management Program In Villaflores, Chiapas

At first, it is important to mention that several actors are involved in the Fire Management Program of Villaflores, from the leadership that has established the H. Municipal Council, including the participation of other environmental and agricultural agencies, highlighting the involvement of institutions of higher and primary education, in addition to NGOs, technicians, professionals, volunteers, environmentalists, journalists, housewives, but especially farmers living in rural areas who use fire as a tool in the preparation of their plots.

In this situation it is logical that there is a level of knowledge and experience at different levels on forest fires, reason why it is necessary to design strategies to address the problem of forest fires, based on "diagnosis and rigorous analysis" as currently happens with Municipal Program of Villaflores, having a methodology for priority areas product of the Municipal System for Forest Fire Management. In this sense, through the reference program, two components are attended: the institutional or classical and social component, with the remaining task of moving towards an initiative of Integrated Fire Management, when one has the conditions to develop the ecological component based and grounded in the knowledge of fire ecology.

The Fire Management Program is designed and made within the framework of public policies on environmental and forestry issues, which for this case, it has a medium-term orientation and is integrated into the State and Regional Program in the field, linking its development and implementation with that of the Biosphere Reserve "La Sepultura" (REBISE), considering that the largest part of area with woods and forests of the Villaflores municipality is located within such ANP. Based on this Municipal Strategic Program, annual operational programs are developed to guide actions in the short term. The Villaflores Municipal Program for Fire Management at medium term is based on an "evaluation of protection priorities" methodology supported by the expertise provided by analytical treatments relative to procure "risk", "danger" and "potential damage". In this case, to know the fire risk an analytical study was performed along with an evaluation of factors that determine the origin or beginning of such disasters in the municipality of Villaflores (problem of fire occurrence), distinguishing 2 fundamental components: historical risk that relates to strategic data in a given time interval and potential risk, which refers to the various human actions that can start fires, and agricultural burning, population density (mainly rural), walkers in forest areas, hunters, etc. The wildfire hazard refers to the analytical study and evaluation of environmental factors that influence the degree of easiness of the vegetation to ignite (burn) and spread the fire, as well as plant fuel characteristics and conditions of ground, mainly slope class, besides the prevailing weather conditions at the time of occurrence of the fire. The potential harm considers the evaluation of potential losses or economic, cultural, social and ecological inflictions that could exist if the presence of wildfires. As a result of the three analyses mentioned above maps of risk, danger and potential damage were obtained adding the scores of the weights of each of the factors scored, with the support of GIS were joined together and once overlapping as layers of information, eventually resulted in a map of priority areas of service for forest fires in the municipality of Villaflores, Chiapas.

The above mentioned was done in order to plan decisions for the prevention, control and management of fire and make efficient resource allocation priorities in

conservation and protection against this phenomenon. For a better understanding of the above, priority of service was divided into five levels: very low, low, medium, high and very high, depending on the score, that is, if the score was low, the range of value is very low, or if the score was high, the value range is very high.

Protection priorities in the municipality of Villaflores are considered, in order of importance and characteristics as:

- 1) Areas core of the NPA's;
- 2) Uninterrupted forested areas as buffer zones and influence of the reserves, including strategic clumps (which have protective, economic, social, cultural or political value),
- 3) Isolated forested areas, which are interspersed with crops, but they also have protective, social, economic value, etc.
- 4) Areas with vegetation in recovery process (shrub), not considered of great value, but are adjacent to lands that require protection (high value) and if a fire occurs there is a danger of spreading.

Based on this analysis of priority of service the following phases of the Municipal Program have been developed:

A) Inter-agency coordination: during the ten years of the program an interagency framework has been formed by which institutional arrangements are made required for the planning, operation, monitoring and evaluation of strategic actions, participating, at least ten government institutions and civil society organizations, under the leadership of H. Municipal Council. Among the involved institutions are CONAFOR, SEMARNAT, CONANP and SAGARPA (at Federal level); Secretariat of the Countryside (at State level); BIOMASA, FMCN, UPROSIVI, AMBIO, PRONATURA South (NGO's); Autonomous University of Chiapas (Education sector), among others.

B) Pre-suppression: related to actions that have allowed to have prepared all human, material and financial elements prior to each critical period of fire, highlighting the establishment and operation of a Municipal Forest Fire Control, an agency that has the task to plan, coordinate and engage the participation of the agencies involved in addressing the problem of forest fires in the municipality, performing at least 15 basic actions for each critical period. This center is integrated by an organization established 100% with technicians and specialists of its own H. Municipality Government, receiving additional technical and logistical support from other institutions as CONAFOR, CONANP and the Chiapas State Government.

C) Prevention: conceiving that prevention intends to prevent forest fires arising due to preventable causes, and by considering that this is an important phase of the program, it is applied in three modalities: "cultural, physical, and legal", whose actions are enabling increased participation of the general population, for serving the

problem of fires in the municipality. In this category, we can mention that in the municipality a joint strategy is developed with CONANP/REBISE, of cultural prevention in the mountains, where they develop coordinated actions between community promoters of the reserve with technicians of the H. Municipal Council, among the activities that have been done in several communities and the Municipality we can mention allusive parades, blanket contests, videos and posters and expositions, special mention receives the Environmental Fair "A qué le tiras cuando quemas, Mexicano"-what do you expect when you burn, Mexican"- made in 2005, with the support and participation of more than 20 agencies, which recorded an attendance by more than 6000 people, mainly children and young people, in just two days of the event.

D) Intra-municipal Linkage: this is a strategy where, in principle, the Fire Program is backed up by the C. Mayor, validated by the Honorable Council, receiving the support of at least 8 directions of the own H. Municipality Council during its development. This is the internal linking that greatly strengthens fire management actions in Villaflores. Among the main areas that support we can enlist Municipal Civil Protection, Agricultural development, Social Communication, Treasury, Municipal Public Security, Municipal Health, Administrative Office, among others.

E) Detection and firefighting: it has a strategy of immediate discovery of fire which means not only the detection of fire in its early stages, but also locates their exact position and warns the staff responsible for firefighting.

The dispatch of the brigades is done under the principles of initial attack, i.e., it seeks to reduce the times of firefighting after receiving the warning, so that the attention of the disaster starts in the first 60 minutes of their development, in order to extinguish them within the first 12 hours of starting. In this regard, the control and firefighting phase is based on a network using radio communication covering more than 90% of the municipal area, with which is monitored, from the communities, the daily fire situation and/or other emergencies. For this, it has the support of two municipal brigades, 10 community brigades under a professionalization process and 20 organized community groups called "agroecological committees", located in priority areas, with voluntary participation. It is worth noting that in these actions the ejido⁴ authorities play a crucial role since they are organizing the participation of these groups.

F) Civilian Participation: it focuses preferentially in 30 rural communities at more critical stage by wildfires, according to the map of priority areas, involving peasant farmers who use fire through extension work, children and young people,

⁴ A legal land tenure designation in which land title is hold communally by all ejido members as group.

with actions of environmental education; women through personal interviews or participatory workshops; elders for his great wisdom and with roots that preserve their customs and traditions, peasant organizations, as key allies of the municipal program, through the management and development of projects related to fire management, for example, the Unión de Productores de la Sierra de Villaflores (UPROSIVI – Sierra de Villaflores Producers Union), deserving recognition for the Conservation of Nature in 2010; civil society organizations, as allies in the management of external resources that strengthened and innovated the program (as an example; BIOMASA, A. C., Mexican Fund for Conservation of Nature, AMBIO, Mesoamerican Biologic Corridor, including the U.S. Forest Service); and governmental institutions, to comply with the environmental regulations in this country. A separate point is that there are communities where land planning work, bylaws proposals for the use of fire and the Community Plans of Integrated Fire Management have been generated in a participatory and actively way with each of them, now these 5 types of jobs have been developed completely in five communities and in 3 are on process.

G) Education and Training: a process of strengthening of local capacities in the community and technical level is developed in order to have qualified, skilled and trained personnel in the subject, emphasizing the safety aspects of firefighters and threatened population. As a cross-cutting strategy, there is staff which has taken a comprehensive training process, participating in courses supported by the curriculum that CONAFOR applies nationally. In this case, we want to improve human security to move towards the formation or preparedness of "fire-adapted" communities, i.e., through provided training conditions so people can live in harmony with normal or abnormal existence of forest fires and their effects, through the organization, improving techniques, infrastructure, protective equipment, etc., that provide an appropriate level of protection against fire phenomenon. On the other hand, a knowledge management is sought through the collection and systematization of information to guide the appropriate use of traditional and local techniques together with results that could generate the specialists and researchers in this field, whereas traditional knowledge can provide much information that is not obtained or identified by the technical work or research.

Results

1. Reduction in areas affected by forest fires over 7,000 hectares period 1995-2001 (when there was no municipal planning) to 700 hectares per year average since the municipal program of fire management exists, registering in addition historical

figures with minimal damage in the years 2008, 2010, 2011 and 2012 were 74, 187 205 and 168 hectares respectively;

2. Empowerment of fire management actions on the part of civil society, through the peasant organization "Union of Producers of the Sierra de Villaflores (UPROSIVI);
3. Training of 52 technicians and specialists and 105 community brigades;
4. Application of alternative projects to reduce the use of fire, for example in 2011 more than \$ 8,000 000 (eight million pesos) were allocated by various institutions;
5. Network of 30 brigades and community committees in support to the municipal program of fire management;
6. Technological advancement to have the first Municipal Information System for Forest Fire Management statewide;
7. The municipality contributes 74% of the participation days/man in the prevention and firefighting in relation to other institutions involved;
8. Origin of an effective and efficient strategy contributing to global and local climate change adaptation.

Beneficiaries of the program

- A) Indirectly the program benefits a population of more than 98,000 inhabitants of the municipality of Villaflores protecting and conserving more than 70,000 h with trees in the municipality; significantly reducing emissions of carbon dioxide produced by smoke and thus undermining global and local warming, improving air quality, protecting springs and water sources for the population, among others.
- B) In average directly 70 firefighters, through official brigades of the municipality and community are benefited.

Transition to the Integrated Fire Management

It is believed that the fire management program of the Villaflores municipality has been institutionalized since it is accepted and supported by internal and external agencies, because of their success and permanence, on the other hand, there are technical, logistical and political conditions for the program to be officially recognized as a "pilot model" for decentralization of resources and functions by regulatory institutions, thereby strengthening the budgetary allocation of human resources with the required technical level as well as material resources. This would help in generating new public policies in this area and the creation of resource transfer agreements and functions from the Federation to the State Government to the Municipality and organized groups of civil society and communities. It is important to emphasize that to achieve this purpose, the two governmental levels above

mentioned must procure integration and allocation of packages and services to facilitate appropriation and empowering of such responsibility since the future strategy of fire management suppose the need to multiply the response capacity against forest fires, particularly at community level (woodlands and forests). Therefore, it is required to strengthen local capacities both at this and at municipal level, in order to acquire knowledge and capacity for action to develop organizations capable of addressing the problem of fires under the environmental, social, political and economic current and future conditions. In this case, in the short and medium term the municipal Villaflores program must have the conditions to begin with the development of the ecological component, under an "adaptive management", considering that the basic and applied scientific research, is the fundamental source of information to move towards a true Integrated Fire Management.

References

- BIOMASA.** 2010. Sistemas de Información para el Manejo de Incendios Forestales (SIMIF), Proyecto: "Elaboración de un Sistema de Análisis, Planeación y Toma de Decisiones para la Protección Contra Incendios Forestales en el Municipio de Villaflores, Chiapas". Biodiversidad, Medio Ambiente, Suelo y Agua, A. C. & Consultoría para el Manejo del Fuego. Chiapas, México. 158 p.
- CECIF.** 2007. Programa Operativo Logístico para la Protección Contra Incendios Forestales. Chiapas. CONAFOR-COFOSECH.
- FAO.** 2007. Manejo del Fuego: principios y acciones estratégicas. Directrices de carácter voluntario para el manejo del fuego. Documento de Trabajo sobre el Manejo del Fuego No.17. Roma (disponible también en www.fao.org/forestry/site/35853/en).
- GOBIERNO DEL ESTADO DE CHIAPAS.** 2010. Decreto de Ley de Desarrollo Forestal Sustentable para el Estado de Chiapas y su Reglamento. Tuxtla Gutiérrez, Chiapas, México.
- H. Ayuntamiento de Villaflores.** Programas Municipal de Manejo del Fuego y Protección contra Incendios Forestales de los años 2002 al 2012. Villaflores, Chiapas, México.
- SEMARNAT.** 2003. Decreto por el que se expide la Ley General de Desarrollo Forestal Sustentable y se reforman y adicionan la Ley General del Equilibrio Ecológico y la Protección al Ambiente, la Ley Orgánica de la Administración Pública Federal y la Ley de Premios, Estímulos y Recompensas Civiles. Secretaría de Medio Ambiente y Recursos Naturales. Diario Oficial de la Federación (Primera Sección), Martes 25 de febrero de 2003.
- SEMARNAT.** 2007. Norma Oficial Mexicana 015 SEMARNAT-SAGARPA. Especificaciones técnicas de métodos de uso del fuego en los terrenos forestales y en los terrenos de uso agropecuario. México, DF.

Wildfire Management Policies in Algeria: Present and Future Needs^{1,2}

Ouahiba Meddour-Sahar³, Armando González-Cabán⁴, Rachid Meddour³, and Arezki Derridj³

Abstract

Algerian forest lands cover 4,115,908 hectares (ha), of which 2,413,090 (58%) ha are bush or *maquis*. Recent work has shown that forest fires are the main factor explaining (90%) degradation of Algeria forest lands at an annual rate of 45,000 to 50,000 ha. From 1985 to 2010 in 40 provinces of northern Algeria, 42,555 forest fires have burned a total of 910,640 ha. On average, 1,636 fires burn 35,024 ha of forest lands annually. The 1985 to 2010 period saw a general increasing trend in annual fire frequency for the area. As in the entire Mediterranean basin, forest fires in Algeria are mostly human-caused, whether by negligence or voluntary. Unfortunately, the majority of fires are of unknown origin (80%), making it difficult to establish an appropriate preventive approach. The current forest fire prevention strategy in Algeria is based on the principle of "minimum damage", reflecting the technical limits of and lack of firefighting resource capability for protecting the entire forest lands from wildfires. Within the constraints of the existing wildfire management programs, it is necessary to improve the alert system, communication, and to intensify preventive silviculture in high-risk areas to reduce forest vulnerability to fire. Similarly, developing wildfire risk maps and providing adequate maintenance to existing infrastructure would help improve the organizational response to the wildfire season, potentially leading to better prevention programs and more efficient wildfire management programs in Algeria.

Keywords: *Fire causes, fire history, fire management, prevention strategy.*

Introduction

Fire is the main cause of forest destruction in the countries of the Mediterranean Basin. Annually, about 50,000 fires sweep through anywhere between 700,000 to 1

¹ An abbreviated version of this paper was presented at the Fourth International Symposium on Fire Economics, Planning, and Policy: Climate Change and Wildfires, November 5-11, 2012, Mexico City, Mexico.

² Survey instrument used in this work was designed and implemented by the senior author in Algeria; no US Federal Government money or employee's time was used in such efforts.

³ Faculty of Biological and Agricultural Sciences, Mouloud Mammeri University, BP 17 RP Tizi Ouzou, 15 000 Algeria; E-mail: o.sahar@yahoo.fr; rachid_meddour@yahoo.fr, respectively.

⁴ Research Economist, USDA Forest Service, Pacific Southwest Research Station, CA 92507 (USA); E-mail: agonzalezcaban@fs.fed.us

million ha of Mediterranean forest, other wooded land and other land, causing large economic and ecological damage, as well as loss of human life (Dimitrakopoulos and Mitsopoulos 2006).

Algeria is a Mediterranean country strongly conditioned by the physical, biological, climatic and environmental characteristics of the area. Wildfires can be so explosive, due to harsh climatic conditions (extreme temperatures and prolonged drought) that in a few hours they can annihilate wide surfaces (Madoui 2000).

According to the 2009 National Forest Inventory (Bneder 2009) the current situation of forests and other wooded lands (OWL) is of concern. Their combined total area is only 4,115,908 ha (1,702,818 ha forests and 2,413,090 OWL), representing only 1.72% of the country's 238,174,000 ha. Furthermore, 84% or 200 million ha of the total surface area is located in the Sahara region. Only the northern mountainous part of the country has a significant forestry cover of about 16.4%.

Climatic conditions are a significant predisposing factor for the forest fire situation in Algeria. Prolonged summers (June to October), with nearly no rain and average daytime temperatures well in excess of 30°C, and with daily peaks reaching up to 50°C (e.g., at In Salah in 2005), reduces forest litter moisture content way below 5%. Under these conditions, even a small addition of heat from natural (lightning) or human sources (a spark, a match, a cigarette butt) can be enough to start a violent wildfire.

In the context of the Mediterranean basin, Algeria is one of the countries with a significant forest fire problem whose impact requires consideration. Managers are facing upward trends in fire frequencies, area burned, fire intensity and severity, and increases in fire season length and risk resulting from changes in climatic conditions.

The objective of this research is to establish an inventory of existing public policies related to wildfires and understand their context in relation to forest fire management in Algeria.

Study Area

Algeria is the largest country in Africa and the Arab world, with a total surface area of 2,381,714 km². It borders with the Mediterranean Sea to the north (1200 km of shoreline), Morocco to the west, Tunisia and Libya to the east, Mauritania and Western Sahara to the south-west and finally Mali and Niger to the south (Figure 1). Algeria is divided into 48 provinces (*wilayas*), 553 districts (*dairas*) and 1,541 municipalities (*baladiyahs*). As of a January 2010 estimate, Algeria's population was 34.9 million. About 90 percent of Algerians live in the northern, coastal area. More than 25 percent of Algerians are under the age of 15.

Geographically, the country is divided from north to south into four natural zones: 1) the Tellian Atlas (or the Tell) is made up of the northernmost steep relief flanked by rich coastal plains such as the Mitidja in the centre, the Chelif to the west and the Seybouse plains in the east; 2) the High plateaus, where the vegetation is steppe Summers are generally dry and winters cold The main cities are Bordj Bou Arreridj, Serif, Tiaret, Dejelfa, M'sila; 3) . . the Saharan Atlas as a succession of NE-SW oriented reliefs spreading from the Moroccan border to Tunisia; and 4) the Sahara desert, composed of large sand dunes (East and West Erg) and gravel plains (regs) with dispersed oases such as El-Oued, Ghardaia and Djanet.

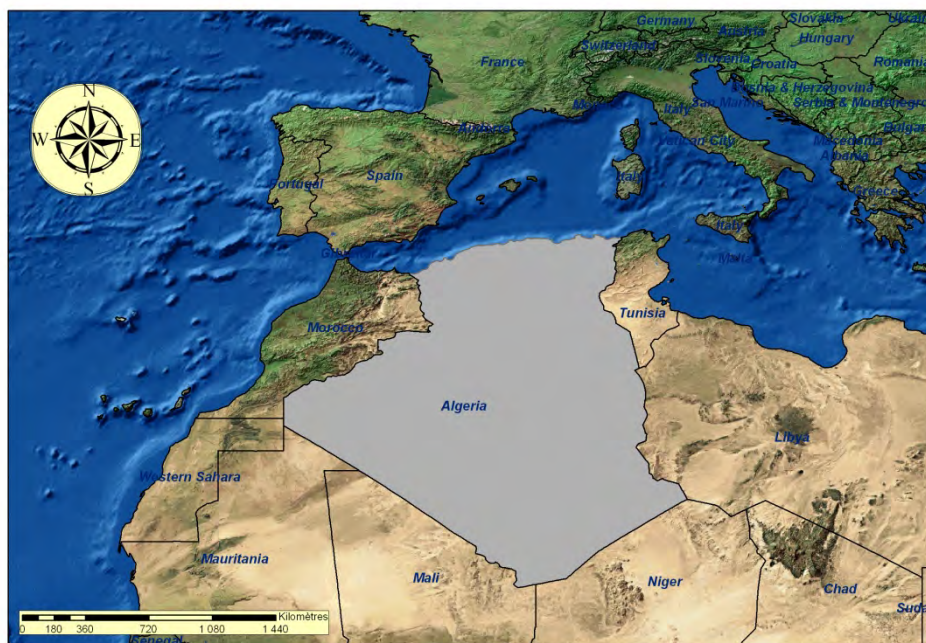


Figure 1—Map of Algeria

Methods

The research reported here was conducted during the spring 2011. Our initial working phase consisted of a review of all existing documents, reports, and legislation dealing with forest fires in the country at the national, regional and local levels. To complement this information we conducted a qualitative survey (structured qualitative interviews) administered to a sample of 35 fire managers in Algeria Central Directorate of Civil Protection and National and Regional Forest Administration. In addition, 70 in-person interviews were conducted at the regional level with forest managers (N=20), firefighters (N=17), and local authorities (N=33) involved in forest fire protection.

Results

Forest fire statistics

Forest fires are a recurring phenomenon, and have always had a pervasive influence on Algerian forests. In the period 1985-2010, a total of 42,555 wildfires burned 910,640 ha of forest land. This represents 1,637 fires and 35,025 ha annually for an average area burned of 21.39 ha per fire (Meddour-Sahar and Derridj 2012b). As shown in Figure 1, the yearly variability in these two statistics is very high. This is corroborated by the large coefficient of variation (40.30%) for number of fires and 143% for area burned. The large number of fires and area burned in 1993, 1994, 2000, and 2007 is of particular note here. A possible explanation for the relationship is the high correlation between area burned and seasonal meteorological conditions.

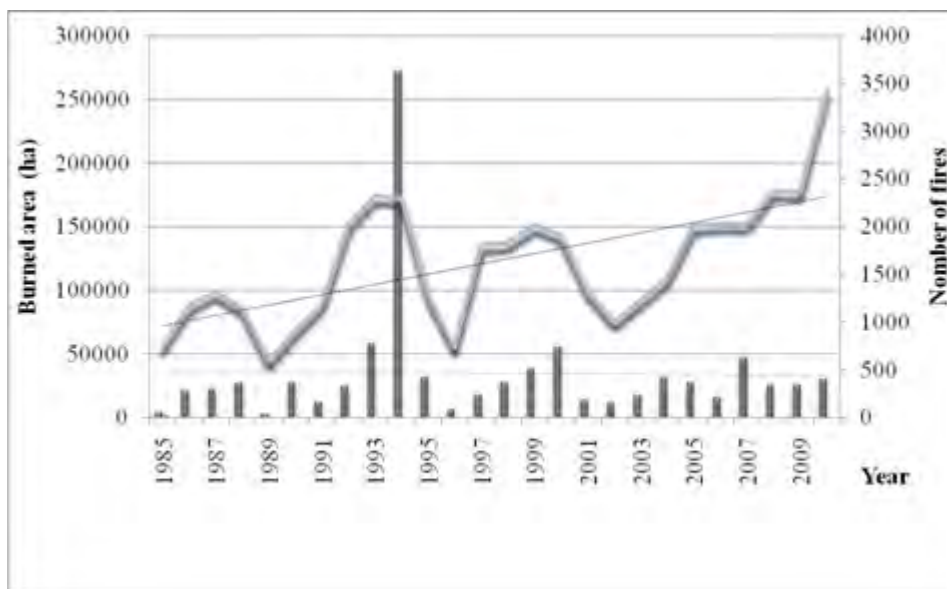


Figure 2—Number of fires and burned area in Algeria, 1985 to 2010

Over the period 1985-2010 the annual average numbers of fires, area burnt, and area burnt per fire are 1,637, 35,027 and 21.39 respectively (Table 1). However, when breaking the full period into two 12-year sub-periods an interesting pattern emerges. While the annual average number of fires increased from 1,348 in the period 1985 to 1997, to 1,925 during 1998 to 2010, the opposite was true for area burnt and burnt area per fire. The area decreased from 41,147 to 28,902 and from 30.52 to 15.01 ha respectively (Table 1). The following factors may have influenced this trend. First, improvements in detection methods (lookout towers, but mainly mobile patrols) have most likely resulted in the detection and reporting of more fires.

Second, the quality of the databases has improved considerably. Third, due to aggressive and effective fire suppression policies, fires are extinguished earlier (after the purchase in 2005 of 4WD pick-up type vehicles equipped with small fire engines (600 liters) and a high pressure pump), which may lead to smaller fires by reducing intervention time.

Table 1—*Forest fires statistics for Algeria.*

Year	Number of fires	Burned area (ha)	Burned area per fire (ha)
Average (1985-2010)	1,637	35,025	21.39
Average (1985-1997)	1,348	41,147	30.52
Average (1998-2010)	1,925	28,902	15.01

As expressed earlier the main cause of wildfires throughout countries in the Mediterranean Basin is anthropogenic. Algeria is marked by a strong prevalence of human induced fires. In some cases, they are purposely started, e.g., for criminal reasons. In many others, they are related to agricultural and forestry activities, e.g., fires for agricultural cleaning that escape control. There are other factors that contribute to fire spreading faster, which makes them more difficult to suppress (Meddour-Sahar *and others*, 2012). Weather conditions are not the cause of fire ignition (except for lightning episodes), but rather have a catalytic effect because they are predisposing factors that make fire propagation easier in a hot and dry environment (typically associated with fuel moisture close to zero).

Unfortunately, the investigation of fire causes in Algeria is in its infancy thus limiting understanding of the main causes of fire in the country. For example, for the 1985 to 2010 time series, for which we have almost complete information, the fire cause cannot be identified in 80% of the cases (Table 2). Even for fires that can be assigned to a category, the categories are very broad such as *negligence*, *accidental* or *voluntary*. A more refined categorization is needed that could aid design of fire prevention programs.

Table 2—*Forest fire causes in Algeria for the period 1985-2010*

Causes	Numbers of fires	%
Negligence	1,260	3
Accidental	256	0.6
Voluntary	7,009	16.4
Unknown	34,030	80
Total	42,555	100

The recorded causes in the fire data do not reflect reality. In Algeria, it is commonly accepted that at least half of the fires attributed to unknown causes are either arson or *security fires*, which are purposely set by the Algerian Army as a counter terrorism measure; making it a rather difficult topic to address.

These fires are listed as of unknown causes either because the arsonist was not arrested or because conclusive evidence of arson was not found (Dimitrakopoulos 1995). Again, this points to the urgent need to improve the capability to investigate fire causes.

Forest Fire Policy in Algeria

The national forest fire policy emanates from Algerian forest legislation containing provisions specifically related to the prevention and organization of the response to forest fires. The following four laws and decrees contain specific elements addressing forest fire concerns.

- Law 84/124 of 23 June 1984, which under Articles 19, 20 and 23 requires the involvement of different state organizations in the fight against forest fires. The law establishes the obligations of certain agencies for carrying out fire protection actions;
- Decree 87-44 of 10 February 1987 establishes rules and standards for prevention against forest fires in and near the national forest domain;
- Decree 87-45 of 10 February 1987 establishes the organization and coordination of actions in fighting forest fires in the national forest domain;
- Decree 301-07 of 27 September 2007, amending and supplementing Decree 80-184 of 19 July 1980, establishing coordinating agencies for implementing actions to protect forests.

In addition to this policy related laws, Algeria and the majority of Mediterranean Basin countries, have a variety of legal instruments to punish violators in the case of a forest fire. Punishment ranges from forced work in Morocco (Zitan 1986), Algeria (Grim 1989) and Tunisia (Chandoul 1986), to jail sentences of only a few months in Cyprus, to life imprisonment in France (Alexandrian and others 1999).

The current national forest fire policy is based on the following three guiding principles: **prevention** (including all measures intended to prevent the occurrence of forest fires), **pre-suppression** (covering all provisions intended to improve interventions and safety in the event of fire), and **suppression** (including all possible types of intervention). Below is a description of activities within each of these three fire management program actions.

Prevention

Prior to the wildfire season, the administration starts a number of prevention activities, such as:

Sensitization and education of the public and forest users—

Among the activities in this program are: 1) organizing conferences on wildfires in centrally located meeting places of easy access by the population to explain the precautions to be observed in the event of fire use, to avoid or reduce the probability of fire spreading into the forest; 2) designing and broadcasting television and radio spots, films and posters; 3) preaching in mosques; 4) articles in newspapers highlighting the benefits of forest and nature; and 5) campaigns in schools starting in September to coincide with the beginning of the school year.

The reinforcement of forest surveillance—

There are three main provisions that regulate the use of fire in forests, or in their vicinity during the period of summer dryness between June 1 and October 31. The intent is to safeguard the population surrounding these areas from potential wildfire occurrence. The provisions are:

1. Establishment of a 50-meters wide buffer zone around villages to ensure their protection. In this zone fruit trees will be maintained, forest trees pruned to a third of their height, brush and dry grass will be systematically removed; all of this in accordance with Article 4 Decree No. 87/44 dated 10 February 1987.
2. Establishment of a 25-meters wide buffer zone devoid of vegetation and other flammable material around schools and socioeconomic units' buildings, yards and other installations; all in accordance with Article 6 of the Decree No. 87/44 dated 10 February 1987.
3. Establishment of a 50-feet wide buffer zone around permitted sanitary landfills; all in accordance with Article 15 of Decree No. 87/44. In addition, those facilities must have a security guard present for safety (to prevent people from entering for salvage activities), burning of materials is prohibited, and fire protection equipment must be present to respond in case of need. Illegal dumps must be eliminated.

Pre-suppression

Fire management protection programs infrastructure and personnel are distributed throughout the country provinces. At present the program consists of a basic pre-suppression force of 2,229 people organized in 456 Forest Mobile Patrols (2 to 5 person crews depending on the province) responsible for initial attack, and 922 employees staffing 375 fire lookout towers. In addition, there are another 6,000

Directorate of Civil Protection employees and 42,088 forest workers available for fire activities when needed. In terms of equipment and infrastructure the program consists of 40, 4WD Medium Tanker (3000 Litres), 800 firefighting trucks provided by the Directorate of Civil Protection when needed, 1,617 water points in or near forests, 32,556 ha of passive firebreaks , and 37,933 Km of forest access roads.

The fire management program is not the only governmental agency with fire protection responsibilities. As such, the program cooperates with other governmental agencies and institutions with fire protection responsibilities. These include:

- The Ministry for Public Works, responsible for weeding along national roads that cross forest lands in accordance with Article 25 of Decree No. 87/44.
- Ministry of Energy and Mining, the Railway Service: SNTF, responsible for weeding along the railway that crosses forest areas in accordance with Article 24 of Decree No. 87/44.
- The Ministry of Interior and Local Governments responsible for weeding 5 meters on each side of communal roads and other access routes located inside and within 500 meters of the national forest domain.
- The National Gas and Electricity Society (SONELGAZ), responsible for weeding the area under power lines crossing forest areas in accordance with Article 21 of Decree No. 87/44.
- The National Meteorological Service, responsible for producing fire weather forecasts during the fire season highlighting potential fire danger. These bulletins are provided to Forest Service managers to strategically place their firefighting resources over areas diagnosed with high fire danger conditions.
- Ministry of Agriculture and Rural Development; responsible for establishing a 5-meters wide vegetation free buffer zone around farms adjacent to forests in accordance with Article 7 and 26 of Decree No. 87/44.

None of the above mentioned institutions uses prescribed fire, which is an unknown practice in the country.

In June, prior to the fire season, Forest Service engineers conduct a series of conferences/workshops targeted at local administrative authorities and fire protection volunteers. The objective of these conferences is to provide a refresher on fire prevention activities, remind local volunteer groups and all community members of their obligation to participate in forest firefighting, and a reminder of the requirements established by the protection provisions of Decree No. 87/44 and 87/45 dated 10 February 1987. A report on the results of this activity has to be sent to Direction of Forestry to ensure accountability of completion.

In each province, the fire management protection organization includes the following agencies: the Provincial Operational Committee (POC), District

Operational Committee (DOC), Municipality Operational Committee (MOC), and the Local Population Operational Committee (LPOC). The following flow chart (fig 3) shows their relationship and the number of agencies within each type in parenthesis.

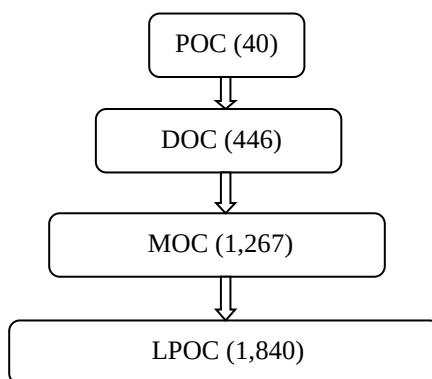


Figure 3—The fire protection organization in Algeria (40 provinces).

Suppression

The initial attack response to a fire alarm is always by the local Forest Mobile Patrol (FMP, CCF in French). This response is by a 5 person crew, with a first strike 4 WD vehicle equipped with a tank with a capacity of up to 600 liters. The goal of this first attack is to arrive within the first 10 minutes of the fire notification. These crews have minimal suppression equipment (shovel, pick, fire swatters, backpack pump and a radio to inform headquarters personnel). These crews will routinely alert Civil Protection and Local Authorities of the fire origins (forest, district, and municipality). The Civil Protection Organization mandate is to respond to all type of emergencies, including forest fires, and to deploy the necessary resources in response to the emergency; and in the case of wildfires, to manage the suppression operations in conjunction with forest fires protection crews. As the fire expands, additional Mobile Forest Patrols are dispatched to reinforce initial attack crews.

Schematically, the intervention in forest fires firefighting is as follows:

- First Response/initial attack by Mobile Forest Patrols (MFP);
- Intervention of Civil Protection with heavy equipment during extended attack;
- Intervention of agencies and other external resources if necessary, including additional MFPs.

Economic Dimension

As in much of the countries of the world the economic dimension of wild land fire management is not well addressed. Algeria is not the exception. Here budget information for a very small segment of the country's areas and estimates of the economic losses associated to wildfires, for the period 1985 to 2006 is provided.

Partial fire management information only for the Tizi Ouzou province for 2009 was obtained. This very limited information concerns the costs for 54 fire protection people, and it is about 9 million Algerian Dinars or about 90,000 Euros. Assuming that all 40 Algerian provinces invest at least the same amount in fire suppression personnel we can estimate a total presuppression expenditure of 3.6 million Euros for the country. However, we do not know if these assumptions are correct.

We also have limited information on the economic impact of wildfires in Algeria. Only Arfa and others (2009) have produced estimates of the economic impact of wildfires in the forestry sector in the country. They estimated that between 1985 and 2006 the forestry sector suffered losses equivalent to 1.11 billion Euros (113 billion Algerian Dinars). These losses include damages to commercial products like timber, cork, and cereals. However, no direct suppression expenditures or losses of homes are included in their estimates. This could be a significant under estimation, because for example, in 2007 alone destruction of 334 houses were directly associated to forest fires. Loss of life is another dimension of the potential impacts that are not considered when evaluating the socioeconomic impacts of fire. For example, before 2007 only 8 fatalities had been directly associated with wildfires, but in 2007 alone 8 civilian fatalities were recorded, and 1 firefighter fatality in 2008. Another significant, but not included, component of losses is the long-term loss of biodiversity and other ecosystem services, such as water production, carbon sequestration or recreation benefits from Algerian forests. However, this limited estimation provides a glimpse of the potential large economic impacts of wildfire.

Discussion and Recommendation

Forest fire prevention must take into account two fundamental factors: treatment of fuels and fire cause. Fuels treatment has to do with the reduction or compartmentalization of existing fuel load in the forest (dead and alive). Knowledge of the causes of fire could help determine the best approach to prevent future fire occurrences. The success depends as well on the integration of the population in some form of fire prevention. Doing this requires at least three types of actions: persuasion, conciliation and sanction (Velez 1999). As discussed by Vélez (1999), *persuasion* intends to modify people's behavior via education and information, by making publics aware of the situational danger. The fire management program devotes a serious effort to this action by engaging the publics in the series of

prevention activities described in the prevention section above. *Conciliation* tries to harmonize communities and agencies interests through forest policy and legislation to remove conflicts, which may lead to fires. The laws and regulations in place in the country, as well as the specific programs engaging the public in prevention and protection activities surrounding their communities shows the agency commitment to conciliation (see, section on reinforcement of forest surveillance above).

Sanctions are used as a last resort, to punish both negligent and deliberate offenders. Algeria laws provide for punishment of offenders and violators of forest fire codes and regulations.

As shown in Figure 2 and Table 1, the number of fires has significantly increased in the last two decades. In contrast, area burnt has shown some stabilization. At the same time, there has been a significant increase in the availability and allocation of firefighting resources for surveillance and suppression actions. However, Vélez (1999, p 93) warn us that although "*the problem of forest fires can be seen in the context of simple cyclical measures, or merely improving techniques used to combat them, but it requires a set of policies affecting their causes*". That is, not only do we need to have better equipment and trained personnel for fire suppression, but we must also attack the root causes of human-caused fire. Understanding of the fundamental causes of anthropogenic fire would lead to better prevention programs to help in the reduction of wildfire occurrence.

A comprehensive analysis of current fire management policies could help us in identifying potential limitations that can reduce their effectiveness in addressing the present wildfire problem in Algeria.

Based on our work, we list below a series of difficulties affecting fire management programs (prevention and suppression) in Algeria and propose recommendations for their resolution.

In terms of prevention

Difficulties	Recommendations
Lack of computerized databases on forest fires.	Create national and standardized fires database within Mediterranean countries.
Increased number of fires as a consequence of the general lack of prevention.	Development of a coordinated prevention policy across all jurisdictions to reduce forest fires.
Insufficient awareness of residents about the risk of forest fires.	Integration of population programs in forestry.
Increase in fires following the careless burning of stubble and weeds by farmers and ranchers.	Increase awareness campaigns among local residents based on mass communication.
Inadequate monitoring of preventive and dissuasive actions in wooded areas because of lack of personnel and	Authorization of prescribed fire in Algeria by an appropriate regulatory authority.
	Recruitment of forest protection personnel, increase mobile surveillance in areas at highest risk, with a minimum density of 5000 ha per

equipment. Lack of specific weather stations in forest areas to identify factors influencing fire in real time.	supervisor. Installation of an automatic weather stations network in forest areas by the National Meteorology Service to facilitate calculation of fire risk indices and help firefighting actions.

In terms of fire suppression

Difficulties	Recommendations
Inadequacy of the first intervention or initial attack.	Increase amount of available initial attack resources and reduce response and intervention times.
Lack of personnel in relation to the country's forest territory; problem of simultaneity of fires and the inaccessibility of some forest.	Increase staffing and budget levels of the Directorate General of Forests to offset the additional operational deficits in agencies with fire suppression responsibilities.
Lack of aerial resources.	Staffing Civil Protection airlift for ferrying personnel and firefighting in rugged terrain.

In terms of restoring forest burned areas

Difficulties	Recommendations
Absence of silvicultural operation over large areas with large accumulation of fine fuels.	Conduct silvicultural operations to remove accumulation of fine fuels (removal of dead wood, suppression of shrub layer, cleaning, etc.).
Repeated fires in some province (coastal province).	Research leading to actions targeted to specific high risk areas for reconsideration of forest policy.

Conclusion

Algeria has a serious wildfire problem. The effort devoted to dealing with it is significant in terms of personnel, material, and financial resources. However, results of the last few years not only on number of fires and area burnt, but in loss of life and property clearly indicate that there is need for improvement, especially in regard to the knowledge and organization of the whole fire management program effort.

The lack of an institutionalized program of investigations of fire causes is a contributing factor in reducing the potential effectiveness of prevention programs. Improving the collection of fire statistics and maintenance of fire databases would provide basic information to fire managers to help guide their decision making process. Limited budgets results in underfunded fire management programs. Increases in fire prevention and presuppression programs at the national and provincial levels would help improve the response capability of the Fire Service. A closer working relationship between the Forest Service and other national agencies

and the Fire Service is necessary to reduce potential duplicity of responsibilities and maximize program efficiencies. A continuous reevaluation and updating of their fire management program planning process would help the Fire Service to account for technological improvements in equipment and personnel to maximize the effectiveness of its forces.

Implementation of these minimum actions would further the effectiveness of the Fire Service in responding to the present and near future wildfire problems in Algeria.

Acknowledgements

We sincerely thank the General Directorate of Forests in Algiers for putting at our disposal the documents necessary to our research and to Drs. Vittorio Leone and Giovanni Bovio for their critical reading of the manuscript and suggestions that improve the clarity and presentation of the material.

References

- Alexandrian, D., Esnault, F., Calabri, G. 1999.** Forest fires in the Mediterranean area. An analysis of trends in forest fire occurrences in the Mediterranean, including comments on underlying policy-related causes. *Unasylva*, 197, 50, 35-41.
- Arfa, A.M.T., Benderradji, M.E.H., Alatou, D.j. 2009.** Analyse des bilans des incendies de forêt et leur impact économique en Algérie entre 1985-2006. *NEW MEDIT* N.1/2009.
- Bureau National des Etudes du Développement Rural (BNEDER). 2009.** Plan national de développement forestier (Pndf) rapport de synthèse nationale, Alger.
- Chandoul, H. 1986.** Le problème des feux de forêts en Tunisie. Paper presented at a seminar on Methods and Equipment used to Prevent Forest Fires, Valencia, Spain, 29 September-4 October 1986. 15 pp. + annexes.
- Dimitrakopoulos, A. 1995.** Analyse des causes des feux de forêt en Grèce. *Options Méditerranéennes, Série A. Séminaires Méditerranéens*, 25 : 33-40.
- Dimitrakopoulos, A.P., Mitsopoulos, I.D. 2006.** Global forest resources assessment 2005. Report on fires in the Mediterranean Region. Working paper FM/8/E, Forestry Department, FAO. Rome, 43 p. [online] URL: <http://www.fao.org/docrep/009/j7564e/j7564e00.htm> accessed 06.04.2012
- Grim, S. 1989.** Le pré-aménagement forestier. Alger ad.CEE et Ministère de l'hydraulique d'Algérie, 1989.
- Madoui A., 2000.** Forest fires in Algeria and the case of the domanian forest of Bou-Taleb. *Inter. Forests Fires News*: 9-15
- Meddour-Sahar, O., Derridj, R. 2012.** Bilan des feux de forêts en Algérie: Analyse spatiotemporelle et cartographie du risque (Assessment of forest fires in Algeria: Spatiotemporal analysis and risk mapping, 1985-2010). *Sécheresse*-23 (2) : 133-141. doi : **10.1684/sec.2012.0342**
- Meddour-Sahar, O., Meddour, R., Lovreglio, R.; Derridj, A. 2012.** Analysis of forest fires causes and their motivations in north Algeria: the Delphi technique. Unpublished draft supplied by author.

- Velez, R.1999.** Protection contre les incendies de forêt : principes et méthodes d'action. CIHEAM, Zaragoza. *Options Méditerranéennes*, Série B : Études et Recherches No. 26, 118 p.
- Zitan, A. 1986.** Les feux de forêts au Maroc. Paper presented at a seminar on Methods and Equipment used to Prevent Forest Fires, Valencia, Spain, 29 September-4 October 1986. 24 pp.

Forest Fuel Characterization Using Direct Sampling in Forest Plantations¹

Eva Reyna Esmeralda Díaz García², Marco Aurelio González Tagle³, Javier Jiménez Pérez³, Eduardo Javier Treviño Garza³, and Diana Yemilet Ávila Flores²

Abstract

One of the essential elements for a fire to occur is the flammable material. This is defined as the total biomass that has the ability to ignite and burn when exposed to a heat source. Fuel characterization in Mexican forest ecosystems is very scarce. However, this information is very important for estimating flammability and forest fire risk, fire behavior, environmental impact assessment and critical decision making related to fire management practices. The aim of this study was to determine the fuel load in a *Eucalyptus sp.* plantation, which has not been given any kind of management over the past 20 years in order to suggest actions and management tools for preventing wildfires. The fuel load estimation was carried out by using the planar intersections technique described by James. K Brown (1974) and adapted by Sánchez and Zerecero (1983). In this work, the study area was divided into five sites, each of them with a control point at its center and from there a series of 20-m long sampling lines were established towards the four cardinal points. At these points, the firewood fuel inventory information was recorded as well as their interceptions according to their delay time. Additionally, using depth and weight parameters, the organic layer or light fuel layer was measured. Along the sampling lines, four quadrants of 0.25 m² each were distributed every 5, 10, 15, and 20m where the depth was measured and material contained in 1m² was collected; the weight was registered *in situ* and dry weight in the laboratory. As for data processing, it was done using the formulas from the technique described above. The results indicate that the total forest fuel load for the plantation was 53.65 ton/ha; wood fuels accounted for 70% of this accumulation with 39.62 tons/ha and the organic layer contributed with 16.81 ton/ha representing 30% of the total fuel load. This large accumulation is mainly due to the lack of plantation management. We recommend implementing management strategies to maintain fuel accumulations at a minimum level while protecting the soil so that the risk of forest fires can be highly reduced.

¹ An abbreviated version of this paper was presented at the Fourth International Symposium on Fire Economics, Planning, and Policy: Climate Change and Wildfires, 56-11 November 2012, Mexico City, Mexico.

² Graduate student, Forestry Sciences School, Autonomous University of Nuevo León. Linares N.L. México; Email: eva.g18@hotmail.com.

³ Research Professor, Forestry Sciences School, Autonomous University of Nuevo León. Linares N.L. México.

Keywords: *Forest fuels, forest fires, fuel inventory*

Introduction

Fire is one of the greatest enemies of forest resources, which along with pests and diseases cause tree deaths, making these, in turn, significant deforestation and degradation factors. In recent years, Mexico has been significantly affected by fires that occur every year, being an ecological factor and one of the most common phenomena in our forest ecosystems, especially in drought times where the fire risk significantly increases because of the large dry organic fuel accumulations. However, in Mexico the main cause of the high incidence of fires is human actions, because more than 90% of yearly fires are due to traditional practices and inappropriate use of fire (agriculture and intentional burning for various reasons in forest areas).

For a fire to develop, it needs the interaction of biological factors that influence fire occurrence and behavior. These factors are mainly climate, weather, topography and fuel material (DeBano 1998). The latter is a very important variable in determining the danger created and the development of forest fires, as these materials directly influence fire behavior.

Forest Fuels

Forest fuel is made up of wood and light materials, living or dead; all are plant matter present in an ecosystem that has the ability to ignite and burn when exposed to a heat source. These fuels are the result of the natural process of leaf, needle and branch fall, as well as humus, although they are also due to human activities, like forest harvesting. Forest fuels are classified under different criteria according to their weight, size, and state of decomposition or location; however, the most common classification is according to their delay time. That is, the time it takes a dead plant fuel to gain or lose two-thirds of the difference between its initial moisture content and its equilibrium moisture content with respect to the environment (Brown 1982). The larger the fuel, the more slowly it will lose or gain moisture and the longer its delay time will be. Thus, the diameter will establish the fuel delay time.

Table 1—*Classification of forest fuels*

Diameter	Delay time	Size and weight
Less than 0.6 cm	1 hour	Fine/Light
From 0.6 to 2.5 cm	10 hours	Small/Light
From 2.6 to 7.5 cm	100 hours	Regular/Medium
Higher than 7.5 cm	1000 hours	Big/Heavy

Hour fuels, also called **fine fuels**, such as leaves and branches are easily ignited and rapidly consumed by fire when they are dry. Ten hour fuels, known as **light fuels**, are mainly twigs. One hundred hour fuels, or **medium fuels**, are branches. As for thousand hour fuels, they are known as **heavy fuels** and consist mainly of thick branches and wood logs. Also in this category, the trunks or branches that are in a state of decay and those which are in a firm state or not rotten are clearly differentiated. Although these fuels protect the soil, it is necessary that the forming layer is not so deep that it facilitates fire dispersion. Therefore, it is necessary to implement management strategies that favor fuel reduction, while protecting the soils, as well as carry out fuel characterizations and spatial distribution studies.

Forest Fuel Estimation

The fuel loading estimate was carried out by the planar intersections technique, which was described by James K. Brown (1974) and adapted to Mexico by Sánchez and Zerecero (1983). This technique consists of counting the interceptions of woody parts in vertical sampling planes, similar to "guillotines cutting" fallen fuels and on the ground it is marked with a sampling line. Some basic rules of this technique are:

1. Fuels that should be measured include dead woody material (twigs, stems, branches or stumps) of trees and shrubs, which have fallen to the ground surface and are separated from the original growth source. Therefore, dead branches that are attached to the trunks of standing trees should be omitted.
2. Branches or twigs that are in or on the litter layer must be considered. However, if the twig lies within the humus layer it must not be measured.
3. If the sampling plane intercepts the end of a log, this will only be measured if the sample plane crosses its central axis.
4. Pieces whose central axis coincides exactly with the sample line will not be measured (event that rarely occurs).
5. If the sampling plane intercepts more than once a curved piece, each intersection will be measured.

6. If there are woodchips or small pieces of wood left after harvesting, they must be studied inside cylinders to determine shape, size, class and record their diameters.
7. Stumps, whether rooted or not, that are covered by soil should be measured. For this, non-fixed trunks are considered as tree trunks or individual roots, depending on where they are intercepted by the sample line. Stumps without alteration should not be measured.

Methods

Study area

The study area is located in the Linares municipality (Nuevo León, Mexico) at 350 meters above sea level (masl), with coordinates 24° 47' north latitude and 99° 32' west longitude (SPP-INEGI 1986) on the Linares-Ciudad Victoria Highway (kilometer 145). This area corresponds to a *Eucalyptus microtheca* and *Eucalyptus camaldulensis* plantation which is 1.98 ha in area. This plantation is located in the experimental campus of the Forestry Faculty at the Autonomous University of Nuevo León.

Parcel delimitation

The study area was divided into two quadrants (CI and CII). In CI, three sites of 40m x 40m were delimited, with an approximate area of 1,600 m². In CII, two parcels of the same dimensions were delimited. The size of these parcels is considered acceptable compared to those used by Flores and Benavides (1994 and 1995) that were 20m x 30m, and those used by Alvarado (1988) in two of his works, which measured 10m x 20m.

Measured variables

The fuel variables were: PROF and PE-HO/HU= litter and humus depth and weight (cm); PE-CO= organic layer weight (t/ ha); PE-1HR= fuel weight with 1h delay time (t/ha); PE-10 HR= fuel weight with 10h delay time (t/ha); PE-100 HR= fuel weight with 100h delay time (t/ha); PE-1000 HR FIRM= weight of solid fuels with 1,000h delay time (t/ha) and PE-1000 ROTTEN= rotten fuel weight with 1,000h delay time (t/ha).

Sampling Design

The measurements were taken under the following sampling design: at each site, four sampling lines were established having a total of 20 sampling lines/ha because as a general rule, it is suggested to have from 15 to 20 lines in any study area, as this number would produce estimates with 20% or less error (Sánchez and Zerecero 1983). The line length was 20 meters long and heading towards the cardinal points.

In the first meter of the sampling line, the frequencies were recorded for fuels with a diameter <0.06 cm, (PE-1HR) in four meters the fuels with a diameter 0.6-2.5 cm were recorded, (PE-1OHR) in the next 6 meters the fuels with a diameter 2.6-7.5 cm were recorded, (PE-100 HR) and lastly, in the 20 meters the fuels with a diameter of >7.5 cm were recorded as well as their state: firm or rotten (PE-1,000 HR). A caliper was used for measuring woody fuel categories with previously established measurements.

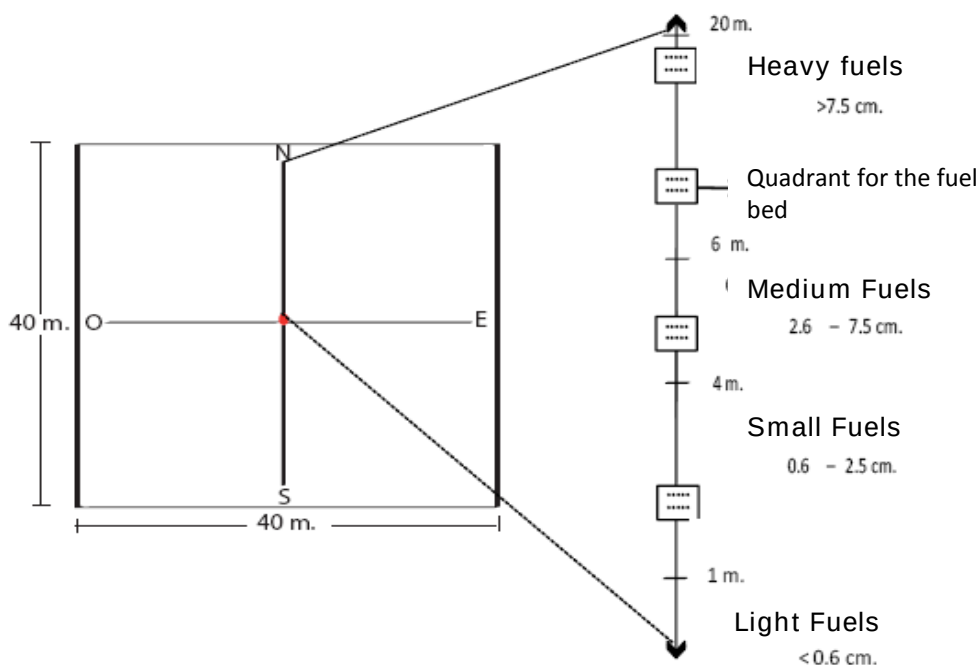


Figure 1—Sampling design. The total length of the sampling line was 20 m, and it was divided into sections in order to record fuel frequency by diameter category. It also shows the quadrant locations for the evaluation of the fuel bed.

For the organic layer evaluation (Image 1), four quadrants of 0.25m^2 were distributed every 5, 10, 15, and 20m along the sampling line (where the organic matter and humus layer depth were measured). As for litter weight in each quadrant,

the material contained in 1m^2 was collected; the weight was recorded *in situ* and the dry weight in the laboratory for dry matter per hectare calculations.



Image 1— **Left:** Sampling lines established in the field for carrying out the forest fuel inventory. **Right:** Calipers used for measuring fuel material intercepted by the sampling line.

Forest Fuel Weight Calculation

The dataset derived from the fuel inventory was evaluated in a database created in Excel using formulas, according to Sánchez and Zerecero (1983), which determine the amount of fuel in ton/ ha.

Table 2— *Formulas used to estimate forest fuels.*

Class size (cm)	Formula
0-0.6	$p = 0.484 \times f \times c$
NI	
0.6-2.5	$p = 3.369 \times f \times c$
NI	
2.5-7.5	$p = 36.808 \times f \times c$
NI	
>7.5 (not rotten)	$p = 1.46 \times d^2 \times c$
NI	
> 7.5 (rotten)	$p = 1.21 \times d^2 \times c$
NI	

Where p is fuel weight, expressed in metric tons per hectare, f is frequency or number of interceptions, c is a slope correction factor, d^2 is sum of squares of the diameters of the branches and logs, and NI is total length of the sample line or sum of the lengths of the lines, in linear feet.

In order to obtain the litter or light fuel weight in ton/ ha, the obtained samples were dried in an oven at 75°C until they reached constant weight, then the conversion to tons of litter per hectare was done. Also, with the data obtained from litter depth, the arithmetic mean of all sites was calculated.

Results and Discussion

Below are the values obtained from the forest fuel inventory (Table 3).

Table 3—*Fuel load in the study area and arithmetic mean of the depth measurements obtained in the organic layer.*

Fuel loads in the study area according to their delay time (Ton/ha)								
Site	1 H	10 H	100 H	1,000 H non rotten	1,000 H rotten	Light (OM)	Total	Organic layer depth (cm)
I	0.44	1.21	8.88	0	0.58	3.08	14.19	2.86
II	0.62	1.92	0.46	0	0	2.96	5.96	4.44
III	0.47	1.21	5.14	0	1.69	3.51	12.02	4.33
IV	0.73	2.18	2.80	0	0.58	4.16	10.45	3.21
V	0.59	2.24	7.01	0	0.86	3.10	13.81	3.07
Ton/ha =	2.87	8.71	24.31	0	3.73	16.81	56.43	

Highest forest fuel amounts were found in sites I and V (Fig. 2), where it can be observed graphically that these two sites are nearly in the same range; similarly, site II showed the lowest fuel accumulation.

Total forest fuel loads

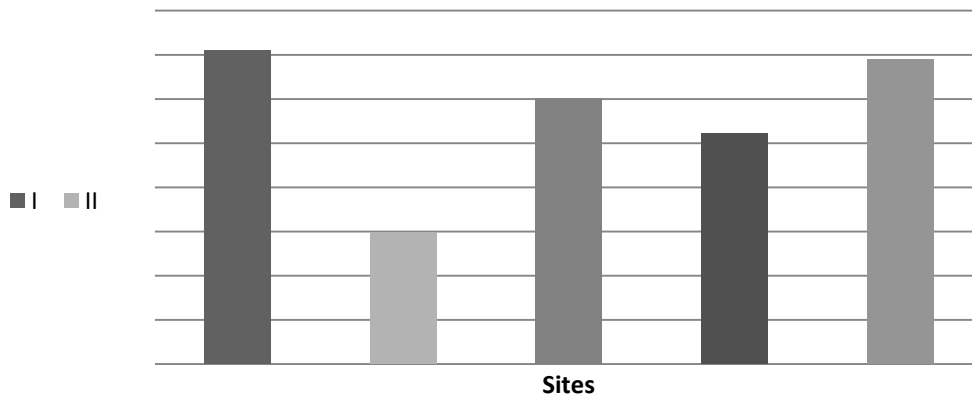


Figure 2—Total forest fuel loads per site.

The forest fuels with the highest accumulation in the planting area are those with a 100h delay time, representing 70% of the total woody material, which was 39.65 ton/ha, of which 24.31 ton/ha correspond to these materials). The 1h fuels had the lowest accumulation, contributing only 2.87 ton/ha.

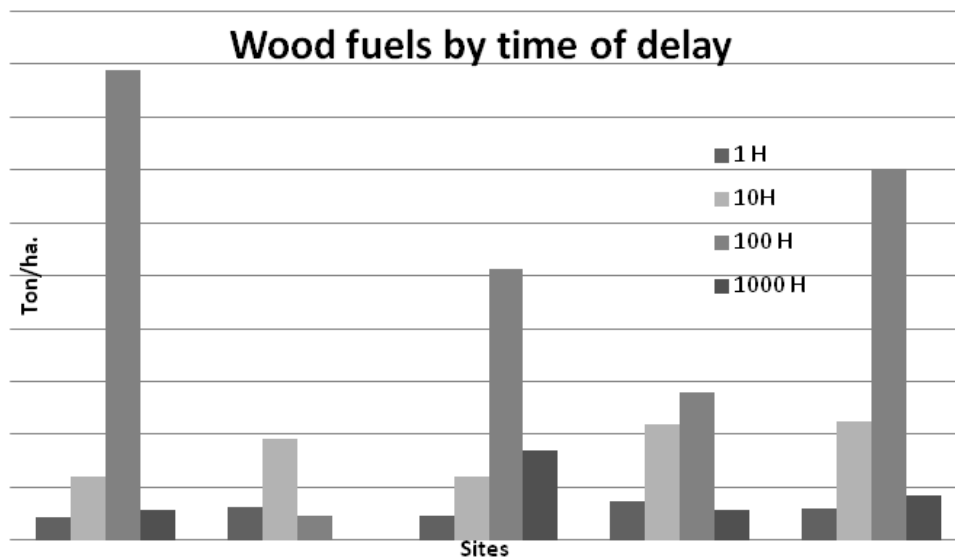


Figure 3 — Wood fuels by time delay (ton/ ha)

The fuel load of the organic layer contributes with 16.81 ton/ ha, representing 30% of the total load in the study area. It can be seen that the highest accumulation of light fuels is in site IV, in contrast with the lowest accumulation of these fuels in site II.

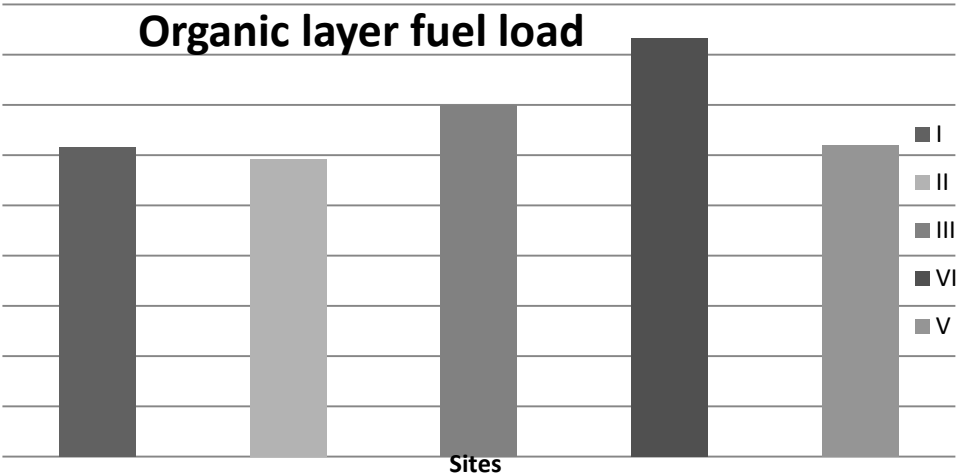


Figure 4—Organic layer fuel load

The arithmetic mean of the organic layer depth for the entire study area was 3.58 cm. The depth for I and III sites are in the same range, which is similar to sites VI and V; in site I, the organic matter layer was not as deep.

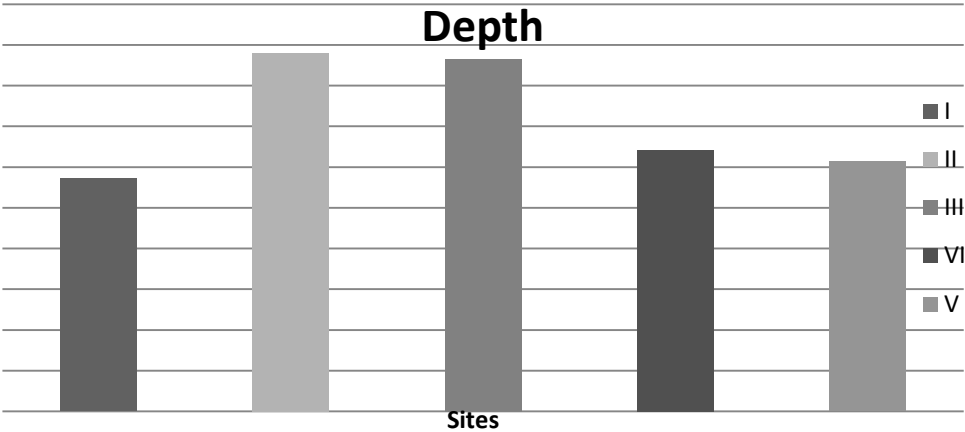


Figure 5 — Organic layer depth

Conclusions

Results indicate that due to the absence of management, there is a large accumulation of forest fuels that increases fire risk.

The implementation of fuel management tools, such as mechanical fuel removal or a controlled burn to reduce fuel availability, taking into account the guidelines established in the NOM-015-SEMARNAT/SAGARPA-2007, is recommended.

Furthermore, in the long term, the fuel accumulation time should be monitored in order to establish a controlled fuel control cycle and thus minimize forest fuel accumulation.

References

- Alvarado C.E. 1988.** Estimación del consumo por el fuego de combustibles forestales en rodales de *Pinus montezumae* Lamb. Combustibles muertos. *Agrociencia* 72: 74-85 pp. Colegio de Postgraduados. Montecillo, México.
- Bermúdez M.E; Anima J.B; Hernández J.A; González J.C. 2008.** Criterios para Evaluar Combustibles en Áreas Forestales. INIFAP. Folleto Técnico Núm 3. Primera Edición. 35p.
- Brown, J.K. 1974.** Handbook for inventorying downed woody material. USDA Forest Service. General Technical Report INT – 16. Utah, USA. 24 p
- DeBano, L. 1998,** *Fire's Effects on Ecosystems*, John Wiley and Sons, Inc.
- Flores Garnica, J. G., Benavides S., J. de D. 1994.** Efecto de dos tipos de quemas controladas en bosques de pino en Jalisco. Folleto técnico Núm. 5. CIPAC-JALISCO, INIFAP, SARH. México. 12 p.
- Flores Garnica, J.G., Moreno G., A.D. Morfín R., J.E. 2010.** Muestreo Directo y Fotoseries en la Evaluación de Combustibles Forestales. INIFAP. Folleto Técnico Núm. 4. Primera Edición. 69 p.
- Flores Garnica, J.G., Xhelhuantza C., J., Chávez D., A. 2010.** Evaluación del Impacto Ambiental de Incendios Forestales en el Bosque de la Primavera. INIFAP. Folleto Técnico Núm. 5. Primera Edición. 109 p.
- Nájera D., A. 2004.** Manejo de combustibles forestales. Apuntes de la materia Control y Uso del Fuego. Departamento Forestal de la Universidad Autónoma Agraria Antonio Narro. Buenavista, Saltillo, Coahuila, México.
- NOM-015-SEMARNAT/SAGARPA. 2007.** Que establece las especificaciones técnicas de métodos de uso del fuego en los terrenos forestales y en los terrenos de uso agropecuario.
- Sánchez, C.J., Zerecero, L.G. 1983.** Método práctico para calcular la cantidad de combustibles leñosos y hojarasca. Nota Divulgativa No 9 CIFONOR – INIF. México. 11 p.

This publication is available online at www.fs.fed.us/psw/. You may also order additional copies of it by sending your mailing information in label form through one of the following means. Please specify the publication title and series number.

Fort Collins Service Center

Web site	http://www.fs.fed.us/psw/
Telephone	(970) 498-1392
FAX	(970) 498-1122
E-mail	rschneider@fs.fed.us
Mailing address	Publications Distribution Rocky Mountain Research Station 240 West Prospect Road Fort Collins, CO 80526-2098

Pacific Southwest Research Station
800 Buchanan Street
Albany, CA 94710



Federal Recycling Program
Printed on Recycled Paper