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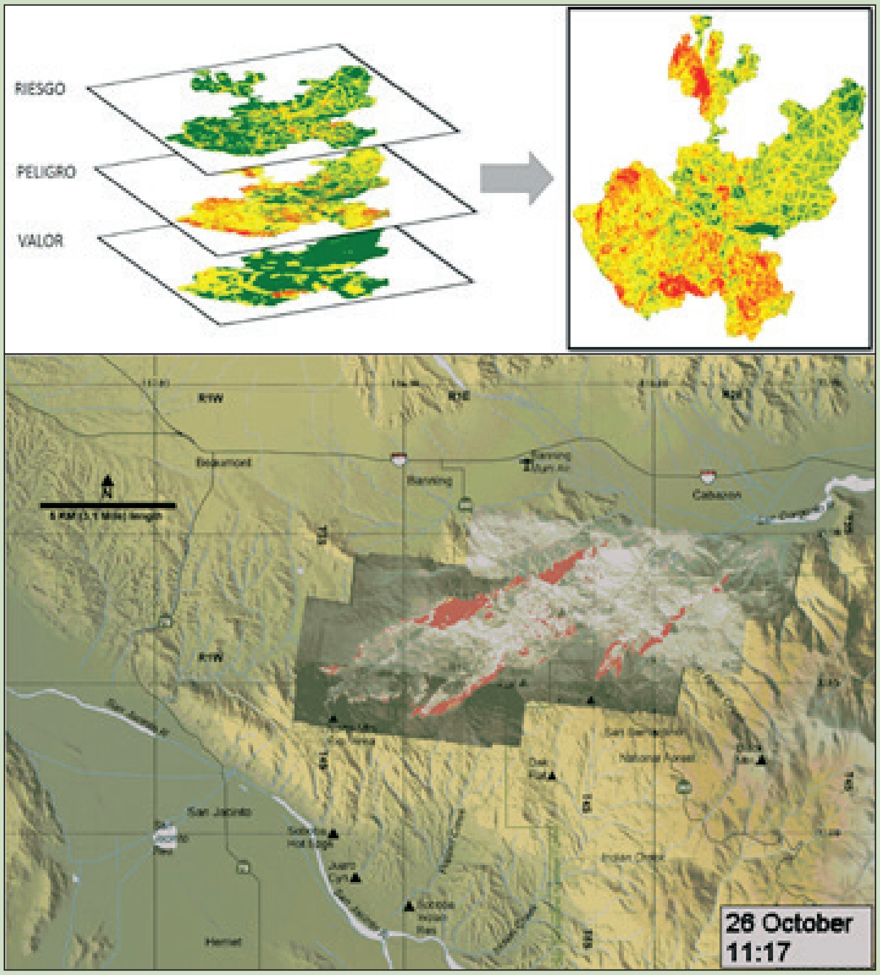

Forest Service

Pacific Southwest
Research Station

General Technical Report
PNW-GTR-261 (English)

February
2019

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Proceedings of the Fifth International Symposium on Fire Economics, Planning, and Policy: Ecosystem Services and Wildfires

Armando González-Cabán and José J. Sánchez

Technical Coordinators

U.S. Department of Agriculture, Forest Service

Pacific Southwest Research Station

Albany, California

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Abstract

González-Cabán, Armando; Sánchez, José J. 2019. Proceedings of the fifth international symposium on fire economics, planning, and policy: ecosystem services and wildfires. Gen. Tech. Rep. PSW-GTR-261 (English). Albany, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station. 241 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 ecosystem services and wildland fires: national and international perspective, 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, a poster session presenting examples of fire management plans and strategic fire resource allocation, and a final round table on ecosystem services and wildland fires, and international cooperation. Representatives from international organizations with fire protection responsibilities in 12 countries presented and discussed their experiences on the same issues. Twentyfour invited and contributed papers and 20 posters were presented at the symposium that described the issues and presented state-of-the-art techniques to address technical issues on fire economics, planning, and policy currently faced by land and fire managers.

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

Preface

Dear members of the Presiding Table, Distinguished Chancellor of the National Forestry Science University, Dr. Emilio Esbeih, Distinguished Secretary of State for My Environment Secretary, Eng. José Galdámez, Distinguished Director of the Institute for Forest Conservation, Wildlife and Protected Areas, Eng. Misael León Carvajal. Authorities, colleagues, ladies and gentlemen. Good morning to all of you with us today and the rest of the week. First of all, the most sincere thank for allowing us to visit your beautiful country and permit us to enjoy your hospitality. From 1991 to 1992 I had the opportunity to live in Honduras participating as a consultant to the then COHDEFOR in a forestry management program. It was a very positive experience in which I made very good friends! I am happy to reestablish my contact with Honduras and to start new friendships and contacts. Following let me share with you the reason for the symposium and its objectives.

The costs of wildfire management have escalated in the first decade of the 21st century, 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 not only true in the USA, but also 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. 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. 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. On the other hand, the increasing operational uncertainty in fire suppression strategies affects the efficient use of fire suppression resources. It is important to include the suppression efficiency of firefighting resources in relation to operational difficulties to find efficient fire management solutions.

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, and most recently in 2008, 2013, and 2014, 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 2010 to 2014 have made painfully clear the urgency to retake discussion of the topic and search for integrated solutions to the problem.

In the spring of 2012, the Fourth International Symposium on Fire Economics, Planning, and Policy to address the issues outlined here. One thing the previous four editions of this symposium has demonstrated is the relevance of incorporating an economic perspective in designing and implementing fire suppression and defence programs. Since then, disastrous events in the 2010 to 2015 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 ecosystem services and wildland fires; 4) pubic policies and forest management; 5) evaluate how international relations can help reduce the impacts of wildfires on ecosystem services, and 6) sharing recent developments in strategic fire management planning models.

Keeping in mind the objectives above let us take full advantage of this forum to communicate the knowledge developed, share experiences and learn from each other to improve our response to the management of wildland fires and understand its relationship with ecosystem services produced by forest resources, and the integration of economic analysis in wildland fire management programs

Thank you!

Armando González-Cabán
Tegucigalpa, Honduras
November 15, 2016

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International Relations for Reducing Wildfire Impacts – Some History and Some Thoughts[1]

Pieter van Lierop and Peter F Moore[2]

Abstract

In this paper, we describe the international activities that FAO has undertaken with partners over the years and then reflect on the role of international relations in reducing wildfire impacts on ecosystem services. FAO has long had a focus on wildfire management and been one of the international organizations facilitating the development of a comprehensive approach of Integrated Fire Management through applying the 5Rs; Review and Analysis, Risk Reduction, Readiness, Response to fires and Recovery. As a neutral global institution, FAO hosts secretariats for global and regional networks on fire management as well as a relevant FAO-statuary bodies. Every year, wildfires burn millions of hectares of forest woodlands and other vegetation, causing the loss of many human and animal lives and an immense economic damage, both in terms of resources destroyed and the costs of suppression. There are also impacts on society and the environment. In many instances, wildfires will have a bearing on the achievement of the Sustainable Development Goals (SDGs) and in some instances may threaten their success. Integrated Fire Management that is data based, information rich, scientifically sound and locally anchored in communities will contribute to successful SDGs and Paris Agreement implementation. Many bilateral agreements exist between countries to cooperate in the case of fire suppression, and many regional networks have been initiated to strengthen capacities in fire management, and mostly all promote integrated fire management, but they have not all been effective and sustained. One might conclude that the success of international efforts in integrated fire management, or any exchange on fires, has been limited. International relationships can undoubtedly contribute to reducing wildfire impacts. The strongest mode of this is likely to be through interaction and exchange, joint problem solving and sharing experience in fire management and research rather than pooling firefighting resources. In this respect the existing networks and working groups should be encouraged and supported.

Keywords: Integrated Fire Management; Wildfires; International Fire Agreements; Networks; FAO.

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[1] An abbreviated version of this paper was presented at the Fifth International Symposium on Fire Economics, Planning, and Policy: Wildfires and Ecosystem Services, November 14-18, 2016, Tegucigalpa, Honduras.

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Introduction

The issue(s) of wildfires and ecosystem services is a broad one but critical and it seems becoming more so. We have already in the last year seen Indonesian peat forests burning again and the Fort McMurray fire in Alberta; both impacting upon the services we expect from our landscapes (but generally do not see very clearly and tend to take for granted).

In this paper, we describe the international activities that FAO has undertaken with partners over the years and some that are in train and in planning. Having set out those elements, we then reflect on the role of international relations in reducing wildfire impacts on ecosystem services.

FAO Fire Management Role and Mandate

The FAO Ministerial Meeting on Forests and the 17th Session of the FAO Committee on Forestry, March 2005 (Rome, Italy 2005) called upon FAO, in collaboration with countries and other international partners, including the UNISDR, to develop a strategy to enhance international cooperation in fire management, that advanced knowledge, increased access to information and resources and explored new approaches for cooperation at all levels. They also requested preparation of voluntary guidelines on the prevention, suppression and recovery from forest fire. The need for such tools to assist in international cooperation had also been highlighted at the 3rd International Wildland Fire Conference and the International Wildland Fire Summit (Sydney, Australia 2003) because of the increasing incidence and severity of impacts of major fires globally.

An international expert consultation in wildland fires (Madrid, May 2006) agreed that the non-legally binding Strategy to Enhance International Cooperation in Fire Management includes the overarching framework and four components:

1. Fire Management Voluntary Guidelines;
2. Implementation Partnership;
3. Global Assessment of Fire Management; and
4. Review of International Cooperation in Fire Management.

These tools have been tailored primarily for land-use policy makers, planners and managers in fire management, including the Governments, the private sector and non-governmental organizations to assist in the formulation of policy, legal, regulatory and other enabling conditions and strategic actions for more holistic approaches to fire management. Their scope includes the positive and negative social, cultural, environmental and economic impacts of natural and planned fires in forests, woodlands, rangelands, grasslands, agricultural and rural/-urban landscapes. The fire management scope includes early warning, prevention, preparedness (international,

national, sub-national and community), safe and effective initial attack on incidences of fire and landscape restoration following fire.

FAO has long had a focus on wildfire management and been one of the international organizations facilitating the development of a comprehensive approach of Integrated Fire Management through applying the 5Rs; Review and Analysis, Risk Reduction, Readiness, Response to fires and Recovery.

Many actors are dealing with fires from different angles and on different levels: NGOs supporting community development; forestry companies; remote sensing research centers; governmental organizations responsible for agriculture, forestry, international cooperation and civil protection. Coordination, communication and a better exchange of experiences between all actors is essential.

In this continuing effort FAO has worked alongside and partnered with UNISDR, WMO, WHO and others including through the Regional Forest Commissions across the world. FAO has contributed an invaluable series of publications, projects, programs and services to its member countries and engagement with many other agencies, multi-lateral agencies, development partners, NGOs and INGOs and networks. Collaborating with these partners and member countries FAO will continue to support, lead and create technical publications of direct relevance in support of Integrated Fire Management that constitutes good practice and supports the implementation of these practices at policy and field level

FAO has a network of Regional Forestry Commissions, made up of the forest management agencies in member countries. Six Regional Forestry Commissions were established by the FAO between 1947 and 1959. Every two years, the Commissions bring together the Heads of Forestry in each major region of the world to address the most important forestry issues in the region. The Commissions consider both policy and technical issues. The Commissions play a key role in the international arrangement on forests, serving as a link between global dialogue at the Committee on Forestry (COFO) and the United Nations Forum on Forests (UNFF), and national implementation. The Regional Forestry Commissions are also active in-between formal sessions. Most of the Commissions have technical working groups or sub-regional chapters that implement projects that benefit from collaboration among countries in the region.

As a neutral global institution, FAO hosts secretariats for global and regional networks on fire management as well as a relevant FAO-statuary body:

- The Fire Management Actions Alliance which promotes integrated fire management through the use of the Fire Management Voluntary Guidelines;
- The UNECE/ FAO Team of Specialists on Forest Fire;

- Silva Mediterranea is an FAO statutory body that covers the Mediterranean region and is a forum for advising and taking action on key forestry issues for Mediterranean countries and also has a Forest Fires working group.

FAO is member of the European Forest Fire Information (EFFIS) Network (http://forest.jrc.ec.europa.eu/effis/about-effis/effis-network) of the European Union which meets twice a year i.e. before and after the main fire season. FAO is also member of the Wildland Fire Advisory Group, which brings the existing regional networks and working groups together and which meets once a year.

FAO works with a wide range of international organizations, multilateral and bilateral donors, regional and national institutions, governments, research and academic institutions, international and national NGOs, private sector (corporate and smallholder), civil society and other stakeholders. Included are organizations working directly or indirectly with fire management, such as:

- CIFOR, Fire Research
- Global Fire Monitoring Center (GFMC)
- Office for the Coordination of Humanitarian Affairs (UN-OCHA)
- International Strategy for Disaster Reduction (UN-ISDR)
- USDA Forest Service
- ITTO

Over the years, FAO has implemented more than 60 field projects in some 40 countries together with other UN Agencies and a number of bilateral donors. In these projects, the need for integrated and participatory approaches to fire management is stressed, including the involvement of local people in the planning and execution of programs; in the prevention, detection and control of wildfires; and in the sound management of the use of fire as a tool in management of agricultural, grazing and forest lands. Each project has also a strong country capacity development and legal review component.

Fires in the Global Context

The global estimate of land area affected by fire in 2000 was 350 million hectares, much of which was forest and woodland. Most of the area burned was in sub-Saharan Africa, followed at some distance by Australia (Fire management global assessment 2006). There have been a number of assessments conducted since and the issues of fires, damage and loss including of ecosystem services remain with us and are global in scale.

The role of fire in the world’s vegetation is mixed. In some ecosystems natural fires are essential to maintain ecosystem dynamics, biodiversity and productivity.

Fire is also an important and widely used tool to meet land management goals. However, every year, wildfires burn millions of hectares of forest woodlands and other vegetation, causing the loss of many human and animal lives and an immense economic damage, both in terms of resources destroyed and the costs of suppression. There are also impacts on society and the environment – for example, damage to human health from smoke, loss of biological diversity, release of greenhouse gases, damage to recreational values and infrastructure. All ecosystem values are being impacted by fires.

Most fires are caused by people. The list of human-induced causes include land clearing and other agricultural activities, maintenance of grasslands for livestock management, extraction of non-wood forest products, industrial development, resettlement, hunting, negligence and arson. Only in very remote areas of Canada and Russian Federation is lightning a major cause of fires.

There is evidence from some regions that the trend is towards more fires affecting a larger area and burning with greater severity, while the risk of fire may be increasing under climate change in association with land-use changes and institutional constrains on sustainable forest and fire management.

According to 11 years of Moderate Resolution Imaging Spectroradiometer (MODIS) satellite data for Tanzania, 10 to 14 percent of the land area is burned each year, or approximately 11 million hectares in a country of 88 million hectares. Protected areas, game reserves, game-controlled areas and forest reserves were found to be a significant proportion of the burned area.

In 2015, fires burned in three protected areas in Chile – China Muerta National Reserve, Nalca Lolco National Reserve and Conguillio National Park: 4 500 hectares were affected. Scientists in Chile are predicting that by 2050 average rainfall will drop significantly as a result of climate change. This can be expected to increase the risk of wildfires.

In May 2016, wildfires forced the biggest evacuation in the history of Alberta, Canada, when over 85 000 people left Fort McMurray in the face of fires driven by strong winds and an extended dry period. More than 2 600 homes and other structures were destroyed by the wildfires, which burned more than 241 000 hectares. The size, severity and intensity of the Fort McMurray wildfires exceeded anything that fire management plans had provided for. The fires affected the city, surrounding community, and the province of Alberta and Canada as a whole. Wildfire researchers noted that this very large fire was consistent with expected changes in Canada's fire regime as a result of climate change.

Fire Management Voluntary Guidelines

FAO has coordinated the development of the Fire Management Voluntary Guidelines aimed at helping countries develop an integrated approach to fire management, from prevention and preparedness to suppression and restoration.

The FAO Guidelines advise authorities and other stakeholder groups that fire-fighting should be an integral part of a coherent and balanced policy applied not only to forests but also across other land-uses on the landscape.

Fire Management Actions Alliance

Fire plays a critical role in nature and in land management:

- in maintaining fire dependent ecosystems,
- in providing an important and cost-effective land use tool, and
- in causing deforestation, forest degradation, emission of greenhouse gases and destruction of livelihoods, biodiversity and infrastructure.

The purpose of the Fire Management Actions Alliance is to stimulate improved fire management and reduce damage from fire worldwide. The Alliance was established 16th May 2007 at the 4th International Wildland Fire Conference in Seville, Spain by 40 founding members.

The Objectives are to:

- review and update the Fire Management Voluntary Guidelines;
- encourage stakeholders at all levels to adopt and use the Guidelines;
- review experiences from applying the Guidelines;
- develops / provides global examples of documents that support the Guidelines;
- strengthen international cooperation in fire management.

Fire Management Global Assessment 2006

Although globally the impacts of vegetation fires are increasingly recognized, there is a lack of information regarding their trends and underlying causes, especially at national level. Obtaining information on the occurrence, scope and damage generated by wildfires is one of the key challenges to be addressed, as a basis for designing effective national fire management strategies, especially in the field of prevention. More data are also needed to better understand the relationship between vegetation fires and climate change.

FAO prepared the Fire Management Global Assessment Study (2006) and since then global fire data were an integral part of the Global Forest Resources Assessment (2010, 2015). The collection of data and information on fires is also being considered for FRA 2020. Further steps are being made to develop a new global assessment to obtain more accurate data on areas burned at global level and to characterize the fire regimes at national level.

Forest Fires and the Law

Additionally to these tools and based on the Voluntary Guidelines FAO has developed Legal Guidelines for fire management and reprinted a Wildland Fire Management Training Manual to complement the fire management strategy publications, originally developed by the Finnish Ministry of Foreign Affairs.

Fire History Product

Wildfire is not being effectively brought under management and is compromising ecosystems, human lives, built assets and infrastructure, livelihoods and food security. Fires continue to effect landscapes and local people and create large volumes of greenhouse gases. In many places wildfires will have implications for achieving the Sustainable Development Goals. Wildfires are increasing and are upsetting the balance between natural fires that stimulate and sustain ecological processes, traditional fire use and community fire use. While what constitutes good practice in Integrated Fire Management is well established, many countries do not have systems in place to support the implementation of these practices at policy and field level.

Data on fire incidence, land area and biomass burned is weak in many countries and incomplete globally. Making available area burnt by fire over time cross-referenced to vegetation types would underpin the understanding and planning for Integrated Fire Management, a core and key step in wildfire Disaster Risk Reduction.

Strengthened country capacities and activities in the collection and flow of data to and within the country; fire management planning including through enhanced analysis of data and stakeholder engagement and implementation of fire management plans will enable the evidence based planning to reduce the number and extent and impacts of wildfires. Wildfires impact most often and most heavily on local people, community assets and the landscape in which they live and work. Reducing the damage and loss of wildfires will directly benefit communities and landscape values.

Good practice in Integrated Fire Management has been documented but a critical input to fire management planning, data on fire incidence, land area and biomass burned is missing. Many countries do not have systems in place to collect basic data to support the implementation of good fire management practices at policy and field level. Making available area burnt by fire over time cross- referenced to vegetation types would underpin the understanding and planning for effective fire management. This analysis can help focus efforts and resources on the critical areas where intervention and investment are needed; and raise awareness of the importance of wildfire management to the achievement of global objectives such as the Sustainable Development Goals and the UNFCCC Paris Agreement.

FAO has prepared a concept and will convene a series of meetings, with international experts and relevant agencies, experienced users and fire managers to; Characterize the needs of countries and prepare a 'State of Knowledge' on remote sensing fire data and identify future potential for fire data sources and their use.

The objective is to provide access to fire data for countries to conduct relevant analyses. The concept is to enable:

- selection of an area (such as country boundary or province or specifying an area)
- setting of time period, size range, other 'settable' aspects
- selection of characteristics to be displayed – active fire data, burnt area, fire radiative power
- potentially interaction with other data sets such as
  - land cover
  - land use
  - vegetation type
  - infrastructure
  - terrain
  - national statistics on population, income and poverty, health,
- summary statistics and analytics on numbers of fires and area burned:
  - by time period (day, week, month, season, year)
  - by tenure
  - by land use
  - by fire size
  - in proximity to means of access, infrastructure, protected areas, land uses, etc.
  - areas burned multiple times

Fires and Greenhouse Gas Emissions

Climate change is now generally acknowledged as the greatest environmental challenge of the twenty-first century, exacerbating major global threats such as hunger, poverty, population displacement, air pollution, soil degradation, desertification and deforestation. Forests play a key role in the global carbon cycle and thus in climate change. They store and, in growing, absorb huge quantities of carbon. When cleared, burned or degraded, however, they release carbon in the form of carbon dioxide and other greenhouse gases. Globally, forests currently contribute an estimated 10–11 percent of total greenhouse gas emissions.

Climate change also increases the risk of wildfires. Fire's behavior is largely determined, in order of importance, by wind, humidity (dryness of the air) and a long way third, temperature (an indirect measure of air dryness). Thus warmer temperatures and associated drier conditions can often increase the likelihood of a wildfire starting or spreading. These conditions also favor the spread of pests and diseases that can weaken or kill trees. Compromised trunks and branches can then accumulate to become a store of easily ignited forest "fuel".

Overall, global wildfires consume an estimated 5 130 million tons of biomass per year, 42 percent of which is burned in Africa, including fires associated with deforestation. This burning releases approximately 3 431 million tons of CO2, as well as significant quantities of other greenhouse gases.

In Tanzania, FAO developed a study on carbon accounting and vegetation fires. The calculation has provided estimates for a single year, annual, of emissions from fire of CO2, CO, CH4, N2O and NOx. The results are directly proportional to the area burnt with a larger area burnt leading to a larger estimate of emissions. Overall figures for CO2 emissions per annum on average for 11 years of burned area for two Districts was approximately 27 million tons of CO2. It has been identified that the amount of CO2 emissions annually from vegetation fires in Africa is very large and for savannah fires is estimated at approximately 22% of the biomass burned globally. A relatively small change to the fire regime could have significant consequences for the net global carbon budget and for Tanzania's reporting under its international obligations.

Indonesia has also been seriously affected by fires. Between June and October 2015, 2.6 million hectares of forested land burned. This is a scenario that has been repeated a number of times in every decade since 1983. The impacts on the population of Indonesia and on some neighboring countries include impaired health, disruptions to transport and to Indonesia's economy in particular. The cost to Indonesia is estimated at more than US$16.1 billion. Greenhouse gas emissions are estimated at approximately 1 750 million metric tons of carbon dioxide equivalent (MtCO2e), nearly the same as Indonesia's estimated annual economy-wide emissions of 1 800 MtCO2e per year. Fires like those in 2015 will make Indonesia's task of reaching its 29 percent GHG reduction target extremely difficult to achieve.

Damage and Loss

FAO has a Strategic Program focused on making the case that prevention (risk reduction) is more economically sensible behavior than firefighting (response). A strong setting out of the impacts on ecosystem services of wildfires will provide further support to that thesis.

The nexus between "damage and loss" as experienced in human terms and the ecosystem "damage and loss" and the issues of pricing these values and the implications of accepting the values and factoring them into national to local planning and international interactions and arrangements. This may potentially lead to rational behavior in planning to manage wildfires. That would see an emphasis on research and analysis of causes, sources and motivations for wildfires, risk reduction and preventing wildfires, preparedness (early warning for early action). It would also include an emphasis on systematic community engagement, alternatives to fire use, planned and programmed deliberate fire use for ecosystem health, and appropriate investment to initiate and sustain such programs including continuous improvement.

Integrated Fire Management and successful SDG and Paris Agreement implementation

In many instances, wildfires will have a bearing on the achievement of the Sustainable Development Goals (SDGs) and in some instances may threaten their success. In relation to the role and impacts of wildfire and fire management on the SDGs, those of particular interest are Goals, 1, 2, 3, 7, 13 and 15. IFM reduces the risk of impacts on the fundamental elements underpinning the SDGs, frames up sensible use of fire where appropriate and seeks to mitigate some impacts. Specifically:

- Fires regularly damage crops, assets and create costs for recovery that impoverish or make people food insecure. Integrating fire management, including prevention and sensible use, into agriculture, pastoralism and forestry reduces the risk of this damage and loss that locks people into poverty and a cycle of food insecurity.
  - Goal 1: End poverty in all its forms everywhere
  - Goal 2: End hunger, achieve food security and improved nutrition and promote sustainable agriculture
- Access to reliable supplies of fuel is a critical aspect for maintaining health and wellbeing. The bulk of the world's poor use wood as fuel, and losses of trees and timber to fires compromise the quality and supply of wood. This leads to the use of less suitable fuels that may require more effort to collect and generate impacts on health; directly through smoke and particulates when poor fuel burns less efficiently, and indirectly through the additional effort – expending more time and energy to collect

fuel?–, range more widely or collect more quantities of less optimal fuels.

  - Goal 3: Ensure healthy lives and promote wellbeing for all at all ages
  - Goal 7: Ensure access to affordable, reliable, sustainable and modern energy for all

- Globally, fires release approximately 3 431 million tons of CO2, as well as significant quantities of other emissions. The scale and scope of wildfires has been increasing. The application of IFM, starting with the compilation of a data and information base that creates understanding, can reduce unwanted fires and their emissions, contributing to the nationally determined contributions that countries made in Paris in 2015.
  - Goal 13: Take urgent action to combat climate change and its impacts
- Wildfires are a significant factor in forest degradation, destruction and land-use change. Landscape integrity and biodiversity as well as catchment, livelihood and protective values can all be compromised by wildfires, sometimes for extended periods perhaps many decades. IFM reduces the risk of these impacts, damage and loss.
  - Goal 15: Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss

Reflection on the Past

Integrated Fire Management that is data based, information rich, scientifically sound and locally anchored in communities will contribute to successful SDGs and Paris Agreement implementation. Using well-conceived IFM policies and programs, countries can plan coherently at the landscape scale to ensure the sustainability of natural resources, livelihoods and cultural values in ways that address poverty, health, equity, sustainability and wellbeing. Appropriate, urgent action on sustainable fire management offers another avenue to reduce greenhouse gas emissions, adapt to climate change and strengthen the planet’s resilience.

Bilateral agreements

Many bilateral agreements exist between countries to cooperate in the case of fire suppression. They depend on the commitment of sovereign countries, each with their own requirements, opportunities and challenges. They set frames for issues like:

- In the case of big and long lasting fires the exchange of fire crews which takes places at times between Canada, USA, New Zealand and Australia took nearly a decade to put in place. It mostly sees middle level fire managers exchanged, as they are the most useful resource and the ones that 'burn out' most quickly hence having to be rotated off the fire for a break. Recently South African crews helped to fight fires in the USA and there has also been exchange of firefighters from Chili to South Africa.
- Bilateral agreements also may help to define cross boarder activities for neighboring countries like in the case of Spain and Portugal and France and Italy.
- Bilateral agreements also might coordinate the use of heavy equipment, such as aircraft, between neighboring countries.
- Based on the existing agreements FAO helped to develop a format for bilateral agreements.
- There are not many examples of coordination of exchange above the bilateral level. One example is the MICC, a European coordination mechanism which tries to coordinate the offer of fire planes in Europe in the case one of the member countries is facing fires above the level they can handle.

Based on many bilateral agreements relating to fire management FAO developed a format for bilateral agreements.

Networks/working groups

Many regional networks have been initiated to strengthen capacities in fire management, and mostly all promote integrated fire management, but they are not all effective and sustained.

Some are working groups with strong institutional settings and national political support like the North American Forestry Commission Fire Management Working Group and the Asian Pacific working group on fire management. The Working Groups are a forum for exchanging experience and technology for the protection and control of forest fires; for cooperation among the member countries to develop strategies and actions to solve technical and management problems; and to actively participate with international agencies to conduct and promote activities that will foster world-wide cooperation and development.

Many other regional networks have been set up under the umbrella of the Global Fire Monitoring Centre and mainly serve for capacity building and exchange of experiences. Without strong government support they depend heavily on project support when projects are available. Lacking a clear institutional base however complicates obtaining projects, so they often depend on bigger national projects.

Especially the Africa regional fire management network is not very visible and lacks activities.

In between these two groups one can place the Silva Mediterranea working group on fire management and the Fire Management Network for Mesoamerica of the Central American Commission of Environment and Development; they have strong institutional settings but also depend on projects for their functioning as they lack strong political support. Because of their strong institutional settings they have been successful in obtaining project support from time to time.

Besides these regional fire management networks or working groups, other thematic ones exist like:

- Several regional networks of the GOFC/Gold Network mostly dedicated to research
- The European Commission's Expert Group on Forest Fires comprises the national correspondents to the European Forest Fire Information System (EFFIS).
- The International Fire Aviation Working Group (IFAWG) comprises representatives from countries and jurisdictions who regularly utilize aerial means in managing landscape fire, including for firefighting

International cooperation

While over the years many projects have taken place in developing countries by national or multilateral development agencies to strengthen national capacities in integrated fire management, it is very difficult to measure the impact and uptake. One might conclude that the success of international efforts in integrated fire management, or any exchange on fires, has been limited. The efforts often include development or revision of national policies and legal frameworks, pilot awareness raising, prescribed burning activities, pilot training of local (community-based) fire crews. What remains behind often are a series of workshop reports, proceedings, guidelines, manuals and other documentation (now often websites).

However the experiences of bilateral and multilateral activities in many cases have also led to the development of guidelines which can be used by other countries or cooperation to strengthen their capacities. (Fire Management Voluntary Guidelines, Legal Framework revision, Best cases in Community Based Fire Management etc.)

More attention should go to these activities which are not visible as fire management activities; land and landscape management activities which reduce the incidence and impacts of fire, as well as supporting policy and legal frameworks.

Conclusions

Reflecting on the experiences of the past efforts at fire management exchange enables some reflections on the potential of international relations for reducing wildfire impacts. The efforts have had mixed success and few of them have been able to persist. Those examples of groups that have continued over time deserve careful study and analysis to better understand the factors that have enabled their endurance. Candidates for analysis include Working Group 1 of Silva Mediterranea, some of the regional networks set up under the umbrella of the Global Fire Monitoring Centre and the European Commission's Expert Group on Forest Fires.

Sustainability requires funding to be available and stable, interested agencies supported by governments and interested and committed individuals to participate. This is not always feasible. Government officers have full time jobs and are accountable to perform their allocated tasks to fulfill the institutional mandate. In many countries governments are still in the process of developing and formulating effective governance and functional agencies, meaning there are usually limitations on resources and constraints on capacity.

International relationships can undoubtedly contribute to reducing wildfire impacts. The strongest mode of this is likely to be through interaction and exchange, joint problem solving and sharing experience in fire management and research rather than pooling firefighting resources. In this respect the existing networks and working groups should be encouraged and supported. FAO through its regional forestry commissions and over 130 country offices can contribute connectivity and create opportunities for continued collaboration.

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Evolution of Nonmarket Values Valuation in Wildland Fires: An Intertemporal Analysis[1]

Jeffrey Englin[2]

Abstract

Forest fires and their legacy form an inherently dynamic relationship between ecology and human uses of the forest. This paper provides an overview of the dynamic dimensions that are present in the aftermath of a fire. These include the evolution of social benefits as the ecology recovers and the role of discounting.

Keywords: Wildfire, non-market valuation, discounting

Introduction

Forest fires vary greatly in their ecological effects. In some fire adapted forests fire is a critical element in the reproductive cycle of the forest. One can think of the Jack Pine forests of central North America. The interruption of the fire cycle there resulted in a generational interruption in the forest's lifecycle. Or the Ponderosa Pine forests of the Sierra Nevada where the suppression of the fire cycle result in forest succession away from Ponderosa Pine and towards White Pine, a pine which is not fire tolerant. In other settings however, especially ones where the fire cycle has been interrupted and the fuel loads are very heavy, fires are quite destructive. The effect of fires is to savagely damage the ecology and make recovery very slow and perhaps impossible.

The social costs and benefits of recovery are dynamic. They evolve over time as the forest adapts to the fire and recovers. The path of recovery provides a path of costs and benefits to society. Englin et al (1996) were the first to suggest a shape to the recovery of benefits from a forest fire. They suggested a sudden loss in recreational benefits that slowly recovered through time as the forest returned with the maximum benefit coming when the forest had returned to old growth status. As will be expanded on later the Englin et al (1996) was naive and later work has fleshed out the actual path that recreational benefits take in recovery.

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[1] An abbreviated version of this paper was presented at the fifth International Symposium on Fire Economics, Planning, and Policy: Ecosystem Services and Wildfires, November 14-18, 2016, Tegucigalpa, Honduras.

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Finally, one must also look carefully at the role of discount rates. There is a burgeoning literature (Arrow et al (2013) on the proper discount rates for projects that that are especially long lived. The return of many forests after a fire is an example of such a resource. This work suggests that evolving social values of forests may have important impacts on cost benefit analyses involving forests. Importantly, if the suggestion by Krutilla (1967) holds any merit the implications for forest policy.

The rest of the paper continues in the following way. It will discuss the issues with static analyses of the forest problem and discuss a case study in Jasper National Park in Alberta, Canada. It will include some observations about what this may mean for Central America. It will then present some findings on the way recreational values for forests are evolving through time. Krutilla's suggestions are fit into this framework. Finally, the paper sums up its suggestions going forward.

The problem with static analysis

Static analysis does not account for the dynamic evolution of the world. It does not account for either ecological or social change. It is well known that interference in natural fire cycles is problematic but even natural fire cycles are dynamic. This section focuses on the recovery of social values after a fire. Englin et al (2006) examined the ecological rate of recovery following a forest fire.

That study utilized the Canadian National Parks Inventory Program which produced a massive, carefully collected, database documenting ecological disturbances going back 700 years. Jasper National Park is a large national park covering 10,878 km^2. It has over 1,000 km of developed trails. It also maintains a mandatory permitting system which provides a source of behavioral data. Most trails start along river basins and precede either along the river or up into the mountains. Some reach 2200 meters. As a result there is a range of ecosystems that are encompassed in the data. Appendix A shows a map of the trails.

Englin et al (2006) analyzed of the Canadian National Parks Inventory and found three main vegetation types in Jasper National park. These include lodgepole pines, spruce-juniper and alpine meadows. In addition the fine detail of the ecological data allows the age of each stand to be identified. The tree cover was broken down to Lodgepole between 30 and 124 years old, Lodgepole between 125 and 299 years old, Lodgepole between 300 and 500 years old, Spruce/Fir between 30 and 124 years old, Spruce/Fir between 125 and 299 years old and Spruce/Fir between 300 and 500 years old. The model also included Alpine meadows and Tundra both measured in km^2.

Since the welfare effects of aging forests was measured using the Small and Rosen (1981) formula

$$Compensating\ Variation = \ 1\ /\ \beta\ \ \ln(\sum \exp(v\hat{}0\ ) - \sum expln(v\hat{}(1))$$

It is important to note that the value of old growth forests will vary considerably depending on the value of other attributes on the trail (see Lancsar and Savage (2004). The results reported in Englin et al (2006) have a couple of important attributes. One is that the lodgepole forest whether young or of medium age (up to 299 years old) has a small positive value. They mostly range from $0.50 to $4.00. The most valuable lodgepole old growth however adds $500 per trip for stands between 300 and 500 years old. This is substantial.

Similar findings follow Spruce/Fir results, although young Spruce/Fir forests are actually negatively valued. This is most likely because young Spruce/Fir forests are thick, dark and house flies and mosquitos. Old growth Spruce/Fir (stands 300-500 years old) were worth $150 per trip.

To summarize the econometric findings there is a bump in amenity values for about 30 years after the initial fire. This is believed to be the result of the novelty value of the fire and the flowers and foliage that grows immediately after a fire. The fire also opens up views that did not exit previously. After that amenity values drop rapidly and become negative and then steadily climb back to zero at about 125 years. Then, the increase continues for more than 400 years! This is all consistent with the ecological changes that are playing out over those time periods. Old growth forests are messy places. They have fallen, rotted trees, which support moss and ferns which in turn support insects, birds and animals consistent with an old growth forest. The entire process of becoming a true old growth forest takes time. What is remarkable is that we can see in actual behavior that people do know the difference and that they value it.

The key finding here is that forest's aesthetic values can recover very slowly. Losses of old growth forests are multi-generational events. It takes a very long time for forests to return to true old growth states. Trees must die and fall and rot before the historical ecosystem can return. Centuries must pass. Recognizing the dynamic nature of these impacts is very important. Note that because of discounting of benefits it is not important to understand the preferences of generations several hundred years out but it does suggest that some of our old growth forests should be thought of a non-renewable. One cannot tree farm their way out of the loss of old growth forests.

Policy in the Long Run

Recently Arrow et al (2013) has raised the specter of uncertainty about of discount rates and its implications for climate change. Interestingly most of the high impact effects fall into the time frames of forestry management. The focus of their line of inquiry is what does it mean when real discount rates have a random component

They suggest the following mind experiment. Consider the case where the average discount rate should be 4%. In a non-random world the discount rate would be 4%; this is the typical application of the cost benefit analysis. Now suppose that the true discount rate 1% is equally as likely as 7%.

Table 1 presents discount value of $1,000 in year zero going forward. The top of the table labels each of the columns. The classic 4% discount case is under the 4% heading. The 1% and 7% cases are under the 1% and 7% headings. These streams behave as one would expect. The value of $1,000 in 100 years at a 7% discount rate is $0.91, not too much. Now examine the equally likely column, this is the average of the 1% and 7% columns. Early on the 4% column and the certainty equivalent column are close, but as time goes on they diverge significantly. The final column provides the certainty equivalent discount rate. Notice that it gets smaller and smaller as time goes on. By year 50 it is 1.28%!

Table 1. Certainty and Certainty Equivalent Discount: An Example

Year	1%	4%	7%	Equally Likely 1% or 7%	**Certainty Equivalent (%)**
1	$990.05	$960.79	$932.39	$961.22	**3.94%**
10	$904.84	$670.32	$496.59	$700.71	**3.13%**
50	$606.53	$135.34	$30.20	$318.36	**1.28%**
100	$367.88	$18.32	$0.91	$184.40	**1.02%**

This suggests that each year going forward should have its own, declining, discount rate. Projects that have benefits reaching out into the future should be discounted at lower rates to reflect the inherent uncertainty surrounding discount rates.

This has dramatic impacts on optimal forestry policies. Future damages that used to be discounted away are now relevant. When damages 30 years out are only discounted at a certainty equivalent discount rate they are valued at $318.36, not $135.34. Future damages will weight much more heavily in any analysis.

One can also speculate about the effects of rising social values. Suppose Krutilla's (1979) speculation that natural environments will grow in value through time is true. One can certainly see that rising values would act as a further reduction on discount rates. If eco-tourism continues growing in stable regions of Central America it means that much greater preservation of natural environments will take place under the certainty equivalent discounting rules.

As discussed below society is changing and certainty discounting rules would give greater voice to the future. Given the relative irreversibility of many change to forests certainty discounting has great value.

Forest Fires in an Evolving World

One also has to consider the evolution of society. Social values are not stagnant. Changes in national wealth, individual incomes, generational cohort effects and other concerns drive social values. These changes seem especially important if one adopts a certainty equivalent discount rate.

Englin and Holmes (2016) have undertaken a study of the long run evolution of recreational values of backcountry hiking. This activity is has been studied extensively and is well understood. The question they sought to address is whether Krutilla's (1967) conjecture that wild places were going to become more valuable in the United States was supported empirically.

Englin and Holmes (2016) based their analysis on backcountry hiking permits. They combined backcountry hiking permits for 21 US Forest Service wildernesses (Alpine Lakes, Ansel Adams, Black Elk, Boundary Waters, Emigrant, Glacier View, Goat Rocks, Golden Trout, Indian Heaven, John Muir, Mokelumne, Mount Adams, Mount Hood, Mount Shasta, Salmon Huckleberry, Sawtooth, Selway Bitterroot, Tatoosh, Trapper Creek, Weminuche, William O. Douglas) with hiking permits from Yosemite National Park.

They were able to develop ecosystem data from the US Environmental Protection Agency’s Level 3 ecosystem categorization. The ecosystem types covered by the data included Blue Mountains, Central Basin and Range, Eastern Cascades Slopes and Foothills, High Plains, North Cascades, Northern Lakes and Forests and Sierra Nevada. These ecosystems cover a broad range of United States ecotypes.

They also developed demographic characteristics using the US Census. They interpolated between the 1980, 1990 and 2000 censuses by zip code to create a series of demographic characteristics. For the years after 2000 they extrapolated from earlier censuses. It should be noted that there is dramatic demographic migration over this time period. Finally, travel costs were assigned using US Internal Revenue tables of the cost per mile to drive. All costs, incomes and other pecuniary variables were brought up to current dollars.

Their econometric analysis was based on the linear exponential demand model (see LaFrance (1990), von Haefen (2002)). Linear exponential model use the exponential link function to link quantity demanded to exogenous regressors. The model is specified as:

$$\lambda_{ij} = e^{(P_{ij}, Z_j, \beta)} \qquad i = 1, 2, \ldots\ldots N \qquad 1$$

where λ_{ij} is the ith person's trips of the jth park, P_{ij} is the travel cost for the ith person to the jth park, and Z contains the characteristics of the parks and individuals and β is a vector of parameters to be estimated. The model is estimated as a log linear model:

$$\ln(\lambda_{ij}) = \alpha + \beta_p P + \sum \beta_k Z_k$$

Where P is the travel cost and Z_k are individual and site attributes.

Welfare calculations in count models are straightforward. One integrates the demand curve with respect to price ($\int \lambda_{ij}\, dp$) and the result is λ/β_p where λ is the trips taken and β_P is the coefficient on the travel cost. A commonly used welfare measure is the per trip consumer surplus which is simply $1/\beta_p$. The econometric results are all well behaved and show the usual signs. Demand curves are downward sloping and all the parameters are significantly different from zero at conventional levels.

The critical finding is that consumer's willingness to pay is rising through time. As a result there is support for Krutilla's supposition that wilderness may grow in value over time. Income elasticity drops over time. The growth in consumer's willingness to pay is small annually, on the order of 0.05%. Nevertheless the growth is significantly different from zero.

In an interesting sidebar Englin and Shonkwiler (1995) developed a model to correct for endogenous stratification and truncation in a negative binomial model of recreational site demand. They apply the model to a 1981 survey of on-site surveys of backcountry hikers in the Cascade Mountains. Using the estimated parameters they forecasted consumer surplus going forward to 2020 using forecasted population characteristics based on census data. This is of course a rather different methodology than using backcountry hiking permits. Nevertheless they projected a growth in consumer willingness to pay of about 0.05% per year. It is striking that the two approaches converge in their estimates of the growth in consumer willingness to pay despite the differences in methodology and time frames of the samples.

This is an important finding if one wishes to consider the effects of certainty equivalence discounting. If certainty equivalent discount rates effectively fall through time and values are growing through time then the appropriate discount rate should fall even faster since it will be the net of the negative effective discount rate and the growing consumer willingness to pay.

Simulations using the findings suggest that the net certainty equivalent rapidly approaches zero near year 50. This suggests that benefits far into the future are essentially undiscounted in a conventional sense.

Conclusions and Observations

Despite the evidence against it static forestry management continues to be practiced regularly. There are many dynamic and uncertain forces arrayed against the static approach. Change matters. Both eco-systems and societies change. These changes need to be modeled effectively.

Forest disturbances such as fires and invasive species impact forest health and utility. The way in which these disturbances impact forests through time has a random component but the paths are knowable. Because we can know the trajectories of recovery we can plan the best paths of recovery. It is possible to incorporate the trajectories and the random components into decision making.

The impact of these choices is extraordinary. After the removal of old-growth forests it can take centuries to recover aesthetic values. The case of Jasper National Park should be a sobering one. But, at least those forests can recover. In some places the impact of fire, insects or harvesting can damage soils making it impossible for the forests to recover. The application of certainty equivalent discounting makes these losses vastly more pronounced.

Certainty equivalent discounting profoundly changes the relationship between current policy choices and the future. With certainty equivalent discounting the future plays a much larger role in current decision making. Future benefits are worth a great deal more in today’s terms. It seems likely that social evolution will also play a role.

While there are large fields of research into the complexion of future societies this work is rarely explicitly incorporated into current cost benefit analysis. Yet, as can be seen, there is every reason to believe that incorporating those effects can completely tilt the balance of how forests should managed.

Finally, much of this should be fairly common sense. The challenge is to quantify these effects and incorporate them into policy models. Quantifying these effects is an effort that requires data and careful analysis. Luckily our access to data models is just getting greater and greater. It seems that one should be optimistic about the future.

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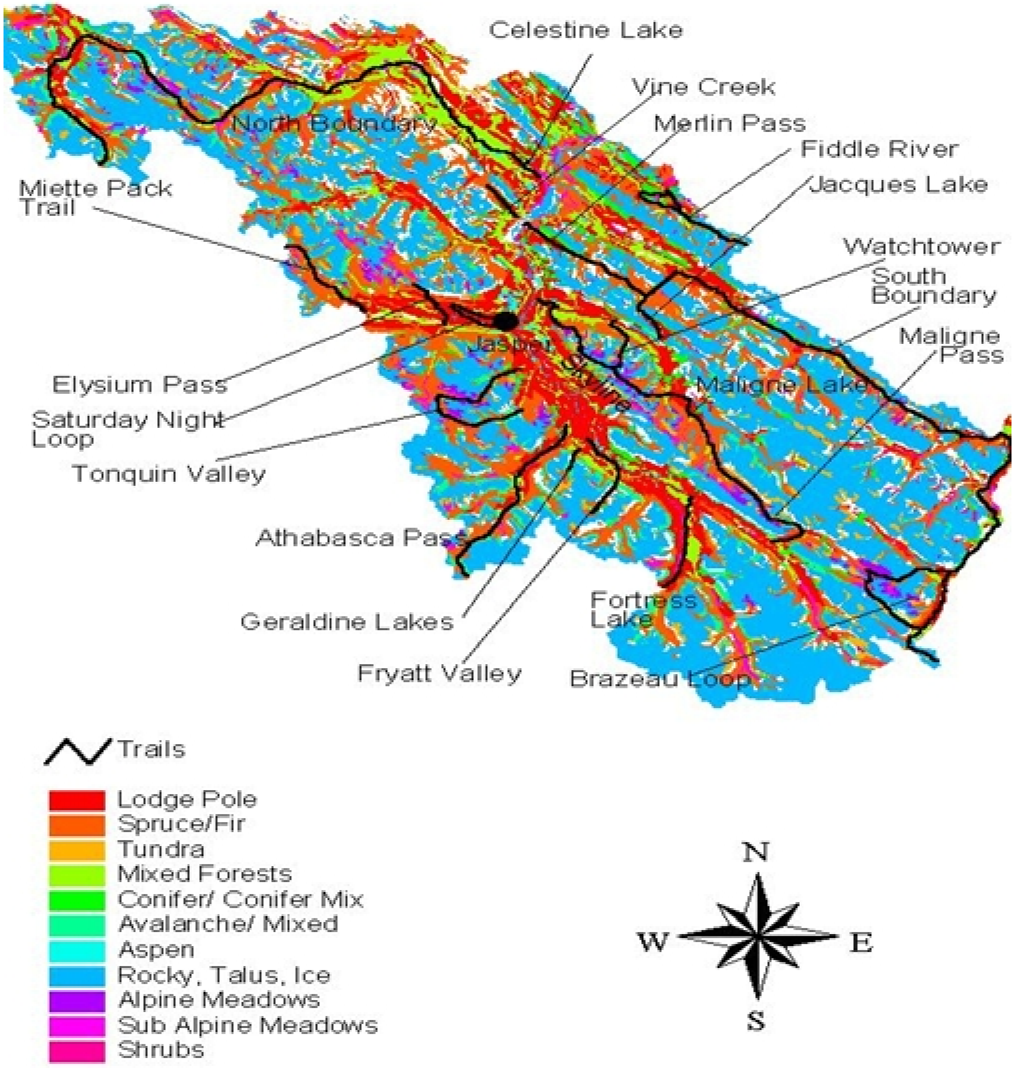
Appendix A



A.1 Trails of Jasper National Park taken from Figure 3.2 in Mc Donald (2000).

FireBuster: A Tool for Fire Management[1]

John W. Benoit and Shyh-Chin Chen[2]

Abstract

We developed an experimental high-resolution fire weather forecast system called FireBuster to help fire management in California. This system streamlines and automates many processes required to deliver timely fire weather intelligence. FireBuster provides routine twice-daily 72-hour weather forecasts in real-time for California at a 5-km grid resolution. Authorized users can select part of the domain and request a 1-km resolution 72-hour forecast with only a few clicks. Forecast outputs include near surface values of temperature, relative humidity, wind speed and direction, precipitation, and several specialized variables. Each forecast run (5-km and 1-km resolution) takes from 1 to 2 hours to process on our in-house computing hardware.

FireBuster delivers information, as each 6-hour increment completes, via a web page which visually depicts the forecast over an interactive map. The user can view future weather conditions hour-by-hour over the entire domain. When available, weather data from the MesoWest observational network can be displayed for post-evaluation. Additional features are in development, such as a format of the gridded output that can be downloaded for input into FARSITE, a popular fire spread model.

The Southern California Geographic Area Coordination Center (GACC), which manages all regional fire-fighting resources, is the intended user of this system. Collaboration with the GACC's fire meteorologists has provided us ongoing feedback on how to best improve FireBuster. The next development phase of the system includes adding forecasted fire danger indices, observed fire perimeters and an economic data layer so that FireBuster can truly be part of an integrated fire management tool.

Also, we developed a related parallel system, called FireBusterSim, to examine the downscale simulation. FireBusterSim works similar to FireBuster, but produces downscaled weather given archived global analysis data. Both 5- and 1-km grid cell resolution model runs are made over the area of the fire. Increased spatial resolution is shown to indeed provide better accuracy in model data. Incorporating finer topographic details into the model improves weather prediction in complex terrain where fires often occur.

Keywords: Decision-making, fire weather, meteorology, high-resolution weather model, fire management.

Introduction

Weather is the most important factor in determining fire behavior, yet it remains the most elusive to predict, especially at high resolution over complex terrain. To forecast future weather conditions, a fire manager may extrapolate from current conditions, given just the observed weather or climatology. However, this method

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[1] An abbreviated version of this paper was presented at the Fifth International Symposium on Fire Economics, Planning, and Policy: Wildfires and Ecosystem Services, November 14-18, 2016, Tegucigalpa, Honduras.

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does not capture variations from the norm, or extreme weather events. It is often necessary to overcome this by relying on output from coarse weather models that still do not accurately represent the area where fire events are occurring. Additionally, such models may not forecast on a timescale that captures the daily variability of local weather patterns.

High-resolution weather models can provide a better picture of what is happening in complex terrain to fire managers and firefighters. Unfortunately, these models can be computationally expensive and require a large amount of time to produce usable output. Complex model output can also be difficult to interpret and require specialized personnel to process.

Fire managers can make use of a fire weather forecasting tool that is easy to use, readily available, and can provide fire weather information that is timely and detailed. This paper describes such a weather forecasting system that we have been developing called FireBuster, which can be used operationally by fire personnel.

Objectives

Although extensive research went into the development of FireBuster, its ultimate purpose it to be use in an operational setting. The main objectives of the FireBuster system are:

- To be easy to understand and use by fire management personnel, including incident meteorologists and firefighters.
- To be accessible to operational personnel.
- To provide timely, accurate, and detailed fire weather information.
- To allow interaction so that the user can extract specific information for a place or time.

The California Department of Forestry and Fire Protection (CAL FIRE)[3], U.S. Forest Service Region 5[4], and other California fire management agencies are currently the intended users.

Methodology

FireBuster uses the mesoscale spectral model (MSM, Juang 2000) from National Center for Environmental Prediction (NCEP). MSM is the non-hydrostatic version of the Regional Spectral Model (RSM, Juang and Kanamitsu 1994), which has been used in many of our previous regional modeling work (e.g. Chen et al. 1999; Chen et

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[3] See http://www.fire.ca.gov .

[4] See http://www.fs.usda.gov/r5 .

al. 2008; Roads et al. 2010). Forecasts are computed for all of California at 5-km grid cell resolution. That is, forecasted values are produced for every five square kilometers over California. The domain grid measures 243 by 243 square cells. The MSM produces a set of weather variable grids for every hour out to 72 hours into the future. We initiate each forecast by downloading a portion of the daily output from NCEP's Global Forecast System (GFS), which has a resolution of 0.5˚ in latitude-longitude interval, and downscaling it using the MSM. The model can also be run at a 1-km cell size, but since it would take an unacceptably long time to process the area all of California at this resolution, we only perform these runs for the areas and the times, usually for fire events, specified by user. The domain for the 1-km run is also reduced to 96 by 96 cells. The 1-km forecast runs use the 5-km forecast for initial conditions, so these finer scale runs must be nested within the coarser, larger ones (Figure 1).

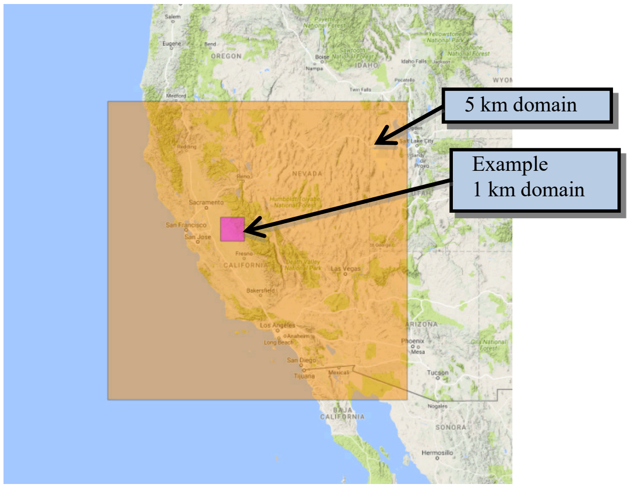


Figure 1: Mesoscale model domains used by FireBuster. The 5-km domain covers all of the state of California (and Nevada as well). Forecasts for the 5-km domain are run twice daily. The 1-km domain forecasts can be run when needed for specific areas.

The MSM forecasts several weather products, including temperature, relative humidity, precipitation, and wind direction and speed. A number of less common variables are also produced, such as convective available potential energy (CAPE) and planetary boundary layer (PBL) height that may be of interest to fire weather meteorologists.

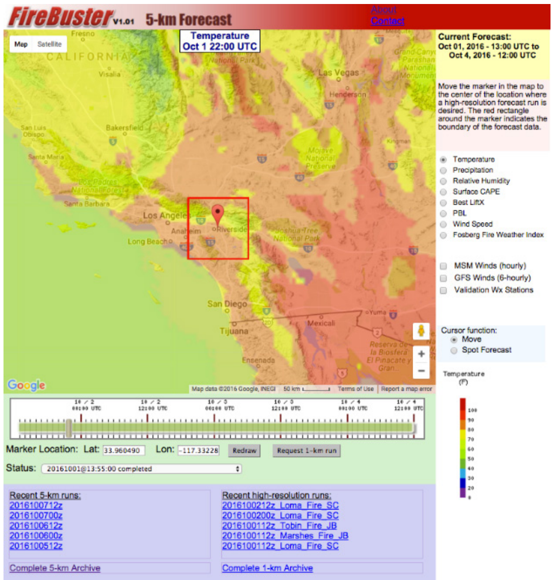
To determine what forecasted information would be of use to fire managers, we worked with a fire weather meteorologist with the Predictive Services program at the Southern California Geographic Area Coordination Center (GACC). The 11 GACCs located around the U.S. are responsible for allocating Forest Service firefighting resources to fire incidents. Understanding future weather conditions is critical to their operations. The FireBuster system is designed with the GACCs' needs in mind.

We use in-house equipment, a Dell PowerEdge R820 server, to perform the downscaling and other related computational tasks (Figure 2). Forecasts for the 5-km domain are run twice each day for 12UTC and 00UTC – at local noon and midnight, respectively – out to 72 hours. The 5-km forecasts typically take about 2 hours to be completely processed. However, the forecast data is divided into files representing 6-hour increments, which are available to access once they are complete. Each increment file is produced every 8 to 15 minutes during a run. The 1-km forecast run takes roughly 1 hour to process a 72-hour forecast. All forecast data is archived for analysis purposes.

Figure 2: The FireBuster forecast model runs on a 40-core Dell PowerEdge R820 server. Mass storage systems are used for archived data. Another server (not shown) converts model output to web-displayable graphics.

Model output is saved in GRIB format, which is a data storage format commonly used in the meteorology community. This format stores weather data in three spatial dimensions as well as time. However, extracting data from GRIB is not easy without specialized software. We wrote code to automatically extract data from each model run's GRIB file into data layers representing individual hourly forecast of weather variables. These data layers are then converted to graphics (PNG images) that are viewable using a web browser or picture-viewing software. The code also creates a web page to display the images. The web page, images, and related files are saved to a web server that is accessible on the Internet. The images representing weather variables are displayed semi-transparently over an interactive Google Maps background. The map can be zoomed and panned similar to the regular Google Maps interface[5]. The user can control which forecasted hour and weather product are being viewed (Figure 3).

Authorized users can submit requests for high-resolution 1-km forecast runs through the FireBuster web page. This feature is intended to allow fire managers run detailed forecasts over areas where fire events are occurring. The web page is continuously updated while the model is producing forecast output; the user does not have to wait until the forecast has entirely finished to see output. Given a latitude and longitude, the user can view an hourly 1-km resolution weather forecast of an area with ease.



Current Forecast:
Oct 01, 2016 - 13:00 UTC to Oct 4, 2016 - 12:00 UTC

Move the marker in the map to the center of the location where a high-resolution forecast run is desired. The red rectangle around the marker indicates the boundary of the forecast data.

- ● Temperature
- ○ Precipitation
- ○ Relative Humidity
- ○ Surface CAPE
- ○ Best LiftX
- ○ PBL
- ○ Wind Speed
- ○ Fosberg Fire Weather Index

- ☐ MSM Winds (hourly)
- ☐ GFS Winds (6-hourly)
- ☐ Validation Wx Stations

Cursor function:
- ● Move
- ○ Spot Forecast

Marker Location: Lat: 33.960490 Lon: -117.33228

Status: 20161001@13:55:00 completed

Recent 5-km runs:
2016100712z
2016100700z
2016100612z
2016100600z
2016100512z

Recent high-resolution runs:
2016100212z_Loma_Fire_SC
2016100200z_Loma_Fire_SC
2016100112z_Tobin_Fire_JB
2016100112z_Marshes_Fire_JB
2016100112z_Loma_Fire_SC

Complete 5-km Archive

Complete 1-km Archive

Figure 3: The FireBuster web page allows the user to see the output of the latest 5-km fire weather forecast run. Authorized users can also request special 1-km forecast runs. Past runs are archived and accessible for review.

Along with producing forecasts, we automated the collection of observed weather data from a large number of stations throughout California on a daily basis. The data comes from the Mesowest station network, and is available through online services (MesoWest & SynopticLabs 2016). We reviewed and selected high quality stations to display on the FireBuster web page. This data is reformatted for display on the page and can be used for model validation (Figure 4). The user can view station data by clicking a checkbox on the page. Displayed station data is hourly, like the forecasted data, and consists of temperature, relative humidity, and wind speed and direction values. This observed data can obviously only be plotted for past hours.

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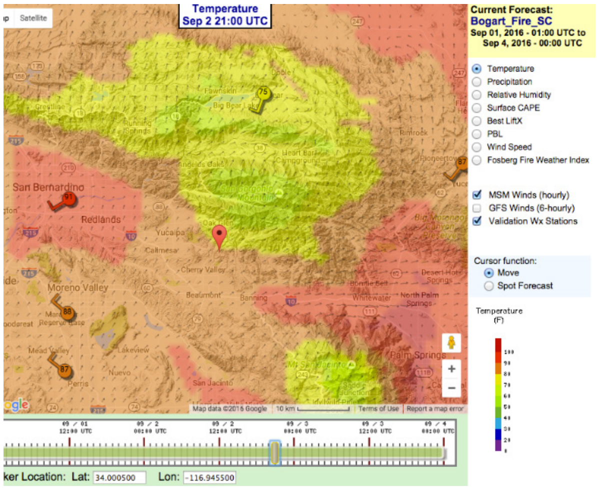
[5] http://maps.google.com .



ker Location: Lat: 34.000500 Lon: -116.945500

Figure 4: 1-km forecast for the area around an active wildfire, showing locations of nearby weather stations. Station icons indicate temperature, wind direction, and wind speed. More station data is available by clicking on the icons.

In addition to viewing weather values over an area by each hour, we added a feature to the web page to perform a 'spot forecast' for any location on the map that the user clicks on. This consists of time series plots of temperature and wind information for a single location (Figure 5). If available, observed data from the closest weather station is also plotted. This allows for validation of forecast values over time.

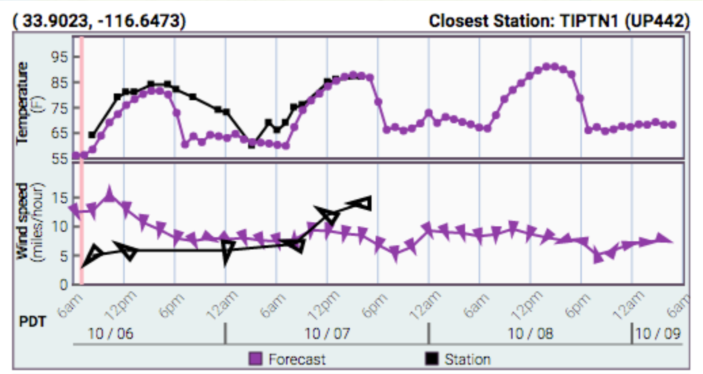


Figure 5: Spot forecast of a single location on the FireBuster web page. Plots of all 72 hours of forecasted temperature and wind values are shown (purple). Available observed data from the closest weather station is also shown (black).

There is often interest in examining past weather scenarios for higher resolution patterns. Along with the FireBuster fire weather forecasting system, we developed a similar product for analyzing past modeled weather data, called FireBusterSim. FireBusterSim provides downscaled *simulations* of weather fields rather than forecasts. The web page is very similar to the regular FireBuster page, but with some variations. FireBusterSim uses archived NCEP GDAS data to produce modeled weather downscaled to a higher resolution. This is useful for studying the added skill of the mesoscale model from the coarser model output. We can use FireBusterSim to learn more detail about near surface flow, and how having a 1-km cell resolution forecast would benefit over the 5-km resolution product.

Case Study: The Esperanza Fire

We looked at how high-resolution weather data like that produced by FireBuster and FireBusterSim might help on a fire incident. We investigated the Esperanza Fire of 2006, which occurred in the San Jacinto District of the San Bernardino National Forest in Southern California. Although this fire happened several years ago, an extensive amount of data has been collected on it due to an investigation on the deaths of five firefighters during its suppression. The fire started during Santa Ana conditions – a period of strong winds descending from the Great Basin accompanied by low humidities and warm temperatures that is common in autumn in Southern California. The accident investigation determined that the fire was primarily wind-driven, with wind speeds around 40 miles per hour (~64 km per hour), gusts around 60 miles per hour (~96 km per hour), and relative humidity below 10% (Esperanza Investigation Team 2007, p. 65). Aerial fire imaging (Riggan et al 2010, Coen and Riggan 2014) showed that it progressing in a southwesterly direction during the first several hours after being initially reported on October 26th, 2006 at 1:11am (Figure 6). Ultimately, the fire grew to 41,000 acres (~16,600 hectares).

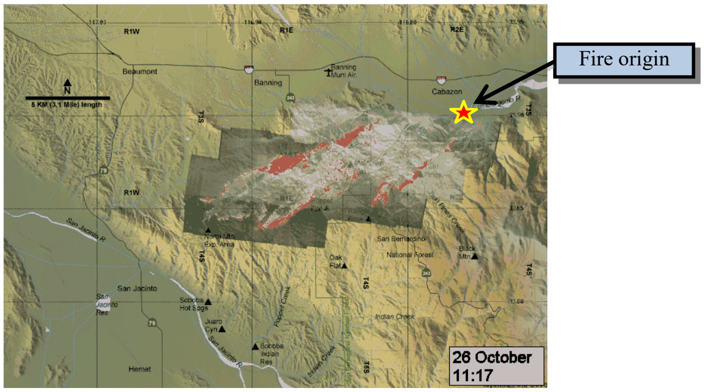


Figure 6: Image from FireMapper, an aerial thermal mapping system that can identify active sections of a fire perimeter. The Esperanza fire is shown burning predominantly southwest after the first several hours.

The Esperanza Fire occurred in steep, rugged terrain, with many hills and canyons. These terrain features would be undetectable to coarse weather models, yet these greatly contribute to fire behavior. For example, along with weather conditions, a narrow "unnamed creek drainage" contributed to the extreme fire behavior near the firefighter fatality site:

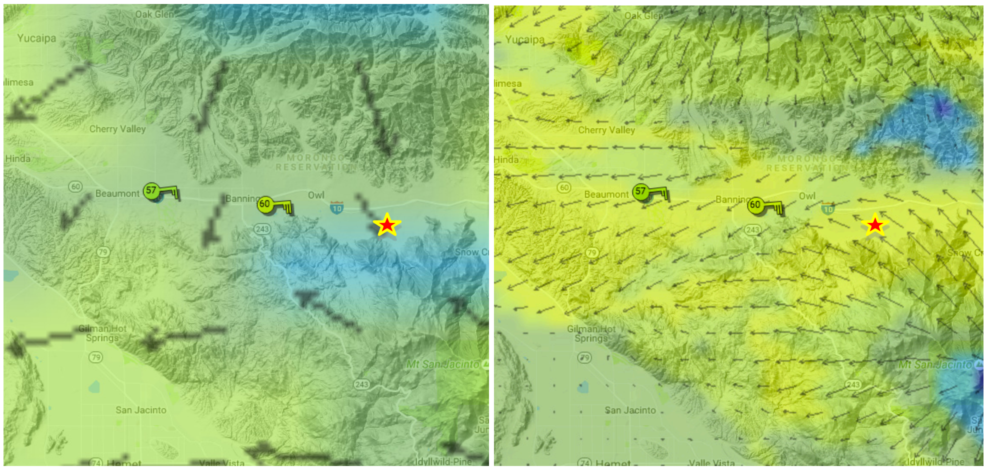
> *"Santa Ana winds came into alignment with the 'unnamed creek drainage' and the inversion was penetrated by the thermal uplifting from a fire run which contributed to extreme fire behavior and area ignition."*
>
> (Esperanza Investigation Team 2007)

We accessed archived initial model data from NCEP to run the MSM for the time of the Esperanza Fire. FireBusterSim runs were performed at 5- and 1-km cell resolutions. As resolution increases, topography has greater influence on the mesoscale model output. The 1-km model data should thus produce more realistic wind and temperature values in complex terrain than the 5-km version. Both 5-km and 1-km FireBusterSim runs are expected to provide more accurate output than the archived data from NCEP Global Forecast Model, which establishes the initial conditions to the model runs. In a similar manner, FireBuster *forecasts* should demonstrate greater accuracy with increased resolution.

Results

We performed a 5-km FireBusterSim run initialized on October 25th, 2006 to capture the starting hours of the Esperanza Fire. At this resolution, general terrain features were taken into account. Over the rugged landscape at site of the fire, however, modeled wind speed and direction were only influenced by large-scale topography. The overall temperature field also appeared to only vary slightly during each hour.

We then modeled the area at a resolution of 1 km. In contrast to the 5-km run, topographic details seemed to have affected wind and temperature values (Figure 7). Likewise, more variation in relative humidity and other variables could be seen in the downscaled model data. The general wind direction and speed as well as temperature produced at 1-km resolution matched observations from two weather stations in the area. The winds from neither resolution seemed to explain the initial southwesterly spread of fire from the origin – the 5-km winds were predominantly southerly, and the 1-km ones were northwesterly during the first few hours. It is possible fuels (mainly dried sage, chamise, and grasses in this area) as well as the uphill slope drove the direction of fire spread during the early morning. The 1-km model output, however, did show winds blowing in a southwesterly direction several kilometers west of the fire's origin. Also, as the day of October 26th, 2006 progressed, the modeled wind did change from a northwesterly to a more westerly direction.



(*a*) **(*b*)**

Figure 7: 5-km (*a*) and 1-km (*b*) FireBusterSim model output for the Esperanza Fire area for October 26th, 2006 at 7am local time. The star marker indicates the approximate location of the fire origin. Two weather stations – Beaumont (left) and Banning (right) are shown. The 1-km run (*b*) shows wind vectors more closely align with weather stations and the fire progression (southwesterly) than in the 5-km run. More variation in temperature values can also be seen in the 1-km image. Note that only *every other* wind vector is shown in the images.

It was possible to compare variations in time for a random fixed location by using the 'spot forecast' feature in the FireBusterSim page. The comparison of model values for temperature, wind speed, and wind direction could be made with observed hourly data for the entire period of the run, since historical station data is archived along with past forecasts. The 5-km and 1-km values could be compared for the same location to examine accuracy over time (Figure 8). The 1-km temperature values seemed to more closely match observed station data[6] than those from the 5-km run. Likewise, wind speed and direction data from the 1-km model was a better fit to the station data than the coarser model data.

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[6] From Beaumont weather station (RAWS Id: BNTC1), approximately 3.3 miles (5.4 kilometers) away.

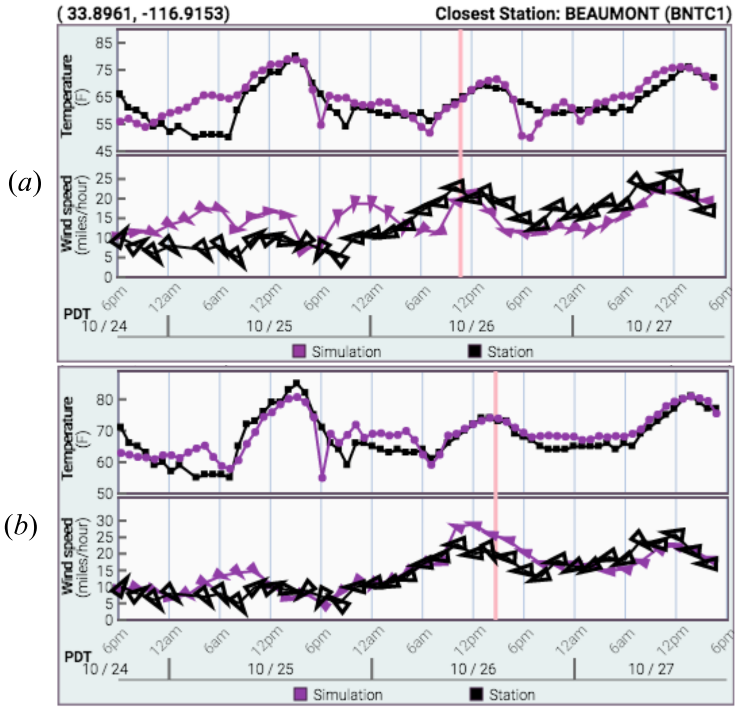

Figure 8: 'Spot forecast' (time series) of a single location. (*a*) shows FireBusterSim and observed values of temperature and winds using 5-km resolution; (*b*) shows 1-km resolution. Triangular wind markers point in the direction wind is going.

Discussion

Technological advances over recent years have allowed us to produce forecasts at the resolution of FireBuster's in a manner timely enough for use operationally. The increasing processing speeds of computer hardware, prevalence of weather data, and network accessibility have contributed to building better fire management tools. FireBuster has the specific goal of helping those who manage fire. It provides high-resolution fire weather forecasting for California, although the domain can likely be adapted to any geographic region globally. Having forecast values at 5- and 1-km spacing, for every hour out to 72 hours, provides a large improvement over coarser scale official forecasts. These higher resolution mesoscale spectral models incorporate finer topographic detail, allowing them to resolve wind, temperature, and other fire weather variables in rugged terrain where fires often need to be fought.

FireBuster may also be the groundwork for forecasting fire danger at high spatial and temporal resolution. The U.S. fire danger rating system relies on knowing weather conditions as well as topography and fuels information for calculating a set of indices that measure fire potential (Bradshaw et al 1984, Cohen and Deeming 1985, Deeming et al 1977). For fire danger computation, fuel moisture values would also need to tracked daily by FireBuster.

Adding an economic data layer to the system may allow users to assess the monetary impact of possible fire events (Benoit et al 2013). However, collecting such data on a state-wide basis is difficult, as it would consist of both market and nonmarket values. Real estate prices and recreational use fees, among other economic data, would need to be assembled into a data layer, which must be periodically updated. There has been discussion of including an economic data into FireBuster in the future – however, it will likely take a considerable amount of time to fully develop this addition.

Currently, FireBuster and FireBusterSim are being used primarily in a research and development setting. Periodic communication with fire management personnel provides suggestions on improvements to the system. Additional features are being developed and will be added soon. Because of the demand for it, the FireBuster system will provide weather data files in a format that can be read directly into FARSITE, a well-known fire spread model used in the U.S. (Finney 1998). Progressive fire perimeters of well-documented fires will be converted to a format that can be displayed on the FireBusterSim web page. A mobile version of the web page is in development, which will allow a smartphone or tablet computer user to view a spot forecast of their current location. This design is intended for fire personnel with Internet access to instantly view predicted fire weather in their area. An operational version of FireBuster should be available next year.

Acknowledgements

The development of FireBuster was supported by funds from the Western Wildland Environmental Threat Assessment Center (WWETAC), the Joint Fire Science Program, and the U.S. Forest Service. We also give sincere appreciation to Tom Rolinski (U.S. Forest Service Meteorologist for the Southern California GACC) for his valuable input on the system's development.

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Development of a National Forest Fire Danger System for Mexico[1]

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Abstract

This presentation introduces the project "Development of a Forest Fire Danger System for Mexico" funded by the Mexican Forest Agency CONAFOR. The goal of the 3-year project is to develop an operational fire danger system for mapping daily and forecasted fire risk occurrence and fire propagation danger in Mexico, which will be online for decision-making on fire management by CONAFOR and fire management actors in Mexico. The presentation summarizes the project goals and structure and the results from the first year of the project, including: 1) The development of a fire occurrence risk module for mapping expected number of fires based on vegetation type, weather and satellite information and 2) The development of an online interface for daily mapping of fire risk and danger in Mexico.

Keywords: fire danger, fire risk, fuel dryness indices, online decision support system, Mexico.

Introduction

No operational fire danger system is currently available in Mexico. This in contrast with countries such as USA, Canada or Brazil that have developed operational fire risk systems based on temporal and spatial quantification of fuel greenness and associated fire risk and danger (e.g. Deeming et al., 1977, Burgan et al., 1997, 1998,

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[1] An abbreviated version of the paper was presented at the fifth international symposium on fire economics, planning, and policy: wildland fires and ecosystem services, Nov 14-182016, Tegucigalpa, Honduras.

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Preisler et al., 2004, 2008, 2011, Riley et al., 2013, Van Wagner, 1987, Sismanoglu and Setzer, 2012).

This lack of an operational fire danger system led the Forest National Commission (CONAFOR in Spanish) and the National Research Agency (CONACYT in Spanish) to fund the national scale project "Development of a Forest Fire Danger System for Mexico". The main objective of the study is the development of an operational fire risk and danger mapping system based on satellite and weather information for Mexico (Vega-Nieva et al., 2015). This document summarizes the project goals and structure and the results from the first year of the project, including:

1) The development of a fire occurrence risk module for mapping expected number of fires based on vegetation type, weather and satellite information and

2) The development of an online interface for daily mapping of fire risk and danger in Mexico.

Goals of the Project "Development of a Forest Fire Danger System for Mexico".

In Mexico, a system for near real-time mapping of fire Hotspots has been implemented by CONABIO (http://incendios1.conabio.gob.mx/), but no operational system for prediction of Fire Risk (probability of fire occurrence) or Fire Danger (expected fire behavior and difficulty of suppression) is currently available for Mexico. The Project 252620 in response to the call 3-C02-2014 by CONACYT-CONAFOR aims at developing an operational Fire Risk and Danger System to be used by the Mexican Government Forest Agency CONAFOR and relevant agents in decision making on fire management in Mexico. The Project is being conducted by a consortium of researchers from several institutions from Mexico, USA, Brazil and Spain.

The goals of the project are

1) To conduct a literature review of Fire Risk and Danger
2) To test existing Fire Risk and Danger systems for the prediction of fire occurrence in Mexico.
3) To develop a Mexican Fire Risk System for the prediction of fire occurrence.
4) To develop a Fire Weather forecast system for Mexico.
5) To develop a module for mapping Fire Area in Mexico.
6) To test existing Fire Danger systems in Mexico against fire area records.
7) To develop a Mexican Fire Danger System
8) To develop and transfer to CONAFOR a online software for mapping of current and forecasted Fire Danger in Mexico.

Modeling fire occurrence risk from monthly satellite fuel dryness by vegetation type and region in Mexico.

Within this national project, a study was conducted by Vega et al. (2016) with the goals of: 1) quantifying the monthly temporal trends of a MODIS satellite based fuel greenness index, DR, and the temporal trends of fire density (FD) by vegetation type and region in Mexico, 2) testing simple regression models for prediction of monthly FD by vegetation type and region from monthly DR values in Mexico. The methodology and the main results of this study are summarized below.

Methodology

Area of study

The area of study was the Mexican Republic. Figure 1 shows the vegetation types present in the country according to the National Institute of Geography and Statistics (INEGI in Spanish) most recent land use map **(**INEGI Land Use Map Series V, 1:25000 http://www.inegi.org.mx/geo/contenidos/recnat/usosuelo/) Four geographical regions , Northwest (NW), Northeast (NE), Center (C), and South (S), were established (figure 1), considering both the potential fire regimes zoning for Mexico (Jardel et al. 2014), based on vegetation types and climatic zones (Holridge, 1996), together with a visual observation of the temporal and spatial patterns of clustering in fire hotspots on the period of study.

Satellite hotspots and fuel dryness indices.

Considering the availability of MODIS fire hot spots information for Mexico we selected the period of 2003-2014 for our study. We compiled monthly MODIS fire hotspots for the 12 years of the study period from CONABIO (http://incendios1.conabio.gob.mx/).

The monthly NDVI composite images with a spatial resolution of 1 x 1 km (MODIS product MOD13A3) from the study period were downloaded from http://modis.gsfc.nasa.gov/data/dataprod/mod13.php.

Following Burgan et al. (1998), Dead Ratio (DR) values were calculated for each pixel based on the values of NDVI for each monthly image, on the maximum and minimum NDVI values for each pixel and on the absolute maximum and minimum NDVI observed values in the area of study for the whole study period. Dead ratio is an empirical index representing the fraction of fuel that is not live (DR= 100- Live Ratio), reaching 100 in a fuel that is completely cured with no live biomass, and with lower values representing fuels with a higher fraction of live biomass (Burgan et al., 1998).

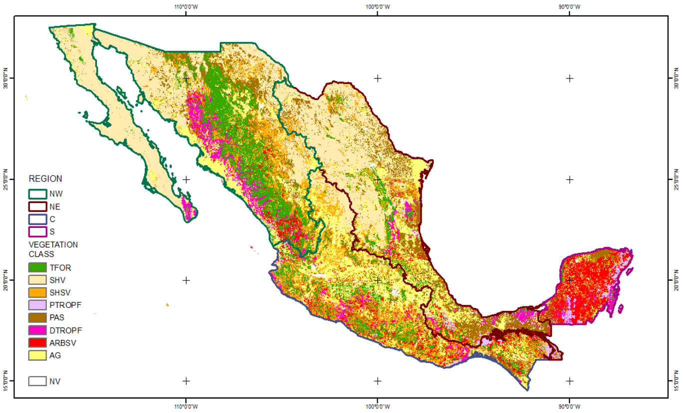

Figure 1. Map of vegetation types and regions considered in the analysis. Where: TFOR: Temperate Forest, SHV: Shrubland Vegetation, SHSV: Shrubby Secondary Vegetation, PTROPF: Perennial Tropical Forest, PAS: Pastureland, DTROPF: Deciduous Tropical Forest, ARBSV: Arboreous Secondary Vegetation, AG: Agriculture, NV: No Vegetation; and NW: North West, NE: North East, C: Centre, S: South regions. Source: INEGI land use map (series V)

Fire Density Index.

For each of the 28 vegetation types and regions considered, monthly Fire Density (FD) was calculated by dividing the number of fires in the area by the surface (km^2) of the vegetation/region considered. Monthly FD values for each vegetation type and region were scaled to a Fire Density Index (FDI) as follows:

FDI= Number of fires / Surface (km^2) x 5000

The FDI index is defined so that a FD of 0.01 fires /km ^{2} – e.g. 1 fire / 100 km ^{2} – is equivalent to an FDI value of 50. Accordingly, a FD of 2 fires / 100 km ^{2} is equivalent to an FDI value of 100, which might be considered an indicator of a high fire density.

Modeling monthly FDI from DR.

Fire season concentrated on the first 6 months of the year for all vegetation types considered. Consequently, all land uses were modeled for the period January-June. We tested linear and nonlinear power equations as regression models. Table 1 summarizes the equations tested. Each month or group of months was allowed to have distinct coefficients by multiplying the observed DR by a dichotomous variable (0 or 1) so that each month or group of months would obtain an individual parameter, both in the lineal and nonlinear models (eqs. 1 and 7, table 1). After observing the coefficients obtained in this approach, several groups of months were tested as candidates for grouping with the same coefficients (eqs. 2-6 8-12). Statistical and graphical analyses were used to evaluate the performance of the equations. The goodness-of-fit of each model was evaluated using the adjusted coefficient of determination (R^2) and root mean squared error (RMSE).

Table 1. ***Equations tested for prediction of monthly Fire Density Index from Dead Ratio values. Where: FDI: monthly Fire Density Index, DR: monthly Dead Ratio, a and b are model coefficients, J: January, F: February, M: March, A: April, My: May, Ju: June, Jl: July, Ag: August, S: September, O: October, N: November, D: December.***

Eq. Num.	Fit type	Grouped months	Equation
1	Linear	-	$FDI = a + (b_J DR_J + b_F DR_F + b_M DR_M + b_A DR_A + b_{My} DR_{My} + b_{Ju} DR_{Ju})$
2	Linear	J&F	$FDI = a + (b_{JF} DR_{JF} + b_M DR_M + b_A DR_A + b_{My} DR_{My} + b_{Ju} DR_{Ju})$
3	Linear	J,F&M	$FDI = a + (b_{JFM} DR_{JFM} + b_A DR_A + b_{My} DR_{My} + b_{Ju} DR_{Ju})$
4	Linear	J,F&M, A&My	$FDI = a + (b_{JFM} DR_{JFM} + b_{AMy} DR_{AMy} + b_{Ju} DR_{Ju})$
5	Linear	J,F&M, A&Ju	$FDI = a + (b_{JFM} DR_{JFM} + b_{AJu} DR_{AJu} + b_{My} DR_{My})$
6	Linear	J,F,M&A, My&Ju	$FDI = a + (b_{JFMA} DR_{JFMA} + b_{MyJu} DR_{MyJu})$
7	Non linear	-	$FDI = (a_J DR_J + a_F DR_F + a_M DR_M + a_A DR_A + a_{My} DR_{My} + a_{Ju} DR_{Ju})^b$
8	Non linear	J&F	$FDI = (a_{JF} DR_{JF} + a_M DR_M + a_A DR_A + a_{My} DR_{My} + a_{Ju} DR_{Ju})^b$
9	Non linear	J,F&M	$FDI = (a_{JFM} DR_{JFM} + a_A DR_A + a_{My} DR_{My} + a_{Ju} DR_{Ju})^b$
10	Non linear	J,F&M, A&My	$FDI = (a_{JFM} DR_{JFM} + a_{AMy} DR_{AMy} + a_{Ju} DR_{Ju})^b$
11	Non linear	J,F&M, A&Ju	$FDI = (a_{JFM} DR_{JFM} + a_{AJu} DR_{AJu} + a_{My} DR_{My})^b$
12	Non linear	J,F,M&A, My&Ju	$FDI = (a_{JFMA} DR_{JFMA} + a_{MyJu} DR_{MyJu})^b$
13	Linear	-	$FDI = a + (b_J DR_J + b_F DR_F + b_M DR_M + b_A DR_A + b_{My} DR_{My} + b_{Ju} DR_{Ju}$ $+ b_{Jl} DR_{Jl} + b_{Ag} DR_{Ag} + b_S DR_S + b_O DR_O + b_N DR_N + b_D DR_D)$
14	Non linear	-	$FDI = (a_J DR_J + a_F DR_F + a_M DR_M + a_A DR_A + a_{My} DR_{My} + a_{Ju} DR_{Ju}$ $+ a_{Jl} DR_{Jl} + a_{Ag} DR_{Ag} + a_S DR_S + a_O DR_O + a_N DR_N + a_D DR_D)^b$
15	Non linear	All but My	$FDI = (a_{JFMAJuJlAuSOND} DR_{JFMAJuJlAuSOND} + a_{My} DR_{My})^b$

Results and discussion

Table 2 shows the models that better fitted the data for each vegetation type and region and the goodness of fit statistics for the best models. With the exception of the deciduous and perennial tropical forests of the NE, the nonlinear models described better the data than linear models for all vegetation types and regions, suggesting that the relationship of DR with fire occurrence is not linearly proportional –e.g. fire occurrence risk increases very rapidly with increasing DR.

Table 2. ***Coefficients and goodness of fit of the best fit equations for the prediction of monthly Fire Density Index from Dead Ratio values for each vegetation type and region. Where: Veg_Reg: Vegetation and region; Eq: best fit equation from table 1, a and b are model coefficients, J: January, F: February, M: March, A: April, My: May, Ju: June, Jl: July, A: August, S: September, O: October, N: November, D: December coefficients for the corresponding month or group of months. RMSE: Root Mean Standardized Error; R^2adj: Adjusted R^2; TFOR: Temperate Forest, PAS: Pastureland, PTROPF: Perennial Tropical Forest, ARBSV: Arboreous Secondary Vegetation, SHSV: Shrubby Secondary Vegetation, DTROPF: Deciduous Tropical Forest, NV: No Vegetation; and NW: North West, NE: North East, C: Centre, S: South regions.***

Veg_Reg	Eq	a	JF	M	JFM	A	JFMA	My	AMy	Ju	AJu	MyJu	b	RMSE	R^2_{ADJ}
TFOR_C	8		0.019	0.021		0.024		0.026		0.023			7.771	33.3	0,75
TFOR_NE	8		0.016	0.018		0.019		0.021		0.019			10.438	15.4	0,62
TFOR_NW	12						0.015					0.017	11.371	32.4	0,62
TFOR_S	9				0.016	0.016		0.015		0.014			25.706	11.7	0,68
PAS_C	8		0.019	0.022		0.028		0.032		0.027			5.276	18.2	0,95
PAS_NE	8		0.019	0.021		0.024		0.026		0.023			5.668	9.3	0,86
PAS_NW	8		0.011	0.011		0.012		0.012		0.013			13.729	3.3	0,60
PAS_S	8		0.059	0.110		0.178		0.197		0.082			2.243	92.3	0,79
PTROPF_C	9				0.024	0.034		0.041		0.034			4.817	35.7	0,79
PTROPF_NE	3	-102.96			2.278	2.794		3.388		2.266			0.000	19.1	0,67
PTROPF_NW	12				0.015							0.020	5.662	9.1	0,67
PTROPF_S	8		0.019	0.021		0.023		0.026		0.023			7.018	7.5	0,70
DTROPF_C	11				0.023			0.052			0.048		3.234	19.5	0,91
DTROPF_NW	9				0.013	0.017		0.024		0.022			5.245	9.8	0,89
DTROPF_NE	2	-219.92	3.503	3.882		4.767		5.615		5.368			0.000	78.6	0,46
DTROPF_S	8		0.037	0.044		0.050		0.049		0.036			3.923	28.0	0,76
ARBSV_C	8		0.019	0.024		0.031		0.035		0.028			5.361	26.5	0,90
ARBSV_NE	8		0.022	0.025		0.028		0.034		0.028			6.131	10.7	0,94
ARBSV_NW	9				0.016	0.024		0.030		0.027			4.706	28.6	0,70
ARBSV_S	8		0.034	0.059		0.080		0.080		0.034			2.956	37.0	0,79
SHSV_C	8		0.017	0.020		0.026		0.030		0.025			5.590	17.8	0,93
SHSV_NE	10				0.017				0.022	0.019			7.257	14.6	0,73
SHSV_NW	9				0.012	0.014		0.015		0.015			11.690	18.9	0,65
SHSV_S	8		0.033	0.048		0.060		0.061		0.033			3.722	59.4	0,79

Different patterns of FDI and DR relationships were observed for different vegetation types and regions, agreeing with observations that point to a variety of fire regimes resulting from combinations of climatology and fuel types in the country (e.g. Rodríguez et al., 1996, 2008, Morfin et al., 2007, 2012, Avila et al., 2010, Jardel et al., 2009, 2014, Perez-Verdin et al., 2014). Derived model coefficients for months and groups of months may offer information about the patterns of timing of fire season and their relationships with DR patterns in different vegetation types and regions. Most of the vegetation types in the south and center region showed an earlier start of fire season (1 month earlier) compared to the NW region, suggesting that either longer periods of accumulated drought in that latter region are required for fire to start, or perhaps reflecting different patterns of agricultural burns timing in the different regions of the country. Within regions, tropical forest showed latter starts of fire season compared to other vegetation types in the same region (1 or 2 more months in the NW), suggesting that longer accumulated drought periods are required in those more humid ecosystems for fire to start.

Development of an online interface for the Mexican Fire Danger System

In the first year of the project, UJED programmed an online test interface for the Forest Fire Danger System of Mexico, freely available online at the link:
http://fcfposgrado.ujed.mx/incendios/inicio/index.php

The interface includes several layers for current situation (figure 2) and a section with evolution of fuel dryness and risk indices. (figure 3), available at:
http://fcfposgrado.ujed.mx/incendios/inicio/historicos_animaciones.php
The layers included in the GIS interface for current situation include observed daily layers for fire hotspots, fuel dryness index, and fire occurrence risk (figure 2).

A number of thematic layers in included in the GIS interface, including: CONAFOR fire priority areas, Regional Fire Management Centers, Type of land cover, Natural Protected Areas, Limits of States, Municipalities and Forest Management Units (figure 1). A base map containing towns, roads and topography from three online sources (Bing Maps, ArcGis Online 1, ArcGis Online 2) is also included .The user can zoom in/off using base maps as a spatial reference. The user can turn on/off any layer in the GIS interface, including the possibility of simultaneously visualizing a combination of layers (e.g. fire risk and a topography/roads map from Bing maps) by regulating the layers level of transparency.

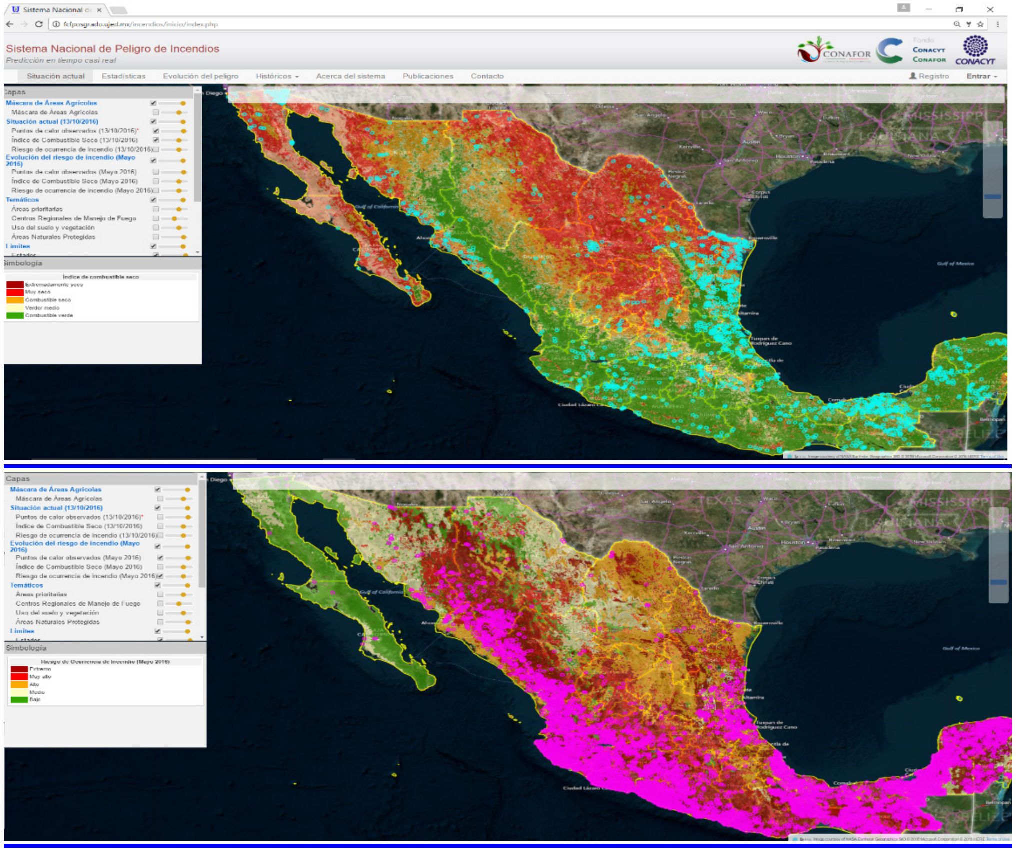

Figure 2. Online interface of the Mexican Forest Fire Danger System: current situation. Top figure shows current fuel dryness index and observed fire hotspots (in blue) in October 2016. Colors represent fuel dryness, with green being very wet fuel and red and light pink being dry and very dry fuel conditions. Bottom figure shows the predicted fire occurrence risk map and observed fire hotspots (in bright pink) in May 2016. Colors represent risk of fire occurrence, with green meaning low probability of fire occurrence and red and dark red representing high and very high fire occurrence risk. http://fcfposgrado.ujed.mx/incendios/inicio/index.php

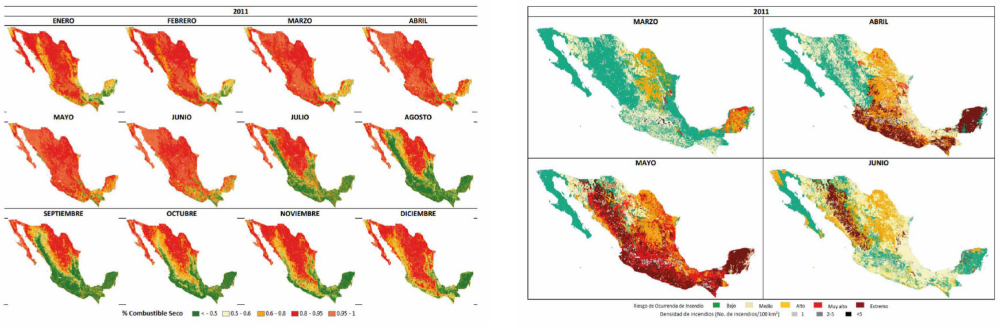

Figure 3. Examples of Fuel Dryness Index (left figure, monthly fuel dryness for 2011) and Fire Ocurrence Risk maps (right figure, march to june 2011). Animations of fuel dryness and fire risk for historic years in Mexico can be consulted at the link:
http://fcfposgrado.ujed.mx/incendios/inicio/historicos_animaciones.php

Summary and conclusions.

The Project “Development of a Forest Fire Danger System for Mexico”, funded by the Forest National Commission (CONAFOR in Spanish) and the National Research Agency (CONACYT in Spanish) aims at developing an operational fire risk and danger mapping system based on daily satellite and weather information, to be used by the Mexican Government Forest Agency CONAFOR and relevant agents in decision making on fire management in Mexico. During the first year of the project, several weather and satellite based indices have been tested, with first results for prediction of fire occurrence risk based on a satellite fuel dryness index for Mexico. Future work in the project will include the development of probabilistic fire risk based on daily weather-based fire danger indices together with spatial factors such as distance to roads and locations. These daily fire risk models will be included in the online platform which will provide daily assessments of fuel drought and expected fire risk occurrence. This operational tool will be used for improving the planning of fire extinction and for strategic fire management decision making in Mexico.

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Coordination Mechanisms for Wildfire Management in the Municipality of Distrito Central, Francisco Morazán, Honduras[1]

Carlos R. Velasquez[2], Sua Gallardo[2]

Abstract

The forest of the Distrito Central (Central District) and surrounding areas is affected in the dry season by wildfires, adding to the damage caused by the bark beetle, which makes it necessary to coordinate inter-agency efforts to address this problem.

The U.S. government through USAID via International Programs was able to bring specialists from the U.S. Forest Service to support the establishment and start-up of the Inter-Agency Wildfire Operations Center (known by its Spanish acronym COIIF). COIIF is an inter-agency center that coordinates efforts for monitoring, detection, surveillance and deployment of resources for fighting and controlling wildfires in the Distrito Central municipality and adjacent areas.

COIIF has a physical location maned by technical staff and equipped with radio communication equipment, telephone lines and Internet. It has its own operational protocols and manages in a general way the response to fires occurring in the municipality and adjoining areas. Its main objective is to provide coordinated management at the inter-agency level for controlling wildfire situations in the Distrito Central municipality.

The Center is made up of institutional links, institutional shift links and crew leaders, trained in COIIF's operational protocols and protocols for dealing with wildfires. The institutions participating in the fire control actions are: Forest Conservation Institute (known by its Spanish acronym ICF), the director of forest resource management in the country, non-governmental organizations, the armed forces, the municipality and various state entities. It also has a surveillance system comprised of observation posts and remote cameras**.**

The Center manages logs, blackboards, and maps to handle wildfire situations. It controls dispatch, mobilization, control and extinguishing of wildfires. In addition, it provides aerial coordination to control fires in priority areas.

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[1] An abbreviated version of this paper was presented at the Fifth International Symposium on Fire Economics, Policy, and Planning: Ecosystem Services and Wildfires, November 14-18, 2016, Tegucigalpa, Honduras. Only abstract available.

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Coordination and Inclusion in the Surveillance, Prevention and Fighting of Wildfires in the South of the State of Puebla[1]

Misaél García Hernández[2]

Abstract

The State Management Office of Mexico's National Forestry Commission (CONAFOR) in Puebla, through the Forest Fire Areas and Payment for Environmental Services program, has implemented a coordination and inclusion strategy for surveillance and protection against wildfires in the southern area of the State of Puebla, specifically in the Tehuacán Valley area. This strategy includes the specific coordination of the different ejidos (communal land areas), communities and technical advisors of the region through inter-ejidal surveillance tours, monitoring and exchange of experiences, as well as the activation of 47 trained and equipped community fire brigades, which are managed and administered from an Inter-municipal Wildfire Control Center.

The above-mentioned inter-ejidal tours are carried out on a recurring basis in different routes and schedules in order to prevent hunting and flora extraction, detect possible forest fires, forest pests and diseases, and become acquainted with local success stories (reforestation work, soil restoration, fuel management, nurseries, ecotourism projects, etc.) within the ejidos visited.

Through the Payment for Environmental Services program, the ejidos and communities have integrated community forest fire brigades which consist of ten trained members. These brigades have specialized equipment to combat wildfires such as backpack sprayers, fire flappers, Mcleod rakes, pulaskis, etc., in addition to personal protection equipment, radio communication equipment (mostly) and a vehicle for mobility. In order to improve the functioning and operation of these brigades, CONAFOR provided support to the Regional Association of Foresters in the area for the establishment of an Inter-municipal Wildfire Control Center (CICIF), which serves as a command center and manages the human resources in case of a wildfire in the region.It is worth mentioning that this region has high conservation value since it has a large amount of biodiversity and endemism. It is also part of the "Tehuacán Cuicatlán Biosphere Reserve."

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[1] An abbreviated version of this paper was presented at the Fifth International Symposium on Fire Economics, Policy, and Planning: Ecosystem Services and Wildfires, November 14-18, 2016, Tegucigalpa, Honduras. Only abstract available.

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The Challenge of Developing Technical Fire Management Skills in Latin America[1]

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Abstract

It has been observed that the bodies, organizations, groups and people responsible for fire management often leave aside, do not value or discourage investment in human capital through the development of technical skills, commonly holding the view that it is a non-refundable expense. Added to this problem is the constant turnover in experienced and trained personnel, due to changes in administration, problems in management-leadership and hiring mechanisms with casual or temporary modalities.

The foregoing generates operational structures that function and deliver results, but more due to the will, motivation and conviction of the firefighters whose safety is put at risk. Moreover, many times there is a lack of productive and effective use of material, human and financial resources, creating a permanent vicious cycle of initial operation, repeating the early stages of integration, team building, basic training and initial experimentation, which does not allow for or hinders the professionalization of the wildfire fighter and fire management technicians.

This is a challenge that requires attention from different perspectives with the participation, will and support of people at all levels of the administration: fire management programs, governmental bodies and environmental agencies.

So what can we do? The decades-long experience of the USAID-USFS can be taken as a reference and basis with its respective adaptation to the social, political, economic and ecological conditions of each country.

There are processes, instruments and management and/or coordination mechanisms, such as a Fire Management Policy in accordance with laws, regulations and decrees, which will allow for the creation of long-term strategic planning with the establishment of a Fire Management Strategy; this, in turn, will foster the preparation and implementation of annual inter-agency operational programs. The design, agreement on and operation of a Certification System based on the Incident Command System with standardized, phased-in training accompanied by task books that accredit the experience and physical fitness tests will promote

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[1] An abbreviated version of this paper was presented at the fifth International Symposium on Fire Economics, Policy and Planning: Ecosystem Services and Wildfires, November 14-18, 2016, Tegucigalpa, Honduras. Only abstract available.

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the safety of the personnel and enhance the professionalization of the activity of the firefighter and fire management technician.

Are There Differences Between Minority Households Willingness-to-Pay for Wildfire Risk Reduction in Florida?[1]

Armando González-Cabán[2] and José J. Sánchez[2]

Abstract

The purpose of this work is to estimate willingness-to-pay (WTP) for minority (African-American and Hispanic) homeowners in Florida for private and public wildfire risk reduction programs. Also to test for differences in response between the two groups. A random parameter logit and latent class models allowed us to determine if there is difference in wildfire mitigation program preferences and whether WTP is higher for public or private actions for wildfire risk reduction, and whether households with personal experience and perceiving living in higher risk areas have significantly higher WTP. We also compare FL minority homeowners' WTP values with general FL homeowners estimates. Results suggest that FL minority homeowners are willing to invest in public programs, with African-Americans WTP values twice as much as Hispanics. In addition, the highest priority for cost sharing funds would go to homeowners in areas who perceive their houses to be at high risk, and especially to cost share private actions on their own land. These results may help fire managers optimize allocation of scarce cost sharing funds for public vs private actions.

Keywords: choice experiment, firewise, latent class model, random parameter logit model, WUI

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[1] An abbreviated version of this paper was presented at the Fifth International Symposium on Fire Economics, Planning, and Policy: Wildfires and Ecosystem Services, November 14-18, 2016, Tegucigalpa, Honduras.

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Introduction

In the recent years, the United States has seen an increase and severity of wildland fires due to growing fire seasons, drier conditions, and accumulation of fuels. From 2000 to 2013, wildfires have affected over 37 million ha of forest and brush lands and federal fire protection agencies spent almost $2 billion in suppression cost (National Interagency Fire Center Wildland Fire Statistics, 2014). Fire suppression expenditures for the first time in fiscal year 2015 exceeding 50% of USDA Forest Service (USFS) budget.

Wildland fires represent a threat to many communities nationwide. However, residential neighborhoods located in the wildland-urban interface (WUI- area where houses and undeveloped wildland vegetation meet)[3] are prone to higher risk for loss of life and property. Increases in wildfire risks has led the USFS and state/local agencies to developed cost shared programs with communities and private homeowners (e.g., firewise communities programs). These programs provide direct payment for fuel reduction efforts on public and private lands surrounding many of these communities. These programs, however, are costly to private homeowners and federal/state/county fire management agencies. Given current funding limitations it is important for the USFS and state agencies to know the benefits of these fire risk reduction programs.

Several contingent valuation method (CVM) survey studies have been done throughout the nation on how much money households would pay to state and county agencies for funding wildfire reductions projects. For example, Loomis and González-Cabán (2010) surveyed households in California, Florida, and Montana and found that the mean willingness to pay (WTP) per household for prescribed burning was $460, $392, and $323 respectively. They also found that the mean WTP per household for mechanical fuel reduction was $510, $239, and $189. Walker et al. (2007) used CVM to compare Colorado WUI residents WTP for prescribed burning versus thinning. They found that for Boulder and Larimer counties, WUI residents WTP was higher for a thinning program ($443 and $311 respectively) than prescribed burning ($202 and $150 respectively). More recently, Sánchez et al. (in review) used a choice experiment survey to determine CA homeowners' preferences and WTP for public and private wildfire mitigation programs. The authors found that CA homeowners that perceived to be living a high risk community, their WTP for a ten-year public program is $1265 and $1733 for a ten-year private program.

However, few studies have studied minority households WTP for fuel treatment projects. A study by Loomis et al. (2009) uses voter referendum survey question to compare across California, Florida, and Montana White and Hispanic

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[3] For a more complete definition of the WUI see Radeloff et al. (2005).

households WTP for prescribed burning and mechanical fire fuel reduction programs. Pooling the data from the three states into one model for each fire fuel reduction program, the authors found that the marginal benefits for prescribed burn (mechanical) fuel treatment of 1 million White households is $2,578 ($3,376) per acre, while the marginal benefits for 1 million Hispanic households would be higher, $10,121 ($31,279).

In a recent study by Holmes et al. (2013) of Florida homeowners preferences and WTP for wildfire protection programs, less than 10% of survey participants were minorities (African-American and Hispanic). However, 28.9% of Florida population are from Hispanic and African-American descent (US Census, 2015). Therefore, their results are based on a partial segment of Florida population and results might not be representative of the entire state. This study expands Holmes et al. (2013) by focusing on the missing minority population. The significant increase in FL minority population from 2010 to 2015 highlights the importance of incorporating these populations when considering households WTP for evaluating fuel treatment reduction programs. In the period from 2010 to 2015 the African-American population in the state increased by 11.7% from 3,008,740 to 3,405,574. For the same period, the Hispanic population increased by 14.8% going from 4,231,037 to 4,966,462. And although the whites population increased by 2.95% for the period, their percent of the total state population decreased from 57.9% to 55.3%[4]. This research is useful to understand the factors that influence minority decisions of whether, and how much, to invest in wildland fire hazard mitigation programs and whether they respond differently to these programs. The research could also help fire managers to identify obstacles to the implementation of efficient fire mitigation programs and policies.

This study contributes to the literature by implementing a choice experiment to understand tradeoff minority's (African-American and Hispanic) households are willing to make between fire mitigation programs. We use the same choice experiment survey as Holmes et al. (2013) to estimate WTP for minority homeowner in Florida for private and public wildfire risk reduction programs. We valued two fire risk reduction programs: (1) a Public Program carried out by public forest managers involving prescribed burning, mechanical treatment and herbicide treatment of forests immediately surrounding their neighborhood; and (2) a Private Program that alters the vegetation surrounding the home such as reducing tall vegetation (more than 3 feet high) within 30 feet of their house[5]. A random parameter logit and latent class models allowed us to determine whether minorities WTP is higher for public or private actions for wildfire risk reduction, and whether households with personal

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[4] Data obtained from US Census (2015).

[5] See www.**firewise**.org for more information on the Private Program.

experience and perceiving living in higher risk areas have significantly higher WTP. We will be able to assess residents' preferences for wildfire mitigation programs and to explore the heterogeneity of those preferences. In addition, analysis were done to ascertain if African American and Hispanic households respond different to WTP for wildfire mitigation programs.

The paper proceeds as follows: first we introduce the choice experiment method, random parameter logit and the latent class models specification, followed by presentation of the choice experiment survey design. Then we describe the data and present the econometric results. In the final section we present our conclusions.

Econometric Models of Choice Experiment Responses

Choice models describe individual's choices among alternatives (Train 2009). The choice experiment (CE) method has been widely used in marketing and transportation literature to analyze consumer choice of products, modes of travel and other items (Adamowicz et al. 1998). This method can also estimate economic values (individual's WTP) for a set of attributes of an environmental good and/or services (Boxall et al. 1996).

The CE method provides more detailed information about public preference on environmental goods and services. The survey presented to respondents includes hypothetical scenarios describing specific issues along with description of attributes. Individuals are given choice sets, each of which usually consist of 3 alternatives (1 must be the status quo or opt-out option) to evaluate. The individuals must select the alternative from the choice set that best reflects their preference. Resource managers and policy makers may use this added information (individuals' preferred attributes) to inform decisions on environmental goods and/or services.

The CE method is based on the random utility theory and random utility theory uses the principle of utility maximization. Random utility models (RUM) describe discrete choices in utility maximizing frameworks. It is assumed that individuals select a good that provides the greatest utility among those available to them (Champ et al. 2003).

RUM assumes that the utility is the sum of a deterministic (v_{ni}) and stochastic components (ε_{ni}):

$$(1) \quad U_{ni} = V_{ni} + \varepsilon_i \equiv \sum_{k=1}^{K} \beta_{nk} x_{nik} + \varepsilon_{ni},$$

where U_{ni} is unobserved utility associated with individual n after selecting attribute i, x_{nik} is the vector of K attributes for alternative *i* and individual *n*, β_{nk} is the vector of preference parameters, and ε_i is the random error term. Logit models assume the error term is independently and identically distributed (iid). Depending on the assumption made on the error term, different probabilistic choice models can be derived (Champ et al. 2003). We can set the probability of individual *n* choosing alternative *i* from the set Θ as[6]:

$$(2) \quad P_n(i) = \frac{\exp(\mu\beta x_{ni})}{\sum_{i\in\Theta}\exp(\mu\beta x_{ni})}$$

where μ is a scale parameter that is typically set equal to one.[7]

The Random Parameter Logit (RPL) model often called Mixed Logit model is a generalization of the MNL model, and allows for random variation in preferences, unrestricted substitution patterns, and correlations among unobserved factors (Train 2009). By using the RPL model we may relax the independence of irrelevant alternatives assumption by introducing additional stochastic components to the utility function through β_n.

We use 500 Halton draws from the normal distribution to estimate Γ for the random parameters in the RPL model. The RPL model captures heterogeneity via a continuous probability distribution for preference parameters. For more information on the MIXL model, readers are referred to Train (2009).

A latent class model (LCM) was used to capture preference heterogeneity for a finite number of heterogeneity classes (Boxall and Adamowicz 2002; Scarpa and Thiene 2005). The LCM assumes the existence of *C* classes (or groups) in a population with individual *n* belonging to class *c*. Individuals within a class are assumed to have homogeneous preferences. The specific utility parameter for each class and the choice probabilities for alternative i for each class is:

$$(3) \quad \pi_{n|c}(i) = \frac{exp(\mu_c\beta_c X_{ni})}{\sum_{k\in C} exp(\mu_c\beta_c X_{nk})}$$

where C is the set of all classes. The probability that an individual *n* belongs to class *c* often is assumed to be logistic:

$$(4) \quad \pi_{nc} = \frac{exp(\alpha\gamma_c Z_n)}{\sum_{c=1}^{C} exp(\alpha\gamma_c Z_n)}$$

where α is a scale parameter (set equal to one), γ_c are specific class-related coefficients, and Z is a vector of individual's socio-demographics and other individual characteristics. The joint probability that an individual *n* belongs to class c and selects alternative *i* can be written as the product of equation 3 and 4:

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[6] This section relies on unpublished work provided José J. Sánchez.

[7] In all of the econometric models we present, the scale parameter is confounded with the β parameters of interest, and therefore we assume that its value is unity. In a single data set, the scale parameter cannot be recovered.

$$(5) \quad \pi_n(i) = \sum_{c=1}^{C} \pi_{nc}\pi_{ni|c}$$

The parameter estimates are estimated by maximizing the log likelihood function:

$$(6) \quad \ln L = \sum_{j=1}^{J} ln\left[\sum_{c=1}^{C} \pi_{nc}\left(\prod_{i=1}^{I}\left(\pi_{ni|c}\right)^{y_{ni}}\right)\right]$$

This model specifies that the choice of an alternative is based on the attributes and respondents characteristics.

In a choice experiment the implicit prices (marginal WTP estimates) of the attributes are measured by the parameter coefficient divided by the absolute value of cost coefficient.

$$(7) \quad MWTP = \frac{\beta_{program\ type}}{|\beta_{cost}|}$$

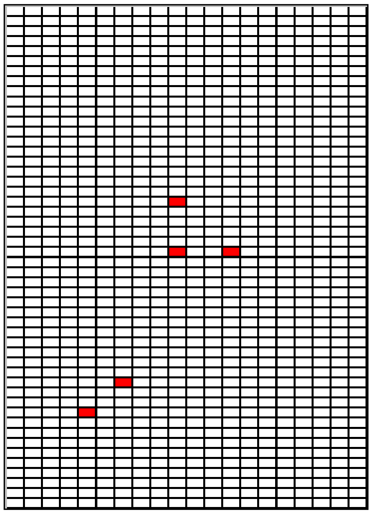
Using this formula and the wildfire hazard mitigation program and cost parameter estimates from tables 2 and 3, the one-time mean WTP for a ten year public and private programs can be derived (table 4).

Choice Experiment Survey Design

We used the same survey as Holmes et al. (2013) and was available both in English and Spanish. The survey began with several questions that asked respondents to answer questions about the vegetation around their home. These questions were followed by a characterization of what certain responses meant for the risk of wildfire in their neighborhood, and the risk of losing their house to a wildfire. Using Florida fire statistics, the current wildfire risk was characterized using a risk ladder and risk chance grid. The chance of a home being damaged by a wildfire, is represented in the chance grid by the number of red squares on a 1,000 cell square grid. The remaining white squares (figure 1) represent the risk of the house being undamaged. A risk ladder (figure 2) was presented to respondents as a way to convey the relative risk of a wildfire damaging a home relative to other ordinary risks (such as having a heart attack for a person over 35 years of age). Both of these risk communication devices have been used in past surveys as a way to convey to respondents the relative and absolute risks (Smith and Desvousges, 1987; Loomis and duVair, 1993; Krupnick et al., 2002).

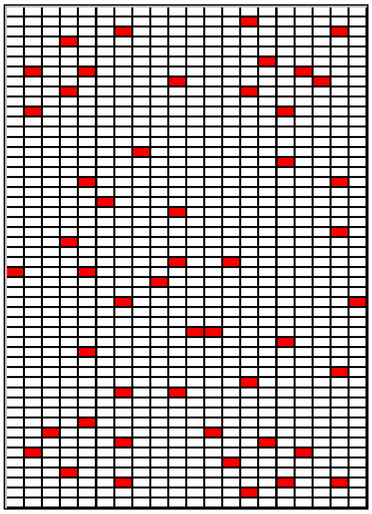
CHANCE GRIDS

(1) UPPER CHANCE GRID: Annual chance



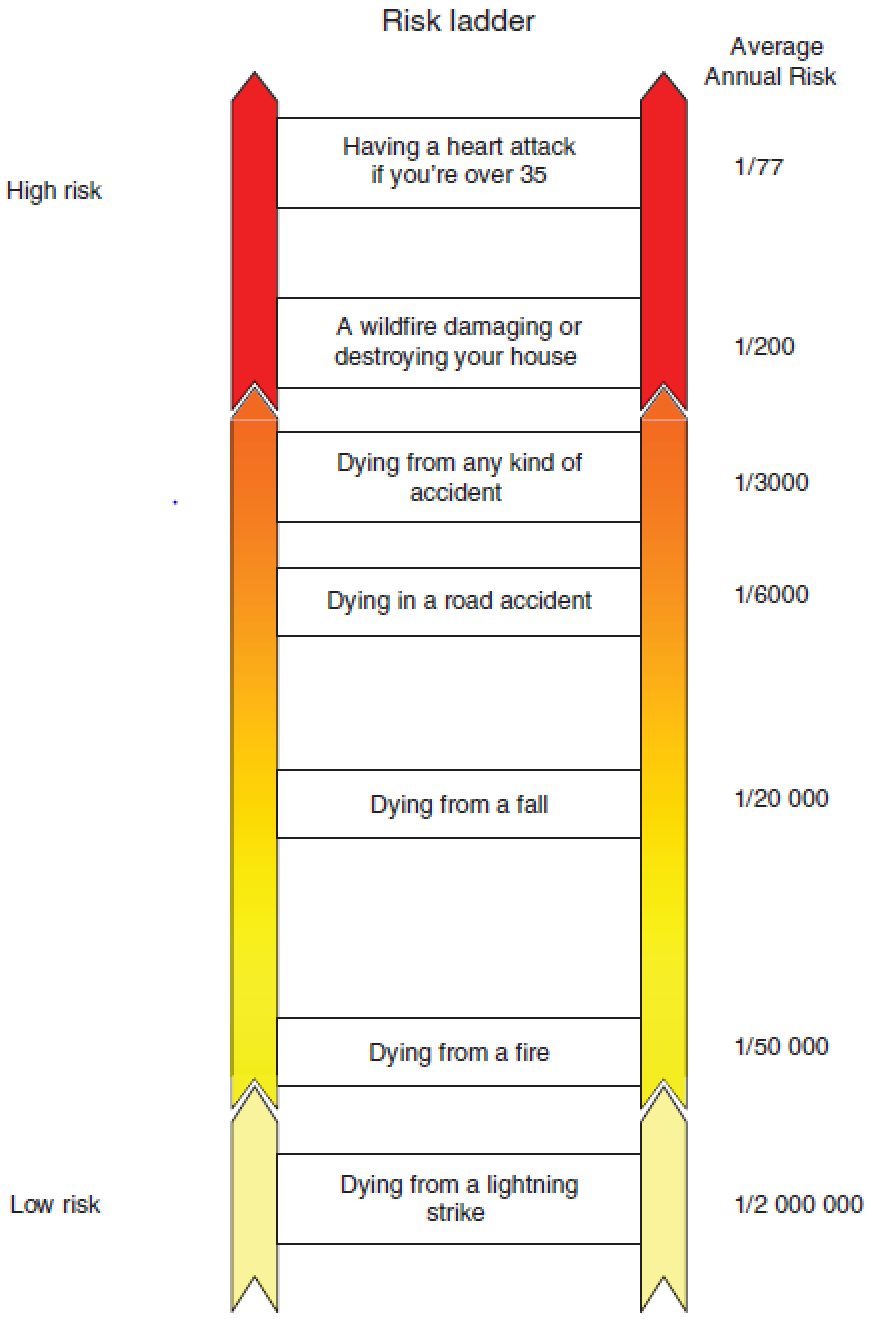
Another way to illustrate the Average Annual Chance of a wildfire damaging your house is shown in the diagram to the left. The "chance grid" shows a neighborhood with 1000 houses, and each square represents one house. The white squares are houses that have not been damaged or destroyed by wildfire, and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

(2) LOWER CHANCE GRID: Ten year chance



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

Figure 1. Risk grids to convey relevant degree of wildfire risk to homeowner survey participants (used with permission from Holmes et al. 2013).



This 'risk ladder' shows the risk of everyday hazards occurring to you over the next 12 months. If you are over 35 years old, the highest risk shown on the ladder is of having a heart attack (this will happen to ~1 in 77 people). The risk of your house being damaged by a wildfire if you live in or near a heavily wooded area (this will happen to ~1 in 200 homeowners) is quite a bit larger than the risk of dying from a fire (this will happen to ~1 in 50 000 people).

Figure 2. Risk ladder to illustrate to survey participants the risk of wildfires relative to other, ordinary daily events (use with permission from Holmes et al. 2013).

The survey implemented a full factorial randomized experiment design (see Holmes et al. 2013) to construct the choice sets. The choice experiment used four attributes of the survey: (1) *risk (%)* or chance (out of 1,000) of your house being damaged by wildfires in the next 10 years; this *risk* varied over five levels, from 1-5%, where 5% was the baseline risk respondents were told was associated with no new investments in wildfire protection programs;[8] (2) monetary damage (*loss*) to property from the wildfire; the *loss* varied over 10 levels that ranged from $10,000-$100,000; (3) expected 10 year loss = chance x damage; attribute #3 is not an independent attribute and was included only to facilitate understanding of how risk and damage interacted to give an "expected value" of the damages; and (4) one-time *cost* to the household for the ten-year program that varied over 10 levels from $25-$1,500 for the Public Program and 9 levels from $50-$1,500 for the Private Program.

An example of a choice question used in the questionnaire is shown in figure 3. Three alternatives were given in each choice set. The first two alternatives represented public and private fire risk mitigation programs. Each alternative program included chance of damage to respondent's house, monetary amount of damage, expected loss (chance times damage), and a one-time cost for implementing the selected ten-year program. In addition, a status quo alternative was included at no cost, representing the typical current situation. This status quo alternative was provided for each choice scenario. A series of three choice questions were asked to each respondent, inducing the panel nature of the response data.

	Alternative 1	Alternative 2	Alternative 3
	Public Fire Prevention	Private Fire Prevention	Do nothing additional
Chance of your house being damaged in next 10 years	10 in 1,000 (1%)	25 in 1,000 (2.5%)	50 in 1,000 (5%)
Damage to property	$10,000	$50,000	$100,000
Expected 10 year loss = Chance x damage	$100 during 10 years	$1,250 during 10 years	$5,000 during 10 years
One-time cost to you for the ten-year program	$100	$500	$0
I would choose: Please check one box	☐	☐	☐

Figure 3. Example of the Choice Set

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

Data

A stratified random sample of households was drawn from the population of African-American and Hispanics households in Florida. The assumption for the stratified sample was because we thought that people living in areas that have a higher risk of damage from wildfires would be both more aware and more concerned regarding wildfire mitigation programs; we developed a weighting scheme where, for each household sampled from low risk communities (as defined by the Florida State Fire Management Agency), two households were sampled from medium risk communities and three households were sampled from high risk communities. Households were recruited using random digit dialing, and basic information was recorded during the initial phone call, as well as identifying if they were African-American or Hispanic. For the interviews we used African-American interviewers to conduct interviews with African-American respondents and Hispanic speaking interviewers to conduct interviews with Hispanic interviewees. Then, households that were willing to participate in the survey were mailed a survey booklet. Two weeks after mailing the booklet, a postcard reminder was sent to households. Out of 500 subjects recruited for participation 319 completed the survey interview for an effective response rate of 63.8%.

Results

Table 1 shows the descriptive statistics for variables in our survey sample and general FL homeowners' data in Holmes et al. (2013). We also test if there was a difference between the variables for both states. The sample consisted of 63% being African-American and 37% Hispanic. The stratified sample included a substantial proportion of respondents with personal experience of the effect of wildfire (31%). 12% of respondents reported health effect from smoke produced by wildfires and 27% reported that they had revised travel plans because of wildfires. Given that 28% of our sample are from communities identified as being at high risk for wildfires, it is surprising that only ~5% of respondents reported that they lived in an area that they perceived to be at *high risk* for wildfires. It is possible that the reason for this is that the majority of respondents that perceive to be living in a high risk community are low-income households (79% have less than $38,000 annual household income). Approximately 72% (*firewise*) of respondents indicated that they previously improved the defensible space on their property (trim lower branches on tree = 58%, removed vines from tress = 50%, remove branches over home = 53%, remove trees and flammable plants = 36%).

In this paper we focus on the RPL model to compare African-American and Hispanic homeowners fire mitigation program preferences and LC model to compare

FL minority homeowners WTP estimates with general FL homeowner data (Holmes et al., 2013).

Table 1. Variables descriptive statistics

Variable	Description	Mean (std. dev.)	Mean (std. dev.)[9]
health (dummy variable)	Health of respondent or family member suffered from breathing smoke from wildfire; if Yes = 1; else = 0	0.12 (0.33)	0.15 (0.35)
Travel[a] (dummy variable)	Household travel plans changed because of a wildfire; if Yes = 1; else = 0	0.27 (0.44)	0.35 (0.48)
personal experience[a] (dummy variable)	If either (health = 1 or travel = 1) = 1; else = 0	0.31 (0.46)	0.43 (0.50)
fire wise (dummy variable)	Household conducted at least one activity to reduce wildfire risk; if Yes = 1; else = 0	0.72 (0.45)	0.76 (0.43)
high risk[a] (dummy variable)	Respondent indicated that home is located in a high fire risk neighborhood; if Yes = 1; else = 0	0.05 (0.22)	0.10 (0.30)
Hispanic[a] (dummy variable)	Respondent indicated that they are Hispanic or Latino; if Yes = 1; else = 0	0.37 (0.48)	0.02 (0.13)
Age[a]	Respondent's age	54.4 (17.01)	58.1 (15.15)
Income[b]	Household annual income	48,317 (43394)	63,410 (47786)
Education level[b]	Respondent's highest education level completed	14.2 (2.47)	14.7 (2.51)

a. The mean proportional values are significantly different between FL and CA at alpha level < .01.
b. The mean values are significantly different between FL and CA at alpha level < .01.

Table 2 show the RPL model results for FL minority homeowners. The cost coefficient has the expected negative sign and is highly significant. Also, the

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[9] General FL homeowners' data from Holmes et al. (2013).

Hispanic dummy variable and cost coefficient interaction is statistically significant at the .10 level. Results suggest that FL minority homeowners perceived to be living in a high risk community are opposed to any type of fire mitigation programs and prefer the status quo (do nothing) alternative. However, homeowners perceived to be living in a low to moderate risk community prefer the public program. Using the public program and cost coefficient, the African-American homeowners marginal WTP is $1,376 while Hispanic homeowners marginal WTP is lower ($639). However, the WTP estimates are not statistically significantly different from each other. These results suggest that minority homeowner are willing to invest in fire mitigation programs; however, Hispanics are willing to invest only half the amount of African-Americans.

Table 2. Random parameter logit model estimates of preference parameters for wildfire hazard mitigation programs with random parameters estimated for risk and loss variables (The dependent variable is the alternative selected in the choice questions).

Variable	Random Parameter Logit Model	
	mean	std. dev.
risk (%)	-0.0702	0.6926***
	(0.6566)	(0.0973)
loss ($1,000)	0.0034	0.0426***
	(0.0038)	(0.0052)
cost ($)	-0.0004***	--
	(0.0002)	
*Hispanic Dummy*cost*	-0.0005*	--
	(0.0003)	
public program	0.6094***	--
	(0.2350)	
*public pro.*high risk*	-0.6122	--
	(0.5963)	
private program	0.2219	--
	(0.2412)	
*private pro.*high risk*	-0.3342	--
	(0.6939)	
*Hispanic Dummy*public*	0.4947	--
	(0.3259)	
*Hispanic Dummy*private*	0.1838	--
	(0.3406)	
N	319	--
McFadden R^2	0.1334	--
Log Likelihood	-911.16	

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

For the LC model, the clearest results were obtained for the 2-class model. In the two-class model (table 3), results show that about 36% of respondents were classified in Class 1 (Less Experience group) and 64% in Class 2 (More Experience group). The Class 1 parameter estimate on risk is not significantly different than zero, while loss is significant, suggesting that respondents focus their attention on losses. Further, the negative sign and statistically significant coefficient for the public and private mitigation programs suggest that these respondents who perceive to be living in a low to moderate risk community are generally opposed to these type of mitigation programs and will need to be compensated to participate. Surprisingly, those homeowners that perceived to be living in a high risk community, prefer the status quo (do nothing) alternative. In contrast, respondents in Class 2 who perceived to be living in a low to moderate risk communities have a positive WTP for reducing the risk of experiencing a financial loss from wildfires. And also have a higher propensity to support public and private mitigation programs as suggested by the positive and statistically significant coefficients. Respondents living in a low and moderate risk area have a positive WTP for 10-year public ($5,610) and private ($4,757) programs.

Surprisingly, Class 2 respondents that perceive to be living in a high risk community have a negative WTP sign for both the public and private program; implying they would have to be compensated (willingness-to-accept - WTA) to participate in the public ($405 annually) and private ($359 annually) programs. A plausible explanation for these findings is that the majority of respondents that perceive to be living in a high risk community are low-income households (79% have less than $38,000 annual household income). This means these households do not have sufficient disposable income to cover the additional expenses for fire mitigation programs. In addition, 79% of households perceived to be living in a high risk community indicated that they have wildfire insurance protection and 63% had previously improved the defensible space on their property. Therefore, they might be under the impression that no additional protection is needed.

Table 3. Latent class model estimates of homeowner preference parameters for wildfire hazard mitigation programs among survey respondents

	Two-class model		Two-class model (Holmes et al., 2013)[10]	
Variable	Class 1	Class 2	Class 1	Class 2
risk (%)	0.0994	-0.1168***	0.0003	-0.1135***
	(0.1070)	(0.0428)	(0.0877)	(0.0263)
loss ($1,000)	0.0149**	-0.0052**	-0.0087*	-0.0041***
	(0.0067)	(0.0022)	(0.0045)	(0.0013)
cost ($)	-0.0016***	-0.0005***	-0.0027***	-0.0007***
	(0.0005)	(0.0001)	(0.3687)	(0.0001)
public pro.	-1.042**	2.5774***	-2.401***	2.1532***
	(0.4352)	(0.3042)	(0.3687)	(0.1682)
public pro.*hi risk	0.4161	-1.8601**	1.6074***	0.8749
	(1.0517)	(0.8304)	(0.4304)	(0.5535)
private program	-1.4469***	2.1853***	-2.5368***	1.8902***
	(0.4743)	(0.3073)	(0.3998)	(0.1708)
private pro.*hi risk	1.424	-1.6508*	-0.601	1.1748**
	(0.9354)	(0.8714)	(1.0937)	(0.561)
Covariates explaining latent class membership[a]				
constant	-0.4100***	--	-0.2594***	
	(0.1511)		(0.0958)	
personal experience	-0.5426*	--	-0.5871***	
	(0.2823)		(0.1457)	
average class probability	0.36	0.64	0.38	0.62
n	319		922	
McFadden R^2	0.227		0.243	

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.

[a] In the two-class model, Class 2 is the baseline.

Comparing results (table 3) with general FL homeowners (Holmes et al., 2013) shows that in general both studies have the same significant coefficients. In both studies, Class 1 homeowners that perceived to be living in a low to moderate risk community generally opposed these type of fire mitigation programs and will need to be compensated to participate. For Class 2, homeowners that perceived to be living in a low to moderate risk communities are in favor of participating in both fire mitigation programs. However, there are differences when comparing households that perceive to be living in a high risk community. Results from general FL data (Holmes et al., 2013) shows that households from both classes prefer either the status quo or one of the fire mitigation programs. This is not the case for minority households in Class 2. These households have negative coefficients meaning that they generally opposed to these type of fire mitigation programs and will need to be compensated to participate.

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[10] Data used from Holmes et al. (2013). Model estimated without public program and defensible space interactions to make comparisons.

Table 4 shows the one-time WTP or WTA (negative values in table) estimates for a 10-year program for both data sets. For FL minority homeowners in the Less Experience group, the one-time WTA estimate for both the public and private programs are always lower than general FL homeowners estimates. However, the large confidence interval suggest the mean WTP amounts are not significantly different across the two studies. For those homeowners in the more experience group, the one-time WTP estimate are higher for both programs for FL minorities than general FL homeowners. However, they are not statistically significantly different across studies. FL minority homeowners that perceived to be living in a high risk community have a WTA while general FL homeowners have a WTP amount.

Table 4. One-time WTP/WTA per homeowner for a ten year Public and Private wildfire risk reduction actions (2009 Dollars).

	Homeowners			
	Mean WTP/WTA Low to Moderate Risk Perception Program		Mean WTP/WTA High Risk Perception Program	
	Public	Private	Public	Private
	------------------- (95% Confidence Interval[b]) ----------------------			
FL minority homeowners	-$640	-$889	-	-
Less Experience	(-$1419, $139)	(-$1815, $37)	-	-
FL minority homeowners	$5610	$4757	-$4049	-$3593
More Experience	($2764, $8456)	($2288, $7226)	(-$8078, -$20)	(-$7699, $512)
FL Homeowners[a]	-$942	-$995	$630	-
Less Experience	(-$1528, -$354)	(-$1637, -$352)	($195, $1065)	-
FL Homeowners[a]	$3387	$2973	-	$1848
More Experience	($2615, $4160)	($2258, $3688)	-	($64, $3633)

a. WTP/WTA estimates were converted from 2006 to 2009 dollars using CPI (Bureau of Labor Statistics, 2016).
b. Delta method was used to construct confidence intervals.

Conclusions

Both the RPL and the LC models used for analysis revealed some interesting findings. Using the RPL model, results suggest that minority homeowner are willing to invest only in a public wildfire mitigation program. In addition, we found that African-American have a higher WTP estimates for public program than Hispanics. For the LC model, respondents in the Less Experience group with exposure to wildfires preferred the do nothing alternative and respondents in the More Experience group with exposure to wildfires that perceived to be living in low to medium fire risk expressed supported for both the public and private wildfire protection programs. However, we were surprise to find that respondents that subjectively rated living in a high risk area would prefer the do nothing alternative. It appears that income is a critical factor when deciding to support wildfire protection programs. When comparing results with general FL household data in Holmes et al. (2013), we found similar results for the Less Experience group. However, for the More Experience group, different household preferences are seen. General FL households (Holmes et al., 2013) prefer the private program, but status quo instead of a public program. Our results show that households in the More Experience group generally opposed to these type of fire mitigation programs and need to be compensated to participate in either of the two programs.

Results suggest the highest priority for cost sharing funds would go to homeowners in areas who perceive their houses to be at high risk, and especially to cost share private actions on their own land. Thus, our results would be informative to fire managers regarding targeting low-income minority households that live in a high risk area. It could also aid decisions on cost sharing funds in terms of what types of actions/programs (private vs public) to cost share.

Acknowledgements

We thank Dr. John Loomis, Department of Agricultural and Resource Economics, Colorado State University for his valuable comments and suggestions that improved the presentation of the material in the manuscript.

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Do Fuel Treatments Reduce Wildfire Suppression Costs and Property Damages? Analysis of Suppression Costs and Property Damages in U.S. National Forests[1]

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Abstract

This paper reports the results of two hypotheses tests regarding whether fuel reduction treatments using prescribed burning and mechanical methods reduces wildfire suppression costs and property damages. To test these two hypotheses data was collected on fuel treatments, fire suppression costs and property damages associated with wildfires on United States National Forests over a five year period. Results of the multiple regressions show that only in California did mechanical fuel treatment reduce wildfire suppression costs. However, the results of our second hypothesis tests that fuel treatments, by making wildfires less damaging and easier to control, may reduce property damages (i.e., structures—barns, out buildings, etc. and residences lost) seems to be confirmed for acres treated with prescribed burning. In three out of the three geographic regions of the U.S. which experienced significant property losses, prescribed burning lowered the number of structures damaged by wildfire.

Keywords: mechanical fuel reduction, prescribed burning, property damage, wildfire suppression costs

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[1] An abbreviated version of this paper was presented at the Fifth International Symposium on Fire Economics, Planning, and Policy: Wildfires and Ecosystem Services, November 14-18, 2016, Tegucigalpa, Honduras.

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Introduction

Around the world, large wildfires and fires in the wildland urban interface (WUI) have escalated in frequency, size, suppression costs and property damages. For example, during the last decade the USDA Forest Service (FS) alone has incurred wildfire suppression costs of over $19 billion fighting wildfires that have burned more than 39 million ha of forest and brush lands (NIFC 2014). Furthermore, in the period from 1999 to 2010 more than 1100 homes were burned and a total of 230 lives lost (Gude et al. 2013). Additionally, there is growing recognition of the futility of fighting fires in ecosystems where prior fire exclusion policies have led to dangerous fuel accumulations. For example see GAO 2015 report (GAO: 1) which states …" *However, over the past century, various land management practices, including fire suppression, have disrupted the normal frequency of fires in many forest and rangeland ecosystems across the United States, resulting in abnormally dense accumulations of vegetation…*" The 2014 *Quadrennial Fire Review* (Hamilton 2015: iii) further states that "…*Fuel levels are also at unprecedented levels due to climatic change, decades of suppression that have limited fire from prewar levels of 25 to 40 million acres burned per year to 5 million or fewer since the 1960s, and a decline in active forest management*…" One strategy for reversing this trend is to perform fuel reduction treatments such as prescribed burning and mechanical fuel reduction. In general, within the fire management community it is believe that such fuel reduction treatments, will be effective in reducing the wildfire suppression costs and property damage. This paper tests the hypotheses that current fuel treatment practices reduce wildfire suppression costs and property damage associated with wildfires on U.S. National Forests over the past five years.

Literature Review

By and large the three most common reasons found in the literature for explaining the current increase in wildfire property damages and suppression costs are: 1) fuels build up resulting in part from past fire suppression policies, 2) warmer temperatures and drought conditions, and 3) expansion of the WUI into fire-prone landscapes. We organize our literature review around these three reasons, although the emphasis is on 1 and 3 since these can be influenced by forest management.

From a theoretical perspective, Rideout et al. (2008) explored the topic of whether fuel treatments have the potential to reduce wildfire suppression costs in the treated area. They showed that it is difficult to establish an unambiguous relationship between fuel treatments and resulting suppression costs, without factoring in the implied level of net fire damage. Further, prior fuel treatments often make fire suppression efforts more effective, and hence more, not less, suppression may be warranted in areas that have been treated, than in untreated areas (which may be too unsafe to engage in wildfire suppression or wildfire suppression will do little to reduce damages). On the other hand, because fire suppression may be more effective the resulting final wildfire size might be smaller, potentially reducing fire suppression costs and property damages. But what the net effect of these possible relationships are is an empirical question that can only be addressed with data on actual fire suppression costs in treated versus untreated areas. Therefore, we first turn to the existing literature to see what prior empirical analyses have found and to guide our empirical hypothesis testing.

A study of suppression costs in Western United States by Gebert et al. (2007), found that higher home values within 20 miles of a wildfire ignition increased suppression expenditures. All other variables that influenced suppression costs were biophysical variables like extreme fire behavior, drought conditions, wildfire intensity levels, and energy release component.

Yoder and Ervin (2012) were one of the first to conduct an analysis of fire suppression costs at the county level in the western U.S. and test whether there is any relationship between fuel treatment costs and wildfire suppression costs. To conduct this analysis, Yoder and Ervin ran suppression costs as a function of: acreage, prescribed (RX) burn acres, mechanically thinned acres, amount spent on RX burning, amount spent on thinning, vegetation type, WUI area, temperature, and precipitation.

Yoder and Ervin included four years of lagged values of burning acres and thinning acres to pick up relative effectiveness of these fuel treatments over time. While their model had reasonably high explanatory power (71% or .71 R^2) generally neither the acres of prescribed burning nor the cost of prescribed burning nor the acres thinned nor the cost of thinning had a negative and significant effect on suppression costs (just one of the 16 variables). However, it is possible that their model exhibits a degree of multicollinearity; as one would expect that acres thinned and cost of thinning as well as acres burned and cost of burning would be highly correlated, and thus this could mask a significant relationship.

More recently, Gude et al. (2013) used fires in California's Sierra Nevada to estimate the relationship between housing and fire suppression costs. That is, whether the presence of homes is associated with increases in fire suppression costs after controlling for other biophysical parameters (e.g., size, terrain, weather, etc.). Their study found a small, but statistically significant increase in suppression costs with the presence of homes within a 6-miles radius of an active wildfire. Scofield et al. (2015) analyzed the effect of the spatial configuration of houses in the WUI on costs of fighting nearly 300 wildfires in Colorado, Montana and Wyoming from 2002 to 2011. Schofield et al. (2015: 3) found that not only does homes in the WUI matter, but that whether the homes are widely dispersed in that landscape (e.g., 35 acre parcel development common in Colorado) versus whether they are clustered together had a significant effect on wildfire suppression costs. Gude et al. (2014) evaluated the factors determining fire suppression costs including the Firewise Program. In their model the fire size, fire duration and terrain difficulty had the biggest influence on fire suppression costs. The Firewise Program variable was not significant.

Finally, Thompson and Anderson (2015) took a modeling approach to evaluating the effects of fuel treatment on fire suppression costs. They compared three modeling approaches that were applied in different geographic areas (i.e., Oregon, Arizona and the Great Basin). Across this broad geographic span they found that the potential existed for costs of fighting wildfires to be reduced by fuel treatments. However, they noted (Thompson and Anderson, 2015: 169): *"Second, the relative rarity of large wildfire on any given point on the landscape and the commensurate low likelihood of any given area burning in any year suggests the need for large-scale fuel treatments….Thus in order to save large amounts of money on fire suppression, land management agencies may need to spend large amounts of money on large-scale fuel treatment".* This will be a point we return to in our conclusion.

What can we conclude from the literature? First, in order to isolate the effect of fuel treatment on wildfire suppression costs, it is important to control for whether the wildfire was in WUI and biophysical variables. Specifically, wildfire suppression costs were related to fire size, terrain (e.g., slope), and wildfire intensity levels. Higher fuel loads (e.g., density and type of vegetation) also appear to affect wildfire suppression cost, and reducing fuel loading is one of the purposes of prescribed burning and mechanical fuel treatments. Thus, our empirical model specification includes all of these factors in an attempt to control for them when testing whether fuel reduction treatment reduces wildfire suppression costs.

Fuel treatments are increasing viewed as a means to reduce the severity of wildland forest fires, and make these fires easier to control and suppress. An ancillary goal is to reduce property damages and lives lost due to wildfires. While these are desirable goals of a fuel treatment program, prescribed burning and mechanical fuel reduction are costly to conduct. As such they have to be budgeted for. In order to budget for them, it is necessary to have some systematic method to estimate the costs.

Empirical Model Specification and Hypothesis Tests

Wildfire Suppression Cost Model

Building upon the Gude (2014) and Yoder and Ervin's (2012) models, particularly in the latter, we estimate a multiple regression model to test hypotheses and quantify the effect of fuel treatment efforts on wildfire suppression costs and structures damaged.

Our regression models account for many of the quantitative and qualitative variables that influence the costs of wildfire suppression costs. In particular:

Dependent Variable

Ln(TSC) = natural log of Total Suppression Costs

Independent Explanatory Variables

Acres_Mech: Acres of the wildfire area with prior mechanical fuel treatment

Acres_RX: Acres of the wildfire area with prior fire fuel treatment

lnWFacres: natural log of wildfire size in acres

WUIY: intercept shifter variable for whether the fire is in a WUI area

Elev: average elevation of the wildfire area

Slope: average slope within the wildfire area

% low fuel load: percent of the area with low level of existing fuel loads

% mixed fuel load: percent of the area in medium or mixed level of existing fuel loads

% **high fuel load**: percent of the area in high level of existing fuels (omitted dummy)

FInt_ft: Fire Intensity Level, measured in feet

Crown Density: Crown bulk density

Fire Return Interval: Mean Fire return interval of the vegetation across the wildfire area

Interaction Term

WUIY * Elev: included to see if there was a differential cost of fighting wildfires in WUI areas as the elevation increased.

The baseline model specified for all geographic regions (defined in more detail below) is:

$$(1)\ \ln(\text{TSC}) = B_0 - B_1(\text{Acres\_Mech}) - B_2(\text{Acres\_RX}) + B_3(\text{lnWFacres}) + B_4(\text{WUIY}) + B_5(\text{Elev}) + B_6(\text{Slope}) - B_7(\%\text{low fuel load}) + B_8(\%\text{mixed fuel load}) + B_9(\text{FInt\_ft}) + B_{10}(\text{Crown Density}) + B_{11}(\text{Fire Return Interval}) + B_{12}(\text{WUIY*Elev})$$

The coefficients on the fuel treatment variables should be negative and significant if presuppression fuel treatment reduces fire suppression costs. Mathematically our hypothesis (with TSC as dependent variable) can be expressed as:

(2) Ho: $B_{AcresRX} = 0$ Ha: $B_{AcresRX} < 0$

(3) Ho: $B_{AcresMECH} = 0$ Ha: $B_{AcresMECH} < 0$

The hypotheses are tested based on asymptotic t-statistics on the two types of pre-suppression fuel treatments.

Property Damage Model

(2) $\mathbf{ln(\#Structures)} = A_0 - A_1(\mathbf{Acres\_Mech}) - \mathbf{A_2(Acres\_RX)} + \mathbf{A_3(lnWFacres)} + \mathbf{A_4(WUIY)}$

Where #Structures is the sum of houses and other structures (barns, out buildings, unattached garages, etc.) destroyed by wildfires.

The hypothesis tests for property damage (# structures) is:

(4) Ho: $A_{AcresRX} = 0$ Ha: $A_{AcresRX} < 0$
(5) Ho: $A_{AcresMECH} = 0$ Ha: $A_{AcresMECH} < 0$

The hypotheses are tested based on asymptotic t-statistics on two types of presuppression fuel treatments.

Data

Study Sites

To make the study as comprehensive as possible and representative of all vegetation types and fuel models, and fuel treatment activities across the U.S. we collected fuel treatment and wildfire suppression costs and associated data in all U.S. National Forest regions of the continental U.S. except Alaska. Ecologically, and in terms of its fire regime, Alaska is very different from all regions in the continental US that it would require a separate modeling effort.

Development of Database for Wildfire Suppression Costs

Individual wildfire suppression data was obtained for years 2010 to 2014. This file includes data on the size of each fire, structures destroyed, and of course the cost of suppression. However, there were significant concerns regarding the accuracy of the cost data reported, especially for small fires. A significant effort was made to collaborate with the USDA Forest Service scientists at the Rocky Mountain Research Station to obtain more accurate wildfire suppression cost data for large wildfires (fires greater than 300 acres). Thus we restrict our analysis to fires 300 acres or larger. This more accurate cost of suppression data was obtained and merged into the other wildfire suppression data describing wildfires to create a master wildfire suppression database where the unit of analysis is the individual fire.

Data on RX burning and mechanical fuel treatment was obtained from the USDA Forest Service FACTS treatment area data. Acres treated by each method were geolocated and then merged into the wildfire suppression cost data and the GIS spatial data on the area of the treatments and wildfires (e.g., slope, elevation, vegetative cover) to create the master dataset used for the regression analysis.

Determining Geographic Regions of Analysis

Given the limited number of observations for each of the USDA Forest Service Regions, we evaluated grouping the data into larger geographic regions. A natural choice for this was the U.S. interagency Geographic Area Coordination Centers (GACC) used by the Forest Service fire management organization for making fire suppression decisions, including logistics and dispatch. An initial national wildfire suppression cost model was estimated that included each GACC as an intercept shifter variable to allow evaluation of the similarity of geographic regions' coefficients. In addition, an ANOVA (Analysis of Variance) was performed on the individual GACC's that showed that some GACC's had statistically significant differences in wildfire suppression costs per acre from each other but others did not. Based on these two statistical analyses as well as geography, the GACC's were put into groups of two or three. Specifically, the Northern and Southern California GACC's were made into one fire suppression cost analysis area. The Eastern and Southern GACC's were also combined. The two Rocky Mountain GACC's and the Southwest GACC were combined into one wildfire suppression analysis area. The Northwest GACC and Great Basin GACC's were combined. Thus we have four wildfire analysis regions. Details on the national wildfire suppression cost model and the ANOVA is available from the senior author.

Selected Descriptive Statistics

Table 1 provides the key descriptive statistics on the number of wildfires, structures destroyed and the average percentage of a wildfire area treated with RX fire and mechanical fuel reduction treatments. As can be seen in Table 1, only small percentages of wildfire areas have had fuel treatments. As can be seen by comparing the mean and median, far less than half the areas had any fuel treatments of any kind.

It is also worth noting that there is insufficient sample size to estimate a regression on structures and houses lost in wildfires with and without treatment for the Eastern and Southern GACC. Specifically, there were only eight structures lost in total in two of the 173 wildfires in the Eastern and Southern GACC.

Table 1. Percent of Wildfire Areas Treated and Structures and Houses Destroyed

GACC Group Wildfires	Percent Treated Fire	 Mechanical	Number Destroyed Structures	 Houses	Sample n
Group 1 East-SO					
Mean	15	0.5	6	2	173
Median	0	0			
Group 2 Rocky-SW					
Mean	8.8	0.4	36	20	390
Median	0	0			
Group 3NW-GB					
Mean	7.3	0.5	35	9	223
Median	0	0			
Group 4 California					
Mean	1	0.13	27	19	115
Median	0	0			

East-So is the Eastern and Southern GACCs; Rocky-SW is the Rocky Mountains and Southwest GACCs. NW-GB is the Northwest and Great Basin GACCs. Calif is the Northern and Southern California GACCs.

Results

Statistical Results of Wildfire Suppression Cost by GACC Groups

In Table 2 we presents the regression results for Group #1 (Eastern and Southern GACC's)

Table 2. Suppression Costs for GACC Group #1 (Eastern and Southern GACC's).

Variable	Estimate	Std. Error	t value	Probability
Intercept	2.6553	1.1021	2.409	0.1712*
Acres_Mech	-0.1913	0.6397	-0.299	0.7653
Acres_RX	-0.0004	0.0004	-1.227	0.2216
lnWFacres	0.9930	0.1358	7.312	1.17e-11***
WUIY	0.8679	0.3539	2.452	0.01526*
Elevation	-0.0015	0.0006	-2.439	0.01058*
Slope	0.1215	0.0264	4.603	8.40e-06***
% low fuel load	-0.0008	0.0333	-0.023	0.982
% mixed fuel load	-0.0650	0.0498	-1.305	0.1939
FInt_ft	0.0848	0.0308	2.753	0.00658**
Crown density	0.1784	0.0835	2.136	0.0342*
Fire Return Interval	0.0810	0.0442	1.833	0.0687.
WUIY*Elevation	0.0001	0.0001	0.125	0.9007
R square	0.4920			

*** significant at the 99.99% level; ** significant at the 99.9%; * significant at the 99% level;
+ significant at the 95% level; . significant at the 90% level.

Most of the variable coefficient signs make sense: wildfires involving WUIY, higher crown density forests, steeper slopes and high fire intensity levels have greater than average suppression costs. Overall the model's explanatory power is reasonably good (49.2%) for cross section data across a broad a geographic scope.

In terms of our hypotheses tests, neither Acres Mech treatment nor Acres RX treatment are statistically different from zero. That is, acres of the wildfire area treated with either mechanical or fire fuel treatments appear not to have a systematic effect on wildfire suppression costs.

Table 3 presents the regression results for the model for Group 2 (Rocky Mountains and Southwest GACC's).

Table 3. Suppression Costs for GACC Group #2 (Rocky Mountains and Southwest GACC's).

Variable	Estimate	Std. Error	t-value	Probability
Intercept	5.0260	0.6357	7.905	2.93e-14 ***
Acres_Mech	0.5056	0.4550	1.111	0.267156
Acres_RX	0.0000	0.0002	0.214	0.830862
lnWFacres	0.5318	0.0760	6.997	1.18e-11 ***
WUIY	2.3740	0.9269	2.562	0.010806 *
Elevation	0.0010	0.0002	3.923	0.000104 ***
Slope	0.0518	0.0159	3.264	0.001197 **
% low fuel load	0.0094	0.0189	0.499	0.617967
% mixed fuel load	0.0302	0.0317	0.952	0.341547
FInt_ft	0.1638	0.0229	7.141	4.74e-12 ***
Crown density	-0.0221	0.0306	-0.724	0.46943
Fire Return Interval	-0.0585	0.0240	-2.440	0.015150 *
WUIY*Elevation	-0.0007	0.0005	-1.488	0.137542
R square	0.425			

*** significant at the 99.99% level; ** significant at the 99.9%; * significant at the 99% level;
+ significant at the 95% level; . significant at the 90% level;

Most of the variable coefficient signs in Table 3 make sense: wildfires involving WUIY, steeper slopes, higher elevation and higher Fire Intensity level all result in higher than average wildfire suppression costs. The explanatory of the model is fairly high (42.5%) for cross section data across such a broad geographic scope.

In terms of our hypotheses tests, Acres Mech Treatment and Acres RX Treatment are not statistically different from zero. That is, acres of the wildfire area treated with either mechanical or fire fuel treatments appear not to have a systematic effect on wildfire suppression costs.

Table 4 presents the regression results for the model for Group 3 (Northwest and Great Basin GACC's).

Table 4. Suppression Costs for GACC Group #3 (Northwest and Great Basin GACC's).

Variable	Estimate	Std. Error	t-value	Probability
Intercept	8.9760	0.8400	10.686	2e-16 ***
Acres_Mech	-0.1818	0.5090	-0.357	0.7213
Acres_RX	0.0001	0.0003	0.247	0.8054
lnWFacres	0.5529	0.0904	6.114	4.74e-09 ***
WUIY	-0.1205	0.7861	-0.153	0.8783
Elevation	0.0001	0.0002	0.358	0.721
Slope	0.0065	0.0174	0.371	0.7109
% low fuel load	0.0215	0.0327	0.657	0.5118
% mixed fuel load	0.0229	0.0364	0.63	0.5294
FInt_ft	0.0262	0.0313	0.837	0.4035
Crown density	0.0630	0.0268	2.351	0.0197 *
Fire Return Interval	-0.0597	0.0272	-2.198	0.0291 *
WUIY*Elevation	0.0005	0.0005	1.15	0.2513
R square	0.26			

*** significant at the 99.99% level; ** significant at the 99.9%; * significant at the 99% level; significant at the 95% level;

The performance of this model is relatively low with wildfire size, higher crown density and longer fire return interval resulting in higher than average wildfire suppression costs. The explanatory power of the Pacific Northwest and Great Basin model is 25%.

In terms of our hypotheses tests, neither Acres Mech nor Acres RX are statistically different from zero. That is, acres of the wildfire area treated with either mechanical or fire fuel treatments appear not to have a systematic effect on fire suppression costs.

Table 5 presents the regression results for the model for Group #4 Northern and Southern California.

Table 5. Suppression Costs for GACC Group #4 (Northern and Southern California GACC's).

Variable	Estimate	Std. Error	t-value	Probability
Intercept	9.6310	1.0980	8.772	4.21e-14 ***
Acres_Mech	-4.2690	2.1490	-1.987	0.04963 *
Acres_RX	0.0000	0.0001	-0.326	0.74547
lnWFacres	0.5859	0.1096	5.344	5.56e-07 ***
WUIY	-0.9208	0.8329	-1.106	0.27148
Elevation	-0.0003	0.0004	-0.805	0.42269
Slope	0.0257	0.0229	1.121	0.26488
% low fuel load	0.0302	0.0289	1.044	0.29918
% mixed fuel load	0.0907	0.0490	1.85	0.06725 .
FInt_ft	0.0652	0.0350	1.864	0.06526 .
Crown density	0.0122	0.0341	0.358	0.72117
Fire Return Interval	-0.1130	0.0414	-2.731	0.00745 **
WUIY*Elevation	0.0006	0.0008	0.822	0.41309
R square	0.49			

*** significant at the 99.99% level; ** significant at the 99.9%; * significant at the 99% level;
+ significant at the 95% level; **.** significant at the 10% level $R^2 = 49.0\%$

The California regression performs reasonably well in terms of signs and significance level. In particular the variable coefficient signs make sense: high percent mixed fuel load fuels, higher fire intensity level, and the longer the fire return interval results in higher than average wildfire suppression costs. We believe that WUIY is insignificant because there is little variation, as most wildfires in California have a WUIY area within them. The explanatory power of the model is reasonably good at 49%.

In terms of our hypotheses tests, the statistical significance and negative sign on Acres Mech indicates that the more acres of a wildfire area treated with mechanical fuel reduction, the lower the costs of fire suppression in California. However, Acres RX is not statistically different than zero. That is, acres of the wildfire area treated with a fire fuel treatment appear not to have a systematic effect on wildfire suppression costs.

Out of the four GACC groups, only one of the fuel treatments had a statistically significant negative effect on wildfire suppression costs (Northern and Southern California GACCs). As noted above in our discussion of hypotheses, it is possible that the lack of statistical significance of the fuel treatment variables may be due to opposing effects: in some wildfires, fuel treatment did lower suppression costs, but in other wildfires, fuel treatments allowed fire fighters to enter areas that would otherwise not be safe, thereby raising wildfire suppression costs. As Rideout et al. (2008) point out this is result is theoretically possible under plausible circumstances. In addition as noted by Thompson and Anderson (2015) there may simply be too few fuel treatments in areas with wildfires to detect any effects of fuel treatments on wildfire suppression costs. That lack of significance of prescribed burning (Acres_RX) and mechanical fuel reduction (Acres_Mech) almost uniformly across all but one GACC regions is consistent with the findings of Yoder and Ervin (2012). Our results are also consistent with the general finding of Gude et al. (2014) that the Firewise Communities Program of reducing vegetative fuels around homes did not reduce wildfire suppression costs.

Results for Effect of Fuel Treatment of Property Damages

Our second hypothesis test is that fuel reduction treatments such as RX burning and mechanical fuel reduction by raising the marginal productivity of a given expenditure of fire suppression money would reduce the number of homes and other structures damaged by wildfires (Rideout et al. 2008). This is the finding of Bostwick et al. (2011) for one fire (Wallow Fire) in the southwestern U.S. Obviously testing with multiple fires in multiple geographic regions is necessary to determine if this is the usual result or not.

As was shown previously in Table 1, the relatively low number of structures (i.e., houses, barns, out buildings) damaged relative to the large number of fires suggested that a count data model might be the appropriate statistical technique to estimate the effect of fuel treatments on property damages. A count data is well suited to handle small integers, including zeros better than OLS regression does. We adopted a rather parsimonious model to test for the effect of the number of acres of the wildfire treated with mechanical fuel reduction (Acres_Mech) and the number of acres treated with prescribed fire fuel treatment (Acres_RX). Other variables included are size of wildfire (lnWFacres) and whether the fire occurred in a WUI area. Due to the fact that GACC Group #1 only had 2 homes lost and 6 other structures destroyed out of 173 wildfires, it was determined that it was not feasible to estimate a count data model regression for GACC Group #1.

The results in Table 6 across the three GACC groups with sufficient data on structures burned, show that larger wildfires and wildfires in WUI resulted in more structures lost. In terms of our hypothesis, the larger the wildfire area treated with prescribed burning the fewer the number of structures destroyed. Specifically, in all three GACC's the coefficient on Acres_RX is negative and statistically significant, indicating as Acres_RX went up, number of structures destroyed decreased (all were significant at the 99% level). The results were more mixed for mechanical fuel reduction. In GACC Group #2 (the Rocky Mountains and Southwest) Acres_Mech was positive and significant at the 95% level. In the Northwest and Great Basin (GACC Group #3) Acres_Mech was negative but not significant at conventional levels.

Table 6. Count Data Regression Results for Number of Structures Destroyed in Wildfires

Table 6a. GACC Group #2 (Rocky Mountains and Southwest GACC's).

	Coefficients Estimate	Std. Error	t-value	Probability
Intercept	-8.364	0.5040	-16.594	< 2e-16 ***
lnWFacres	0.8113	0.0506	16.032	< 2e-16 ***
WUI	1.483	0.1577	9.406	< 2e-16 ***
acres_RX	-2.494e-04	8.795e-05	-2.835	0.0046 **
acres_Mech	0.5697	0.2949	1.932	0.0533 .

Significance codes: 0.0001***; 0.001**; 0.05 .

Table 6b. GACC Group #3 (Northwest and Great Basin GACC's).

	Coefficients Estimate	Std. Error	t-value	Probability
Intercept	-6.8109	0.4335	-15.713	< 2e-16 ***
lnWFacres	0.7159	0.0426	16.814	< 2e-16 ***
WUI	1.4699	0.1372	10.711	< 2e-16 ***
acres_RX	-0.0013	0.0004	-3.472	0.0005 ***
acres_Mech	-0.4496	0.4387	-1.025	0.3055

Significance codes: 0.0001***

Table 6c. GACC Group #4 (Northern and Southern California GACC's).

	Coefficients Estimate	Std. Error	t-value	Probability
Intercept	-4.8659	0.2750	-17.694	< 2e-16 ***
lnWFacres	0.6749	0.0297	22.739	< 2e-16 ***
WUI	0.7749	0.1089	7.108	1.18e-12 ***
acres_RX	-0.0291	0.0038	-7.737	1.01e-14 ***
acres_Mech	4.8093	1.3655	3.522	0.0004 ***

Significance codes: 0.0001***

Conclusion

Overall we found that fuel treatments rarely had a significant effect on reducing wildfire suppression costs. As noted in the literature (particularly Thompson and Anderson, 2015), it may be that for fuel treatments to have a significant effect on wildfire suppression costs, there has to be a more substantial effort on prescribed burning and mechanical fuel reduction than is currently the case. Alternatively, as pointed out by Rideout et al. (2008) fuel treatments may increase the effectiveness of wildfire suppression efforts leading to reduced resource and property damages. In the case of property damages, Rideout et al. (2008) hypothesis seems borne out. In our data, areas with prescribed burning did have lower property damages from wildfires. This may suggest emphasizing presuppression fuel reduction in WUI areas as the primary benefits of such fuel reduction projects is in reducing property damages rather than reducing wildfire suppression costs. But this evidence should be revisited after data on the 2016 wildfire season is available, since 2016 had a substantial number of homes lost compared to what is in our data set.

Of course all research conclusions are subject to limitations, and ours is no exception. As noted in the data section, we focused on fires of 300 acres and larger as we were told by fire management personnel this was the best quality data available on fire suppression costs and that fire suppression cost data on smaller fires was not reliable. It is possible that with data on a wider range of fire sizes (e.g., fires of 50 acres and larger) that there may be more of an effect of presuppression fuel treatments in reducing fire suppression costs.

In addition, the current research results also suggest a new hypothesis. Specifically, that one potential effect of presuppression fuel treatments may be to keep small fires from growing into larger, more expensive to control fires. Unfortunately we do not have data to test this hypothesis but it seems like this may be an important avenue for future research, if the quality of fire data on small fires is improved in the future.

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Wildfire Fuel Reduction Cost Analysis: Statistical Modeling and User Model for Fire Specialists in California[1]

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Abstract

This research provides wildfire specialists with tools for estimating the cost of conducting various types of wildfire fuel treatments. The dependent variable in the cost regression is what the USDA Forest Service calls Planned Direct cost per acre. Independent variables included the setting in which the fuel treatment took place (e.g., the wildland-urban interface (WUI) and Metropolitan area), acres of the treatment and the specific fuel reduction activity. The primary data for the analysis came from the Forest Service Activities System (FACTS). Separate models were estimated for activities related to or conducted as part of prescribed burning fuel reduction projects and for mechanical fuel reduction activities. In addition, California is split into two Geographic Areas Coordination Center (GACC): Southern California and Northern California GACCs. Not surprisingly, costs of performing prescribed burning and mechanical fuel reduction are higher in WUI areas and in Metro areas where labor costs are higher. The explanatory power (R^2) of the models is 12% to 24%. An Excel spreadsheet program has been built to allow managers to easily use the four regression models to estimate the cost of any specific fuel treatment program on the land. The user selects up to three FACTS fuel treatment(s) being proposed, whether the fuel treatment is in Northern or Southern California GACC, then the specific county of the treatment, and whether the proposed treatment is in a WUI area. Based on this selection the spreadsheet model utilizes the respective regression model to provide an estimate of the cost per acre for each FACTS activity and the total treatment cost reflecting the number of acres of the project that the user has previously specified. The spreadsheet adds up the costs for each FACTS activity that the overall fuels treatment project would entail. The model has been "tested" with fire specialists in California who felt it was a useful tool to aid in estimating the costs of fuel reduction projects.

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[1] An abbreviated version of this paper was presented at the Fifth International Symposium on Fire Economics, Planning, and Policy: Wildfires and Ecosystem Services, November 14-18, 2016, Tegucigalpa, Honduras.

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Keywords: FACTS, mechanical fuel reduction cost, multiple regression, prescribed burning cost

Introduction and Objectives

Fuel treatments are increasing viewed as a means to reduce the severity of wildland forest fires, and make these fires easier to control and suppress. An ancillary goal is to reduce property damages and lives lost due to wildfires. While these are desirable goals of a fuel treatment program, prescribed burning and mechanical fuel reduction are costly to conduct. As such they have to be budgeted for. In order to budget for them, it is necessary to have some systematic method to estimate the costs.

The overall objective of this research project is to provide forest managers and wildfire specialists with tools for estimating the cost of conducting various types of wildfire fuel treatments. Specifically this research provides a: (a) statistical analysis of USDA Forest Service data to develop a cost estimating model; and (b) user friendly macro driven spreadsheet model based on the statistical analysis for easy USDA Forest Service field use.

Statistical Cost Analysis of Mechanical Fuel Treatment and Prescribed Burning

Since our primary objective with this model was to give managers a cost estimating tool in California, our analysis was guided by a certain degree of pragmatism. While the model had to be conceptually correct and consistent with the past literature, it also had to provide as accurate an estimate of cost per acre consistent with the USDA Forest Service data. Thus this is applied research, not an attempt at advancing the econometric methods used to estimate the fuel reduction treatment costs. The reader should keep this in mind in the discussion that follows.

Initial Model Specifications

Guided by the literature review (González-Cabán and McKetta, 1986; Rideout and Omi, 1995; Wood, 1998), an initial multiple regression model was specified. The dependent variable was what the USDA Forest Service called Planned Direct cost per acre in its data set. The independent variables included the setting in which the fuel treatment took place (e.g., WUI and Metropolitan area), acres of the treatment, and each FACTS activity.

WUI: whether the activity occurred in or adjacent to a "…area, or zone where structures or other human development meet or intermingle with undeveloped wildland or vegetative fuels" (FACTS manual, page 39). The expected sign is positive (it is more expensive to conduct activities in WUI area due to extra precaution needed). Specifically, the WUI variable signifies the fuel treatment area is in a Wildland Urban Interface area. Using the drop down menu the user selects whether it is in a WUI (Yes) or not (No). If a fuel treatment area includes both then the program should be run twice: once with the acres in WUI and once with the acres not in WUI. The total cost of the treatment is the sum of the costs in the WUI and non-WUI areas.

Metropolitan County: A dummy variable equal to 1 for urban counties, zero otherwise created using the name of the county entered in FACTS. This designation was based on the USDA Economic Research Service classification of economic areas. The rationale for this variable is that cost per acre of fuel treatment is usually influenced by whether the treatment area is in a metropolitan area where wages are higher. The user selects the county that contains the fuel treatment from the drop down menu, and then the variable for whether that county is in a metropolitan area or not is set to 1 or 0 automatically for the user. As with WUI, if the treatment area spans two counties, the user model should be run twice, one time with the amount of acres in one county and another time with the acres in the other county. The total cost of the treatment is the sum of the costs in the metropolitan and non-metropolitan counties.

Acres: The number of acres actually treated by the activity

Data

The primary data for the analysis came from the Forest Service Activities System (FACTS). This system covers all the work codes routinely used by the USDA Forest Service. From the large list of activities available in FACTS, we used the model specification above and the literature to request a subset of all the variables. Further, variables that were often coded as text were recoded to numerical values. Other variables included Work Agent and Ranger District. This resulted in 25 variables. For the preliminary analysis the following activity codes were considered fuel related in the sense that one or more of these activities were conducted as part of fuel reduction projects. Table 1 on the next page provides a short definition of the FACTS Activities in the User Model. Detailed descriptions of these variables can be found in the FACTS User Guide (USDA Forest Service, 2013; http://fsweb.nrm.fs.fed.us).

Table 1. Listing of Fuel Related FACTS ID Considered for the Statistical Analysis

FACTS ID	Activity Name
1111	Broadcast Burn
1112	Jackpot Burning
1113	Underburn Low Intensity
1120	Remove fuels by Yarding
1130	Burning Piled Material
1131	Cover Brush Pile for Burning
1136	Pruning to Raise Canopy
1150	Re-arrange Fuels
1152	Compacting/Crushing Fuels
1153	Piling of Fuels Hand/Mach
1154	Chipping Fuels
1160	Thinning for Fuels
1180	Fuel Break
2360	Range Control Vegetation
2370	Range Piling Slash
2530	Invasive-Mechanical
4220	Commercial Thinning
4231	Salvage Cut (Intermediate Treatment
4455	Slashing Pre-Site Preparation
4471	Site Prep for Planting-Burn
4474	Site Prep for Planting-Mechanical
4475	Site Prep for Planting-Manual
4511	Tree Release & Weed
4521	Pre-Commercial Thin
4530	Prune
4540	Control for Understory Vegetation
6101	Wildlife Habitat RX Burn
8000	Insect & Disease Activities
10100	Other activities

Detailed descriptions of these variables can be found in the FACTS User Guide (USDA Forest Service, 2013; http://fsweb.nrm.fs.fed.us)

After reviewing the initial data sets there was a significant amount of discussion about a few concerns with the data. Some costs per acre were reported as zero. There was a significant amount of discussion about whether these were simply place holders entered into the program, as it did not seem likely that the particular activity had zero costs. There were also a large number of costs that were $1 per acre. The consensus was to drop these observations with zero costs and $1 per acre costs as they are not likely to reflect actual costs incurred. At the high end of the spectrum some costs per acre were more than five standard deviations. There were some costs that were even ten standard deviations from the mean costs. At five standard deviations from the mean the cost was $1818 per acre. At ten standard deviations from the mean, the cost was $3843 per acre, with the next highest cost being more than $1,000 higher than $3843. The decision was made to cut off costs at 10 standard deviations from the mean ($3843). This resulted in just 15 observations being lost (.1% of the sample).

Regression Modeling Strategies

Given the small sample sizes for some of the fuel reduction activities, there was exploratory analysis on whether to estimate separate regressions for the FACTS activities for which there were minimum sample sizes (e.g., $n \geq 20$) or pool the data on various activities and estimate one model with intercept shifters for each activity. Only four FACTS activities had a sample size over 100 (piling of fuels, pre-commercial thin, rearrangement of fuels and crushing of fuels) and only four had sample sizes between 77 and 99 (site preparation, tree release & weed, yarding and chipping of fuels). If individual activity level regressions were to be run, it was felt there were not enough degrees of freedom to include activities with much smaller samples. Thus, estimating one model with all the activities included and distinguishing the activities by intercept shifters had several advantages: (a) initially allowing for inclusion of all activities; (b) testing for whether there was statistically difference in the cost per acre by activity; (c) higher R2 explanatory and predictive power. Given these advantages it was decided to go with the pooled model.

Two separate pooled models were estimated. One for activities related to or conducted as part of prescribed burning fuel reduction projects and one for mechanical fuel reduction activities. In addition, California is split into Southern California GACC and Northern California GACC geographic areas (GACC stands for Geographic Area Coordination Centers, each responsible for leading wildfire efforts in their respective regions). A statistical analysis of a single state model versus splitting the state into north and south showed the separate models were statistically superior. Thus, the costs of treatment varies systematically between Northern and

Southern California. Therefore we have a total of four individual regressions: two for Northern GACC and two for Southern GACC. Each region has a model for prescribed fire fuel reduction and a model for mechanical fuel treatment.

In the fire fuel treatment model, FACTS Activity 1111 Broadcast Burning is used as the reference activity and a separate coefficient is not explicitly estimated. However, as there is no constant in the model, Broadcast Burning is essentially the constant. Thus, all the FACTS Activity cost coefficients are measured relative to Broadcast Burning. The user model automatically adds or subtracts (depending on the sign of the other FACTS Activity coefficient) the cost of that particular activity from the default average cost of Broadcast Burning ($231 Planned Cost per acre).

Statistical Results

Table 2 presents the results for the four models that correspond to Southern California (Models 1 and 2 for prescribed burning and mechanical fuel reduction, respectively) and Northern California (Models 3 and 4 for prescribed burning and mechanical fuel reduction, respectively).

The dependent variable is the natural log of the costs per acre to allow for non-linearity in costs per acre. The base case for prescribed burning models 1 and 3 is FACTS activity 1111 (broadcast burning). So when all the other activity variables are set to zero, the model estimates the cost per acre of broadcast burning (the spreadsheet program in Section 3 accounts for this automatically).

Likewise the omitted activity for mechanical fuel reduction is FACTS activity 1130 (burning piled material).

The results (negative sign on the **LN of acres treated** coefficient) suggest that in three out of the four regressions that the cost per acre does fall slightly as the number of acres treated increases. Thus there is a slight degree of economies of scale for prescribed burning and mechanical fuel reduction in Northern California. Not surprisingly costs of performing prescribed burning and mechanical fuel reduction are higher in **WUI** areas, and in **Metro** areas where labor costs are higher. The explanatory power of the models is lower than desirable (about 12% to 24% of the variation in costs per acre is explained by the independent variables in the models). We attribute much of the low explanatory power to the "noisiness" in the FACTS treatment cost data, which as was mentioned in the previous section didn't always appear to be accurate. While we removed "inliers" (obviously incorrect $0 and $1 costs per acre), and outliers that .1% of observations with costs more than 10 standard deviations from the mean, the data has a great deal of variation that could not be explained by the particular activity and whether it occurred in WUI or a Metropolitan area.

Table 2. Multiple Regressions of Fuel Treatment Costs per Acre in Northern and Southern California

	Dependent Variable: LN of Costs Per Acre			
VARIABLES	**(1)**	**(2)**	**(3)**	**(4)**
	South RX Burn	South Mech	North RX Burn	North Mech
LN of acres treated	-0.0694***	0.0138	-0.0637**	-0.0544***
(standard errors)	(0.0130)	(0.0137)	(0.0248)	(0.0132)
WUI	0.170***	0.466***	0.366***	0.273***
	(0.0409)	(0.0393)	(0.0635)	(0.0355)
Metro	0.547***	0.447***	0.481***	0.339***
	(0.0430)	(0.0398)	(0.116)	(0.0716)
1131.activity		-1.184**		-1.615***
		(0.461)		(0.203)
1136.activity		0.761***		-0.117
		(0.143)		(0.132)
1150.activity		0.212**		0.204*
		(0.0910)		(0.124)
1152.activity		1.229***		0.0424
		(0.0924)		(0.108)
1153.activity		0.329***		0.181**
		(0.0773)		(0.0809)
1154.activity		0.343***		-0.0859
		(0.0966)		(0.123)
1160.activity		0.295***		0.242***
		(0.0799)		(0.0891)
1180.activity		0.523**		0.426***
		(0.203)		(0.138)
2360.activity		-0.863***		
		(0.238)		
2370.activity		0.0598		
		(0.143)		
4220.activity		0.782***		0.0764
		(0.0907)		(0.0959)
4231.activity		0.382*		-0.183
		(0.217)		(0.171)
4331.activity		-0.966***		
		(0.164)		
4474.activity		-0.0215		0.941***
		(0.329)		(0.162)
4511.activity		0.743***		0.210*
		(0.133)		(0.117)
4521.activity		0.475***		0.224***
		(0.0769)		(0.0794)
4530.activity		-0.442***		-0.409
		(0.167)		(0.310)
4540.activity		0.850***		0.543***
		(0.290)		(0.165)
1112.activity	-0.926***		-0.319	
	(0.127)		(0.319)	
1113.activity	-0.333***		0.414**	
	(0.106)		(0.181)	

1130.activity	-0.550***		-0.433**	
	(0.0884)		(0.169)	
6101.activity	-1.424**		0.347	
	(0.707)		(0.290)	
4471.activity			-0.0811	
			(0.291)	
2530.activity				0.997***
				(0.175)
4455.activity				0.431**
				(0.203)
4475.activity				0.354**
				(0.140)
4494.activity				1.161***
				(0.208)
Constant	5.351***	4.621***	4.772***	5.290***
	(0.0993)	(0.0856)	(0.188)	(0.0846)
Observations	1,238	2,135	1,018	2,408
R-squared	0.168	0.243	0.121	0.136

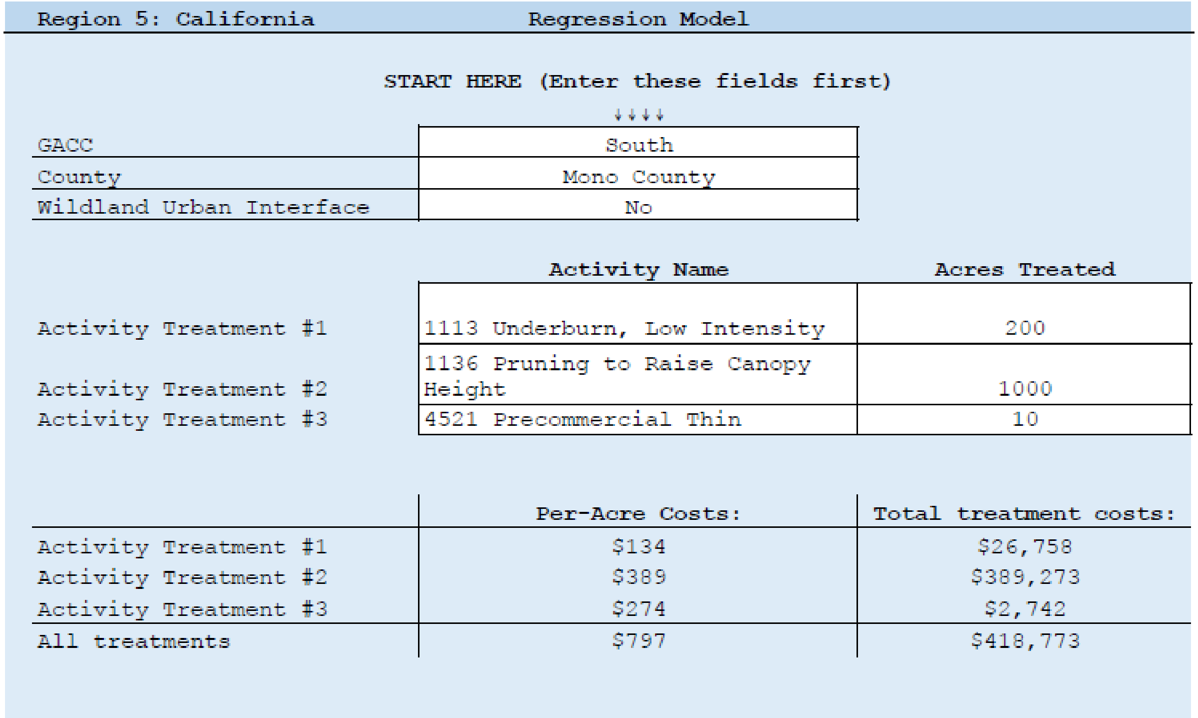
significant at the 99% level, ** is significant at the 95% level,
* is significant at the 10% level.

User Cost

Estimating Program

An Excel (version 2007 or later) spreadsheet program has been built to allow managers to easily use the four models estimated above to estimate the cost of a fuel treatment program.

To start the analysis, first step is to open Excel and do File Open the Fire Treatment Cost Estimator file. Once the file has loaded the user should have a spreadsheet that looks like Figure 1 on the next page. In general the **white areas are what the user fills in using drop down menus on the right side of each cell).** The gray shaded area below the white input cells is the results area showing Per Acre Cost and Total treatment costs. In the example, the fuel treatment being proposed is in the Southern California GACC geographic region, County is Mono, and the proposed treatment is not in a WUI. In this example, three FACTS fuel treatment activities have been selected, each with different acres. Given this input, the costs are calculated and displayed in the gray cells.



Region 5: California **Regression Model**

START HERE (Enter these fields first)

↓↓↓↓

GACC	South
County	Mono County
Wildland Urban Interface	No

	Activity Name	**Acres Treated**
Activity Treatment #1	1113 Underburn, Low Intensity	200
Activity Treatment #2	1136 Pruning to Raise Canopy Height	1000
Activity Treatment #3	4521 Precommercial Thin	10

	Per-Acre Costs:	**Total treatment costs:**
Activity Treatment #1	$134	$26,758
Activity Treatment #2	$389	$389,273
Activity Treatment #3	$274	$2,742
All treatments	$797	$418,773

Figure 1. Screen shot of the R5 Fuel Treatment Cost Estimator Spreadsheet Interface

To set the input values, the fire specialist uses the drop down on the right side of each white cell. In order to get the drop down menu indictor to be visible, the user must click on that input cell, then on the right of the cell, the drop down menu indicator triangle will appear. The drop down is indicated by a square box with a downward facing triangle in it (▼). The drop down triangle only appears when you click on the cell, otherwise it is not visible. There are six input cells. These area:

- whether the project is in Northern California or Southern California GACC. The drop down menu has North or South as the choices.
- what county. The drop down is a list of counties in that GACC. The program then automatically (without any separate display) links to whether the county in that GACC is considered a metropolitan county or not.
- whether the project is in a Wildland Urban Interface (WUI) area or not. The drop down menu is simply Yes or No
- Then the user specifies up to three fuel treatment activities from a drop down list of FACTS activities.

These activities can be all prescribed fire, all mechanical or a combination of both. The program selects the appropriate set of FACTS activity variable coefficients to bring in to perform the calculations on.

- Then the user provides the number of acres that each FACTS Activity will be performed on. Each activity can have a different number of acres.

Based on this selection the spreadsheet model selects the appropriate coefficient from the appropriate statistical model to provide an estimate of the cost per acre for each FACTS activity and the total treatment cost reflecting the number of acres of the project that the user has previously specified. The spreadsheet adds up the costs for each FACTS activity that the overall fuels treatment project would entail.

Conclusion

The objective of this research was to provide wildfire manages with a simple tool for estimating the cost of fuel treatments. To achieve this objective, we developed a spreadsheet cost estimator, the foundation of which is a multiple regression model. To develop the regression model of the costs of fuel treatments in California we obtained USDA Forest Service FACTS fuel treatment cost data for California. This data was first “cleaned” of obvious errors such as fuel treatments whose costs were reported as zero or one dollar per acre. At the other extreme was some fuel treatment costs per acre that were reported to be more than 10 standard deviations from the mean (e.g., about 10 observations had costs slightly more than $4,000 an acre). With a clean data set we estimated four pooled fuel treatment cost models:

- Northern California prescribed burning
- Southern California prescribed burning
- Northern California mechanical fuel treatment
- Southern California mechanical fuel treatment

Overall these models are reasonably good statistical models of the factors influencing costs of prescribed burning and mechanical fuel reduction. In particular, in all four models treatment costs increased in WUI and metropolitan counties (i.e., higher labor costs). There was a slight degree of economies of scale as the cost coefficient was negative and statistically significant in three of the four cost regressions.

Each of these equations were programmed into one macro driven Xcel (2007 or later) spreadsheet that was designed to be easy for fire specialists to use. The data inputs for the spreadsheet are only:

- Whether the fuels treatment would be in northern or southern California

- The county where the fuel treatment would be located (drop down list is provided)
- Whether the fuel treatment would be located in a WUI
- Up to any three FACTS fuel treatment activities. These can be any combination of three burning or mechanical treatments (a drop down list is provided)
- Acres of each treatment (these can be different or the same for each fuel treatment activity).

After these data are input, the program automatically calculates the per acre costs of each treatment activity and the total cost of each treatment activity and the total cost.

We feel this is a useable tool and a useable approach. Depending on the reception of fire specialists as to the utility of this tool, it could be improved by professional programming into a more polished program. Further, it could be expanded to other GACC's in the U.S. Our preliminary investigation into these other USDA Forest Service Regions indicates that similar FACTS data, with equivalent data quality issues, does in fact exist and is amenable to the same type of statistical analysis and hence program as performed here.

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Socioeconomic Factors Affecting Forest Fires: A Case Study of Antalya, Turkey[1]

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Abstract

The Mediterranean part of Turkey (Southern and Western Anatolia) is intensively subjected to forest fires. Within this region the Antalya province places first in terms of area burnt with an annual area of 2633 ha for the period of 2000-2009. Additionally, the biggest forest fire in the history of the Turkey Republic; with an area of about 15000 ha, occurred in Antalya in 2008. Because of the fire problem in this region special attention is given to forest fire management works in Antalya. This situation makes it necessary to observe and understand the structure of, and the reasons for, forest fire occurrence.

Socioeconomic factors are relevant in determining the root causes forest fires. For example, for the years 2000-2009 only 11% of all fires in Turkey were classified as resulting from natural causes (i.e. lightning). The rest of the fires (89%) were classified as resulting from negligence, intentional, carelessness, accidental or unknown causes. The majority of causes are strictly related to socio-economic factors.

The main goal of this work was to defining the relationships between forest fires and socio-economic factors in Antalya. The forests cover in Antalya is about one million hectares that are managed by twelve governmental forest enterprises. The socio-economic data used for the analysis in this work were obtained from those twelve enterprises. For the analysis we used a total 28 of socio-economic factors components for 3 periods: 1980-1990, 1990-2000, and 2000-2010; and fire statistics between the periods of 1980-2010. Panel Data was used for the Analyzes.

Results show a significant correlation between area burnt and socioeconomic factors like the proportion of population working in agriculture and service sectors, unemployment rate, population and illegal cutting. Similarly, number of fires is statistically significantly correlated with the proportion of working population in the service sector, population, illegal cutting and grazing. The relevance of these socioeconomic factors is important for fire

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[1] An abbreviated version of this paper was presented at the Fifth International Symposium on Fire Economics, Planning, and Policy: Ecosystem Services and Wildfires, November 14-18, 2016, Tegucigalpa, Honduras. Abstract only available.

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management in the region; and highlights the need to incorporate them in any new fire management policy for the region and the country.

Economic Analysis of Risk and Choice under Uncertainty in Landscape Planning in Relation to Wildfires[1]

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Abstract

Economic decision-making in wildfire defense and fire management programs is not easy when performed under efficiency criteria. The determination of variables to be considered and the lack of data analyzed in relation to the results achieved by the action plans adopted to reduce the impact of fires condition the adoption of strategic solutions, both in the management of the landscape against fires and in suppression operations. If, by itself, the decision on how much, where and how to invest protection budgets is complex, the choice in environments of risk and uncertainty undoubtedly increases the difficulty in finding the right solutions.

Determining the expected utility function and measuring risk aversion provide interesting and advanced diagnostic tools that allow comparing the responses that can be provided by the application of different action plans in the forest landscape. Based on the results obtained, the best solution under uncertainty scenarios can be selected. The integration of variables that identify the initial extinction difficulty of the landscape under study, as well as the potential danger of wildfires and their effects on the net change in the value of resources due to the fire's impact and the extinction costs, help characterize the behavior of the expected utility functions. This paper analyzes the results of different utility functions and compares them with the purpose of identifying the expected utility function with the best explanatory capacity when choosing among different fire protection options under situations of uncertainty generated by climate change, the probability of occurrence, and the influence of social behaviors, as well as the different extinction capacities, among other factors. The management of forest fuels and the different opportunities for extinction depending on the combinations of means of suppression can be treated from the approach of choosing strategic solutions in scenarios of uncertainty. The SINAMI (Rodríguez y Silva, González-Cabán, 2010) and Visual-SEVEIF (Rodríguez y Silva, et al. 2013, 2014) models provide the baseline

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[1] An abbreviated version of this work was presented at the fifth International Symposium on Fire Economics, Planning, and Policy: Ecosystems Service and Wildfires, November 14-18, 2016, Tegucigalpa, Honduras.

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data for decision-making and choice of solutions under conditions of uncertainty in the forest landscape.

Keywords: Operational plans, resources net-value change, suppression, suppression costs

Introduction

The fire suppression actions within the framework of landscape fire management programs have changed over time. Scientific advancements in the spatial dynamics of fire propagation in forest lands and better understanding of the fire severity consequences, economic and ecological damages and environmental services have made possible to progressively accommodate fire suppression actions to the knowledge gained and experiences learned.

However, at the same time the complexity of forest scenarios have been modified more or less over the last 50 years depending on the fire incidence in different countries. On one hand, demographic and socioeconomic changes, and on the other hand, the complex accumulation of biomass in conditions ready to ignite and propagate due to severe meteorological conditions are generating new forest landscapes and mix forest-urban landscapes in which the traditional fire suppression programs cannot provide and effective and secure response.

Within this reality decision making becomes uncertain and complex (Mina et al. 2012). In addition, the important budget requirements to administer fire suppression resources incorporates variables and factors difficulting even more development efficient suppression actions (Rodríguez y Silva and González-Cabán. 2016). Uncertainty is a conditioning factor when selecting an ideal solution in decision making, particularly when making strategic changes to improve the fuels distribution over the landscape and in management of an emergency given an action plan.

Finding a solution to the problem at hand (for example, finding the right combination of firefighting resources, number and type, for a specific fire suppression action) usually generates characteristics associate with a more or less risk averse postures. Sometimes, a high risk solution may lead to a highly efficient result, but the uncertainty of what may happen and how the relevant variables would affect or condition the selected option reduces the probability of selecting such option to the emergency.

On the other hand, the selection of solutions in an uncertainty environment (as characteristic of fire suppression actions) frequently are separate from decision models based on economic and results optimization prediction assumptions. This is due in part to the lack of knowledge of these disciplines, and also conditioned by the paucity of models developed for and available for wildland fire management providing solutions considering uncertainty. The selection of solutions continues to be anchored in the actor’s empirical experience.

In this work we present a line of inquiry to finding modeled solutions based on economic efficiency principles to generate tools and conceptual contributions that while reducing uncertainty, progressively provide a catalogue of solutions increasing the efficiency and reducing costs of fire management and fire suppression actions (Rodríguez y Silva, and González-Cabán, 2016).

Material and methods

Uncertainty is present in the majority of selections to be made, not only in development of, but in the execution of fire management programs. For example, the selection of the number and type of helicopters based on fire line production capability given different fire behavior scenarios, presence of turbulence and erratic winds on the fire front or the final results of a specific fire suppression action to stop fire progression on a determined sector. In addition, behind the decisions there are also economic criterion, given the decisions that can be adopted with consequences for generating extraordinary expenses and increasing costs.

Therefore, the objective of modeling decision support algorithms should be to reduce, as much as is possible, uncertainty (Minas et al. 2012); by generating a work environment in which the variability of parameters affecting decision making and solutions are qualified by the information explaining the uncertainty framework.

Using experiences from the “choice selection under uncertainty theory” (Gollier 1999), can lead to solutions by the definition and individual valuation of uncertainty. This imply achieving a high scenario knowledge in which the decision to make varies with the decision makers greater or lower willingness to expose themselves to the level of risk and its consequences.

In this work the methodology used correspond to a process integrating thematic blocks that allows to understand through their interconnections the assumptions facilitating the uncertainty reduction in the selection of strategic solutions (Figure 1).

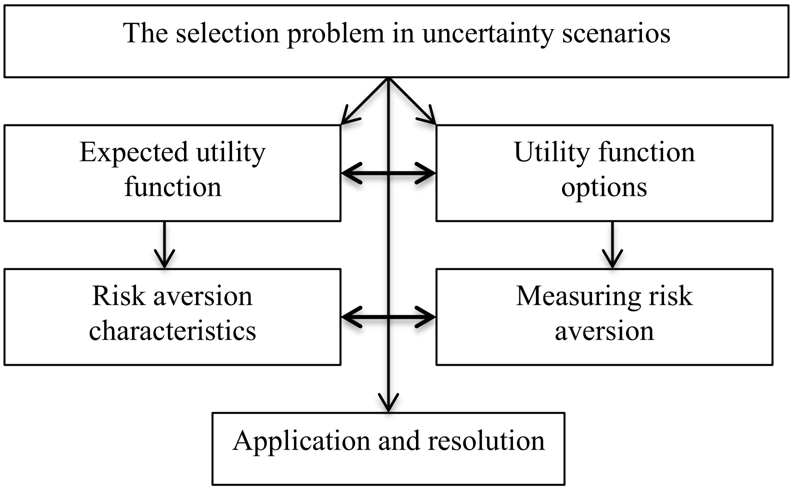

Figure 1. Integration of thematic blocks that facilitates uncertainty reduction in the selection of strategic solutions.

1. **Expected utility function**

In uncertainty scenarios the selection possibility by decision makers is conditioned by factors unbeknown to decision makers themselves. The "state of nature" represents a group of uncertainty scenarios in which the actors do not have concrete factors of control (Variant 2005). On the other hand, it is important to indicate that, conceptually, the influences or effect of positive (benefits) or negative (deterioration and impacts) characteristics depend on actor's preferential criterions and of how they can influence the results.

One state of nature can be defined as the description of a determined uncertainty result. Representing (E) as the set of all possible states of nature and (e) as a finite element of the total possible states, then the probability of that state to occur is given by p(e), and by definition must comply with following conditions:

a) $P(e) \geq 0$
b) $\Sigma_{e \in E} p(e) = 1$

As defined, the solution goes through the contingent plan construction and determination. The contingent plan means the consumption plan representing a concrete specification of the number of units to consume in each of the states of nature. That is, the consumption contingent plan can be defined as a random variable which takes a response value with a specific probability.

If we understand a specific strategic decision in terms of fire suppression or fire management in the ordering of forest fuels as a consumption action from one basket of available goods (strategic opportunities for actions), and at the same time that the consumption option behaves as a random variable (c) then, subject to the comparative preferences conditions, we can determine the expected utility of being able to develop the selected contingent plan.

Mathematically, the definition can be identified by the following expression: $E[U(c)]=\Sigma p(e)U(c))$. Given this relationship, and knowing the different consumption contingent plans or stated differently; different options of fire suppression operational plans or different strategic combinations of firefighting resources in the same operational plan (Castillo and Rodríguez y Silva 2015), it is possible to compare two operational plans in terms of the expected utility each plan can provide: $E[U(c_1)]> E[U(c_2)]$. In some instances, the “consumption contingent plan” can be considered as a “certainty plan”, thus the uncertainty scenario becomes a certainty scenario. That is, the number of consumption units in the different states of nature is invariant, thus the expected utility of the different strategic options is the same

To clarify these concepts, as an example, below we present two contingent plans (c_1) and (c_2) in terms of their suppression capabilities, duration of their interventions, and suppression costs (Tables 1 and 2).

Table 1. Contingent plan C_1

Nº of units Contingent Plan C1	Firefighting resource type	Unit productivity (m/min)	Hourly fire suppression costs (€)	Total intervention time in minutes	Total suppression costs (€)	Effectiveness weighting factor	Suppression capability (m/min)
3	Airplane CL215T	85	4,571.92	826	188,820.27	0.143	36.53
3	Helicopter Bell412	55	1,828.57	456	41,691.35	0.079	13.05
3	Helicopter KAMOV K32	75	2,101.09	350	36,769.06	0.061	13.66
4	airplane Air Tractor 802	65	652.99	458	19,937.98	0.079	20.65
10	Hand crew (15 person)	8.5	551.00	1,670	153,362.19	0.290	24.62
1	Bulldozer	35	73.29	256	312.71	0.044	1.55
4	Cistern tank	15	94.01	1,750	10,967.53	0.304	18.21
Operational index C1	15.82			5,766	451,861.09		128.27

Table 2. Contingent Plan C_2

Nº of units contingent Plan C2	Firefighting resource type	Unit productivity (m/min)	Hourly fire suppression costs (€)	Total intervention time in minutes	Total suppression costs (€)	Effectiveness weighting factor	Suppression capability (m/min)
4	Airplane CL215T	85	4,571.92	950	289,554.89	0.1746	59.38
4	HelicopterBell 412	55	1,828.57	321	39,131.35	0.0590	12.98
4	Helicopter KAMOV K32	75	2,101.09	185	25,913.43	0.0340	10.20
2	Airplane Air Tractor 802	65	652.99	750	16,324.76	0.1379	17.92
10	Hand crew (15 person)	8.5	551.00	934	85,772.63	0.1717	14.59
2	Bulldozer	35	73.29	450	1,099.37	0.0827	5.79
5	Cistern truck	15	94.01	1,850	14,492.81	0.3401	25.51
Operational index C2	16.54			5,440	472,289.25		146.37

As seen in the tables, because of different types and combination of firefighting resources selected for each options c_1 and c_2 results show interesting differences for the two contingent plans. Though option c_2 is more expensive, have a higher productivity capability and thus the fire is suppressed faster. However, though option c_1 has lower suppression costs, it also has lower productivity capability and thus the fire takes longer to suppress. This can be seen by looking at the operational index value for contingent plan c_1, which is 15.82 units and for contingent plan c_2, which is 16.54 units. Meaning that contingent plan c_2 is more effective in suppressing the fire. The operational index was computed as follows: $Iop_i=10^{-4}\cdot[0.35\cdot(\text{Total suppression costs})_i + 0.65\cdot(\text{Suppression capability})_i]$.

Taken as random variables c_i, these consumption options or contingent plans imbedded in the utility function defined in the fire management protection plan or fire management plan, allows us to determine their utility as seem the final results obtained. For example, these results can be measured in terms of efficiency or their benefit cost relationship. While selecting the utility function to help us determine the results for comparing the different contingent plans we must consider the economic value of saving the market and nonmarket goods and services affected by forest fires, by interrelating it mathematically with the consumption value of each solution combining the firefighting resources.

2. **Measuring risk aversion**

The decision to select a contingent plan (operational suppression plan) among several considered incorporates an important component of the decision maker attitude towards risk. To better explain this we must conceptualize what is known as an "actuarially just game." This is defined as that game or lottery with an expected value equal to zero. Considering (p) as a probability with values between (0) and (1), then $px + (1-p)y = 0$.

Starting with this concept we can then define a decision maker posture towards risk (Arrow 1965):

a) Risk Averse. A decision maker is risk averse when is not willing to accept any actuarially just game. This can be explained by looking at an individual initial wealth M_0, with x and y as possible gains (increase in wealth) and according to its respective probabilities (p) and (1-p); with U equals to the individual's utility function. Then:
$U(M_0)>p\cdot U(M_0+x)+(1-p)U(M_0+y)$
$U(M_0)=U(p\cdot(M_0+x)+(1-p)\cdot(M_0+y))> p\cdot U(M_0+x)+(1-p)\cdot U(M_0+y)$
Which is a strictly concave function.

b) Risk neutral. A decision maker is risk neutral when it is indifferent to any actuarially just game. Mathematically this can be expressed as:
$U(M_0)=U(p\cdot(M_0+x)+(1-p)\cdot(M_0+y))= p\cdot U(M_0+x)+(1-p)\cdot U(M_0+y)$
Which is a lineal function.

c) Risk taker. A decision maker is risk taker when it is willing to accept any actuarially just game. Mathematically this can be expressed as:
$U(M_0)=U(p\cdot(M_0+x)+(1-p)\cdot(M_0+y))<p\cdot U(M_0+x)+(1-p\cdot U(M_0+y)$
Which is a strictly convex function.

The measurement of a decision maker risk aversion depends more or less on the concavity of the decision maker utility function (Pratt 1964). The absolute curvature value of a utility function is given by ($-U''$). That is, the second derivative of the utility function provides information on the degree of the function concavity; the greater the function concavity the greater is the decision maker risk aversion. Normalizing the second derivate with respect to the first derivative of the utility function we obtain a measurement of risk aversion invariant to related transformations (Arrow 1964, Pratt 1965). The following expression represents the coefficient of the absolute aversion measurement: $R_a(M)= -[U''(M)/U'(M)]$. To measure the aversion in proportion to the starting wealth we use the relative aversion measurement expressed as: $R_r(M)= -[U''(M)/U'(M)]\cdot M$.

The following variables have been considered in determining the consumption function:

- The per hectare value (V_R) of natural resources (market and nonmarket) present in the area where the contingent plans (operational plans defined by their combination of firefighting resources) would be compared.

- The potential per hectare losses (P_R) as a function of fire behavior (depreciation matrix of affected resources values) (Rodríguez y Silva and González-Cabán 2010, Molina et al. 2009, Rodríguez y Silva et al. 2014).
- The operational capacity index (Iop) obtained from the interrelation of firefighting resources type, the unit costs, the intervention times, and the resulting operational capacity (fireline control).

Combining these variables in the consumption function we obtain the "wealth" concept from the considered contingent plan. This new variable becomes the independent or explanatory variable of the utility function in the analysis of the decision maker risk aversion.

Mathematically, the consumption function is given by::

$$C=\frac{(VR-PR)}{Iop}$$

The selected utility function for analyzing aversion is U=ln(C); this function behavior in relation to the Arrow-Pratt criterion is as follow:

1. Absolute Risk Aversion (ARA):

$$ARA=-\frac{U''}{U'}=-\frac{\frac{-1}{C^2}}{\frac{1}{C}}=\frac{1}{C}>0,\ Risk\ Aversion$$

The ARA is decreasing with respect to consumption (C); in effect, the differential ARA with respect to an infinitesimal change in consumption is strictly decreasing:

$$\frac{dAAR}{dc}=-\frac{1}{c^2}$$
$$<0, Absolute\ Risk\ Aversion\ is\ decreasing\ with\ consumption$$

2. Relative Risk Aversion (RRA):

$$\text{ARR}=c\cdot AAR=c\cdot\frac{1}{c}=1, Constant\ Relative\ Risk\ Aversion$$

We can use the expected utility function to determine the decision maker risk posture. To do this first we need to determine the expected utility value and make a comparison with the expected value. To perform this operation we need to assign the probability (p) that we think makes the decision maker to select contingent plan C_1, and probability (1-p) corresponding to contingent plan C_2. As explained before the computational procedure is as follows:

Phase a), determining the expected value:

$$V(C_1, C_2) = p \cdot C_1 \; + (1-p) \cdot C_2$$

Phase b), determining expected value utility:

$$U\big(V(C_1, C_2)\big) = \ln(V(C_1, C_2)$$

Phase c), determining expected utility:

$$U(C_1, C_2) = p \cdot Ln(C_1) - (1-p) \cdot Ln(C_2)$$

Making the comparison to:

$U(M_0)=U(p\cdot(M_0+x)+(1-p)\cdot(M_0+y))> p\cdot U(M_0+x)+(1-p)\cdot U(M_0+y)$,

confirms the existence of a strictly concave functions making the decision maker risk averse.

Application of this procedure to the landscape scenario were the fire takes place we can evaluated the decision maker risk posture with regard to selection of a contingent plan.

There are other consumption utility functions that can be considered similarly to the selection presented in this work. Among the family of utility functions we could consider the following (Gollier 1999), (Table 3):

Table 3. Comparison between utility functions depending on the consumption value (c).

Utility function U(c)	Mathematical formula	Absolute risk aversion	Relative risk aversion	Considerations
Quadratic	$U(c) = c - \frac{b}{2}c^2$ $con\ b > 0$	$Ra(c)) = \frac{1}{1 - bc}$	$Rr(c)) = \frac{b^2}{(1 - bc)^2}$	Treatment as an inferior good (the greater the (c) value, greater the absolute risk aversion in selecting a contingent plan). Conservative strategy
CARA (Constant absolute risk aversion function)	$U(c) = -\frac{1}{\gamma}e^{-\gamma c}$ con γ>0	$Ra(c) = \gamma$	$Rr(c) = \gamma c$	When relative risk aversion is increasing with the consumption the model provides a direct proportion with consumption.
CRRA (Constant relative risk aversion function)	$U(c) = \frac{c^{1-\sigma} - 1}{1 - \sigma}$ con σ≥0 When σ➔1, then $U(c)) = Lnc$	$Ra(c) = \frac{\sigma}{c}$	$Rr(c) = c\frac{\sigma}{c} = \sigma$	When the absolute risk aversion is decreasing with consumption the model predict a predisposition to select the contingent plan with higher consumption.

In relation to its applicability in evaluating contingent plans under uncertainty environments, the study of different utility functions behavior provides an important tool in the comparative strategic analysis of operational suppression plans. The results provide the possibility of creating a book of standardize and eligible solutions according to identified forest landscape uncertainty scenarios to protect from forest fires.

Results

The model application requires setting specific territorial characteristics where the working scenario is defined. Accordingly, as an example, we have considered a 2km^2 pixel. The economic valuation of the natural resources (market and nonmarket) within the pixel showed a value of 2,425€/ha. Calculation of the economic value of damages caused by a forest fire are analyzed under two aspects. Those defined by the operational results of contingent plans (C_1) y (C_2). The contingent plan (C_1) suppression capability is smaller than that for contingent plan (C_2), its suppression costs are also less, but the total suppression time is larger.

On the other hand, the results from studying the fire occurrence danger index points towards the probability of high velocity drying winds in the 15% range, as compared to a more benign less dangerous situation and therefore, less operationally conflictive, characterized by higher intensity, but also high humidity winds with a 85% probability.

In addition to higher suppression costs and higher suppression capability, selection of contingent plan (C_2), represent differences in the final total fire area affected. By selecting contingent plan (C_2) the total fire area affected is reduced by 15%, though suppression costs increased by 4.3%.

Another important factor is the computation of natural resource NVC after a fire. This value can be estimated using the SEVEIF methodology (Molina et al. 2009, Rodríguez y Silva 2014). Computation of the pre- and post-fire resources economic value allows to determine the saved values. Integrating the saved values information with the operational index (Iop) for the selected contingent plan through its consumption function gives us the "wealth" value in terms of the fire impact economic value saved.

Table 4 shows the results for the selection between the contingent plans given the risk under uncertainty scenarios for the analysis presented in this work.

Table 4. NVC values for each contingent plan and meteorological scenario

Meteorological scenarios	Occurrence probability (%)	NVC/Plan C_1 (€/ha)	NVC/Plan C_2 (€/ha)
EM_1	15	2,425-850=1,575	2,425-550 = 1,875
EM_2	85	2,425-650=1,775	2,425-450 = 1,975

The consumption function values allows us to determine the comparative "wealth" derived from the contingent plans considered. These values are the explanatory variable of the utility function selected for the decision maker risk aversion analysis. In determining the corresponding "wealth" values is necessary to consider the results from each operational index (I_{op}), and apply the consumption function to every resource NVC value resulting from the selected contingent plan and existing meteorological scenarios (Table 5).

Table 5. Consumption function values by contingent plan, meteorological scenarios and operational index

Contingent plan	I_{op}	Meteorological scenarios	NVC (€/ha)	Consumption function values (€/ha)
C_1	15.82	EM_1	1,575	99.55
	15.82	EM_2	1,775	112.19
C_2	16.54	EM_1	1,875	113.36
	16.54	EM_2	1,975	119.40

From these results we can analyze the decision maker decision considering the expected value and expected utility given the consumption function values for each contingent plan available and each meteorological scenarios. Following are two possible solutions decision maker can select:

A)

- Select a fixed solution given by contingent plan C_1 and consumption function value of 112.19 €/ha.
- Select a dynamic solution with a 35% probability of reaching a consumption function value of 99.95 €/ha by selecting contingent plan C_1, and 65% probability of reaching a consumption function value of 119.40 €/ha by selecting contingent plan C_2.

A.1. Fixed expected value

VE(fixed solution) = 0.35 x 112.19 + 0.65 x 112.19 = 112.19 €/ha

A.2. Dynamic expected value

VE(dynamic solution) = 0.35 x 99.95 + 0.65 x 119.40 = 112.59 €/ha

B.1. Fixed expected utility

UE(fixed solution) = 0.35 x Ln(112.19) + 0.65 x Ln(112.19) = 0.15 x 4.72 + 0.85 x 4.72 = 4.72 €/ha

B.2. Dynamic expected utility

UE(dynamic solution) = 0.35 x Ln(99.55) + 0.65 x Ln(119.40) = 0.15 x 4.6 + 0.85 x 4.78 = 4.71 €/ha

Because the expected utility value for the fixed solution is greater than the expected utility value for the dynamic solution (UE(fixed solution) > UE(dynamic solution) the decision maker risk posture is determined by the expected utility and not the expected value. Therefore, we should use the expected utility when evaluating what decision the decision maker will take under conditions of uncertainty.

The error probability of the decision maker being indifferent between the two options (fixed or dynamic solution) is given by the following equation:

0.35 x Ln(112.19) + 0.65 x Ln(112.19) = 0.15 x 4,.72 + 0.85 x 4.72p´x Ln(99.55) + (1-p´) x Ln(119.40) 4.72 = p´ x 4.6 + (1-p´) x 4.78 ➔ p´= 0.33

The result indicates that the error probability must change from 35% to 33% for the decision maker to become indifferent between selecting either of the two solutions: fixed or dynamic solution.

The "certainty equivalent" value of the dynamic solution option is obtained by considering the expected utility of the dynamic selection:

U(EC)=UE(dynamic selection)

Ln(EC) = 4.71➔ $EC = e^{4,71} = 111.05$ €/ha

The "certainty equivalent" value provides us information on the decision maker behavior, which is indifferent between getting a "certainty equivalent" consumption value of 111.05 €/ha and risking obtaining an increase in suppression costs and a reduction in the natural resources value saved, equal to a consumption value of 112.19 €/ha.

Finally, the "risk premium" understood as the maximum amount a decision maker would be willing to pay to not encounter risk is given the difference between the expected value of the fixed solution and the determined "certainty equivalent" value. For the case presented here the risk premium is:

PR=VE(fixed solution) - EC =112.19 -111.05 = 1.14 €/ha

That is, the maximum amount the decision maker is willing to give up to avoid risk is 1.14 €/ha. In other words, is the maximum amount that a risk averse decision maker is willing to accept (pay) to avoid facing risk. Incorporating this information in the utilities versus consumption graphic we can show both "the certainty equivalent' value and the "risk premium" (Figure 2).

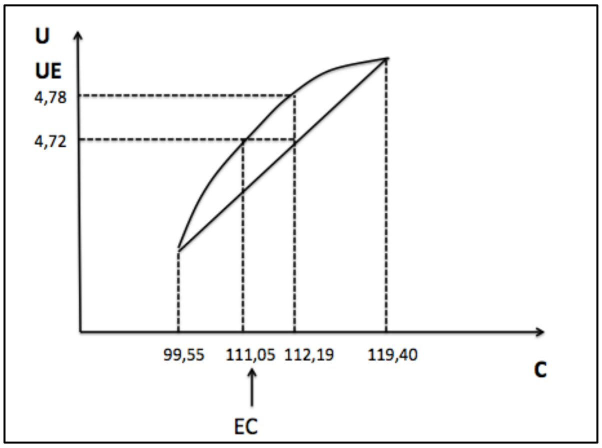

Figure 2. Graphic of the expected utilities versus expected consumption values obtained from the contingent plans analysis.

Discussion

The operational management of forest fires suppression activates is complex given that the fire suppression technical management takes place under conditions of uncertainty. The gathering of agents/actors experience in prior process of capitalization (collection of incident manager's experiences) is not frequent. This implies a continued loss of prior experiences by not establishing protocols to properly collect, filter, order and classify the information. The lack of customarily monitoring fire suppression related data is one the most limiting factors in reducing the lack of knowledge about forest fires suppression actions.

The capitalization of fire suppression experiences and scientific studies provide important opportunities for operational improvements and to progressively increase fire suppression operations. In this regard decision making processes based on reducing the level of uncertainty lead to more efficient solutions in fire suppression plans. The methodology proposed here is a first step in the use of economic and prediction analysis tools helping to clarify the horizon of uncertainty scenarios.

Using the expected utility to analyze the uncertainty and risk provides diagnosing opportunities for selection of fire suppression strategies within the framework of fire suppression and forest landscape management. Understanding decision makers risk posture under uncertainty scenarios and how it may affect their decision making process provides new insights into fire suppression operational plans that include a strategic combination of firefighting resources, suppression costs and the affected resources net-value change.

Including in the analysis factors related to the probability of success provides in a comparative way the "benefits" in terms of the resulting payments from the analysis of the defined contingent plans. One of the most important parts of this methodology contributing to the analytical process is the utility function selection. There are different options for studying the quality of the information each information provides varying from mathematical to econometric functions providing results in terms of productivity (Cobb-Douglas, CES, Translog, etc.).

In this work we have chosen the utility function derived from the Napier logarithm for the consumption variable. This function characterize the decision maker risk posture behavior given the concavity of the utility curve (Graphic 2). It is important to point out that in conditions of uncertainty in the operational management of emergencies decision makers tend to adopt a risk aversion posture in the possible application of more efficient contingent plans, but without experience about their results or the success probabilities are difficult to ascertain, thus to establish.

In any case, the experiences from commercial decision making under conditions of uncertainty (investments on equipment and goods, stocks investments, purchasing of financial goods, and insurance purchases, etc.), and also scientific research on uncertainty and risk microeconomic models provide a solid foundation for development of planning and decision support tools for forest fire suppression operations.

Acknowledgements

The author thanks the GEPRIF (RTA2014-00011-C06-01) Project, financed by Spain Ministry of Science and Innovation through the National Institute for Research and Agriculture and Food Technology for their financial support and help in conducting this work.

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A Comparison of Wildland Urban Interface Households WTP for Wildfire Risk Reduction Programs in California and Florida[1]

José J. Sánchez[2], John Loomis[3], Armando González-Cabán[2], Tom Holmes[4]

Abstract

Using the same choice experiment surveys and same specification of mixed logit models are used in California (CA) and Florida (FL) to compare homeowners willingness to pay (WTP) for two types of fuel reduction programs. Comparing the WTP of homeowners in CA and FL for private and public wildfire risk reduction show that WTP for the private actions among households who perceive low to moderate wildfire risk is quite low, and probably lower than what their cost share would be for making significant wildfire risk reductions on their property and to their residence. However, these same individuals would pay substantially more for public programs to reduce wildfire risk in their neighborhoods and common/public lands around their neighborhoods. The results also suggest the highest priority for cost sharing funds would go to homeowners in areas who perceive their houses to be at high risk, and especially to cost share private actions on their own land.

Keywords: benefit transfer, fuel reduction programs, mail survey, mixed logit model, willingness to pay.

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[1] An abbreviated version of this paper was presented at the Fifth International Symposium on Fire Economics, Planning, and Policy: Wildfires and Ecosystem Services, November 14-18, 2016, Tegucigalpa, Honduras.

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Introduction

Over the last two decades, there has been a large movement of the United States' population into Wildland Urban Interface (WUI) areas. This is particularly evident in California (CA) and Florida (FL), two of the most populous states in the USA. These states also have millions of residents living in WUI areas with high or in the case of CA, extreme risk of severe wildfires. To reduce wildfire risk, the USDA Forest Service (USFS), State Forestry agencies and local counties have cost shared with private homeowners and communities wildfire risk reduction actions. Further, these agencies have directly paid for fuel reduction efforts on public and private lands surrounding many of these communities. However, these are costly programs to private homeowners and federal/state/county fire management agencies. To induce participation, cost share programs have been provided. However, there are very limited federal funds and it is important for the USFS to know what geographic areas have the highest economic values for reducing wildfire risk and the relative values of wildfire risk reduction actions to homeowners. In particular, the cost sharing only reduces the cost to the landowner, and if their WTP falls below their cost share, they will not engage in private actions to reduce wildfire risk on their properties or support homeowner associations' actions.

Thus, the purpose of this paper is to derive and compare the WTP of homeowners in CA and FL for private and public wildfire risk reduction. We estimate homeowner willingness to pay (WTP) to reduce the risk of forest fire in and around where people live in the two states. Two fire risk reduction programs are valued: (1) a Public Program that would be carried out by public forest managers involving prescribed burning, mechanical treatment and herbicide treatment of forests immediately surrounding their neighborhood; and (2) paying for a Private Program that alters the vegetation surrounding the home such as reducing tall vegetation (more than 3 feet high) within 30 feet of their house.

We choose CA and FL because there are active fuel reduction programs in both states. While the forest type may be different, the experience of large and repeated wildfires in these two states suggests that residents living there are familiar with wildfire risk from forests. We valued the same two programs with the same choice experiment survey using the same survey mode in both CA and FL.

The paper proceeds as follows: first we review the literature, followed by presentation of the choice experiment survey design and survey mode. Then the data is described, the mixed logit specification discussed, and then the econometric results are presented. These results are followed by the WTP estimates in FL using two different approaches for inflation adjustment to the date of the CA survey.

Literature Review

There have been two sets of CVM surveys of what households would pay for state and county wildfire risk reduction projects in CA, FL and Montana (MT) (Loomis and González-Cabán, 2010) and in Colorado (Walker et al., 2007). The wildfire risk reduction projects all involved mechanically thinning and prescribed burning of the forests in the county where the households reside. Thus, there is some similarity of the programs valued in those studies to our Public Program as both involved prescribed burning and mechanically reducing forest vegetation. The CVM surveys used a voter referendum format where households voted in favor or against paying their household's share of a county fuel reduction program. The exact form of the payment (e.g., sales tax, property tax, etc.) was purposely not made explicit to reduce protest responses. Loomis and González-Cabán's (2010) CVM studies reported mean WTP per household for prescribed burning for CA, FL, and MT at $460, $392, and $323 respectively. The mean WTP per household for the mechanical fuel reduction method in CA, FL and MT was $510, $239, and $189 respectively. Of particular interest for our case study is the comparison of the CA and FL. These values per household are relatively similar for prescribed burning in the two states, but different by a factor of two for mechanical fuel reduction. All three studies reported in Loomis and González-Cabán (2010) specified a public program that would reduce the number of acres burned and the number of houses that would be destroyed.

However, none of these three past CVM studies explicitly stated the amount of risk to a person's house from wildfires, and the monetary amount of damages likely to their house from wildfires as the choice experiment study we are reporting on in this paper. In this new study we specify to the respondent the monetary damage, which ranged from partial loss to complete loss of their home. In addition, we computed for the respondents their expected damages (risk times damages) to property. Our new study in CA and FL also includes a separate WTP estimate for a Private Program around the individual person's house. Despite the difficulty with risk communication (see Smith and Desvousges, 1987) we feel that discussing risk to their homes may be a more meaningful way to communicate the potential effects of forest fires on WUI homeowners than just acres burned in the county or state, and houses completely destroyed. Thus, focusing on risk of fires to their house and damages might improve the WTP estimates for wildfire mitigation programs in CA and FL.

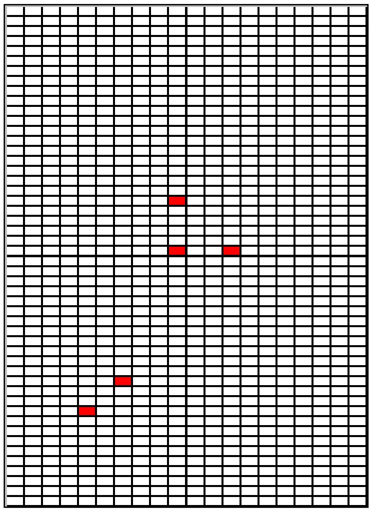
Choice Experiment Survey Design

The survey began with several questions that asked the respondent to answer questions about the vegetation around their home. These questions were followed by a characterization of what certain responses meant for the risk of wildfire in their neighborhood, and the risk of losing their house to a wildfire. Using fire statistics from the respective states, the current wildfire risk was characterized using a risk ladder and risk chance grid. The chance grid illustrated the chance of a home being damaged by a wildfire, represented as the number of red squares on a 1,000 cell square grid. The risk of the house being undamaged was represented by the remaining white squares (fig. 1). To convey the relative risk of a wildfire damaging a home relative to other ordinary risks (such as having a heart attack for a person over 35 years of age), a risk ladder (fig. 2) was presented to respondents. Both of these risk communication devices have been used in past surveys as a way to convey to respondents the relative and absolute risks (Smith and Desvousges, 1987; Loomis and duVair, 1993; Krupnick et al., 2002; Holmes et al., 2013).

Fig 1 Risk grids to convey relevant degree of wildfire risk to homeowner survey participants.

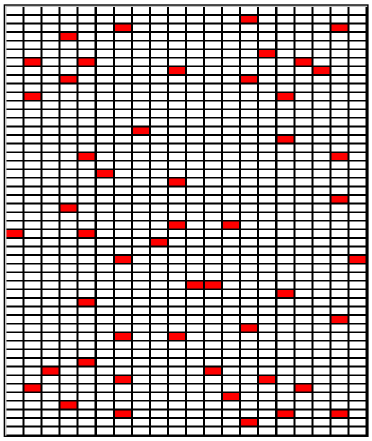
CHANCE GRIDS

(1) UPPER CHANCE GRID: Annual chance



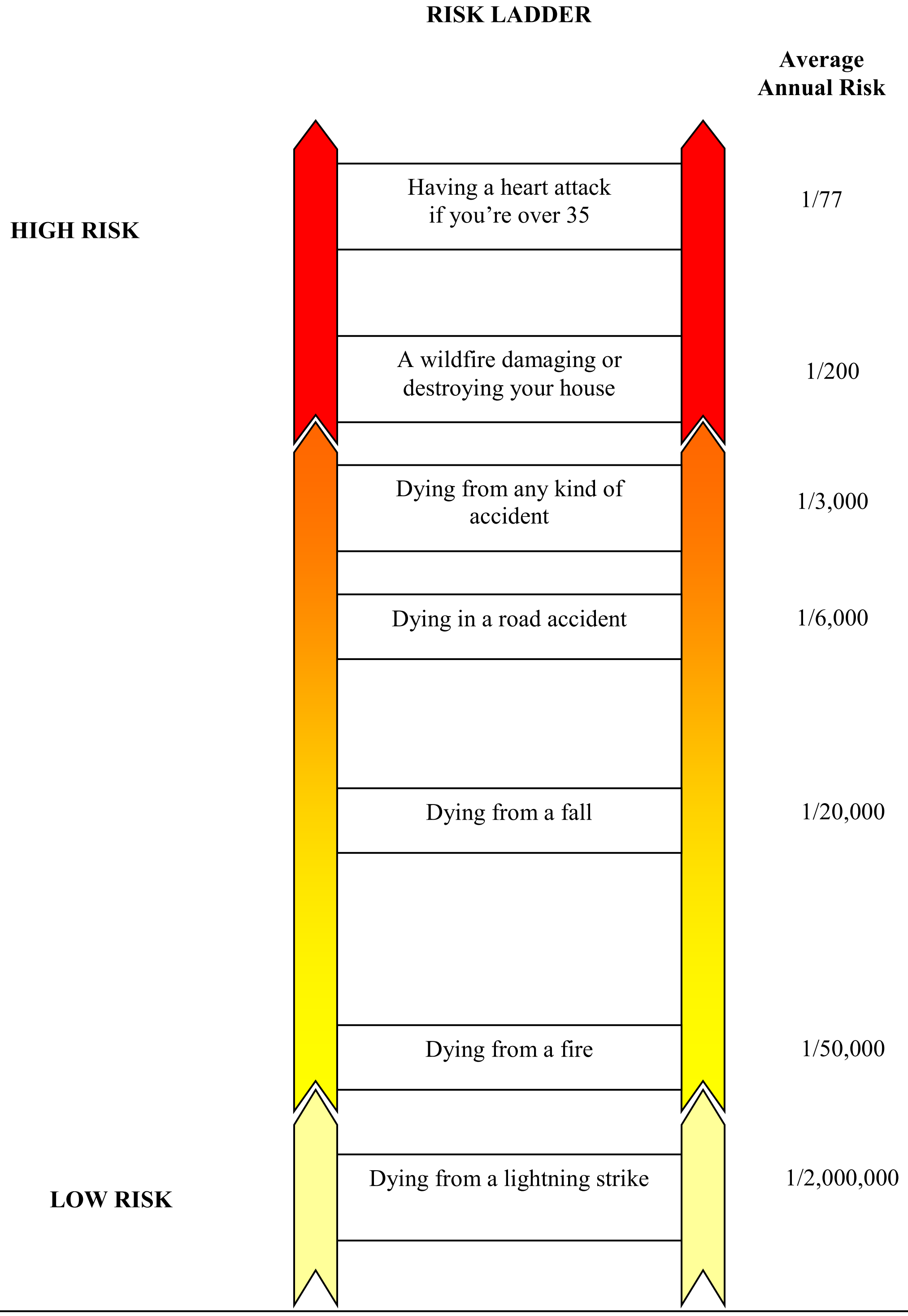
Another way to illustrate the Average Annual Chance of a wildfire damaging your house is shown in the diagram to the left. The “chance grid” shows a neighborhood with 1000 houses, and each square represents one house. The white squares are houses that have not been damaged or destroyed by wildfire, and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

(2) LOWER CHANCE GRID: Ten year chance



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

Fig 2 Risk ladder used to illustrate to survey participants the risk of wildfires relative to other, ordinary daily events.



This "risk ladder" shows the risk of everyday hazards occurring to you over the next 12 months. If you are over 35 years old, the highest risk shown on the ladder is of having a heart attack (this will happen to approximately 1 in 77 people). The risk of your house being damaged by a wildfire if you live in or near a heavily wooded area (this will happen to approximately 1 in 200 homeowners) is quite a bit larger than the risk of dying from a fire (this will happen to approximately 1 in 50,000 people).

The FL survey implemented a full factorial randomized experiment design to construct the choice sets. See Holmes et al. (2013) for information on constructing the full factorial design. For the CA survey, we used an efficient fractional factorial design using Ngene software (Rose et al., 2014). Both surveys used the same four attributes of the choice experiment: (1) *risk (%)* or chance (out of 1,000) of your house being damaged (by wildfires) in the next 10 years; this *risk* varied over five levels, from 1% to 5%, where 5% was the baseline risk respondents were told was associated with no new investments in wildfire protection programs;[5] (2) monetary damage (*loss*) to property from the wildfire; the dollar amounts of the *loss* varied over 10 levels that ranged from $10,000 to $100,000; (3) expected ten year loss = chance x damage; attribute #3 is not an independent attribute and was included only to facilitate understanding of how risk and damage interacted to give an "expected value" of the damages; and (4) one-time *cost* to the household for the ten year program; the *cost* of the programs varied over 10 levels from $25 to $1,500 for the Public Program and 9 levels from $50 to $1,500 for the Private Program.

Three choice sets, each with three alternative programs, were presented to respondents: (1) Public Fire Prevention in the forests around their neighborhood; (2) Private Fire Prevention; and (3) Do nothing additional. Each alternative program included chance of damage to respondent's house, monetary amount of damage, expected ten year loss, and a one-time cost for implementing the selected ten year program. Fig. 3 present an example of one of the three choice sets presented in the survey.

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[5] We use *italics* to denote variables used in the empirical analysis.

Fig 3 Example of the Choice Set

	Alternative 1	Alternative 2	Alternative 3
	Public Fire Prevention	Private Fire Prevention	Do nothing additional
Chance of your house being damaged in next 10 years	10 in 1,000 (1%)	25 in 1,000 (2.5%)	50 in 1,000 (5%)
Damage to property	$10,000	$50,000	$100,000
Expected 10 year loss = Chance x damage	$100 during 10 years	$1,250 during 10 years	$5,000 during 10 years
One-time cost to you for the ten-year program	$100	$500	$0
I would choose: Please check one box	☐	☐	☐

Data

Stratified sampling of households in the two states was used with more homeowners chosen from counties rated as having high or extreme wildfire danger than from those with medium or low wildfire risk. Data were collected using random digit dialing of households followed by a mail survey sent to single family homeowners providing an address (we did not survey renters). We obtained 922 usable surveys out of 2,000 mailed in FL for a 46% response rate. In CA, from 1,449 deliverable surveys we obtained 429 usable surveys for a 30% response rate.

Table 1 compares the descriptive statistics about homeowners in CA and FL. The survey responses indicate that when it comes to experience with wildfires the homeowners in FL and CA are quite similar. Homeowners were similar in their responses to whether they or a family member had ever experienced wildfire health effects from breathing wildfire smoke **or** had to change their travel plans due to wildfires. The two responses were merged into a new variable (*Personal Experience*) and used to capture the influence of respondent experience with actual wildfires. In particular, forty-three percent (43%) in FL and 47% in CA had experienced health effects or changes in travel plans due to wildfire. After reading the descriptions of high, medium and low fire risks landscapes around homes and neighborhoods respondents were asked whether they perceived their house and neighborhood to be at high, medium or low risk. Those that thought they were at high wildfire risk were labeled *high risk* as our measure of a risk perception variable. Approximately a tenth of homeowners perceived they were in a high risk area (10% in FL and 7% in CA).

Thus, in terms of wildfire experience and risk perception, FL and CA homeowners are quite similar. Using a proportional test, we found that there was a significant proportional mean difference (alpha level < .01) between CA and FL for the *high risk* variable, but no significant difference for the *personal experience* variable.

Table 1 also shows the three demographic variables we collected. To test whether there were statistically significant differences between CA and FL age, education and income, we first tested whether the variances were equal for these variables between the two states. Specifically, Bartlett's tests were performed independently to test the equal variance assumption for *age*, *income*, and *education level* variables. Results suggest that the variance is different between FL and CA for the *age* and *education level* variables. Therefore, Welch's two sample t-tests, which assumes unequal variance, was performed to test the mean difference for *age* and *education level* and a t-test was perform for *income* variable. Results show that the mean values for *age*, *income*, and *education level* variables are significantly difference between the two states. The largest difference between FL and CA homeowners is for age, with FL homeowners being younger than CA homeowners by seven years. Therefore we test for whether an age interaction coefficient was statistically significant and resulted in economically meaningful differences in WTP. In addition, we conducted a likelihood ratio test to test whether the two datasets should be pooled or have two separate models. Results suggest that we should have two models, one for each state.

Table 1. Descriptive statistics of homeowners in Florida (FL) and California (CA)

Variable	Description	Mean (std. dev.) FL	Mean (std. dev.) CA
personal experience (dummy variable)	If either (health related = 1 or travel disruption= 1); else = 0	0.43 (.50)	0.47 (0.50)
high risk[a] (dummy variable)	Respondent indicated that home is located in a high fire risk neighborhood; if Yes = 1; else = 0	0.10 (0.30)	0.07 (0.26)
Age[b]	Respondent's age	58 (15.15)	65 (13.10)
Income[b]	Household annual income	$87,178[c] (50,283)	$83,695 (51,107)
Education level[b]	Respondent's highest education level completed	14.66 (2.51)	15.66 (2.78)

a. The mean proportional values are significantly different between FL and CA at alpha level < .01.
b. The mean values are significantly different between FL and CA at alpha level < .01.
c. Adjusted to 2014.

Econometric Models of Choice Experiment Responses

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

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

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 error term that reflects factors unobservable to the researcher and hence is treated as a 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:

$$P_n(j) = \frac{\exp(\mu\beta x_{jn})}{\sum_{j\in\Theta} \exp(\mu\beta x_{jn})} \qquad (2)$$

where μ is a scale parameter that is typically set equal to one.[6]

The Mixed Logit (MIXL) model is a generalization of the MNL model, and allows for random variation in preferences, unrestricted substitution patterns, and correlations among unobserved factors (Train 2009). 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:

$$\beta_{nk} = \beta_k + \Gamma\upsilon_{nk} \qquad (3)$$

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. This is true only when the marginal utilities are

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[6] In all of the econometric models we present, the scale parameter is confounded with the β parameters of interest, and therefore we assume that its value is unity. In a single data set, the scale parameter cannot be recovered.

assumed to be normally distributed across respondents and correlation of preferences across attributes is permitted.

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

$$\pi_{nj} = \int L_{nj}(BX_j) f(B|\theta) d\beta \tag{4}$$

where

$$L_{nj}(\beta X_j) = \frac{\exp(\mu\beta X_j)}{\sum_{j=1}^{J} \exp(\mu\beta X_j)} \tag{5}$$

The function f(β|θ) can be simulated using random draws from various functional forms (Train 2009). We use Halton draws from the normal distribution to estimate Γ for the random parameters in the MIXL model. The MIXL model captures heterogeneity via a continuous probability distribution for preference parameters.

Because the FL data was collected in 2006 and the CA data was collected in 2014, we need to scale up FL 2006 WTP estimates to 2014 (Eiswerth and Shaw, 1997). Eiswerth and Shaw indicate they see “no flaw” in updating the WTP estimates by the Consumer Price Index (CPI) for use oriented values (Eiswerth and Shaw, 1997: 2382). Since our study is of homeowners WTP to reduce the risk of damage to their home from wildfire, we would characterize this as a use value, and apply the CPI (US Census Bureau, 2015) to the estimated 2006 WTP values. In this paper we also offer a different way to use the CPI: update the “bid” or cost amounts households are asked to pay in the choice experiment by the CPI and re-estimate the model. That is, if we were to re-run the choice experiment survey in 2014 in FL, we would have set a bid vector and the monetary amount of the house loss that was higher than what the pre-tests suggested was appropriate in 2006. Given the sizeable non-linearity in a mixed logit model we want to test whether these two approaches (i.e., updating the model estimates of the WTP values versus updating the bid and house loss vectors) will yield the same inflation adjusted WTP estimates. Thus, we compare the resulting two approaches to update WTP for inflation. A priori given the non-linearity in the MIXL model, it is not clear whether these two approaches would yield similar estimates in WTP.

Econometric Results

Initially MNL, MIXL were estimated in CA and FL. The MIXL model was the most robust in terms of statistically significant coefficients with signs consistent with economic theory. In addition, the MIXL model specification greatly improved the pseudo-R^2 values relative to the MNL model. Therefore, in the remainder of the paper we focus on the results from MIXL model. Part of the improvement in goodness of fit is due to the statistical significance of the standard deviations of the variables. These standard deviations have an economically meaningful and management relevant interpretation: there is a great deal of heterogeneity of preferences or attitudes toward what the variable represents. For example, significant standard deviations on risk might signal that some people are more risk averse than others, and some might even be risk neutral, focusing primarily on the expected value of the risk of loss and hence more tolerant of living in areas where there is a risk of forest fires. From a statistical standpoint controlling for heterogeneity in preferences helps to ensure an unbiased coefficient on the main attribute variable itself.

Identical specifications of the MIXL models were estimated in CA and FL. The models included two Alternative Specific Constants (ASC); one for the Public Program (*public program)* and one for the Private Program (*private program*). Because a respondent's preference may vary by whether the respondent perceives they live in an area of high wildfire risk or not, we created an interaction term relating the perception of living in high risk wildfire areas (*high risk)* with the Public wildfire Program ASC (*public pro*high risk)* and Private Program (*private pro*high risk*). In both CA and FL, coefficients on both of these interaction variables were positive and statistically significant suggesting the importance of risk perception in the choice to pay for the Public and Private Programs (see Table 2 for FL and Table 3 for CA). The positive signs on the two risk perception interaction terms will result in higher WTP for both programs by homeowners who perceive they live in areas at high risk of wildfire.

Table 2. Florida Mixed logit (MIXL) model estimates of preference parameters for wildfire hazard mitigation programs with random parameters estimated for risk and loss variables (The dependent variable is the alternative selected in the choice questions)[7].

Variable	Mixed logit Model Original Cost Bids		Mixed logit Model Adjusted Cost Bids	
	(mean)	(std. dev.)	(mean)	(std. dev.)
risk (*%*)	0.1180*	0.8760***	0.1152*	0.8694***
	(0.0604)	(0.0657)	(0.0601)	(0.0656)
risk personal exp.*	-0.1801**	0.0035	-0.1789**	0.007
	(0.0830)	(0.3058)	(0.0825)	(0.3109)
loss ($1,000)	0.0072**	0.0424***	0.0061**	0.0362***

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[7] Both analyses used the same fix seed.

	(0.0030)	(0.0033)	(0.0025)	(0.0028)
loss personal exp.*	-0.0123***	0.0022	-0.012***	0.0025
	(0.0040)	(0.0130)	(0.0039)	(0.0133)
cost ($)	-0.0011***		-0.0009***	
	(0.0001)		(0.0001)	
public program	0.7853***		0.7827***	
	(0.1224)		(0.1223)	
*public pro.*high risk*	1.1016***		1.0968***	
	(0.3087)		(0.3083)	
private program	0.4038***		0.3978***	
	(0.1257)		(0.1255)	
*private pro.*high risk*	1.4749***		1.4738***	
	(0.3127)		(0.3124)	
N	922	--	922	--
McFadden R^2	0.1590	--	0.1587	--
Log Likelihood	-2556.4933		-2557.4179	

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.

In FL we estimate two models: (a) the MIXL with the original cost bids (and then apply the CPI to the resulting WTP estimates) and (b) a MIXL model with the cost bids and the monetary amount of the house loss updated for inflation. Because the CA data was estimated using 2014 data, only one MIXL model is estimated.

In FL (Table 2), the econometric results indicate that coefficients on *risk* and *loss* are statistically significant, but have incorrect signs. Respondents that have no personal experience with fire appear to be confuse on the *risk* and *loss* attributes and tend to focus the program labels. The *risk* and *loss* interaction terms (respondents with personal experience with fire) are statistically significant with the correct signs, i.e., respondents presented with higher risk of damage to their home and higher monetary losses in the survey were more likely to agree to pay for the two programs than those who faced lower risks. In CA (Table 3) the econometric results indicates that the *risk* variable coefficient is statistically significant with incorrect sign. Similarly to FL results, CA respondents with no personal experience with fire are confuse on the *risk* attribute. The *loss* and *loss*personal experience* interaction term are not statistically different from zero. In both FL and CA the coefficient on the *cost* of the program is statistically significant, with the expected negative sign, suggesting internal validity of the results (i.e., the higher the dollar amount households were asked to pay the less likely they were to pay—indicating they were paying attention to the cost of the program to themselves). In both states the alternative specific constants for *public program* and *private program* are statistically significant as are the interactions with risk perception.

Table 3. California Mixed logit (MIXL) model estimates of preference parameters for wildfire hazard mitigation programs with random parameters estimated for risk and loss variables (The dependent variable is the alternative selected in the choice questions).

Variable	Mixed logit Model (mean)	(std. dev.)
risk (*%*)	0.2543**	0.7889***
	(0.1035)	(0.1511)
risk personal exp.*	-0.3807***	0.3717
	(0.1381)	(0.4223)
loss ($1,000)	-0.0012	0.0513***
	(0.0054)	(0.0064)
loss personal exp.*	-0.0068	0.0205
	(0.0072)	(0.0179)
cost ($)	-0.0021***	--
	(0.0002)	
public program	1.2776***	--
	(0.2184)	
*public pro.*high risk*	1.4399**	--
	(0.6867)	
private program	0.8674***	--
	(0.2317)	
*private pro.*high risk*	1.9589***	--
	(0.6929)	
N	429	--
McFadden R^2	0.2393	--
Log Likelihood	-992.8505	

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

Mean WTP Results

In a choice experiment the implicit prices (marginal WTP estimates) of the attributes are measured by the parameter coefficient divided by the absolute value of cost coefficient. Using this formula and the wildfire hazard mitigation program parameter estimates from Tables 2 and 3, the one-time mean WTP for a ten year Public and Private programs can be derived for FL and CA homeowners (Table 4).

Table 4. One-time WTP per homeowner for a ten year Public and Private wildfire risk reduction actions and benefit transfer error (2014 Dollars).

	Homeowners			
	Mean WTP Low to Moderate Risk Perception Program		Mean WTP High Risk Perception Program	
	Public	Private	Public	Private
	(95% Confidence Interval)[a]			
California Homeowners	$610	$414	$688	$936
	($429, $792)	($223, $606)	($22, $1354)	($264, $1608)
Florida Homeowners WTP=CPI x $\$MV_0$	$831	$427	$1,166	$1,561
	($600, $1062)	($186, $669)	($494, $1838)	($877, $2245)
Florida Homeowners WTP=CPI x $Bids	$832	$422	$1,166	$1,566
	($600, $1064)	($180, $665)	($492, $1840)	($880, $2254)

[a] Krinsky-Robb method using 10,000 draws were used to construct confidence intervals.

Updating Mean WTP Values for Inflation

Rows two and three of Table 4 report the two different approaches for making the WTP values from the 2006 FL data in the same year as the 2014 CA data. There turns out to be little difference between applying the CPI to the marginal values estimated using the original 2006 data and the alternative of applying the CPI to the cost bids prior to estimation of the mixed logit model. Thus, despite the non-linearity in the mixed logit model, the null hypothesis of no difference in results by using either method cannot be rejected, and simply updating the WTP estimates for inflation between the two time periods when performing BT appears to be a reasonable approach.

Differences in Mean WTP Estimates for Low to Moderate Risk Homeowners Compared to High Risk Homeowner

The dollar amounts reported in the second and third columns of Table 4 are the WTP estimates for the Public Program or the Private Program for those respondents who perceive they live in low to moderate fire risk areas. Among households that perceive low to moderate risk, the WTP is quite a bit higher for the Public Program than the Private Program around their home in both CA and FL. Apparently if you perceive a low fire risk you would prefer to reduce fire risk in the forests around the community rather than reducing trees and bushes around your own yard. However, for those households perceiving high wildfire risk, columns four and five indicate a higher WTP for the Private Program around their home rather than in the forests around their community in both CA and FL.

WTP amounts of homeowners that perceive low to moderate risk are lower for both the Public and Private Programs than those homeowners who perceived high risk of wildfire to their home and neighborhood. This difference in WTP is especially true to undertake the Private risk reduction actions around their own home. The higher WTP of homeowners perceiving high risk of damages makes sense as homeowners perceiving high risk likely feel they will benefit more from a given fire risk reduction program than those homeowners that think they are only at low risk of fire.

Discussion

The homeowners in both states appear similar on prior experience with the health effects and travel disruptions associated with wildfires. However, FL's consistently higher WTP than CA, may be consistent with three differences between homeowners in FL and CA. While there appeared to be similar percentages of homeowners in each of the two states that perceived their homes/neighborhoods to be at high risk of wildfire, FL homeowners risk perceptions were statistically higher than CA. As shown empirically in this paper higher perceptions of risk do translate into higher WTP amounts. Further, FL homeowner income was also statistically higher than that of CA.

Another factor that might help explain the differences in WTP between FL and CA is differences in homeowner age. In particular, responding homeowners ages are statistically different between FL and CA, with FL homeowners' age seven years younger than CA homeowners' age. To determine if age was a significant factor in the selection of alternative fire programs, we ran a mixed logit model that interacted age with Public Program and Private Program. In FL these interaction coefficients were negative and significant, but not in CA. In FL older homeowners do have lower WTP. Nonetheless, the higher WTP in FL than CA is consistent with FL homeowners being significantly and substantially younger than CA homeowners.

Conclusions

Identical choice experiment surveys of CA and FL homeowners were conducted to estimate the homeowner WTP for a Public Program to reduce wildfire risk in the neighborhood where they live, and a Private Program to reduce wildfire risk around their home. We adjusted FL 2006 WTP estimates to 2014 using two methods. First method consisted in using the CPI to scale up the estimated 2006 WTP values to 2014. For the second method, we update the “bid” or cost amounts households are asked to pay in the choice experiment by the CPI and re-estimate the model. We find no difference on the method used.

Results show that FL homeowners’ WTP for each of the two programs is consistently higher than CA homeowners. We also found similar results as Holmes et al. (2013) that respondents with no personal experience with fire are confused regarding *risk* and *loss* levels presented in the experiment, as the estimate parameters have the wrong sign. In addition, results show that respondents selection is based on the *cost* attribute and anchoring on the fire mitigation program labels.

Overall, the results suggest the highest priority for cost sharing funds would go to homeowners in areas who perceive their houses to be at high risk, and especially to cost share private actions on their own land. Thus, our results should prove informative to the USFS for targeting cost sharing funds in terms of what types of actions/programs to cost share and in what states to prioritize funding. In particular, the results suggest the order of priority would be to target cost sharing private actions among High Risk Perception households in FL, then private actions by CA High Risk Perception households. These results could help the USFS optimize its allocation of scarce cost sharing funds among states and public vs private actions.

Acknowledgements

The authors would like to thank Dr. Juan Marcos González of Research Triangle Institute for his review comments and suggestions. This research was funded by the USDA Forest Service under Research Joint Venture Agreement 13-JV-11272131064 and Colorado State University Regional Research Project W3133.

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Integrating Teledetection and Economic Tools in the Evaluation of Wildfires Impacts. The Alhama de Almería Fire (Spain) Case[1]

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Abstract

Valuation of natural resources requires a multifunctional vision incorporating market and nonmarket values like environmental services and landscape goods. Though widely used in forest firest analysis, teledetection has never been used in the economic valuation of forest fires damages. Application of this tool in the valuation of forest fires damages provides a versatile tool with many benefits. For example, it allows identification and valuation of large forest fires inexpensively compare to on the ground monitoring by providing periodic information of vegetation post-fire behavior.

Using Landsat 8 satellite images and the economic procedure in Visual SEVEIF we provide an economic valuation of the damages caused by the Alhama de Almeria fire (3,260 ha). The satellite images are an important source of georeferenced information and can be used to determine the resource net-value-change based on fire intensity by classifying the vegetation indexes as resource depreciation rates. For the Alhama de Almeria fire the dNBR index provides a more robust representation of fire severity than RdNBR because of the boosting effect caused by the pre-fire NBR due to the areas scant vegetation, low precipitation and intense sun light. The economic valuation of the damages caused by this fire was estimated at 656,981 € or 201.53 €/ha. The most important resources in the valuation were landscape goods because of their closedness to the province capital. Over 57% of the total losses correspond to landscape goods and environmental services.

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[1] An abbreviated versión of this work was presented at the Fifth International symposium on Fire Economics, Plannig, and Policy: Ecosystem Services and Wildfire, November 14-18, 2016, Tegucigalpa, Honduras.

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Keywords: Economic damages, environmental services, resource valuation, nonmarket valuation, vegetation index

Introduction

The increasing climate and socioeconomic changes are provoking a paradigm shift in forest management adopting a multifunctional function with landscape goods and environmental services as its main actors (Contanza et al. 1997). An integrated valuation of natural resource damages is fundamental for an effective disturbances planning to mitigate the disturbance impacts on rural populations (Vélez 2009). Within the Mediterranean environment a methodological procedure integrating net-value change variables and economic tools has practical utility at the post-fire and the preventative level. The Geographic Information Systems (GIS) become essential not only for the development of fire protection plans but also in their optimization (Chuvieco et al. 2010). For this reason we develop the methodological procedure anchored on a GIS to facilitate the spatial-temporal monitoring maps and a decision aid for restoration and forest fires control.

The economic valuation of fire damages on a large forest fire requires an intense field work, commanding a large number of economic and human resources, often not available. In related developments studies have shown the potential of satellite images to identify the area burned and different levels of fire severity or damages on a forest fire (Chivieco at al. 2005). The benefits associated with teledection are its capacity to measure large areas, low cost per area, and availability of periodic information. However, its use also present some limitations particularly in the lower stratum of the forest canopy or some type of forests (Miller and Thode 2007, Soverel et al. 2010); and in the economic valuation because its difficulty in measuring some variables (Rodríguez y Silva et al. 2013a). Therefore, the use of satellite images requires field work for validation and calibration.

Using vegetation indeces like the Normalized Difference Vegetation Index (NDVI), the Normalized Burn Ratio (NBR), and the Relative difference Normalized Burn Ratio (RdNBR) we can identify the different fire severity or damage levels by the spectral differences existing immediately pre- and post-fire (Key and Benson 2006, Miller and Thode 2007). Even after considering the spectral differences associated with seasonality, the reflectance property of different soils, and time since the fire occurrence these works have reached a high level of robustness in determining damage levels. Likewise, a study using MODIS images done by our own fire laboratory was quite accurate for several large fires in southern Spain (Rodríguez y Silva et al. 2013). In this study, though the fire is large enough to use MODIS imagery (per our preliminary findings) we dediced to use Landsat 8 images. The change in remote sensing imaging is justified by the higher quality of spatial resolution; as well as for the improvements in natural resources mapping.

The general objective of this study is the development of a georefenced economic valuation of forest fires impacts. Fire damages economic valuation requires the following: a prior characterization of resources, identification of the fire different intensity levels, and an accurate representation of the relationship between vegetation damage and each pixel reflectance.

Materials and methods

Study site

The methodology was applied in Almeria (Spain), the most southeastern province of the Iberian Peninsula (Figure 1). The factors for selecting this fire included its size (3,260 ha), seasonality (winter, outside of the maximun fire risk, large private property presence (difficult to inventory), and the landscape diversity wit large dense forest zones, low density forest zones, and zones without forest cover.

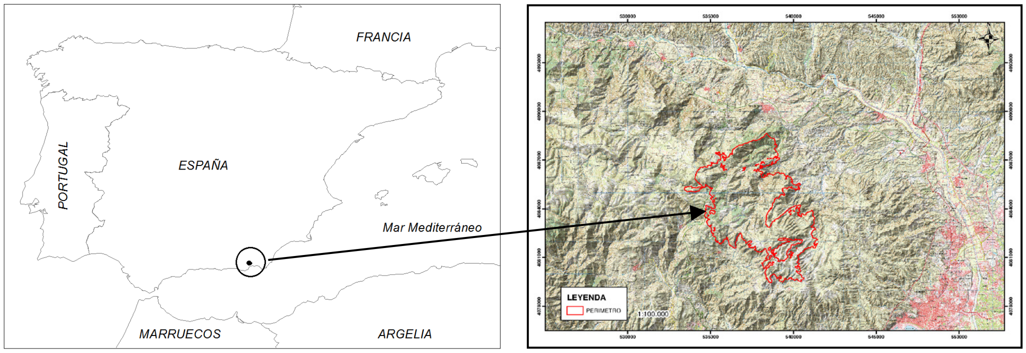


Figure 1- Alhama de Almería fire location

Methodological procedure

The economic valuation of forest fires impact, integrating economic and teledetection tolos, requires four interrelated phases (Ruíz 2015) (Figure 2):

- Economic valuation of the natural resources
- Spatial identification of the different levels of damage
- Identification and testing of the severity levels
- Identification of resources net-value-change

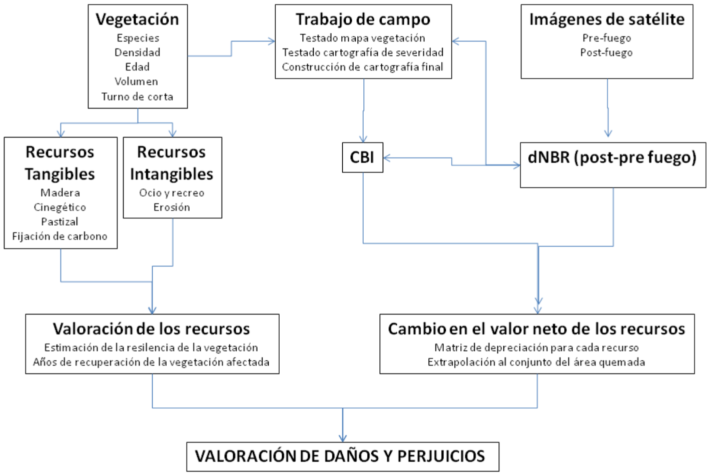
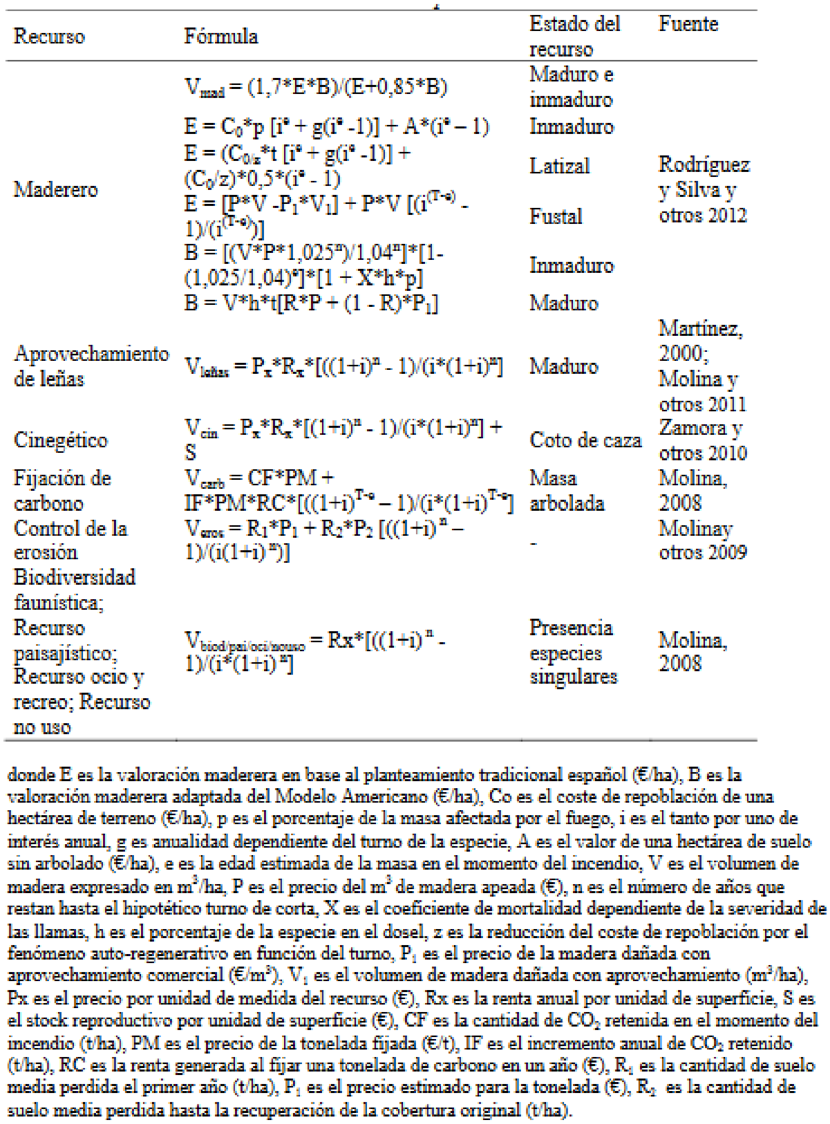


Figure 2- Methodological framework for the economic valuation (Ruíz 2015)

Economic valuation of natural resources

The natural resources economic valuation was done using the mathematical formulas in Visual SVEIF (Rodríguez y Silva et al. 2013a, 2013b). For the Alhama fire we included four market goods: timber (rodrígue y Silva et al. 2012), hunting (Zamora et al. 2010), pastoral use (Molina et al. 2011), and carbon sequestration (Molina et al. 2009); and fire nonmarket goods: protection of erosion, biodiversity, landscape, leisure and recreation, and non-use (Molina et al. 2009). Formulas in Figure 3 were used to compute their values considering local technicians experience for determing harvesting rotation turn or maturity, vegetation groups' resilience, and age of affected stands. Stands volume was computed using information from the National Forestry Inventory and from public forests planning projects. The pastoral and hunting rent was coumputed using the existing hunting technical and exploitation plans approved by the Regional Authority. The biodiversity valuation was conducted using a study by the University of Cordoba, based on the level of protection for the existing species in the area. For the indirect valuation of nonmarket landscape values, and due to the absence of information for the study are we used the average value of a similar burned area with urban centers nearby. The annual visitation rate to the area was developed using the expert opinion of the local environmental rangers.



Recurso	Fórmula	Estado del recurso	Fuente
Maderero	$V_{mad} = (1,7*E*B)/(E+0,85*B)$	Maduro e inmaduro	
	$E = C_0*p\ [i^e + g(i^e - 1)] + A*(i^e - 1)$	Inmaduro	
	$E = (C_{0/z}*t\ [i^e + g(i^e - 1)] + (C_0/z)*0,5*(i^e - 1)$	Latizal	Rodríguez y Silva y otros 2012
	$E = [P*V - P_1*V_1] + P*V\ [(i^{(T-e)} - 1)/(i^{(T-e)})]$	Fustal	
	$B = [(V*P*1,025^n)/1,04^n]*[1-(1,025/1,04)^e]*[1 + X*h*p]$	Inmaduro	
	$B = V*h*t[R*P + (1 - R)*P_1]$	Maduro	
Aprovechamiento de leñas	$V_{leñas} = P_x*R_x*[((1+i)^n - 1)/(i*(1+i)^n]$	Maduro	Martínez, 2000; Molina y otros 2011
Cinegético	$V_{cin} = P_x*R_x*[(1+i)^n - 1)/(i*(1+i)^n] + S$	Coto de caza	Zamora y otros 2010
Fijación de carbono	$V_{carb} = CF*PM + IF*PM*RC*[((1+i)^{T-e} - 1)/(i*(1+i)^{T-e}]$	Masa arbolada	Molina, 2008
Control de la erosión	$V_{eros} = R_1*P_1 + R_2*P_2\ [((1+i)^n - 1)/(i(1+i)^n)]$	-	Molinay otros 2009
Biodiversidad faunística; Recurso paisajístico; Recurso ocio y recreo; Recurso no uso	$V_{biod/pai/oci/nouso} = Rx*[((1+i)^n - 1)/(i*(1+i)^n]$	Presencia especies singulares	Molina, 2008

donde E es la valoración maderera en base al planteamiento tradicional español (€/ha), B es la valoración maderera adaptada del Modelo Americano (€/ha), Co es el coste de repoblación de una hectárea de terreno (€/ha), p es el porcentaje de la masa afectada por el fuego, i es el tanto por uno de interés anual, g es anualidad dependiente del turno de la especie, A es el valor de una hectárea de suelo sin arbolado (€/ha), e es la edad estimada de la masa en el momento del incendio, V es el volumen de madera expresado en m^3/ha, P es el precio del m^3 de madera apeada (€), n es el número de años que restan hasta el hipotético turno de corta, X es el coeficiente de mortalidad dependiente de la severidad de las llamas, h es el porcentaje de la especie en el dosel, z es la reducción del coste de repoblación por el fenómeno auto-regenerativo en función del turno, P_1 es el precio de la madera dañada con aprovechamiento comercial (€/m^3), V_1 es el volumen de madera dañada con aprovechamiento (m^3/ha), Px es el precio por unidad de medida del recurso (€), Rx es la renta anual por unidad de superficie, S es el stock reproductivo por unidad de superficie (€), CF es la cantidad de CO_2 retenida en el momento del incendio (t/ha), PM es el precio de la tonelada fijada (€/t), IF es el incremento anual de CO_2 retenido (t/ha), RC es la renta generada al fijar una tonelada de carbono en un año (€), R_1 es la cantidad de suelo media perdida el primer año (t/ha), P_1 es el precio estimado para la tonelada (€), R_2 es la cantidad de suelo media perdida hasta la recuperación de la cobertura original (t/ha).

Figure 3- Mathematical formulas from the SEVEIF application for naturla resource valuation (Rodríguez y Silva 2013a, 2013b)

Spatial identification of the different damage levels

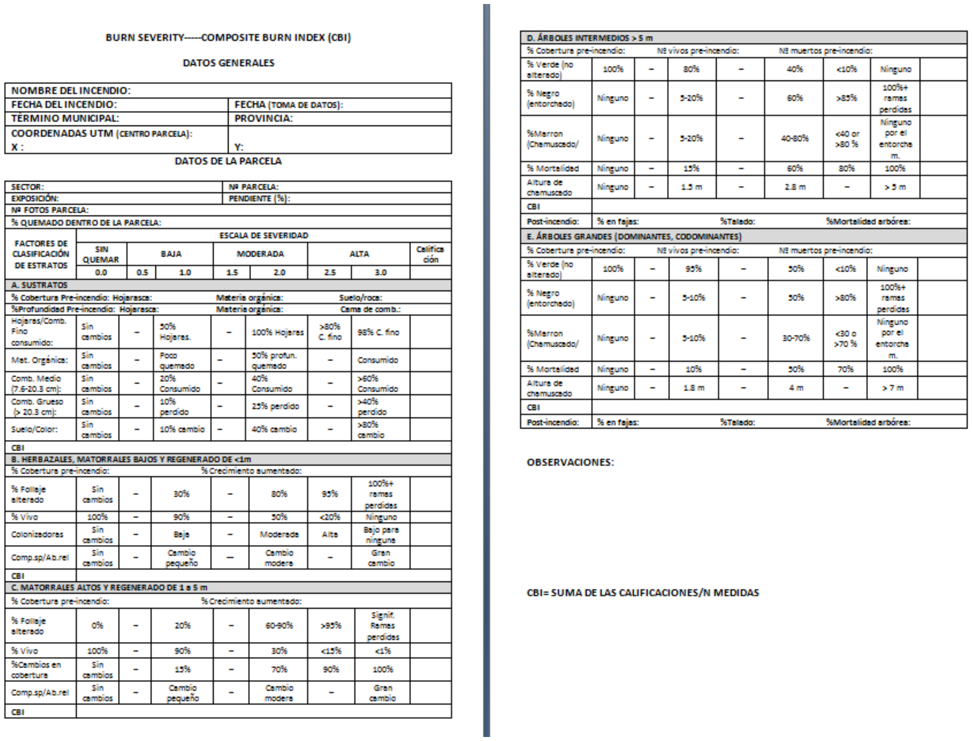
The pre- and post-fire images used were Landsat 8 LDCM (Landsat Data Continuity Mission). We used three vegetation indeces to test the spatial identification of the different fire severity levels (Table 1); selecting the most statistically robust one for the study area given the local reflectance characteristics.

Table 1- *Tested vegetation indeces for severity levels identification*

Vegetation index	Equation	Range
NBR	$NBR = \frac{(R5 - R7)}{(R5 + R7)} * 1000$	-1000 a 1000
dNBR	$dNBR = (NBRpre - NBRpost)$	-2000 a 2000
RdNBR	$RdNBR = \frac{dNBR}{\sqrt{Abs(NBRpre)}/1000}$	-2000 a 2000

__Identification and testing of severity levels__

The information derived from the vegetation indeces was field tested in the fall prior to the fire. The severity was tested using the Composite Burned Index (CBI) protocol (Key and Benson, 2005) that cuantify damage levels from variables easily identified in field inventories such as soil color, presence of organic matter, loss of leaves, changes in vegetation color, and vegetation mortality for each of the ecosystem components: soil, pastureland, scrub and regeneration, trees < 5 meters, trees >5 meters (Figure 4).



BURN SEVERITY-----COMPOSITE BURN INDEX (CBI)

DATOS GENERALES

NOMBRE DEL INCENDIO:
FECHA DEL INCENDIO: FECHA (TOMA DE DATOS):
TÉRMINO MUNICIPAL: PROVINCIA:
COORDENADAS UTM (CENTRO PARCELA):
X : Y:

DATOS DE LA PARCELA

SECTOR: Nº PARCELA:
EXPOSICIÓN: PENDIENTE (%):
Nº FOTOS PARCELA:
% QUEMADO DENTRO DE LA PARCELA:

FACTORES DE CLASIFICACIÓN DE ESTRATOS	ESCALA DE SEVERIDAD							
	SIN QUEMAR	BAJA		MODERADA		ALTA		Calificación
	0.0	0.5	1.0	1.5	2.0	2.5	3.0	
A. SUSTRATOS								
% Cobertura Pre-incendio: Hojarasca: Materia orgánica: Suelo/roca:								
%Profundidad Pre-incendio: Hojarasca: Materia orgánica: Cama de comb.:								
Hojaras/Comb. Fino consumido:	Sin cambios	–	50% Hojaras.	–	100% Hojaras	>80% C. fino	98% C. fino	
Mat. Orgánica:	Sin cambios	–	Poco quemado	–	50% profun. quemado	–	Consumido	
Comb. Medio (7.6-20.3 cm):	Sin cambios	–	20% Consumido	–	40% Consumido	–	>60% Consumido	
Comb. Grueso (> 20.3 cm):	Sin cambios	–	10% perdido	–	25% perdido	–	>40% perdido	
Suelo/Color:	Sin cambios	–	10% cambio	–	40% cambio	–	>80% cambio	
CBI								
B. HERBAZALES, MATORRALES BAJOS Y REGENERADO DE <1m								
% Cobertura pre-incendio: % Crecimiento aumentado:								
% Follaje alterado	Sin cambios	–	30%	–	80%	95%	100%+ ramas perdidas	
% Vivo	100%	–	90%	–	50%	<20%	Ninguno	
Colonizadoras	Sin cambios	–	Baja	–	Moderada	Alta	Bajo para ninguna	
Comp.sp/Ab.rel	Sin cambios	–	Cambio pequeño	–	Cambio modera	–	Gran cambio	
CBI								
C. MATORRALES ALTOS Y REGENERADO DE 1 a 5 m								
% Cobertura pre-incendio: % Crecimiento aumentado:								
% Follaje alterado	0%	–	20%	–	60-90%	>95%	Signif. Ramas perdidas	
% Vivo	100%	–	90%	–	30%	<15%	<1%	
%Cambios en cobertura	Sin cambios	–	15%	–	70%	90%	100%	
Comp.sp/Ab.rel	Sin cambios	–	Cambio pequeño	–	Cambio modera	–	Gran cambio	
CBI								

D. ÁRBOLES INTERMEDIOS > 5 m								
% Cobertura pre-incendio: Nº vivos pre-incendio: Nº muertos pre-incendio:								
% Verde (no alterado)	100%	–	80%	–	40%	<10%	Ninguno	
% Negro (entorchado)	Ninguno	–	5-20%	–	60%	>85%	100%+ ramas perdidas	
%Marron (Chamuscado/	Ninguno	–	5-20%	–	40-80%	<40 or >80 %	Ninguno por el entorcham.	
% Mortalidad	Ninguno	–	15%	–	60%	80%	100%	
Altura de chamuscado	Ninguno	–	1.5 m	–	2.8 m	–	> 5 m	
CBI								
Post-incendio:	% en fajas: %Talado: %Mortalidad arbórea:							
E. ÁRBOLES GRANDES (DOMINANTES, CODOMINANTES)								
% Cobertura pre-incendio: Nº vivos pre-incendio: Nº muertos pre-incendio:								
% Verde (no alterado)	100%	–	95%	–	50%	<10%	Ninguno	
% Negro (entorchado)	Ninguno	–	5-10%	–	50%	>80%	100%+ ramas perdidas	
%Marron (Chamuscado/	Ninguno	–	5-10%	–	30-70%	<30 o >70 %	Ninguno por el entorcham.	
% Mortalidad	Ninguno	–	10%	–	50%	70%	100%	
Altura de chamuscado	Ninguno	–	1.8 m	–	4 m	–	> 7 m	
CBI								
Post-incendio:	% en fajas: %Talado: %Mortalidad arbórea:							

OBSERVACIONES:

CBI= SUMA DE LAS CALIFICACIONES/N MEDIDAS

Figure 4- Field forms for evaluating the Composite Burn Index

The CBI parcel (30 meters radius and spaced 90 m between them) evaluation was stratified by each severity level representativeness. Once the inventory was completed a statistical analysis was performed using the CBI as an independent variable, and the indeces value as the dependent variable. The SPSS$^{(C)}$ software allowed us to estimate the confusion matrix and the Kappa statistic identifying the best vegetation index for the study zone.

Identification of the resources net-value change

We used satellite images together with the field inventory for a prior identification of severity, allowed us to estimate a resources net-value change (NVC) (Rodríguez y Silva and González-Cabán 2010) based on damage levels. The NVC is not homogeneus for all resources, but will be estimate individually in terms of an identifiable parameter in the field inventory. Like in other studies (Zamora et al. 2010, Molina et al. 2011, Rodríguez y Silva et al. 2012), for its simplicity of identification in-situ, we use the flame length as the variable to measure the degree of resource degradation.

Initially, we considered the depreciation rates from these previous works and the FIREMAP, SINAMI and INFOCOPAS research studies based on a large number of fires in Andalusia; as the field work will permit adjetment and validation for the study area local conditions.

Results

Natural resources economic valuation

The natural resources total economic value of the area burned was 1,074,798 €; equivalent to 329.69 €/ha. Percentage wide, there was little difference in the economic value of market (timber, hunting and pasturelands) and nonmarket (landscape, leisure and recreation, and non-use values) goods with a 40.95% and a 40.85% respectively. Hunting, which is the principal economic activity of these forest areas was also highly valued at 298,601 €.

Spatial Identification of damage levels

Independently of using a continuous or categorical classification the severity levels identification showed uneven results in terms of the vegetation index used. The worst results were for the NDVI; results improved by using the dNBR and RdNBR indeces; thogh they still also showed differences between them (Figure 5). Using the dNBR index a 66.92% of the area burned was identified as moderate severity; while using the RdNBR brings this number to only 17.84%. This is due to a more unfavorable result for the RdNBR index, which identify a larger area in the high severity category.

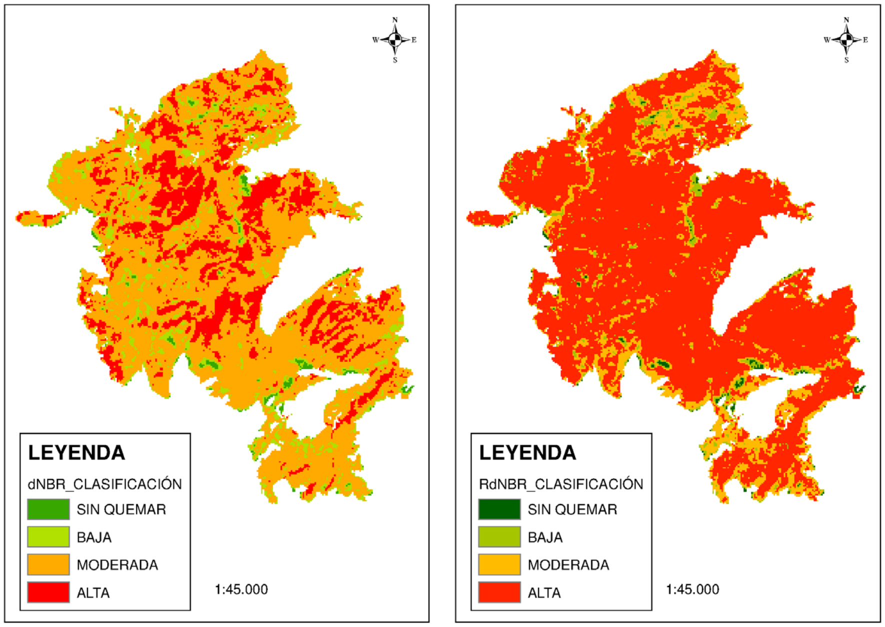


Figure 5- Severity identificación using dNBR and RdNBR (Ruíz 2016)

Identification and testing of severity levels

Statistical testing of the severity field work with information from satellite images showed a general tendency towards models with a potentially relationship between the reflectance level and CBI. The dNBR vegetation index provided a more robust information than the RdNBR index as measured by the coefficient of determination or R^2 with 0.706 vs. 0.604 respectively. The R^2 increased significantly when considering the forested zones to 0.827.

Likewise, the confusión matrix showed better results for the dNBR (82%) than for RdNBR (50%). The principal errors in the fire severity level were associated with the lower levels (moderate and low severity); with the low severity level showing the higher number of incorrect classifications for both the CBI-dNBR and CBI-RdNBR. The Kappa statistic values for dNBR was 0.751.

Identification of resources net-value change

From the fire severity analysis (relationship between the CBI and vegetation indeces) we determided an unique categorical representation: low, medium and high severity. However, the existance of pole and timber stands, and thicket areas lead us to determine the insufficiency of using only three levels to represent the resources NVC for all the area burned. Therefore, we developed a new classification using the six fire intensity levels (FIL) based on the average flame length from the field inventories (Table 2).

Table 2-*Vegetation indeces tested for identifying fire severity levels*

Vegetation	Category	Flame length (m)	FIL
Areas without trees Pole stands	Low severity	< 2	I
	Moderate severity	3-6	III
	High severity	6-9	IV
Timber stands	Low severity	2-3	II
	Moderate severity	9-12	V
	High severity	>12	VI

Fire impacts valuation

The total economic valuation of damages in the Alhama fire was 656,981 € or 201.53 €/ha. Of the total damages caused by the fire about 42.32% are associated with the market goods in the fire area (timber, hunting and pasturelands) and 39.11% are associated with nonmarket goods in the fire area (landscape, leisure and recreation, and nonuse values).

Table 3-*Individual resource economic valuation for the Alhama de Almería fire.*

Resource	Damage (€)	Representativeness (%)
Timber	99,558.78	10.52
Hunting	205,979.48	31.35
Pasturelands	2,944.61	0.45
Carbon sequestration	55,192.18	8.40
Erosion control	40,516.88	6.17
Biodiversity	26,273.04	3.99
Landscape	57,419.42	8.74
Eisure and recreation	20,004.11	3.04
Nonuse	179,545,54	27.33
TOTAL	656,981.04	

Discussion

The multifunctional reality of the Mediterranean forests is reflected on the economic valuation of the Alhama fire. The market resources in the fire area represent a relative small proportion (42.32%) of the total like in other studies (Rodríguez y Silva et al. 2013b). Even though, the study are is not within any protected natural space it is subject to a great human pressure because the hunting activities and its strategic location close to the province capital.

Given the present budgetary restrictions the use of satellite images is fundamnemtal for the evaluaton of areas burned (Chuvieco el at. 2005). Identification of fire severity levels in large fires with teledetection (Key and Benson 2006, Miller and Thode, 2007, Soverel et al. 2010) represents a support tool for prioritization of restoration actions. In addition, the use of satellite images allows of the spatial-temporal monitoring of the resources recovery at basically a zero cost. However, we must be cognizant that any teledetection work requires field validation, especially in identifying fire severity levels (Key and Benson 2005).

Contrary to Miller and Thode (2007) results, the classification of fire serverity levels through dNBR showed better results than through RdNBR. This could be due to the NBR pre-fire small values that result in exceptionally very large values of RdNBR. As expected the statistical analysis showed a better relationship between CBI and dNBR than between CBI and EdNBR possibly due to the lower pre-fire reflectance values. Though the Kappa statistic values are similar, the global precision of dNBR is larger than in other studies (Miller and Thode 2007, Soverel et al. 2010). The adjustment significance increases in forested lands due to pre-fire reflectance values.

The economic valuation of the Alhama de Almeria fire reveals a greater impact on the nonmarket goods and services (envirnmentla services and landscape values) than on the market goods (timber, hunting and pasturelands) (Table 3). This coincide with results from other studies (Rodríguez y Silva et al. 2013a). Therefore, as other authors recommend (Vélez 2009, Rodríguez y Silva and González-Cabán 2010), the economic valuation of damages must recognize the multifunctionality of Mediterranean forest and include not only the damages to marke goods like timber.

Combining the satellite images with flame length in the economic valuation of damages provides a useful tool for agencies responsable for management of forest lands (Rodríguez y Silva et al. 2013a). The availability of georeferenced information of the forest fire damage on a per hectare basis, not only at the individual resource level, but at the integrated ecosystem vulnerability is important for fire management decision making and budgets allocation (Molina et al. 2009). The greatest advantage of products and tools based on GIS (thematic mapping) and teledectation is the simplicity of incorporating additional needs or novel ideas, thus making the digital information an indispensable working tool for fire protection programs (Chuvieco et al. 2010). In addition, let's not forget that the methological procedure presented here is based on free satellite images available every 16 days (Landsat 8). Therefore, even when we have selected only one fire for development of the procedure the methodology can be extrapolated to any fire and scale of work, as long as we consider the prior knowledge of resources affected, and the necessary and mandatory adjustments for all works done with satellite images.

Conclusions

The new social paradigms for the valuation of natural resources requires the incorporation of nonmarket goods and services (environmental servies and landscape values), as many times they represent a larger proportion of the total values. Integrating satellite images and economic tools reduces the need for economic and human resources, and facilitate the spatial-temporal monitoring of areas burned. In addition, using vegetation indeces allows the incorporation of the resources NVC providing a closer representation of reality and optimizing budget allocation. The dNBR index provides a better fire severity classification for the study area than RdNBR due to high solar radiation, low precipitation and scant vegetation.

Acknowledgments

This work was funded by the Ministry of Science and Innovation public project GEPRIF (RTA2014-00011-C06-01).

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Factors Explaining Forest Fires in the Serik and Taşağıl Forest Provinces (SW Anatolia - Turkey)[1]

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Abstract

This study was undertaken to determine the factors causing forest fires in Serik and Taşağıl forest provinces of Antalya Forest Regional Directory in Turkey. These neighboring forest provinces including 78 forest villages was the site of one of the biggest forest fires in the Turkish Recorded History affecting about 15000 hectares. The area is also known to have a high frequency of forest fires.

To accomplish this goal, we gathered information on 21 forest related characteristics, 22 socioeconomic factors for the years from 1998-2010, fire number, and two different index derived by climatic factors. Socioeconomic factors were obtained by scanning the local, regional and national registrations in different databases. All these 43 factors belonging to 78 forest villages were used for the analysis. Different multi numerical analysis techniques such as factor analyzes, cluster analysis and multi regression analysis were applied to reveal the most important factor groups explaining fires in the region. The analyses were done separately for Taşağıl and Serik forest provinces.

Four factor groups including eleven variables were selected for the Taşağıl forest province. These factors groups explained 85 % of the total variance. Similarly, for Serik forest province, four factor groups containing fourteen variables were determined. These groups explained 87% of the total variance. The villages of Taşağıl and Serik provinces were classified according to these factor groups, which could be a useful tool for the fire management in the region.

Keywords: Correlation function, fire-socioeconomic factors, forestry management, social-fire danger factors

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[1] An abbreviated version of the paper was presented at the Fifth International Symposium on Fire Economics, Planning, and Policy: Ecosystem Services and Wildires, November 14-18, 2016, Tegucigalpa, Honduras.

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Introduction

The forests of Turkey are part of the Mediterranean Forests, and Turkey's forest belt in the Aegean and Mediterranean Regions shows many ecological similarities with Mediterranean forests. On the other hand, Turkey's geographical location and physical structure is quite different from countries that have a Mediterranean forest belt. This difference is reflected on the biological diversity. In addition, Turkey also has a very different socioeconomic structure from Mediterranean countries. Turkey's forests are administered by the Ministry of Forestry and Water Affairs. The General Directorate of Forestry (GDF) is the largest management unit, with a mission to protect, develop and manage Turkey's forest area of 21.3 million hectares. This unit works with 27 equivalent regional "General Directorates of Forest" organizations at the national level. During the period 1937–2010, 86,769 forest fires were recorded in Turkey, destroying an area of 1,617,701 hectares.

There are 10 functioning "General Directorates of Forestry" in the Aegean and Mediterranean regions. Of the total forest area destroyed by fires between 2000 and 2009, 81% belongs to General Directorates of Forestry in the first 10 areas. When these 10 areas are sorted by area affected, the largest area is within the General Directorate of Forestry of Antalya. These first 10 areas account for 63.35% of the total forest fires that occurred from 2000–2010. The General Directorate of Forestry of Antalya is rank second in the number of forest fire.

The firefighting system in Turkey work mostly in post-fire activities. As a result, a major part of the resources are spent in the post-fire extinguishing activities. The GDFs, which effectively managed forest fires, could develop an action plan with their teams waiting in permanent specific sites in case of any fire (after receiving news of fire outbreaks) and to take action (Passive Defense System) (AKKAŞ et al., 2008).

The GDF approach towards fire prevention measures is as follows: "… It is known that forest fires in Turkey are 91% human-related. Accordingly, the basis of all the preventive measures is societal education. Necessary studies should be undertaken to increase social awareness among universities, high schools, elementary schools, villages, cities, military units, summer villages and holiday sites; and among people working in the tourism sector and campers" (DOĞAN, 2009). However, the investment and action planning for fire prevention are insufficient.

"… The fact that forest fires in Turkey are mostly human-related clearly shows the importance of socioeconomic research studies about communities. Therefore, for a country where 91% of forest fires are human-related, it seems more logical to urgently start working to determine "social fire danger factor" according to socioeconomic variables instead of funding efforts to form a risk assessment system associated with natural variables such as pure flammable substances and weather conditions."(AKKAŞ et al., 2008).

Various national and international studies were conducted on this subject. In a study of the relationships between forest fires and socioeconomic parameters and agroforestry in Portugal, Almeida and Moura (1992) collected agroforestry and socioeconomic parameters that seem related to forest fires from 274 settlement units in Portugal. Eight settlement area groups were identified via principle components analysis and classification. The study identified principle parameters and information that were effective in each group, to act as a starting point for fire prevention.

Almeida et al. (1986) identified 27 variables from 3 large groups (human, livestock and occupations with soil), which were thought to be related to forest fires. The chosen variables were re-arranged for the settlement areas with consistently homogenous zoning because the area had very heterogeneous socioeconomic structure. A data matrix was formed with 274 units and 27 variables. The data were then analyzed to identify inter-relationships.

In a study of "fire protection system and forest fire management", Kallidromitou1 et al. (1999) defined socioeconomic factors and numbers and types of forest fires. In many areas of the Mediterranean region, the root cause of forest fires are socioeconomic factors, which are the basic elements of causality classification. The application of a Socioeconomic Risk Model (SER) is necessary to characterize the predicted number of forest fires within a unit area, and the factors causing them. Appropriate analytic classes were formed by considering the risk factors. Two different methods were used. Five specific factors were revealed for the socioeconomic model by analyzing data from 4 forest areas and qualitative measurements. The Socioeconomic Risk Model (SER) used 156 risk variables. The study area was classified according to 10 main characteristics (Forestry, Livestock, Agriculture, Land Usage, Demographic Structure, etc.) and 48 sub-groups.

In the present study, the socioeconomic factors affecting forest fires were determined via factor analysis of 45 socioeconomic variables. The grouping of villages at provincial and regional level was determined by cluster analysis, based on the same 45 socioeconomic variables. Forest fires from 1998 to 2010 were classified according to their numbers, and relationship functions between socioeconomic variables and forest fires were developed via multiple regression analysis including stepwise regression method.

In the working area of Directorates of Forestry Management of Taşağıl and Serik, forest villages were ranked according to the distribution of forest fires between 1979 and 2010. Factor groups are composed of socioeconomic variables that were identified by factor analysis as being effective in explaining the occurrence of forest fires. Forest villages were also ranked according to factor groups. The forest villages with the highest number of forest fires mostly paralleled the rankings for socioeconomic causes of forest fires. Therefore, these factors were termed “**social-fire danger factors.”**

“**Fire - socioeconomic reasons correlation function**” was determined between socioeconomic reasons and forest fires for forest villages located in the working areas of Directorates of Forestry Management of Taşağıl and Serik. It was seen that the villages with the largest number of forest fires according to the fires between 1979 and 2010 were generally similar to the villages that were in the first rank according to the variables in the present function.

Material and Method

Fire-related data for the study consist of statistical data about forest fires that occurred in the General Directorate of Forestry of Antalya and in Turkey. Socioeconomic data were obtained from the Turkish Statistical Institute (TUİK) and District Governorship of Serik sources, such as the District Directorate of Agriculture, Directorate of Forestry Management of Serik data, and District Governorship of Manavgat to which Taşağıl town is linked, District Directorate of Agriculture of Manavgat, Directorate of Forestry Management of Taşağıl and Regional Directorate of Forestry of Antalya registers.

Table 1—Counts of Sampled Forest Enterprise Directorate and Forest Villages Number

Towns/ Forest Enterprises	**Villages Counts**
Manavagat/Taşağıl	26
Serik	52
Tolam	78

Forest fires that occurred in villages linked to Directorates of Forestry Management of Serik and Taşağıl and some socioeconomic features of people living in these villages were examined as variables. In this context, the distribution of forest villages examined in the Directorates of Forestry Management of Serik and Taşağıl are given in Table 1. The socioeconomic variables of 78 villages obtained from both Directorates of Forestry Management and the distribution of forest fires that occurred in these villages between 1998 and 2008 were evaluated. Fire and socioeconomic data used in the current study were obtained from the related institutions and organizations via a source scanning method. Articles about the socioeconomic factors were also evaluated. The socioeconomic factors contributing to fires within the Directorates of Forestry Management of Serik and Taşağıl include 45 variables classified according to the scope of the main subject (Table 2).

Table 2—General Distribution of Socioeconomic Variables

Variable types	Counts
Forest Area Variables	21
Education Level and Populasyon	7
Agriculture and Animal Husbandary	6
Employment Status	3
Çalışan Nüfusun Is Kollarına Dağılımı	5
Forest Number (1998-2010)	1
Forest Fire İndeksi	2
Total	45

The data were evaluated in two stages. In the first stage, fire data of Directorate General of Forestry of Antalya and the Directorates of Forestry Management of Serik and Taşağıl were evaluated with simple statistical evaluations, expressed as total, average, and percentage. In the second stage, socioeconomic evaluations of both Directorates of Forestry Management were conducted, using multiple numerical analysis methods.

The relationship between the number of forest fires that occurred in forest villages and the socioeconomic structure of the village population was examined using factor analysis, cluster analysis and multi regression analysis (Anonymous, 2012). In the factor analysis in the first group, it was seen that many variables were included in the same factor group. Among the first ranked variables, those with factor loads of 0.8 or more were taken into consideration, with the aim of more reliably identifying the most effective variables.

Next, the clustering of the settlements was examined, using the minimum variance clustering (WARD) method (Murtagh and Legendre 2011). This revealed how the settlement units were grouped according to the chosen socioeconomic variables. The grouping of villages was monitored at district and regional levels, using cluster analysis according to the 43 socioeconomic variables. Multi regression analysis was used to examine the relationship between the 43 socioeconomic variables formed for districts and according to the number of forest fires that occurred between 1998 and 2008. Relationship functions between the selected socioeconomic variables and forest fires identified using multiple and stepwise regression analysis.

Discussion and Results

Forest Fires in Regional Directorate of Forestry of Antalya

From 1979 to 2011, over 6,000 forest fires in the Regional Directorate of Forestry of Antalya affected 56,248 hectares (Anonymous, 2011), (Table 3).

A little over 57% of burned forest areas in the Regional Directorate of Forestry of Antalya between 1979 and 2011 were within the borders of the Directorates of Forestry Management of Serik and Tasşağıl. For the selected years the largest area burned was in the Regional Directorate of Forestry of Taşağıl (35%), followed by the Directorate of Forestry Management of Serik (22%) (Anonymous, 2011). The ranking of Directorates of Forestry Management within the Antalya region differs in terms of the number of forest fires between 1979 and 2011 (Anonymous, 2011). When ranking the directorates by the number of fires, the directorate of Forestry Management of Serik is ranked second, whereas the Directorate of Forestry Management of Taşağıl is ranked fifth (Table 3).

Within the Directorate of Forestry Management of Serik, the settlement of Etler reported the highest number of fires (12%); Yumaklar is ranked second (11%), and Akbaş and Alacami (7%) villages are ranked third and fourth (Table 4) (Coşgun and others 2010).

Within the Directorate of Forestry Management of Taşağıl, the settlement unit with the highest number of fires is Sağirin village (13%), followed respectively by Çardak village (11%), Bozyaka, Karabük (9%), and Altınkaya village (8%) (Table 5) (Coşgun and others 2010).

Table 3—Forest Fire Area in the Forest Enterprises from 1979 to 2011

Forest Enterprises	Number of fires	Total Area
Aksek	363	727.29
Alanya	692	3098.65
Antalya	1255	5869.57
Elmali	35	153.49
Finike	162	1042.45
Gazipaşa	385	1345.20
Gündogmuş	346	1976.91
Kaş	578	2971.79
Korkuteli	78	117.78
Kumluca	372	3176.10
Manavgat	721	3688.31
Serik	908	12460.96
Tasşağıl	591	19619.71
Total	6486	56248.21

Table 4—Distribution of Forest Fires Occurred In Accommodation Unit of the Directorate Land of Serik Forest Enterprises (1998–2008)

Village name	1	5	20	50	200	500	500+	Toplam
Akbas	14	4	1	2	2	1	1	5
Akcapınar	1							1
Alacamı	22	1			1			24
Asagıoba	2	2						4
Belek	9	3						12
Bılgınler	11		1					12
Bozdogan	9	3						12
Bucak		4						4
Bugus	5	1		1		1		8
Catallar	6	1						7
Demırcıler	4	2						6
Denıztepesı	5	2						7
Etler	38	5						43
Gebız	15	3	1	1				20
Gokcepınar	19		1					20
Hacıosmanlar	1							1
Hasdumen	7	3						10
Hasgebe	8	1	1					10
Haskızıloren	3							3
Kadrıye	7	1						8
Kayadıbı	3							3
Kırbas	13	3						16
Kozan	14	4						18
Kumkoy	16	1	1	1				19
Sarıabalı	7	4						11
Serık	1							1
Tekke	1							1
Tonguclu	11							11
Yesılvadı	3							3
Yesılyurt	3		1					4
Yumaklar	37	4	1					42
Zırlankaya	1							1
Total	296	52	8	5	3	2	1	367

Table 5—Distribution of Forest Fires Occurred in Accommodation Unit of the Directorate Land of Taşağıl Forest Enterprises (1998–2008)

Village name	1	5	20	50	200	500	500+	Total
Altınkaya	13	3	1					17
Ballıbucak	7	2						9
Bereket		1	1					2
Beydıgın	7	5	1					13
Bozyaka	11	6					1	18
Burmahan	6						1	7
Cakıs	1							1
Cardak	17	5	2					24
Cavuskoy	1							1
Degırmenozu		2						2
Demırcıler	1	1						2
Denızkent	1	1						2
Duzagac	3	2						5
Gazıler	1	1						2
Gundogdu	5	1						6
Hocalar	5	1	1					7
Karabucak	1	4						5
Karabuk	15	3						18
Kırkkavak	3	2						5
Kısalar	1							1
Kızıldag	4	5	1					10
Sagırın	18	7	1				1	27
Salur	1							1
Tasagıl	8	2	1	1				12
Yavrudogan	7	2						9
Yesılbag	1		1			1		3
Yesılvadı	1							1
Total	139	56	10	1		1	3	210

Socioeconomic Factors related to Fires within Directorates of Forestry Management

The relationship between fires that occurred in the Directorate of Forestry Management of Taşağıl and socioeconomic factors was determined by factor analysis (Tables 6, 7, and 8).

The consistency of the variables used in the factor analysis was tested with KMO (Kaiser-Meyer- Olkin Test) (Kaiser 1974, Cemi and Kaiser 1977) (Table 6). The matrix of variables shows that 4 factors have a high explanatory power of 84.7% (Table 7).

Table 6—KMO and Bartlett's Test of Factor Analysis for Taşağıl Directorate of Forestry Management

KMO and Bartlett's Test		
Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		0.565
Bartlett's Test of Sphericity	Approx. Chi-Square	206.414
	df	55
	Sig.	0.000

Table 7—Total Variance Explained of Factor Analysis for Taşağıl Directorate of Forestry Management

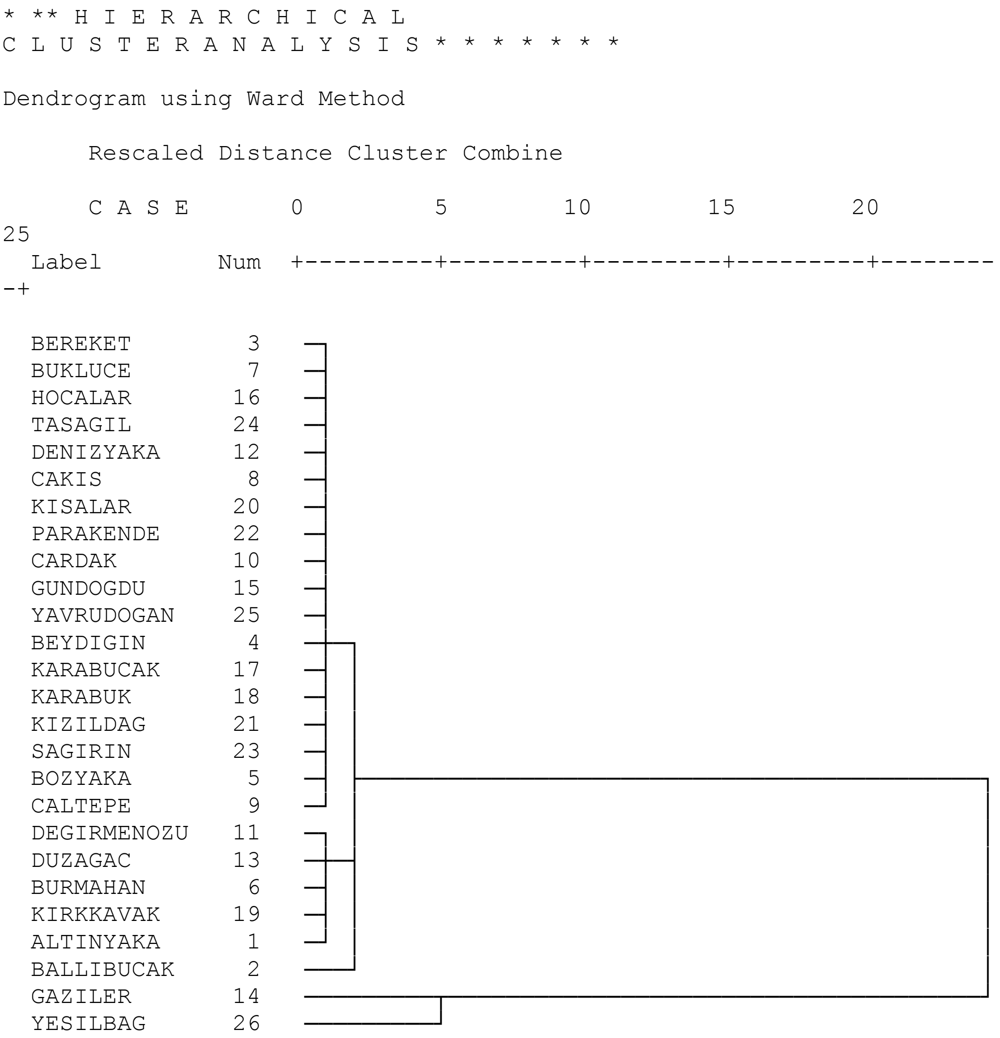
Total Variance Explained

Component	Initial Eigenvalues			Extraction Sums of Squares Loadings			Rotation Sums of Squares Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulat %
1	3,735	33.95	33.95	3,735	33.95	33.95	3,166	28.78	28.78
2	2,400	21.82	55.77	2,400	21.82	55.77	2,306	20.97	49.748
3	1,877	17.07	72.84	1,877	17.07	72.84	2,033	18.48	68.228
4	1,306	11.87	84.71	1,306	11.87	84.71	1,814	16.49	84.71

Table 8—Rotated Component Matrix of Factor Analysis for Taşağıl Directorate of Forestry Management

Rotated Component Matrix				
Variables	Component			
	1	2	3	4
KPL3	0.887			
BNT3	0.867			
GLSMCGC	0.928			
M4	0.844			
ILKMZN		-0.856		
INSTSNY		0.902		
HBNUF		0.764		
KPL1			0.949	
GLSMCGA			0.971	
M3				0.888
HBKBHS				0.905

The analysis shows that there are different variables within four factors (Table 8). The relationship between forest fires and socioeconomic factors includes variables such as the proximity to forests, site (place of growth, productivity power class), age structure of stands, and fire danger class. This factor may be termed “high-value-quality forest areas qualification”. The second factor includes elementary school-graduate, population working in the construction sector, and population per household variables. This factor can be termed “education and employment”. The third factor, termed “low-value forest areas qualification”, includes stand closure and age structure variables. The fourth factor, “sheep and goat farming with low-risk forest area”, includes fire risk and the presence of small livestock per household (sheep and goats). Villages are divided into 2 classes in this classification (Figure 1). Two villages in the second group have the lowest incidence of forest fires. The first group is composed of villages such as Beydiğin, Karabucak, Karabük, Sağirin and Bozyaka, most of which are in the upper group in terms of the number of fires.,



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* ** H I E R A R C H I C A L
C L U S T E R A N A L Y S I S * * * * * * *

Dendrogram using Ward Method

      Rescaled Distance Cluster Combine

      C A S E       0         5        10        15        20
25
  Label         Num  +---------+---------+---------+---------+--------
-+

  BEREKET         3
  BUKLUCE         7
  HOCALAR        16
  TASAGIL        24
  DENIZYAKA      12
  CAKIS           8
  KISALAR        20
  PARAKENDE      22
  CARDAK         10
  GUNDOGDU       15
  YAVRUDOGAN     25
  BEYDIGIN        4
  KARABUCAK      17
  KARABUK        18
  KIZILDAG       21
  SAGIRIN        23
  BOZYAKA         5
  CALTEPE         9
  DEGIRMENOZU    11
  DUZAGAC        13
  BURMAHAN        6
  KIRKKAVAK      19
  ALTINYAKA       1
  BALLIBUCAK      2
  GAZILER        14
  YESILBAG       26
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Figure 1—Forest Villages Ranking According to Socioeconomic Factors for Taşağıl Directorate of Forestry Management

The villages of Burmahan, Kırkkavak, and Ballıbucak (except Altınkaya village) in the second sub-group, have a medium ranking in terms of the number of fires. The results of multi regression analysis between socioeconomic factors and the number of fires within the Directorate of Forestry Management of Taşağıl are consistent, and the relationship between variables has a high R^2 value (Table 9). In the relationship between number of fires and socioeconomic factors, variance analysis shows the significance of the coefficient and variables explaining the equation (Table 10).

Table 9—Regression Model Summary on Relationship Between Number of Fire and Socioeconomic Factors in the Taşağıl Directorate of Forestry Management

Model Summary									
				Change Statistics					
R	**R^2**	**Adjusted R^2**	**Std. Error**	**R^2 Change**	**F Change**	**df1**	**df2**	**Sig. F Change**	**Durbin-Watson**
0.878^d	0.772	0.728	4.753	0.154	14.202	1	21	0.001	1.679

Table 10—Regression Anova Analysis on Relationship between Number of Fire and Socioeconomic Factors In the Taşağıl Directorate of Forestry Management

ANOVA					
Model	**Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**
Regression	1604.01	4	401.00	17.75	0.000^d
Residual	474.50	21	22.60		
Total	2078.50	25			

The equation describing the relationship between socioeconomic factors and forest fires within the Taşağıl Directorate of Forest Management between 1979 and 2011 is:

Y = -63.019 + 0.274 KPL1 – 0.211 HBTARALN + 3.143 SIINDSK + 0.642 GLSMSGD (Table 11).

Table 11—Regression Anova Analysis Coefficients on Relationship between Number of Fire and Socioeconomic Factors in the Taşağıl Directorate of Forestry Management

	Coefficients				
	Unstandardized		**Standardized**		
Model	**Beta**	**Std. Error**	**Beta**	**T**	**Sig.**
Constant	-63.019	15.769		-3.996	0.001
KPL1	0.274	0.070	0.42	3.886	0.001
HBTARAL N	-0.211	0.052	-0.499	-4.094	0.001
SIINDKS	3.143	0.703	0.626	4.471	0.000
GLSMCGD	0.642	0.170	0.513	3.769	0.001

Relationship between Socioeconomic Factors and Fires in Serik Directorate of Forest Management

The relationships between socioeconomic factors and forest fires within the Serik Directorate of Forest Management were determined by factor analysis (Tables 12, 13 and 14). The consistency of variables used in the factor analysis was tested with KMO test (Table 12).

Table 12—KMO and Bartlett's Test of Factor Analysis for Serik Directorate of Forestry Management

Kaiser-Meyer-Olkin Measure of Sampling Adequacy		0.670
Bartlett's Test of Sphericity	Approx. Chi-Square	757.329
	Df	91
	Sig.	0.000

In the matrix of variables obtained, four factors have a high explanatory power (86.7%) (Table 13).

Table 13—Total Variance Explained of Factor Analysis for Serik Directorate of Forestry Management

Total Variance Explained

Component	Initial Eigenvalues			Extraction Sums of Squares Loadings			Rotation Sums of Squares Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	4,748	33.916	33.916	4,748	33.916	33.916	4,471	31.932	31.932
2	3,360	24.002	57.919	3,360	24.002	57.919	2,963	21.166	53.098
3	2,494	17.813	75.732	2,494	17.813	75.732	2,837	20.268	73.366
4	1,530	10.926	86.658	1,530	10.926	86.658	1,861	13.292	86.658

There are different variables in four factors (Table 14). The first factor in the relationship between forest fires and socioeconomic factors includes the employment status variables according to population and sectors. This factor can be termed "population and employment sectors". The second factor, named "coniferous mixed and damaged/low-quality forests", includes forest areas that have a damaged site, coniferous mixed forests, and low fire risk forest areas variables.

The third factor, named "young aged and qualified forest areas and uneducated population" comprises qualified stand closure status and stand development period, forests with a medium-degree fire risk and population variables, which is the education variable. The fourth factor, named "high risk damaged forests", includes forests with high fire risk and damaged forest areas.

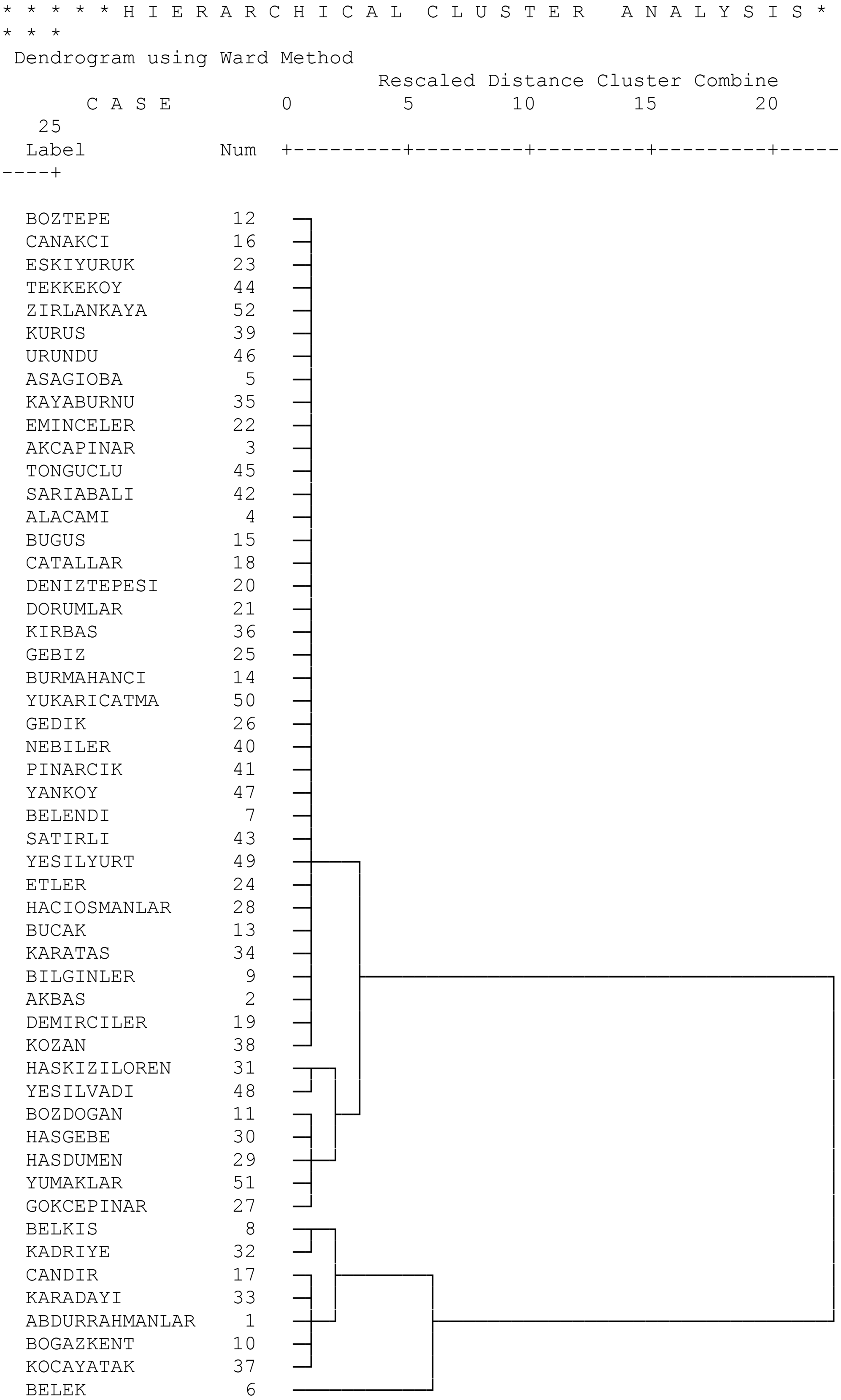
Table 14—Rotated Component Matrix of Factor Analysis for Serik Directorate of Forestry Management

Rotated Component Matrix

Variables	Component			
	1	2	3	4
HBACNP	0.939			
HBNUF	0.937			
TARORMISTHDM	-0.899			
INSTSNY	0.869			
TICLKNTOTEL	0.898			
BNT4		0.964		
M5		0.960		
IBRKAR		0.886		
KPL3			0.922	
GLSMCGB			0.850	
OKBLMYN			0.583	
M3			0.907	
BZK				0.932
M1				0.963

The analysis of fire numbers and socioeconomic variables indicated two classifications (Figure 2). The villages in the first class are large villages and even some that became towns, such as Belkız, Kadriye, Çandır, Karadayı, Abdurrahmanlar, Boğazkent, Kocayatak, and Belek. Because of lack of data the number of fires in the villages in this group could not be determined. Only two villages are in the group with the lowest number of fires. Belek village is in the middle class in terms of number of forest fires. When Belek is excluded, villages in this group transformed into town and were categorized under a sub-group. Similarly, it is interesting that forest fires did not occur in the majority of these villages. Therefore, in terms of the selected socioeconomic variables and number of fires for the years 1979 to 2011, the variables is consistent.

The villages in the second group are more complicated (figure 2). Results show that these villages are divided into two more sub-groups, comprising villages that are mostly in the middle and upper class in terms of the number of forest fires. The equation obtained via multi regression analysis between the number of fires in the Directorate of Forest Management of Serik and socioeconomic factors is consistent, and the relationship between the variables shows a relative high R^2 value of 0.53% (Table 16). In the relationship between the number of fires and socioeconomic factors, analysis of variance indicates that the coefficients and variables that explains the equation are significant (Table 17).



```
* * * * * H I E R A R C H I C A L   C L U S T E R   A N A L Y S I S *
* * *
 Dendrogram using Ward Method
                                Rescaled Distance Cluster Combine
      C A S E         0         5        10        15        20
    25
  Label           Num  +---------+---------+---------+---------+-----
----+

  BOZTEPE          12
  CANAKCI          16
  ESKIYURUK        23
  TEKKEKOY         44
  ZIRLANKAYA       52
  KURUS            39
  URUNDU           46
  ASAGIOBA          5
  KAYABURNU        35
  EMINCELER        22
  AKCAPINAR         3
  TONGUCLU         45
  SARIABALI        42
  ALACAMI           4
  BUGUS            15
  CATALLAR         18
  DENIZTEPESI      20
  DORUMLAR         21
  KIRBAS           36
  GEBIZ            25
  BURMAHANCI       14
  YUKARICATMA      50
  GEDIK            26
  NEBILER          40
  PINARCIK         41
  YANKOY           47
  BELENDI           7
  SATIRLI          43
  YESILYURT        49
  ETLER            24
  HACIOSMANLAR     28
  BUCAK            13
  KARATAS          34
  BILGINLER         9
  AKBAS             2
  DEMIRCILER       19
  KOZAN            38
  HASKIZILOREN     31
  YESILVADI        48
  BOZDOGAN         11
  HASGEBE          30
  HASDUMEN         29
  YUMAKLAR         51
  GOKCEPINAR       27
  BELKIS            8
  KADRIYE          32
  CANDIR           17
  KARADAYI         33
  ABDURRAHMANLAR    1
  BOGAZKENT        10
  KOCAYATAK        37
  BELEK             6
```

Figure 2: Forest Villages Ranking According to Socio Economic Factors for Serik Directorate of Forestry Management

Table 16: Regression Model Summary on Relationship Between Number of Fire and Socioeconomic Factors in the Serik Directorate of Forestry Management

Model Summary

				Change Statistics					
R	**R^2**	**Adjusted R^2**	**Std. Error of Estimate**	**R^2 Change**	**F Change**	**df1**	**df2**	**Sig. F Change**	**Durbin-Watson**
0.730^e	0.532	0.482	7.218	0.053	5.234	1	46	0.027	1.77

Table 17: Regression Anova Analysis on Relationship between Number of Fire and Socioeconomic Factors In the Serik Directorate of Forestry Management

ANOVA

Model	Sum of Squares	df	Mean Square	F	Sig.
Regression	2727.873	5	545.575	10.472	0.000
Residual	2396.435	46	52.096		
Total	5124.308	51			

Table 18: Regression Anova Analysis Coefficients on Relationship between Number of Fire and Socioeconomic Factors In the Serik Directorate of Forestry Management

Coefficients

Model	**Unstandardized Coefficients**		**Standardized Coefficients**		
	B	**Std. Error**	**Beta**	**t**	**Sig.**
(Constant)	89.889	21.670		4.148	0.000
BNT3	0.368	0.147	0.283	2.511	0.016
SIINDKS	-3.723	0.915	-0.527	-4.07	0.000
BNMINDKS	-0.018	0.006	-0.412	-3.308	0.002
GLSMCGA	0.207	0.083	0.269	2.505	0.016
ISSIZ	1.560	0.682	0.236	2.288	0.027

The equation describing the relationship between socioeconomic factors and forest fires in the Serik Directorate of Forest Management from 1979 to 2011 is:
Y = 89.889 + 0.368 BNT3 – 3.723 SIINDKS – 0.018 BNMIDKS + 0.207 GLSMSGA + 1.560 ISSIZ. (Table 18).

The relationship between forest fires and socioeconomic variables is done by multi regression analysis. This is a highly significant stage. In the present study, the function "fire-socioeconomic reasons relation" between socioeconomic variables and forest fires was determined for the forest villages located in the working area of Directorate of Forest Management of Taşağıl.

The results shows that the number of fires is directly proportional with a closed forest area, indirectly proportional with an agricultural area per household, in direct proportion to temperature index variable and in direct proportion to forests composed of "D" aged stands.

Important findings are observed when we rank the villages according to the indirectly proportional variables and when we look at the top-5 ranked villages for each variable: Within the Taşağıl Directorate of Forestry Management, this comparison shows that the majority of the villages have a high number of forest fires (Table 19).

Table 19: Forest Villages Ranking According to Function of Relationship Between Number of Fire and Socioeconomic Factors In the Taşağıl Directorate of Forestry Management

VILLAGES	KPL1	VILLAGES	HBTARALN	VILLAGES	SIINDKS	VILLAGES	GLSMCGD
YAVRUDOGAN	53.88	BALLIBUCAK	6.25	BOZYAKA	24.70	ALTINYAKA	33.58
CARDAK	49.70	KIRKKAVAK	8.55	CARDAK	24.64	KARABUK	15.59
HOCALAR	36.52	BOZYAKA	9.87	BEYDIGIN	24.61	BALLIBUCAK	12.91
TASAGIL	32.37	DUZAGAC	9.97	KARABUK	24.61	GAZILER	11.88
ALTINYAKA	25.98	BEYDIGIN	11.42	TASAGIL	24.60	CALTEPE	11.82

The "fire socioeconomic reasons relation function" between socioeconomic variables and forest fires was determined for the forest villages within the Serik Directorate of Forestry Management. The results show that the number of fires is in direct proportion to the third class of site forest areas, in indirect proportion to temperature index and relative humidity index variables; and in direct proportion to forests composed of "A" aged stands and local unemployment levels.

When the "fire- socioeconomic reasons relation function" ranking for forest villages in the Serik Directorate of Forestry Management is compared with fires that occur in villages, the relationship shows that the villages that have a high number of forest fires are in that ranking (Table 20).

Table 20: Forest Villages Ranking According to Function of Relationship Between Number of Fire and Socioeconomic Factors In the Serikl Directorate of Forestry Management

VILLAGES	BNT3	VILLAGES	SIINDKS	VILLAGES	GLSMCGA	VILLAGES	ISSIZ
ALACAMI	30.56	DEMIRCILER	20.03	BILGINLER	62.16	KADRIYE	6.28
DORUMLAR	28.20	BOZDOGAN	20.16	BUGUS	46.71	BELEK	4.66
BUGUS	26.45	YESILVADI	20.23	DENIZTEPESI	39.32	YESILVADI	3.11
GEBIZ	19.32	HASKIZILOREN	20.23	SARIABALI	32.07	TONGUCLU	1.57

Conclusions

Studies of forest fires can be examined in various dimensions. The first dimension could be the examination of the relationships between the values of the number of fires per year and burned areas. The second stage of studies on understanding fires would examine the ‘fire triangle’ of fire causes (1. inflammable material; 2. oxygen; 3. temperature), the relationship between climate elements, number of fires and burned areas. The third stage comprises modeling studies of the content of flammable substances and their density, etc., which represent an important dimension in understanding forest fires. The most important dimension for understanding forest fires in developed, developing and undeveloped countries is the relationships between socioeconomic factors and, size of burned area and the number of fires.

In the present study, we specifically evaluated the relationships between the number of fires and socioeconomic factors. The first stage determined the socioeconomic variables that are important for forest fires. The socioeconomic variables included in each group were determined by factor analysis. These factors are also effective in the occurrence of forest fires.

According to these factors, classification of the forest villages in the area of study shows that the villages rank by the number of fires occurring for the period 1979 to 2008 track very well the resulting factors. Therefore, these factors should be named as “**social-fire danger factors**”.

Cluster analysis is an important indicator as it shows that villages can be grouped according to socioeconomic variables. This analysis method can be used as a complementary analysis method as it allows supporting the evaluations obtained in the process of analyzing forest fires and socioeconomic variables.

An important finding of this work is that the number of fires is directly proportional with a closed forest area, indirectly proportional with an agricultural area per household, in direct proportion to temperature index variable and in direct proportion to forests composed of "D" aged stands. Also, when ranking the villages according to the indirectly proportional variables and when we look at the top-5 ranked villages for each variable within the Taşağıl Directorate of Forestry Management, this comparison shows that the majority of the villages have a high number of forest fires.

The "fire socioeconomic reasons relation function" between socioeconomic variables and forest fires was determined for the forest villages within the Serik Directorate of Forestry Management. The results show that the number of fires is in direct proportion to the third class of site forest areas, in indirect proportion to composed of "A" aged stands and local unemployment levels.

When the "fire- socioeconomic reasons relation function" ranking for forest villages in the Serik Directorate of Forestry Management is compared with fires that occur in villages, the relationship shows that the villages that have a high number of forest fires are in that ranking.

The relationship between forest fires and socioeconomic variables can differ between regions (Coşgun, et al. 2010). It is known that variables have different values in different regionstemperature index and relative humidity index variables; and in direct proportion to forests.

Their effects also differ in magnitude within the analyses.

Results of this work shows that a variable that is effective in one region is not necessarily effective in another region. It is also normal that there are different variables for each region. Therefore, separate evaluations should be made for different regions.

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Econometric Model for the Diagnosis and Evaluation of Costs in the Planning of Prescribed Fires in the Forest Landscape[1]

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Abstract

The increasing use of prescribed fires, as a fire management technique for preventing wildfires and reducing their impact, demands the development of tools that enable performing the necessary studies for determining application opportunities in the territory. The generation of interesting uses of this technique not only directed to the control of forest fuel loads, but also to the creation and maintenance of operational scenarios related to the extinction and suppression of forest fires, requires analysis of the landscape on the basis of the multiple variables that influence decision-making. In this sense and in relation to the planning of budgetary investments in space and time, the incorporation of prescribed fires in the framework of wildfire defense programs requires the corresponding cost analysis, in order to integrate this information into the total budget for the wildfire defense and fire management program. At present, there are no models available to forecast and estimate the economic cost levels involved in the use of prescribed fire in different forest scenarios.

The selection of the appropriate variables directly related to the planning, execution and evaluation phases that involve the use of prescribed fires in the forest landscape, enable, together with the costs incurred and the factors related to fire propagation, as well as the different ignition techniques, determining the set of factors that make it possible to undertake the econometric analysis directed to the predictive modeling of the costs per hectare, derived from the execution of the prescribed fire in the forest environments, in which it has been decided to apply prescribed fires as a forest management tool. Determination of the econometric model facilitates opportunities for planning the costs of applying this technique; moreover, the results obtained can even be extended towards geo-referencing in the landscape and be integrated with the effect of reducing extinction costs and increasing extinction safety by decreasing propagation intensities. Application of the proposed econometric model aids in budgetary decision-making in wildfire prevention management for the forest landscape.

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[1] An abbreviated version of this paper was presented at the Fifth International Symposium on Fire Economics, Policy, and Planning: Ecosystem Services and Wildfires, November 14-18, 2016, Tegucigalpa, Honduras. Only abstract available.

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Perception and Management of Sociopolitical Risks on Large Fires[1]

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Abstract

This work examines the perceived impact of sociopolitical factors on large fire decision making. The study is based on a set of 74 large fires in USDA Forest Service Regions 5 and 6 for the years 2009-2013. All participants were fire managers, some as part of units affected by incidents and others associated with incident management teams. A protocol was developed and implemented to support a combination of information collection approaches, including interviews, survey-type data collection, and encoding of information from incident documentation sources. Participants were asked whether there was direct involvement from influential individuals or groups in the incident management process. Their combined responses to these questions suggests that about 50% of the time they were aware of direct involvement by influential individuals and influential groups. When queried whether or not they personally saw, heard or read media coverage associated an incident *at the time of the incident*, the majority (63%) reported that either they had not or could not recall. Overall, respondents were somewhat aware of media reporting of incidents at the time of the incidents, and their knowledge of media reporting types covered a broad range of media pathways, including the Internet.

Keywords: Career risk, media influence, risk management, social capital, wildfire decision making

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

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[1] An abbreviated version of this paper was presented at the Fifth International Symposium on Fire Economics, Planning, and Policy: Ecosystem Services and Wildfires, November 14-18, 2016, Tegucigalpa, Honduras.

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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.

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 potential 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 (National Environmental Protection Act) actions). Similarly, risk managers working together on a risk management problem (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). For organizations that rely on public support to achieve their mission, as does the USDA Forest Service, a high level of social capital is critical to achieving organizational objectives, particularly in the context of fire management.

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). Therefore, 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. [4]

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 on cost and cost management. However, 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 (Canton-Thompson et al. 2006, González-Cabán 1997, González-Cabán et al. 1984, Gebert et al. 2007, McKetta & González-Cabán 1985). Some research suggests that fire costs may be associated with social factors such as media coverage (e.g., Donovan, Prestemon & Gebert 2011). However, the role of decision making in cost as an outcome of fire management remains unclear.

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

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[4] In the context of safety management, a report by the organization *Dialogos* to the USDA Forest Service has provided anecdotal evidence that in some contexts employees are reluctant to express concerns due to perceptions of career impacts. The report titled "Taking All Employees on A Safety Journey" is accessed at: http://www.reclink.us/page/taking-all-forest-service-employees-on-a-safety-journey-slp-7-saf. (Last access: 10 Jun 2015).

image of fire managers for failing to take action even if that action is not likely to achieve a positive result 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 those that involve the 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 negative impacts to social relationships, personal career, and confidence in leadership. These perceptions may lead to a generalized belief that it is better to do all that can be done even if such actions do not produce a positive physical result, but do produce a valued sociopolitical result. Thus, hypothetically, risk management can have a variety of purposes as its goal or objective; some of which can be non-physical.

The research reported here is a step toward extending our understanding of the relationship between sociopolitical factors and incident-level decision making. Although incident documentation does report on factors such as resource assignments, cost, acres impacted and values at risk, these are not accompanied by an indication of sociopolitical factors, such as media reporting and political involvement on an incident, that may have an influence on, for example, fire management strategies, tactics, suppression resource ordering and suppression resource assignment.

To circumvent these challenges, the present research focused on elements of incident decisions and called upon personnel associated with actual incidents to report on their experiences with sociopolitical influences on incidents as well as the impact of those influences on key incident decisions, including strategies, tactics and fire management objectives. The approach generally followed along the lines of previous research that used decision modeling as a basis for characterizing fire management decisions (MacGregor & González-Cabán 2008).

Study Approach

The methodology for this research was based on a combination of structured interviews and self-reports of fire managers, including agency administrators, fire management officers and incident command staff that synthesized their experiences on specific fire incidents. In addition, information was also gathered from a number of existing fire-related databases, particularly the Fire & Aviation Management web site FAMWEB (http://www.famweb.gov), the Wildland Fire Decision Support System (WFDSS, http://www.wfdss.gov), and the on-line incident website *InciWeb* (http://www.nwcg.inciweb.gov).

A self-report protocol was developed that also served 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, including: 1) political influences and pressures, and influential groups; 2) media reporting and coverage, including type of media and timing of media reporting and actions taken in response to media reporting; and 3) actions taken to manage the risks associated with sociopolitical pressures through modification of incident strategies, incident tactics, changes in objectives, and changes in number and type of suppression resources.

Incidents were 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 were wholly (or primarily) on lands under USDA Forest Service jurisdiction or were managed by a USDA Forest Service agency administrator; were managed by either a Type I or Type II incident management team (IMT); and had a cost of $2,000,000 or more.[5]

For each incident, an Incident Time Line was prepared based on information from the various information documentation sources discussed above. To the degree possible, fire managers were contacted as soon as practical after the incident to solicit their responses to the protocol.

Several challenges were encountered in conducting a study of this type: 1) large fires generally occur during the most active part of the fire season and fire managers are not readily available; 2) the14-day personnel rotation that results in a given incident being managed sequentially by a number of different incident management teams; and 3) line officers and fire management officers unavailability because of the high workload during fire season. To circumvent some of these problems, if possible, individuals were identified and contacted by e-mail to solicit their participation. If agreeable, they received an electronic copy of the research protocol. Though incident documentation does not generally contain electronic addresses for relevant personnel, line officers and their staff are generally located with the land management unit on which an incident occurs, making them more readily identified and contacted. However, incident management team personnel are drawn from a number of units and participation on an incident management team constitutes an additional duty.

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[5] Fire years 2009, 2010 and 2011 were relatively slow in Regions 5 and 6 and fire costs were somewhat lower than average.

Contact by e-mail was accomplished when possible and respondents were provided a copy of the protocol to complete and return. If not possible, we engaged participants by telephone to administer the protocol by personal telephone interview. Because of the difficulty of interviewing them during the fire season most interviews were delayed until fire season had abated.

Incident-specific details collected from the sources discussed above were used to describe the incident and to establish a context for responding that focused on the particular incident on which the individual had participated. In addition, other venues provided opportunities to conduct interviews with fire management personnel, and these venues provided a substantial number of respondents. Often times this yielded additional individuals to engage as study participants. `

Finally, on large and sometimes long-running incidents a particular incident management team may spend only two weeks (or even less). Local management staff may change responsibility for a fire incident on their unit as the incident changes in size, scope and complexity. As a result, it is relatively rare on large incidents for a single individual to have a complete picture of all aspects of an incident, and particularly those elements that are not a part of the standard process by which incident management is documented and reported.[6] Our approach gives, at best, a glimpse into how sociopolitical factors are perceived by fire managers and the role that those factors may play in risk-based decisions on an incident.

To improve candidness of responses, all respondents were assured of their anonymity and all identifying information was removed from survey and interview protocols.

Results

A total of 74 incidents occurred in Regions 5 (n=46) and 6 (n=28) for the years 2009 – 2013 that met the criteria outline above. A total of 173 protocols were obtained through the combination of methods described in the study approach. Some individual respondents appeared more than once in the resulting dataset because they were associated with more than one of the 74 incidents. This can occur, for example, when a particular forest had more than one incident that met the selection criteria during the five years of the study. Likewise, incident command staff may serve on a number of different assignments not only over a five-year period, but even within a given fire season.

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[6] An exception to the 14-day duty cycle for incident management teams is NIMO (National Incident Management Organization) that was established in part to provide on-going incident management without rotation on long-running fires.

The first three study years (2009-2011) had unusually slow fire seasons, particularly Region 5 for the years 2010 and 2011. Incidents ranged in acres burned from a low of 142 acres to a high of 257,135. The range in Region 6 was narrower than that for Region 5. Ignition cause tended to be toward human causation, but with a large difference between regions. Human caused fires accounted for over 76% of the incidents in Region 5, but only about 21% of those in Region 6. Numbers of incidents by year were too small to draw a reliable comparison of causation on a yearly basis.

Involvement of Influential Individuals and Groups

Respondents were asked to indicate the direct involvement of influential individuals and groups on the incident in question. Direct involvement was defined as "expressing a direct interest in the incident through contact with fire managers either in person or on the telephone". Influential individuals included various government elected officials and/or their delegate(s). Influential groups included cultural or tribal groups as well as broad categories of groups that included public groups, government groups and other concerned groups. In all cases, respondents were free to give more than one response since more than one influential individual or group might have been involved.

In the majority of cases (52.5%) respondents indicated "don't know" or the question about influential individuals directly involved in the incident was not answered. Most of the influential individuals involved were at the state or lower governmental levels, comprising 81% of the responses for which at least one influential individual (or delegate) was indicated. Higher-level involvement (i.e., governor or congressional level) was relatively infrequent though present on some incidents at some time.

With respect to influential groups, about 67% responded "don't know", which is higher than that for influential individuals. Of the specific groups mentioned, "public groups" received the highest response rate (13%), followed by "cultural/tribal" (9%).

Taken together, the results suggest that respondents were about half of the time aware of the direct involvement of influential individuals and (to a lesser degree) influential groups. However, it is important to remember that respondents varied in terms of the stage of an incident where they might have been in a position to directly know whether influential individuals or groups were involved in some way. In general, it appears that at some time during some incidents respondents did have knowledge of influential parties who were directly involved with incident personnel.

Media Reporting and Coverage

Fire events, and particularly large fires, have the potential to attract media attention. Typically, incident management teams have as part of their staff either a Public Affairs Officer (PAO) or a Public Information Officer (PIO), and sometimes both. Local management units (e.g., Forest, Ranger District) may also have public affairs staff and information officers that provide information to the media upon request.

Respondents were asked to indicate through a set of items their experience of media reporting and coverage on the specific incident(s) in which they were involved, including the type of reporting that occurred, presence of media personnel on the incident, and their personal engagement with media personnel.

The majority of participants (63%) reported that either they had not or could not recall when asked whether or not they personally saw, heard or read media coverage associated with an incident *at the time of the incident*. Of those who reported (37%) they personally saw, heard or read media coverage at the time of the incident, the most common response was for print media (92%), followed by television (65%), radio (52%), and Internet (41%). Overall, respondents were aware of the media associated with an incident at the time of the incident and in its diverse forms; including the Internet and the use of social media to provide not only public information but also to provide opportunities for the public to respond to the progress of an incident and their perceptions of incident management through mechanisms such as *Twitter* and *Facebook*.

When asked about the presence of media personnel on the incident, either at the offices of unit management (e.g., Forest supervisor's office, Ranger District office) or at the Incident Command Post (ICP), respondents were unaware of media personnel at either location (72%) or they responded "don't know" (19%). From these responses it appears that actual media personnel presence on-site at incidents, does not occur very frequently.

Overall, respondents were somewhat aware of media reporting of incidents at the time of the incidents, and their knowledge of media reporting types covered a broad range of media pathways, including the Internet. Most respondents were either unaware of media personnel present on-site or did not know. Again, however, respondents varied in terms of the time of their engagement on an incident and their responses cannot be taken to mean that media personnel were not present on a given incident during its entire duration. A relatively small percentage of respondents reported participating in actual interviews with media personnel, either in-person or over the telephone. When they did, the tone of the resulting media interviews were reported to be either supportive or factual. Though in the case of the Station Fire (2010) media reporting took a critical tone (Pringle, 2009).

Media Reporting and Incident Decisions.

Respondents were asked about the potential influence of media reporting on incident decisions both in general terms and specific to the incident in question (*table 1*).

Table 1. Media Reporting and Incident Decisions

Query	Percent Indicating
Did media reporting caused you to feel pressured to question or change incident decisions?	
No	77.5%
Yes	9.8
Don't know/Not answered/Unsure	12.7
In general, do you believe that media reporting of large fires influences incident decisions?	
No	57.2%
Yes	13.3
Don't know/Not answered/Unsure	29.5

As seen in the table, in the general case, respondents were less inclined to see media reporting as an influence on decisions than in the specific case (57% vs. 78%). In addition, in the general case, about twice as many respondents failed to answer the question or were unsure about making a response than for the specific case (30% vs. 13%). Also in the general case, respondents were more inclined to feel pressure from media reporting to question or change decisions (13%) than in the specific incident (10%).

Actions Taken to Manage Sociopolitical Risks

Respondents were asked to indicate the types of actions taken to manage sociopolitical risks and objectives (*table 2*). Potential actions included changes to incident strategies, tactics and objectives, as well as changes to ground and aviation resources.

Table 2. Actions taken in the interests of managing sociopolitical risks.

Query	Percent Indicating
To the best of your knowledge, what actions were taken with respect to Incident Strategies in the interests of managing sociopolitical risks?	
More aggressive	7.5%
Less aggressive	0.0
No change in strategies	76.9
Don't know/Not answered	15.6

Incident Tactics?	
More aggressive	17.3%
Less aggressive	0.0
No change in tactics	67.6
Don’t know/Not answered	15.0
Incident Objectives?	
Broadened existing objectives	6.4%
Narrowed existing objectives	0.0
Eliminated (some) incident objectives	0.0
Added incident objectives	9.2
No change to incident objectives	49.7
Don’t know/Not answered	22.5
Incident Ground Resources?	
Added ground resources	3.5%
Reduced ground resources	0.0
No change in ground resources	72.8
Don’t know/Not answered	23.7
Incident Aviation Resources?	
Added aviation resources	15.0%
Reduced aviation resources	0.0
No change in aviation resources	54.3
Don’t know/Not answered	30.6

Overall, only a small percentage indicated that in response to sociopolitical pressures more aggressive response were applied in: strategies, incident tactics, broadened incident objectives, and adding incident objectives. By and large most respondents reported no change in any of these categories.

With respect to changes in suppression resources, only a small percentage indicated an increase in ground resources and a slightly higher percentage indicated an increase in aviation resources. Once again, respondents for the most part indicated that there were no changes in either ground or aviation resources in the interests of managing sociopolitical pressures.

Sociopolitical Pressures and Perceptions of Incident Risk

Respondents were asked to indicate their perceptions of the influence of sociopolitical pressures on incident operational risks and the degree to which increases in risk (if any) were mitigated.

Responses here were generally in line with early responses pertaining to changes in incident factors such as tactics and resources: only 19% of respondents indicated that operational risk on the incident increased as the result of sociopolitical pressures, while 47% indicated no effect on risk. For the subset of respondents (n=32) that indicated an increase in risk, the majority thought that the increase was somewhat mitigated. However, responses here were mixed with percentages indicating that risks were fully mitigated (59%) while others either (19 %) did not know or did not answer the query. None of the respondents indicated that risks were not mitigated.

With respect to cost, most respondents (68%) either did not respond or did not know the effect of sociopolitical pressures on cost. The remaining respondents indicated that the cost either increased (18%) or there was no effect on cost (14%).

Perception of Career Risk

Decision maker concerns about career risks associated with the outcomes of decisions they make has received relatively little to no research attention in the context of fire management decision making, and initial responses to the research protocol indicated a high level of non-responding to probes relating to the concept of career risks. Subsequent reviews with a small set of respondents revealed that although personnel sometimes refer to career risk in conversation, the concept itself is complex, and highly personal. “Career” can be interpreted in a number of ways depending upon an individual’s aspirations and desire to advance in their work life, which is affected by their inherent abilities to achieve such advancement. Thus, a career risk to one individual may not be a risk to another simply because they have different objectives with respect to their career and place a different value on career as an element of their overall life satisfaction. In addition, the notion of career risk carries with it some type of loss, which could take on a number of personally defined forms ranging in severity depending upon career objectives. Finally, personnel sometimes apply the referent “career-ending event” to describe an action or outcome that is catastrophic in nature with respect to one’s career. In actuality, career-ending events are extremely rare and interviews with upper-level managers have identified few cases in which an Agency employee has been terminated with cause for an action they took. Nonetheless, the nomenclature exists and, in all likelihood, forms at least part of the psychological basis for perceiving the potential for personal career-related losses associated with risk management in their role as decision maker.

To bypass some of these difficulties a subset of respondents was selected to engage in an interview-based approach, either in-person or by telephone. An interview protocol was developed that utilized both open-ended and structured response formats, thereby allowing respondents to more freely discuss their perspectives on career risk while at the same time eliciting their views in a structured format where possible. Open-ended responses to the interview protocol were coded and categorized. A total of 39 respondents (from the total respondents in the study, n=173) participated in this aspect of the study.

In general, respondents saw career risk as referring to any event or outcome that affects them personally and negatively in the context of their work life. Expressions like “bad things that happen” or “possible loss of credibility” characterized some of the mentions. When asked if there was a time (or times) in their career when they felt exposed to career risk, 100% of respondents indicated that they were exposed to career risk. Situations in which they were so exposed varied and respondents sometimes had difficulty characterizing them. Some of the more common situations had to do with risks associated with the situation itself (26%), perception of legal liability issues (23%), unclear or conflicting management directions (56%) and complex sociopolitical situations (78%).

When asked their perceptions of the consequences associated with career risk, responses were varied and generally focused on loss of either leadership image or trust and credibility. About 36% perceived psychological impacts included regret and blame. Others mentioned potential impacts to career motivation (23%). Some (18%) perceived career risk consequences in terms of loss of promotion opportunities, while a fairly large portion perceived the consequences in terms of greater difficulty doing their job (62%).

What fire managers do to manage these risks is an important consideration. Given the range of expressions that respondents gave to the consequences of career risk (above), it is to be expected that risk management along these lines would focus on either reducing exposure or behaving in ways that either call upon or build social capital. Deciding as others have decided in the past (“herding”) was fairly common risk management strategy for dealing with career risk (41%), as was limiting responsibility (36%). Others, however, reported doing nothing to manage career risk and considered it a part of the job that can’t be avoided (33%).

Respondents were then asked to turn their thoughts toward the specific incident associated with their participation in this study. When focusing on the particular incident they reported on this study, the category of experienced career risk dropped considerably to only15%. It appears that although relatively large numbers of respondents had experienced career risk, on a given incident the likelihood was fairly low. From a psychological standpoint, this suggests that career risk experiences are impactful and, therefore, memorable. Accordingly they may have the ability to influence attitudes and behaviors for a significantly long period of time (e.g., months or years). More focused study of career risk with respect to types of management situations in which it occurs might reveal useful information on how to improve practices for contexts that produce perceptions of career risk.

Discussion and Conclusions

This was a challenging study on several counts. First, the intention was to move away from general impressions that fire managers have about sociopolitical factors and their relationship to incident factors and move toward more incident-specific judgments based on personal experience with a given incident of sufficient size to potentially attract sociopolitical attention. By focusing on key fire managers who are likely to have played at least some role in overall incident decision making, a perspective on the bigger picture of the incident is potentially obtainable. On the other hand, no single individual on a large fire completely defines and represents the decision making on the fire.

We see the present study as an entrée into developing a greater understanding between social context within which fire management occurs, and the relationship of social contextual factors on incident decision making. In this spirit, the study seeks to open avenues by which a deeper awareness can be gained of the myriad of psychological factors that play a role in incident management and associated risk-based decisions.

Although we are cautious about what we have learned here, we can offer some interpretations and speculations based on the results obtained. We note that for many of the queries put before respondents relatively high levels of imprecise responses were obtained. These were along the lines of “don’t know”, “unsure” or “no response.” We do not take this as uncooperativeness, but rather as a potential indicator of the difficulty fire managers have with a complete understanding of how social context influences their own decision making processes. Furthermore, and to be fair, some of the queries posed in the research protocol may have probed topics that were either uncomfortable given the specifics of an incident, or relatively novel given that many had not been asked before in a structured and research-oriented context. In this context, we note that the influence of sociopolitical factors *on* incident decisions goes hand-in-hand with the influence of incident decisions *on* sociopolitical factors.. To date, we have not developed models that illuminate this relationship in much detail. And, without this deeper understanding of the complexities of the sociopolitical environment we may always be at risk of managing risk with a limited ability to account for the multiplicity of factors that both drive incident decisions and related outcomes including costs.

With respect to career risk, it appears from the results that fire managers are not only aware of this aspect of risk management, but also have some articulated perceptions of the consequences of career risk on them personally. Whether these perceptions are matched by actual effects on the careers of fire managers is another matter. Nonetheless, we take the difficulties some respondents had in expressing their views about career risk as at least a partial confirmation that the topic requires further research with an eye toward clarifying the root causes of career risk as well improving our understanding of career risk perceptions and incident-related decisions.

Acknowledgements

Support for this project was provided by the USDA Forest Service, Pacific Southwest Research Station, under Agreement No. 09-JV-11272165-072 to MacGregor Bates, Inc. We would like to thank all of the individuals who gave of their time and experiences in support of this study. Their contribution is greatly appreciated.

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Standardized Process to Generate Mapping of Priority Areas for Protection against Wildfires[1]

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Abstract

In the field of geographic information systems (GIS) there are certain tasks that are performed repetitively and are thus sometimes monotonous, where it is necessary to structure, integrate and analyze a series of georeferenced information, which, however, always carries the same sequence. Therefore, we developed a sequential model which allows automating certain processes in the definition of priority wildfire protection areas. For this, we used the Model Builder tool (ArcGis), which is based on a visual programming language that allows structuring the sequence of processes. To illustrate this, we used vector-type information layers corresponding to the variables of three criteria, namely risk, hazard and value, such as: towns and roads in forest areas, the historical fire record, burned land polygons, fire behavior in forest ecosystems, ecosystem classification, slope, exposure, precipitation, temperature, drought, fire regimes, protected natural areas, bird conservation areas, RAMSAR sites, payments for environmental services, priority land areas, indigenous communities, poverty levels and timber value. As a result, we obtained a sequential model of priority wildfire protection areas, based on which a map where these areas are located and dimensioned according to their classification (very low, low, medium high and very high) was generated. It is therefore concluded that it is a practical tool which saves time in processes and sequences, in addition to avoiding human errors when working manually. Finally, it is pointed out that the sequence model is useful for designating protection areas. This information is important to support decision-making in the definition of fire management strategies.

Keywords: ArcGis 10.1, GIS, Model Builder, Modeling

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[1] An abbreviated version of this paper was presented at the Fifth International Symposium on Fire Economics, Policy, and Planning: Ecosystem Services and Wildfires, November 14-18, 2016, Tegucigalpa, Honduras.

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Introduction

Mexico is a mega diverse country due to the great biological richness of its ecosystems. These ecosystems are considered part of Mexico's national heritage and should therefore be a conservation priority (Comisión Nacional Forestal, 2013). However, these resources are being affected by various factors, including wildfires. In Mexico, it is estimated that each year fires burn on average 250,000 hectares of forest ecosystems. Most of these (98%) are caused by man, while the rest are caused by natural phenomena (CONAFOR, 2013). In order to deal with the problem of wildfires, several strategies have been implemented, integrated under the concept of fire management, under which, due to limited human and economic resources among other aspects, areas requiring priority protection against wildfires should be defined (Nolasco, 1993).

For the definition of priority areas there are multiple methodologies, which generally consider risk, hazard and value criteria. Because these criteria involve a large number of variables, it is necessary to use technologies that are practical and ensure efficient management of georeferenced data and that optimize the management and analysis of geospatial information, such as geographic information systems. Accordingly, the purpose of this work is to perform geoprocessing for the generation of thematic cartography on priority areas for protection against wildfires, in such a way that it serves to homogenize processes and thereby make their overall results comparable and compatible, as well as allowing for the exchange of georeferenced information on the subject of wildfire protection areas. In addition, this paper presents an innovation, which consists of a generated application aimed at standardizing mapping. This methodology will support the evaluation processes for priority wildfire protection areas.

Model Definition

A model is a real representation or set with a certain degree of precision that is developed in the most complete way possible, but without attempting to provide a replica of what exists in reality (FAO, 2016). Models are useful for describing, explaining or understanding quality better, when it is impossible to work directly in reality itself (FAO, 2016).

The use of models is very common and they are especially important in GIS use, because with them spatial data functioning and structuring can be understood (FAO, 2016). The sequential model, also called the "classic life-cycle" or "cascade" model, suggests a systematic approach, in successive actions for the development of software that begins with the establishment of requirements and then passes to the analysis, design, coding, testing and maintenance phases (Flórez, 2009).

The "Model Builder" tool is an application in ArcGIS which is used for the creation, editing and management of models in an automated way. It is a visual programming language for building geoprocessing workflows (MappingGIS, 2016). For Esri (2012) Model Builder is an application that creates, edits and manages data. In addition, they are workflows that chain the sequenced execution of geo-processing tools and provide interaction with another complementary tool. The application can be very useful when it is necessary to perform repetitive and complex tasks (SIGnatura, 2014).

Study area

The analysis was applied to the state of Jalisco, located between the geographic coordinates of 101° 28' North latitude and 105° 42' West longitude. It is located in the central-western part of Mexico and is bordered to the northwest by the state of Nayarit, to the north by the states of Zacatecas, Aguascalientes and San Luis Potosí, to the east by the state of Guanajuato and to the south by the states of Colima and Michoacán (Fig. 1). Due to the different elevations in the state of Jalisco, it is located at a maximum elevation of 4,260 meters above mean sea level. Its territory covers 80,386 square kilometers (Municipios, 2016).

The state includes part of the Sierra Madre Occidental, the Central Mexican Plateau and the Trans-Mexican Volcanic Belt. It accounts for 4.01% of the national territory (INEGI S/F). The climate is warm sub-humid with an average annual temperature of 20.5 °C and average annual rainfall of 850 mm. The dominant vegetation is the coniferous and oak forests, followed by the tropical deciduous and perennial forests (Instituto Nacional para el Federalismo y el Desarrollo Municipal “Inafed”, 2016). There are also grasslands in the north and northwest (INEGI, 2016).

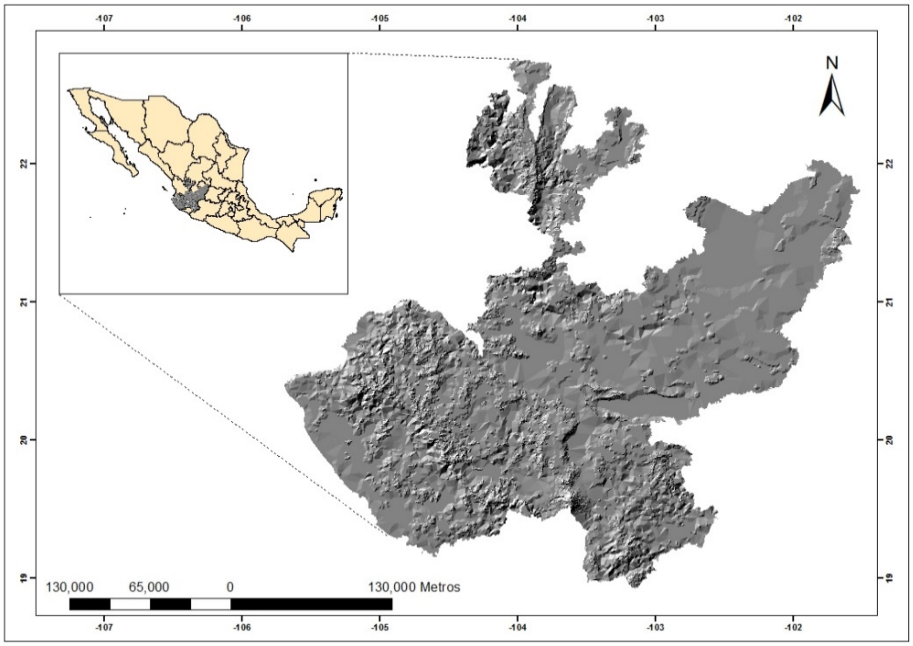

Figure 1– Study area, the state of Jalisco, used as a testing region to generate standardized mapping of priority wildfire protection areas.

Risk Analysis

It refers to a study of the variables that favor the start of wildfires, such as the presence of urban areas, agricultural activities with fire use, and roads or accesses near and within protection areas, among others (*Table 1*) (CONAFOR, 2010).

Table 1– Information used for the wildfire risk criterion.

CRITERION	VARIABLE	FORMAT	SOURCE
RISK	Town proximity		INEGI
	Number of town residents	Vector, points	INEGI
	Road proximity	Vector, lines	INEGI
	Type of road	Vector, lines	INEGI
	Occurrence of nearby fires	Vector, points	CONAFOR
	Occurrence of fire causes	Vector, points	CONAFOR
	Burned land polygons	Vector, polygons	CONAFOR

Hazard Analysis

It refers to the analysis of environmental variables, such as fuel characteristics and terrain conditions, which determine the possibility of a fire spreading (*Table 2*) (CONAFOR, 2010).

Table 2– Information used for the wildfire hazard criterion.

CRITERION	VARIABLE	FORMAT	SOURCE
HAZARD	Fire behavior and effect in ecosystems	Vector, polygon	INEGI
	Ecosystem classification (sensitive, dependent, independent)	Vector, polygon	CONAFOR
	Slope	Raster	INEGI
	Exposure	Raster	INEGI
	Hurricanes	Vector, line	SMN
	Mean annual temperature	Vector, polygon	CONABIO
	Mean annual precipitation	Vector, polygon	CONABIO
	Drought	Vector, polygon	SMN
	Fire regimes in forest ecosystems	Vector, polygon	Jardel

Value Analysis

It refers to the valuation of elements that socially, culturally and/or ecologically represent an interest in protection from the effects caused by wildfires (*Table 3*) (CONAFOR, 2010).

Table 3– Information used for the wildfire value criterion.

CRITERION	VARIABLE	FORMAT	SOURCE
VALUE	Protected natural areas	Vector, polygon	CONANP
	Important area for bird conservation	Vector, polygon	CONABIO
	RAMSAR sites	Vector, polygon	CONABIO
	Eligible hydrological areas	Vector, polygon	CONAFOR
	Areas for biodiversity conservation	Vector, polygon	CONAFOR
	Priority land areas	Vector, polygon	CONABIO
	Indigenous communities	Vector, points	CONABIO
	Human development index	Vector, polygon	CONABIO
	Degrees of poverty	Vector, polygon	CONABIO
	Priority attention areas	Vector, polygon	SEDESOL
	National Anti-Hunger System	Vector, polygon	SEDESOL
	Actual natural forest stocks	Vector, polygon	INEGI
	Timber value	Vector, polygon	INEGI

Information processing

The aforementioned georeferenced data were used in this geo processing, with the aid of a geographic information system (ArcGis 10.1). Also, the sequential model (Model Builder) was used as a tool to standardize this information. First, a search was made of the vector and raster information, through different available and reliable information sources that exist in the country and the state. Subsequently, data-cleaning was performed so that each variable would be assigned the same coordinate system and the same representation size (scale), in order for the variables to be extrapolated from each other. The projection type assigned to the state of Jalisco corresponds to WGS84 zone 13 North, according to the UTM (metric) coordinate system. Subsequently, the variables were assigned to the criterion to which they correspond, namely risk, hazard and value, and then the weighting criteria for each of the variables were assigned. This was done to obtain a value for each pixel to be able to perform arithmetic operations such as the adding of layers (map algebra) (*Fig. 2*)..

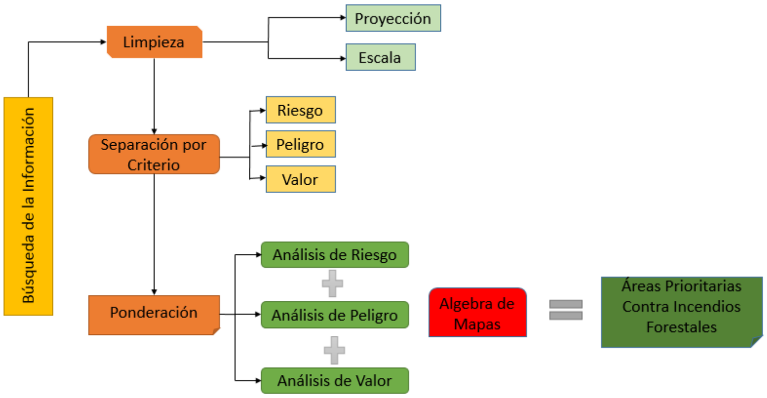

Figure 2–Structure of the process to map areas requiring priority protection against wildfires.

Starting with a series of geoprocesses for the wildfire "risk analysis," tools assigned to the sequential model were used. Subsequently, the raster-format layers for each of the variables are obtained as results. This is done in order to obtain values in the pixels and be able to calculate the map algebra. In the case of wildfire risk, the geoprocessing established for this analysis is shown in *Figure 3*. The geoprocess allowed standardizing the tools which were worked with to obtain the risk map. It is also a practical application, where the circles (blue) are the parameters or fields where the variables are assigned, in this case the risk ones; then the model is "*run*" and automatically the tools (yellow circles) begin to work and results are thus obtained (green circles).

Figure 3– Structure of the sequential model to generate standardized processes for the wildfire risk analysis.

In the case of *"hazard analysis,"* a procedure similar to that used in risk analysis is performed; however, different variables and tool methods are used in this. Once again the Model Builder application is used, with the aim of automating and/or standardizing the mapping, subsequently obtaining the results of the information layers in raster format of each of the variables, and again applying the map algebra calculation to finally obtain the wildfire hazard map. The sequential model for the hazard analysis allows automating the tools which are being worked with, and also assigns parameters so that the mapping is obtained in a standardized way (*Fig. 4*).

Figure 4– Structure of the sequential model to generate standardized processes for the wildfire hazard analysis.

In the case of *"value or potential damage analysis,"* a procedure similar to that used for risk and hazard analysis is performed; however, in this different variables and tool methods are used. The main objective in using the Model Builder application is to automate the geoprocesses and standardize the mapping, where finally the results of the information layers are obtained in raster format of each of the variables; in addition, the map algebra calculation is applied to finally obtain the wildfire value map (*Fig. 5*).

Figure 5– Structure of the sequential model to generate standardized processes for the wildfire value analysis.

Results

The *"thematic risk map"* was obtained according to the indicators used, which were based on background information on the location and size of population centers, the network of roads classified according to their surface types, the historical occurrence of fires and their possible causes, and lastly the size of the areas affected. This was done with the integration of the aforementioned variables in a standardized way in a sequential model.

The three analysis categories ("low, medium and high") were classified by means of an arithmetic operation, which consisted of a division, where the minimum score obtained was "0" and the maximum "20". Based on this, it was decided to respect the weighting proportions initially granted, with which this grade obtained proportionally for each of the levels was divided, that is, into thirds, where the low risk level was assigned scores from 1 to 6, the medium risk level from 7 to 12 and the high risk level from 13 to 20. With this, the wildfire risk map was generated (*Fig.* 6).

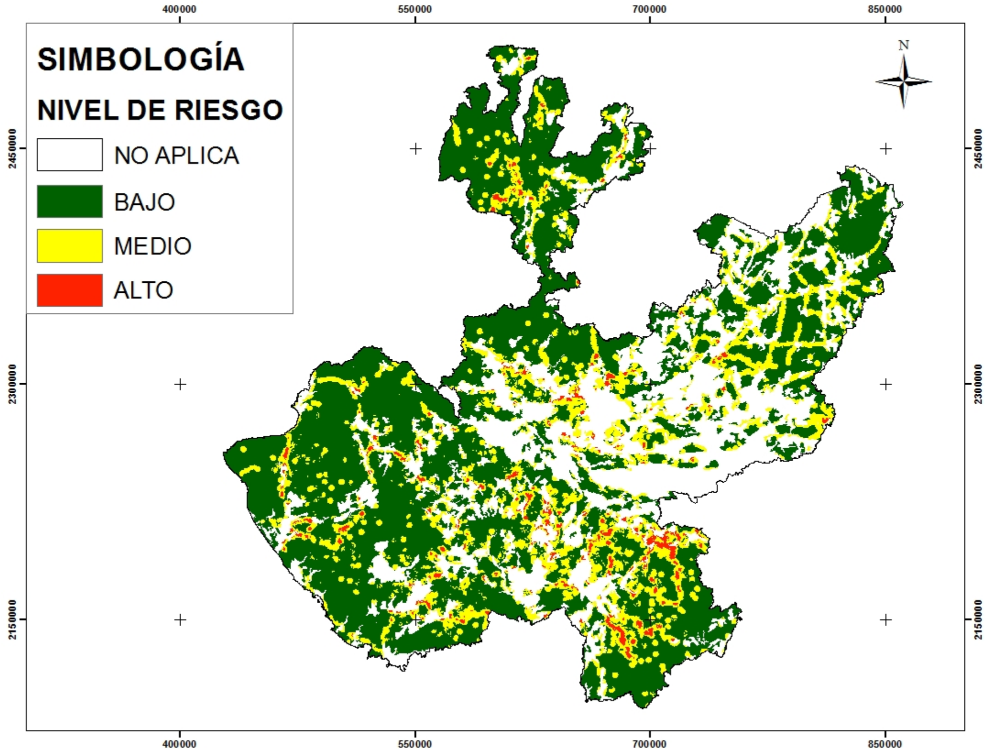

Figure 6– Wildfire risk in the state of Jalisco, with its three categories of analysis ("low, medium and high").

After analyzing each variable for the fire hazard criterion, they were all integrated, resulting in *"the thematic hazard map."* It is important to understand what aspects are taken into account and how the different values for each of the variables for the geozoning process are handled. It is also necessary to determine what level of danger each variable represents. Therefore, it is considered appropriate to analyze each of them in detail, in order that the scores are granted for zoning and on what criteria they were based.

The three analysis categories ("low, medium and high") were classified by means of an arithmetic operation, where the minimum score obtained was "5" and the maximum "29". Based on this, it was decided to respect the weighting proportions initially granted, with which this grade obtained proportionally for each of the levels was divided, that is, into thirds, with which the low risk level was assigned scores from 5 to 13, the medium risk level from 14 to 21 and the high risk level from 22 to 29. With this, the wildfire hazard map was generated (*Fig. 7*).

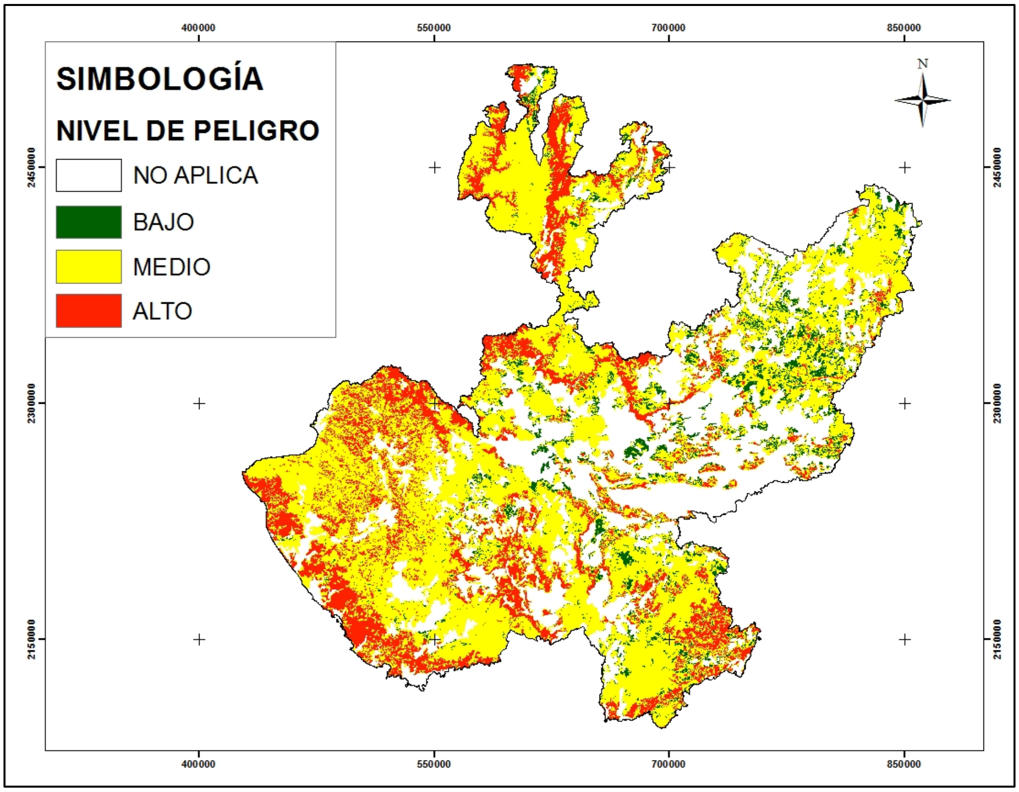

Figure 7–Wildfire hazard in the state of Jalisco, with its three categories of analysis ("low, medium and high").

When summing the information layers with their weighted values for this analysis, they are categorized into three different grade types, according to the level that corresponds to them. The three analysis categories ("low, medium and high") were classified by means of an arithmetic operation, where the minimum score obtained was "1" and the maximum "24". Based on this, it was decided to respect the weighting proportions initially granted, with which this grade obtained proportionally for each of the levels was divided, that is, into thirds, with which the low risk level was assigned scores from 1 to 8, the medium risk level from 9 to 16 and the high risk level from 17 to 24. With this, the *"thematic wildfire value map"* was generated (*Fig. 8*).

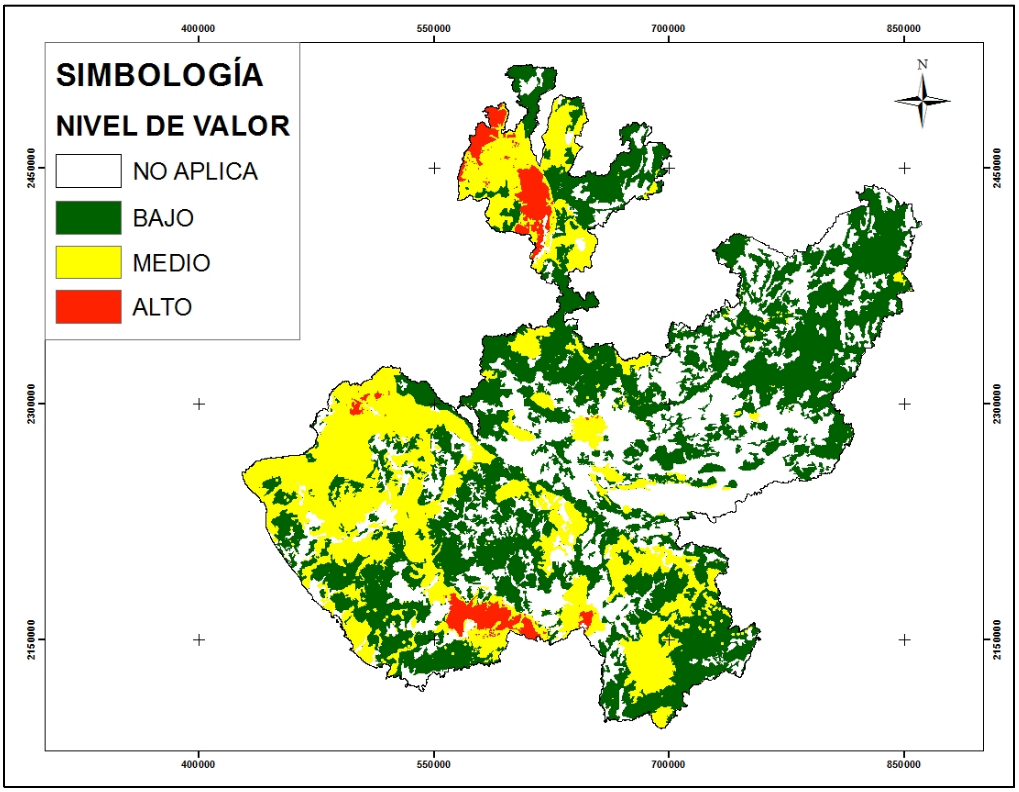

Figure 8– Value of wildfires in the state of Jalisco, with its three categories of analysis ("low, medium and high").

Thematic mapping of priority areas for protection against wildfires

The integration of the risk, hazard and value criteria allows establishing areas with protection priorities for wildfire control. The procedure consisted of assigning weighted scores to each of the criteria. These scores are summed by means of the math algebra calculation, and each pixel contains a priority value (*Fig. 9*).

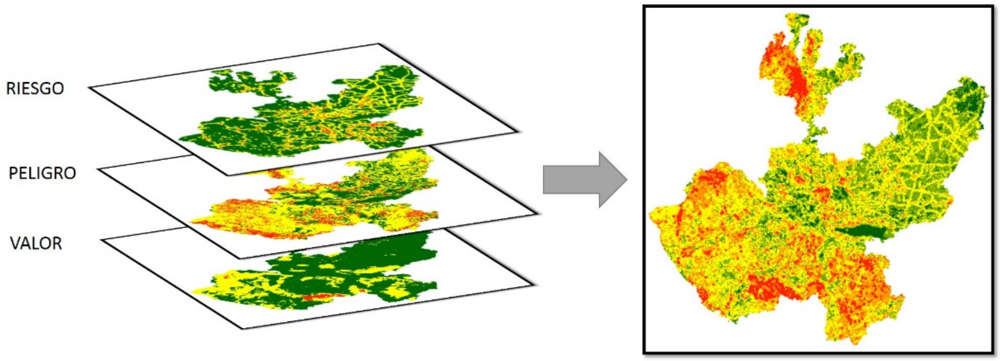

Figure 9–Arithmetic operation, for the summing of layers for the risk, hazard and value criteria, to establish the map showing priority areas for protection against wildfires.

The sequential model for the priority analysis allows automating the *"Raster Calculator or Map Algebra*" tool that was used to generate the thematic map showing areas requiring priority attention against wildfires (*Fig. 10*).

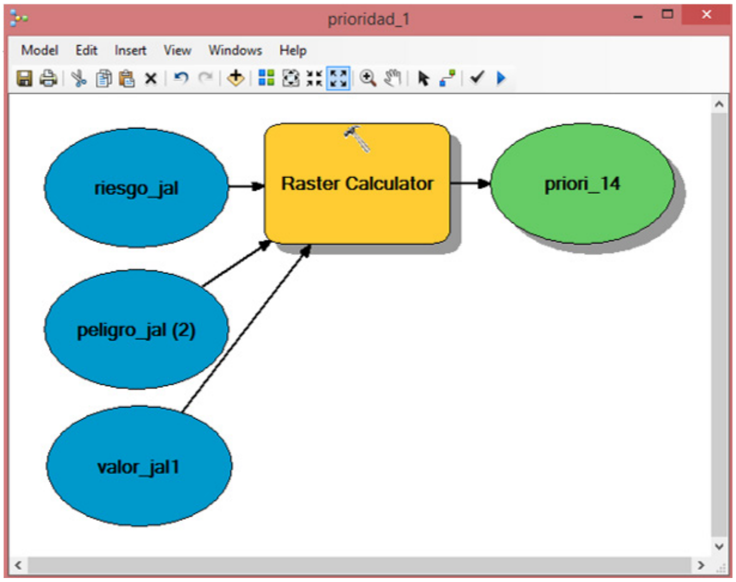

Figure 10– **Structure of the sequential model to generate standardized processes for the analysis of areas requiring priority protection against wildfires.**

Priority areas for protection against wildfires allows assessing the spatial distribution of the problem caused by the occurrence and spread of wildfires and provide the basis for the planning of prevention and combat activities that need to be implemented or reformulated in a protection program (Nolasco, 1993). A classification of five categories (very low, low, medium, high and very high) was used, in order to determine more precisely the areas to be protected (*Fig*. 11).

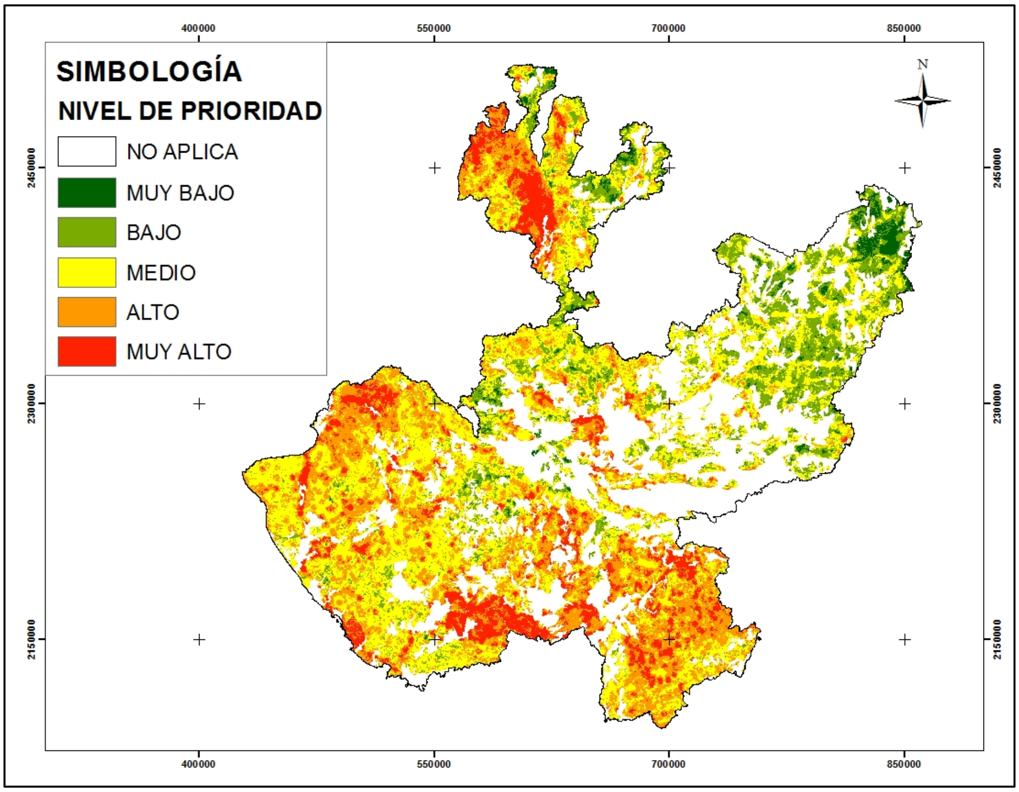

Figure 11– Priority areas for protection against forest fires in the state of Jalisco, with their respective categories of analysis ("very low, low, medium, high and very high").

Conclusions

One of the main advantages in using a sequential model is the automation of work, in that it allows the users to avoid having to repeatedly use the same tools with which they are working. It is a clear and simple application, since its visual environment greatly simplifies the understanding of the geoprocesses that are carried out. It is a way of understanding how geospatial processes work. In addition, the user does not need to know a programming language like Java, html, php and sql, among others, since the graphical environment allows understanding the model structure.

The use of compact models prevents making mistakes when running the tools. It also saves time and effort. It is also possible to know the time each tool is run. Finally, the analysis of the thematic map provides the necessary basis to design, implement, organize and apply in future periods the best decision-making in fire management. It also allows using the maps for dissemination purposes at conferences and as teaching material in Mexican and foreign universities.

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The Experience of Using Forest Incentives as a Tool to Reduce the Impact of Wildfires in Guatemala[1]

Mairon Méndez[1], Byron Palacios[2]

Abstract

In 1996 the Forest Act (Decree 101-96) was approved, giving life to the National Forest Institute (INAB) as the autonomous and decentralized public entity responsible for forest administration outside protected areas. Together with the Forest Act, the State of Guatemala, through INAB, created the Forest Incentives Program (PNFOR) to promote the establishment of plantations and sustainable forest management. Given the experiences with PINFOR, and the demands of small holders and community groups, in 2007 the Forest Incentives Program for Smallholders (PINPEP) was created through the cooperation of the Kingdom of the Netherlands to promote reforestation, agroforestry systems and natural forest management. This program was institutionalized in 2010 through Law 51-2010.

These programs, with the implementation of more than 29,000 thousand projects, have contributed to the management and conservation of more than 430,000 ha of forest and plantations, representing a public investment of more than $290 million. Economically, these projects have created community employment and improved the economy for more than 900,000 people. They have also contributed to the provision of timber products and ecosystem services such as water regulation, biological connectivity, and reduced greenhouse gas emissions, among others. These incentive programs are a clear example of a payment for results, where the evaluation instrument is compliance with the forest management plan which includes forest protection activities.

Approximately 25% of the incentive payment budget is allocated to wildfire protection activities to comply with forest protection activities. These investments in forest protection have made a direct contribution to the reduction in fires within the areas under management. INAB statistics indicate that less than 1% of projects have been affected by fires thanks to the establishment and maintenance of more than 50,000 km of firebreaks and the commitment of program users to wildfire control activities, thus creating a culture of responsibility in the use and management of fire.

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[1] An abbreviated version of this paper was presented at the Fifth International Symposium on Fire Economics, Policy, and Planning: Ecosystem Services and Wildfires, November 14-18, 2016, Tegucigalpa, Honduras. Abstract only available.

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Latin American Strategy for Strengthening Fire Management Education[1]

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Abstract

Central America, Mexico, the Dominican Republic, Colombia, Venezuela and Peru are projected to experience an increase over the short term in the number of recorded wildfires and area affected, accompanied by an obvious loss of housing units, infrastructure and in extreme cases human lives. Hence, there is an indisputable need for Wildfire Protection and Fire Management to be assumed responsibly and on an academic basis by professionals in forest and related sciences in Latin America, which necessitates the adoption and development of a "Latin American Strategy for Strengthening Fire Management Education 2017-2023 (ELFAMF for its initials in Spanish). This initiative aims to address from the outset the demand for: establishment of training and updating approaches and actions for university and vocational training center teachers; inclusion of Fire Ecology and Effects and Fire Management courses in the curriculum; development of didactic teacher's, student and field practices manuals: establishment of permanent pilot research units, workshops and forums for updating and results analysis, joint collaboration agreements for teacher and student exchange and mobility, and teacher training programs. The results of the strategy will generate greater interest and a broader capacity for decision-making in research, development, operation, economics and evaluation of fire protection and management programs by forest and related professionals at the national level in protected natural areas, areas with environmental services, plantations, forest management areas, wildlife management areas, watershed and reservoir protection areas, areas with cultural resources, recreational areas and rural units, among others. With actions such as these, each of the countries will be addressing in the short and medium term, on a scientific and ecological footing, what is set out in their current forestry regulations, and indicated in the Guidelines on Forest Fire Management in Temperate and Boreal Forests (FAO 2002); Fire Management: Voluntary Guidelines (FAO 2007) and the Regional Fire Management Strategy for Central America and the Dominican Republic 2015-2025 (CCAD 2015).

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[1] An abbreviated version of this paper was presented at the V International Symposium on Fire Economics, Planning and Policy: Wildfires and Ecosystem Services, November 14-18, 2016, Tegucigalpa, Honduras.

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Keywords: strategy, strengthening, teachers, curricular inclusion, didactic materials, pilot units, agreements, evaluation.

Introduction

Globally, an increase in the recorded number of wildfires and area affected is projected over the short term, coupled with the obvious loss of infrastructure, housing units and human lives.

Latin American countries such as Mexico, Guatemala, Honduras, Colombia, El Salvador, the Dominican Republic and Peru, among others, and very soon Panama as well, are currently working on wildfire protection and fire management programs, mainly as a result of the emergencies they have experienced in recent years. This situation demands the creation and development of a national strategy for protection against wildfires and fire management to be addressed operationally in a responsible and academically-based manner by professionals in forest and related sciences.

In this field, science, technology and interdisciplinary research are aimed at improving our knowledge of complex processes and fire-atmosphere-climate interactions. Support is required to establish and continue these investigations and promote interaction among these fields, which is fundamental if the technical community engaged in and responsible for fires and fire management is to advance in terms of new knowledge, instruments and technologies (FAO, 2006).

Research and transfer of scientific knowledge through university-level vocational teaching is fundamental to implement and put into practice advanced fire management. Public education is essential for fire prevention and, above all, for fire management actions such as ecologically reliable and safe burning techniques (FAO, 2006).

However, the current state of the universities and higher education centers in Latin America that train and produce the professionals have neither trained teachers nor curricular subjects on fire ecology and effects, which provide the necessary grounding in the field of fire management, which would allow graduates to meet the demands of wildfire protection and fire management in their country. The foregoing requires the adoption, development and evaluation of a Latin American Strategy for Strengthening Fire Management Education 2017-2023 (ELFAMF), taking into account that five years are normally required for curricular reform in university degree programs. This initiative ensures that from the outset the lack of knowledge, practices and professionalism of the technicians responsible for the implementation of National Fire Management Strategies in each of the countries is addressed.

Reference framework

Conceptual framework

Fire management is the discipline aimed at using fire to achieve traditional land-use management and objectives along with the protection of life, property and resources, through the prevention, detection, control, restriction and extinction of fires in forests and other types of vegetation in rural areas. It includes programmed and naturally generated fires, and comprises research and technology transfer (FAO, 2006).

Integrated fire management includes the integration of science and society with multilevel fire management technologies. It considers a comprehensive, holistic approach to deal with fire-related issues, taking into account biological, environmental, cultural, social, economic and political interactions (Kaufmann et al., 2003).

The term "integrated" has been used to describe other natural resource management approaches, such as "integrated forest management" or "integrated community development." It is generally held that "integrated" concisely describes the state of synergistically gathering various concepts and issues to produce effective results that cannot be achieved by technology alone (Myers, 2006).

It is considered that in its initial application phase in fire management, it was explained with this differentiation, that the application of fire management strategies and actions would have to consider the integrated scenario, which is why the term "integrated" is ingrained in fire management.

Wildfire protection consists of pre-suppression strategies and actions, prevention which includes education, outreach and prediction, detection, combat, liquidation, rehabilitation and fire use by controlled burns, black lines and prescribed burning tests, which are carried out within a national program (Nájera, 2016).

Fire Management takes into account the development, monitoring and evaluation of the strategies and actions that are carried out in the Wildfire Protection Program, including fire use strategies and actions as an ecological management tool, research on fire ecology and effects, in the context of benefits and damages, and the socioeconomic and cultural environment of society (Nájera, 2016).

The above indicates that we are in the transition stage from wildfire suppression to fire management.

Institutional framework

In general, all countries have an agency at the institutional or ministerial level that includes the forestry sector and natural resource conservation and development, which is responsible for regulating, operating and addressing wildfire protection and fire management. However, there is also usually a delegation of this function to mainly Fire Departments, the Armed Forces and Protected Natural Areas, institutions and agencies that were created with another mission and primary responsibility. However, it is generally here where professionals who have graduated from educational institutions work as public officials in charge of wildfire protection and fire management; because of their curricular training, they usually do not have the main knowledge bases and practices to address the fire management issues facing their institution.

Political and legal framework

In recent years, Latin American countries have included wildfire fighting in their national policies; some of them are in the process of developing a National Strategy for Protection against Wildfires and Fire Management, a process that marks the transition from firefighting to fire management.

This represents a weakness, since there is no significant economic support for the national fire protection and fire management programs of Central America and the Dominican Republic (CCAD, 2015).

Currently, the Regional Fire Management Strategy for Central America and the Dominican Republic, 2015-2025, is in place; it outlines the strategic lines, objectives, components, actions and activities to be carried out in fire management (CCAD, 2015).

Usually Latin American countries have a Forest Act and its Regulations, or a Forest and Wildlife or Protected Natural Areas Act, an Act for the Conservation and Development of Natural Resources, and in particular cases, the regulations are complemented by Official Rules, which indicate who is responsible for regulating, coordinating, operating and evaluating wildfire protection and fire management.

Background

In the late 80's, Mexico began within the framework of the Memorandum of Understanding between the United States and Mexico, through coordination with the Forest Service (USDA FS) and the then-Secretariat of Agriculture and Water Resources (SARH for its initials in Spanish), a series of training and technical assistance lines and actions in the field of wildfire protection, in which technical staff from other Latin American countries participated; this situation is still in force today, with adjustments and strengthening to fire management.

In Central America, with Mexico's leadership and support, in the 1990s the Republic of Guatemala served as the headquarters for the training of technical staff from

Central American countries in Mesoamerican Wildfire Protection courses (ICF-CONAFOR- USDA FS- USAID, 2014).

Currently, Guatemala and Honduras have their own technical assistance and training process in the field of wildfire protection and fire management, achieving progress mainly in the formation of their own national team of instructors and wildfire control centers. For their part, Colombia, Peru, the Dominican Republic and possibly Panama have begun the USFS consultancy process to develop their own National Fire Management Strategy, being appropriate to consider community development, traditional fire use and the latter's relationship to the causes of fires to meet local needs and provide technical assistance and regulatory support for the application of fire, thereby leading new generations of peasants towards fire management.

Justificaction

It is important to mention that the actions undertaken in Mexico and other Latin American countries, as part of the strategies, lines and actions carried out in wildfire protection and fire management, do not provide for the academic strengthening of teachers who give topics related to these subjects; it is therefore necessary to develop and adopt a "Latin American Strategy for Strengthening Fire Management Education" 2017-2023 (ELFAMF). This initiative aims to address from the outset the demand for: establishment of training and updating approaches and actions for university and vocational training center teachers; inclusion of Fire Ecology and Effects and Fire Management courses in the curriculum; development of didactic teacher's, student and field practice manuals: establishment of permanent pilot research units, workshops and forums for updating and results analysis, joint collaboration agreements for teacher and student exchange and mobility, and teacher training programs.

The results of the strategy will generate scientific bases and derivations for decision-making in research, development, operation, economics and evaluation of fire management programs by forest and related professionals at the national level in protected natural areas, areas with environmental services, plantations, forest management areas, wildlife management areas, watershed and reservoir protection areas, areas with cultural resources, recreational areas and rural units, among others. With actions such as these, each of the countries will be addressing in the short and medium term, on a scientific and ecological footing, what is set out in their current forestry regulations, and indicated in the Guidelines on Forest Fire Management in Temperate and Boreal Forests (FAO 2002); Fire Management: Voluntary Guidelines

(FAO 2007) and the Regional Fire Management Strategy for Central America and the Dominican Republic 2015-2025 (CCAD 2015).

Strategic framework

Vision

Address and develop in Latin America national fire management policies, regulations and strategies, from the teaching and training of forestry and related science professionals.

Mission

Strengthen fire management at the Latin American level, by teaching support and curriculum formation strategies and actions to ensure optimal professional performance for the protection, conservation, management and development of natural resources and wildlife, within the framework of community and societal development.

Overall objective

Implement strategies, lines and actions to strengthen teaching and curriculum formation in fire ecology and management for the development, operation, research and evaluation of the national fire management strategy.

Specific objectives

Socialization and implementation of the "Latin American Strategy for Strengthening Fire Management Education" 2017-2023 (ELFAMF).

Strengthen the institutional teaching staff that gives the subjects related to wildfires and fire management, including them in training and updating programs that are carried out in the tiered experience-grading system used in fire management in each country.

Establish, as part of the curriculum development of degree programs in forest engineering and related sciences, compulsory Fire Ecology and Effects and Fire Management subjects, preferably in the final semesters.

Develop didactic materials such as teacher's, student and field practices manuals, as well as lectures on fire ecology and effects and fire management.

Institute the establishment of permanent "pilot" research units with different management objectives, in ecology and evaluation of the effects of fire on fire-maintained ecosystems and protected natural areas.

Formalize the holding of national and international forums and workshops to present strategy updates, progress and results.

Manage and consolidate the signing of joint collaboration agreements between national and international universities and vocational training centers for the exchange and mobility of teachers and students.

Carry out the monitoring and evaluation of the strategy to measure the level of progress in terms of results and the fulfillment of the established objectives, adjusting the established actions to achieve the proposed mission and vision.

Strategic lines

Strategy implementation

Actions

Apply for the inclusion of the ELFAMF in the training and technical assistance activities that the USFS IP currently carries out in the country.

Formalize the consent of the USFS IP and the national government for the development of the ELFAMF jointly and in coordination.

Adapt and reproduce the ELFAMF for its socialization in the educational institutions and countries with which USFS IP works for its implementation.

Draw up and obtain approval of the annual operating plan by institution and country for implementation of the ELFAMF.

Teacher training

Actions

Request on behalf of the university or educational center that the agency responsible for conducting training in fire management in each country allocate 1 to 2 places for teacher and assistant attendance.

Attend and pass courses taught by the USFS IP and the national government covering fire management, the Incident Command System (ICS), fire behavior and prescribed fires at the basic, intermediate and advanced levels.

Maintain coordination with the agency responsible for responding to wildfires and carrying out prescribed fires in each country and attend combat and ignition application technique actions to gain practical experience.

Maintain good health and physical fitness, necessary to perform arduous tasks safely in the fire and fire management areas.

Curriculum development

Actions

Generate in a timely and appropriate manner the support, justification and analytical programs to include the fire ecology and effects and fire management subjects in the curriculum and initiate the relevant procedures.

Formally request that the academic affairs office or the academic vice-president's office of your educational institution include, as compulsory subjects in the forestry engineering or related science degree programs, the fire ecology and effects and fire management subjects.

Consider the January-June semester to impart fire ecology and effects and the July-December semester for fire management, in agreement with the regulations, and report the approval of the two subjects in the curriculum, final semesters and the professional career programs that decide to teach them.

Didactic materials

Actions

Develop and reproduce didactic materials such as the teacher's, student and field practices manuals for the fire ecology and effects and fire management subjects.

Design PowerPoint lectures on the two subjects for use with a multimedia projector, combined with interactive DVD materials to reinforce the subjects.

Establish an area for field practices, fuel assessment, ignition tests and application of case studies.

Request funding for the acquisition of personal protective clothing, hand tools, and materials and equipment used for firefighting and conducting prescribed burn tests.

Pilot units

Actions

Develop research lines and specific objectives in different ecosystems, prioritizing protected natural areas, commercial plantations and areas with environmental services.

Establish, in different ecosystems, "pilot" research units on fire ecology with different management, conservation, development and protection objectives.

Carry out monitoring and evaluation in the pilot units on the effects of fire on pests, plants, forests, grasslands, scrub, soil, water, air, wildlife and cultural resources, among others.

Establish "pilot" community development units to provide attention and follow-up to fire causes, technical assistance for traditional fire uses and the adoption of community fire protection and fire management activities.

Institute a university research or community development project to obtain the funds and resources necessary for research and/or community development of fire management, in which the institution's Forest Fuel Management Team, composed of students and coordinated by teachers, is formed.

Forums and workshops

Actions

Organize and lay the foundations for the holding of national and international forums in coordination with the national government to analyze, report on the progress and results of the actions carried out in each country and share experiences with other countries.

Organize and justify the holding of national and international Workshops in coordination with the national government for training and updating in the field of fire ecology and effects and fire management.

Agreements

Actions

Formalize the drawing up and signing of inter-institutional joint collaboration agreements between universities and centers of higher education at the national and international level, prioritizing wildfire protection and fire management actions.

Develop, within the framework of general agreements, student and teacher exchange and mobility agreements, focusing on research activities related to fire ecology and effects and fire management.

Strengthen international linkage in the fire management area in terms of teaching, research and community development.

Monitoring and evaluation

Actions

Schedule and perform the monitoring and evaluation of the strategy, measuring the progress achieved and the achievement of objectives to fulfill the mission and vision of ELFAMF.

Establish and operate the National Fire Management Teaching Team (ENDMF for its initials in Spanish) in each country to carry out the evaluation of the strategy based on the annual plan proposed by each institution.

Appoint an International Fire Management Teacher Coordinator (CIDMF) to strengthen the organization's logistics and the evaluation of the actions to be carried out as part of the ELFAMF.

In regards to the seeking of Economic Resources for the implementation of ELFAMF, each university or center of higher education will schedule its actions based on its annual operating plan and will agree on contributions from national governments and international agencies for participation, research and exchange of experiences; in addition, these educational institutions must report the results of these activities. Implement, formalize and develop the first stage of the ELFAMF in the countries of Belize, Guatemala, Honduras, El Salvador, Nicaragua, Costa Rica, Panama and the Dominican Republic.

Strategy implementation

The implementation of the Latin American Strategy for Strengthening Fire Management Education (ELFAMF) 2017-2023 has, as its integrated development core, the training and technical assistance support program provided by the United States Forest Service (USFS) mainly in the countries of Mexico, Honduras and Guatemala**;** under it, the University and/or Higher Education Centers of each country will establish contact and arrange with the National Agency responsible for conducting training in the field of fire management, namely the National Forestry Commission (CONAFOR-Mexico), National Institute of Forest and Wildlife Conservation (ICF-Honduras) and the National Forestry Institute (INAB-Guatemala), the allocation of at least two places to attend training courses in the NWCG fire management scheme being carried out in the country. It is also advisable to seek funding from the national office of USFS International Projects for teachers to attend training events that are carried out in coordination with the national governments.

Universities and/or centers of higher education in each country will request internal and external resources, through the implementation of national and international projects to strengthen the ELFAMF counterpart, and conduct teacher-training, carry out curriculum development by including compulsory subjects, generate didactic materials, set up “pilot” research units and for community development, form the institutional fuel management team, coordinate and host evaluation and updating forums and workshops, bring about the signing and development of joint national and international collaboration agreements and coordinate with national institutions and international agencies to carry out and host the annual evaluation of the ELFAMF in each country.

Each university and/or center of higher education must carry out its annual operating program of activities and submit a report on activities, results, and progress to the representatives of the National Fire Management Teaching Team (ENDMF) and the International Fire Management Teacher Coordinator (CIDMF), who in turn will inform the pertinent national government institutions and international cooperation agencies.

With ELFAMF advances and results in each country, a theoretical-practical professional strengthening, improvement and growth is guaranteed, which ensures that the national fire management strategy is carried out by forestry and related science professionals who are officials and managers responsible for staff safety and regulatory, operational, community development, and fire management assessment actions.

The demand for the design, development and evaluation of Fire Management Plans to reinforce the Management Programs of protected natural areas, areas with environmental services, commercial plantations, forest management areas, wildlife management areas, watershed and reservoir protection areas, areas with cultural resources, recreational areas and rural units, among others, necessitates research, community development and their economic and operational evaluation, which are fundamental strategic lines and actions that are considered within the ELFAMF.

Action Plan for the Latin American strategy for strengthening fire management education

Strategic line: Approval of the strategy.
Objective: Approval, socialization and implementation of the "Latin American Strategy for Strengthening Fire Management Education"
Component: Development and approval.

Action	**Activity**	**Indicator**	**Goal**	**Agency responsible**	**Resources**	**Year**						
						2017	2018	2019	2020	2021	2022	2023
Implement the Latin American Strategy for Strengthening Fire Management Education (ELFAMF)	USFS IP consent for the development of the ELFAMF.	Adherence to USFS IP activities	Proposal document per country	National institution and CIDMF	NA	X						
	Digital and printed reproduction of the ELFAMF.	Publications	Document per country	National institution and CIDMF	NA	X						
	Carrying out the socialization of the ELFAMF.	Events	Two events per country.	National institution and CIDMF	NA	X						
	Preparation of an annual operating plan by each educational institution.	Plans	Plan per institution per country.	National institution and CIDMF	NA	X	X	X	X	X	X	X
	Formalization of annual operating plans.	Approval	Response document per country.	National institution and CIDMF	NA	X	X	X	X	X	X	X

Figure 1- Strategic line: approval of the strategy. Approval, socialization and implementation of the ELFAMF

Strategic line: Teacher-training.
Objective: Strengthen the institutional teaching staff that imparts the subjects related to wildfires and fire management.

Component: Development and strengthening.

Action	Activity	Indicator	Goal	Agency responsible	Resources	Year						
						2017	2018	2019	2020	2021	2022	2023
Strengthen the institutional teaching staff that imparts the wildfire and fire management subjects, including them in training programs that are carried out in the tiered training and experience-grading scheme used by other countries.	Request the assignment of places with the person responsible for fire management training in each country.	Acceptance of participation in USFS IP courses	Proposal document per country	Educational institution per country and CIDMF	NA	X						
	Approve fire management courses at basic, intermediate and advanced levels.	Attendance and passing of courses	Course passed	Teacher per educational institution and CIDMF	NA	X						
	Coordinate with the agency responsible for attending wildfires and participate.	Events attended	Two annual events per teacher per country	Teacher per educational institution and CIDMF	NA	X						
	Maintain good health and the required physical fitness.	Certificate and test	Annual test	Teacher per institution and CIDMF	NA	X	X	X	X	X	X	X

Figure 2 – Strategic line: teacher-training. Strengthen the institutional teaching staff that imparts subjects related to wildfires and fire management.

Strategic line: Curriculum development and didactic materials.
Objective:
Include, as part of curricular development of forest engineering and related science degree programs, compulsory fire ecology and effects and fire management subjects.
Develop didactic materials, including teacher’s, student and field practices manuals, and lectures on fire ecology and effects and fire management subjects
Component: Development, approval and teaching materials.

Action	**Activity**	**Indicator**	**Goal**	**Agency responsible**	**Resources**	**Year**						
						2017	2018	2019	2020	2021	2022	2023
Justify and request that the academic affairs office or the vice-president’s office of each educational institution in each country include, as part of the curriculum, compulsory fire ecology and effects and fire management subjects.	Justify and approve the analytical programs of both subjects in the curriculum of the forestry engineering and related careers	Approval of subjects	2 compulsory subjects	Each higher institution per country	NA	X	X	X	X	X	X	X
Develop and reproduce didactic materials for the Fire Ecology and Effects and Fire Management subjects.	Design teacher's student and field practices manuals, as well as presentations.	Manuals	3 manuals per subject	Each higher institution per country	NA	X	X	X	X	X	X	X

Figure 3 – Strategic line: curriculum development and didactic materials. Include, as part of curriculum development, fire ecology and effects and fire management as compulsory subjects, and develop didactic materials.

Strategic line: Establishment of "pilot" units and holding of forums - workshops.
Objective:
Institute the establishment of permanent "pilot" research units with different management objectives, in ecology and evaluation of fire effects.
Formalize the holding of national and international forums and workshops to provide updates and report progress.

Component: Management of "pilot" units, forums and workshops.

Action	**Activity**	**Indicator**	**Goal**	**Activity responsible**	**Resources**	**Year**						
						2017	2018	2019	2020	2021	2022	2023
Establish permanent “pilot" research units with different Fire Ecology and Effects and Fire Management objectives.	Arrange with land owners or holders permission for establishing "pilot" units.	“Pilot” unit	3 pilot units per institution	National institution and CIDMF	NA	X	X	X	X	X	X	X
Develop national and international forums and workshops for providing ELFAMF updates and reporting progress.	Design teacher's student and field practices manuals, as well as presentations.	Forums and workshops	1 forum and 3 workshops per country	National institution and CIDMF	National institution and USFS IP	X	X	X	X	X	X	X

Figure 4 – Strategic line: Establishment of "pilot" units and holding of forums. Establishment of permanent "pilot" research units and holding of national and international forums and workshops.

Strategic line: Agreements and evaluation of ELFAMF.
Objective:
Arrange for the signing of joint collaboration agreements between universities and national and international vocational training centers.
Carry out evaluation of progress and fulfillment of strategy objectives to fulfill the proposed mission and vision.

Component: Arrangement of agreements and evaluation of the ELFAMF

Action	**Activity**	**Indicator**	**Goal**	**Agency responsible**	**Resources**	**Year**						
						2017	2018	2019	2020	2021	2022	2023
Signing of joint collaboration agreements between national and international higher education institutions.	Conclude the signing and development of collaboration agreements.	Agreements	2 national and international agreements per institution	Each higher institution per country	NA	X	X	X	X	X	X	X
Hold events to evaluate progress, results and fulfilment of ELFAMF objectives.	Arrange for the holding of ELFAMF evaluation and compliance events.	Evaluation event	1 annual event per country	National institution and CIDMF	National institution and USFS IP	X	X	X	X	X	X	X

Figure 5 – Strategic line: Agreements and evaluation of the ELFAMF. Signing agreements between universities and assessment of progress and compliance.

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Risk Factor as a Strategy to Validate the Prioritization of Areas for Wildfire Protection[1]

José G. Flores Garnica[2], Alejandra Macías[3], Uri D. Casillas[4]

Abstract

The limited availability of resources for wildfire management necessitates prioritizing forest areas for protection. For this purpose, criteria such as fire risk are used to generate thematic maps intended to support decision-making. However, prior to this, the information must be validated under a statistically robust process. Unfortunately, no such process currently exists, so it must be formulated from the most basic aspect, which is the definition of the sampling unit. This was the objective of this study, where different-sized reference sites (RSs) were tested under four sampling intensities randomly distributed throughout the state of Jalisco, Mexico. Within each RS, the number of fires was determined for the period 2005-2013. It was found that variability in the number of fires decreased as the size of the RS increased, until reaching an asymptotic behavior (around 100 km^2). In this way it was determined that a RS of 100 km^2 captures the variability in the number of fires, which was termed Risk Factor (RF). Finally, the use of this parameter will support the definition of the risk validation process. In addition, the standardization of the RS will generate information, in different regions, that is not only comparable but also compatible.

Keywords: Priority areas, risk factor (RF), reference sites (RS)

Introduction

Wildfires are one of the major causes of forest cover loss in the country. An estimated 8,900 wildfires occur in Mexico every year (Cibrián et al., 2014), of which 97% are caused by human activities (CONAFOR, 2010). Because of this, the

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[1] An abbreviated version of this paper was presented at the V International Symposium on Fire Economics, Planning and Policy: Wildfires and Ecosystem Services, November 14-18, 2016, Tegucigalpa, Honduras.

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National Forestry Commission, through the National Wildfire Prevention Program, has implemented a general strategy for wildfire prevention and control. However, because human and economic resources are limited, it is necessary to define areas requiring priority attention (CONANP, 2009). For this reason, systems have been developed that evaluate the factors that determine the occurrence of fires and their behavior (Dentoni and Muñoz, 2012; July, 1990). These factors are generally integrated into criteria such as risk, hazard and vulnerability (Hardy, 2005), each of which is based on the evaluation and weighting of a number of specific variables (Red et al., 2001). This weighting can be done under different approaches, such as multicriteria analysis (Golubov et al., 2014), where groups of experts establish comparisons among the variables used, and decide by means of different methods those which have the greatest influence and assign them priority values. Based on this, it is possible to generate cartography and statistics, which allow locating and dimensioning areas requiring priority protection against wildfires (Ager, Vaillant & Finney, 2010; CONAFOR, 2010).

However, the use of information pertaining to priority wildfire protection areas is totally conditioned upon the verification of their results, since one can fall into the error of addressing areas that are not, in fact, priority areas or, on the contrary, not addressing priority areas. However, on this topic there are few papers that refer to some form of validation. Moreover, there is no standardized methodology which allows for a systematic validation process, neither for the prioritization in general, nor for each of the criteria that define it (Salvati & Ferrara, 2015). For example, in the case of risk criterion, there are various strategies, such as: a) logistic regression analysis to establish the most important variables, through the random sampling of 10 km^2 units (determined by the spatial resolution of the information used) and the evaluation of the goodness of fit of the logistic regression model (Hosmer and Lemeshow test) (Carillo, 2012; Mohammadi, Bavaghar & Shabanian, 2014); b) use of the Moran Index and Geary's C-Coefficient to validate the risk index defined by spatial autocorrelation (Pérez et al., 2013); c) use of databases with a history of 160 days, chosen systematically and randomly (5 days per month and for each of the seasons of the study period) (July, 1990); d) use of satellite images (e.g. Modis active fire) to supplement the recorded fire data (Yeguez & Ablan, 2012; Chuvieco et al., 2007).

On the other hand, it has been found in this type of study that the size of the sampling unit, which is used for validation, is not adequately justified. And again, there are different ways in which this sampling size is determined, such as: i) the variables are mapped to a spatial resolution of 1 km^2 (Chuvieco et al., 2007). Regardless of the method used, in all cases the selection of the sampling unit size is arbitrarily made. Accordingly, one of the first points that must be defined, in the process of validating fire risk areas, is a methodology that allows standardizing both processes and the size of the sampling unit. Therefore, the purpose of this study was to determine the statistically appropriate site size to support such validation. Such areas are referred to as Reference Sites (RSs), while the number of fires that are located in each RS is called the Risk Factor (RF). Thus, a specific risk validation would basically consist of a comparative analysis between the RF determined at a given point and the RF corresponding to a certain wildfire risk class. Traditionally, these classes are defined by dividing the sum of the weighted values of each variable by the number of classes to be considered (Castillo et al., 2013; July, 2010). However, this paper proposes determining the ranges of number of fires based on their probability of occurrence (that is, considering a certain number of variances for each wildfire risk class to be determined).

Materials and methods

To define the wildfire risk reference area, information was used for the state of Jalisco, which is located in western Mexico: to the North 22^{0} 45´ and to the South 18^{0} 55´ of North latitude, to the East 101^{0} 30´ and to the West 105^{0} 42´ of East longitude (*figure 1*). It covers a 78,588 km² area, where a warm sub-humid climate predominates in 68 % of the territory state (coast and center), a temperate sub-humid climate in 18 % (upper mountain areas) and a dry/semi-dry one in 14 % (North and Northeast). The mean annual temperature is 20.5° C and the average annual rainfall is approximately 850 mm, although in the coastal zones it is more than 1,000 mm. Conifer and oak forests dominate, followed by deciduous and sub-deciduous forests (sierra bordering the coast); there are also grasslands (North and Northwest of the state), scrub and grass-covered areas, palm groves, mangroves and tulare wetlands (coastal zone) (IIEG, 2014).

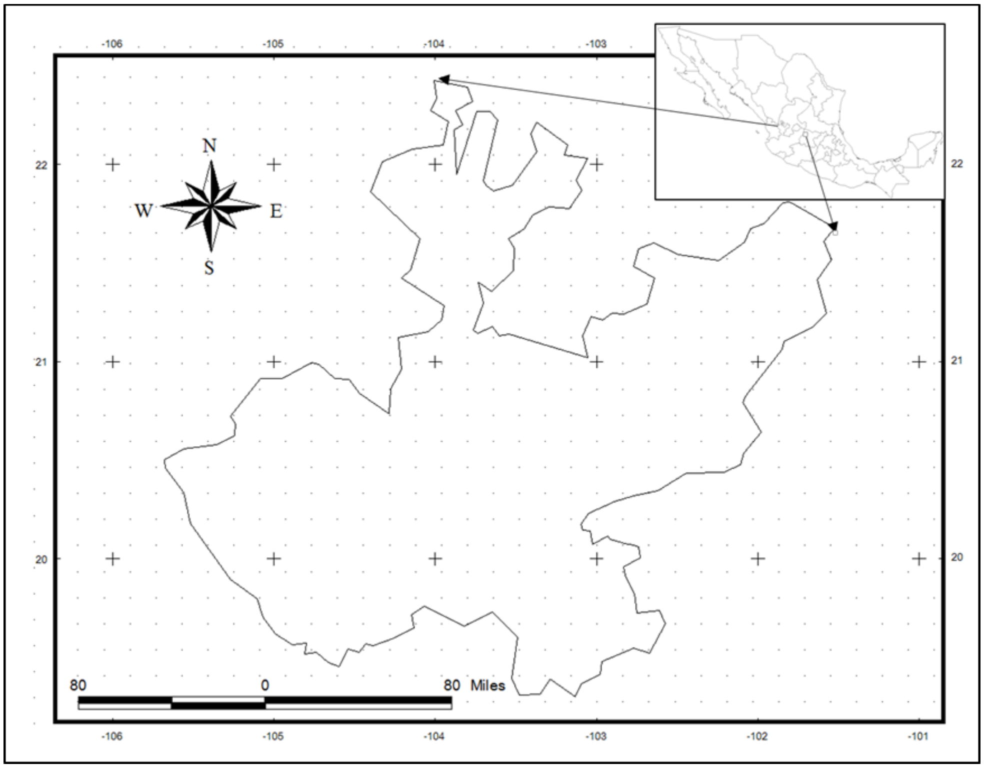

Figure 1— Location of the study area, corresponding to the state of Jalisco, Mexico.

Wildfire occurrence

On average, in the state of Jalisco, between 17,000 (SEMADET, 2014) and 20,761.58 (figure estimated based on data from the CONAFOR Database, 2015 fire occurrence record) hectares are burned each year, with an average number of 500 (SEMADET, 2014) to 566 (CONAFOR, 2015) fires per year. The type of vegetation most affected is grassland, with an average of almost 7,000 ha per year, followed by forest areas with shrubs and scrub, where each year an average of almost 6,000 ha are burnt. On average, 2,500 ha of areas with adult trees are burnt per year (SEMADET, 2014).

Reference sites

This project defines the sampling unit area that would be most suitable for capturing variability in the number of wildfires. For this purpose, a number of areas, termed reference sites (RSs), were analyzed. These sites were circular polygons, defined with the following areas: 1, 2, 4, 8, 10, 15, 30, 50, 70, 100, 150 and 200 km². These polygons were located concentrically in the sampling sites. And subsequently, based on statistical fire information obtained from CONAFOR (2005 - 2013) (*figure* 2), each of the wildfires reported was located geographically. This allowed for making a count and record of the fires that were located within each RS (*figure* 3). On the other hand, four sampling intensities (100, 300, 500 and 1000 points) were established in order to capture the variability in the number of fires that could occur due to the density of sampling points. In all cases, sampling was distributed completely at random throughout the state of Jalisco, Mexico.

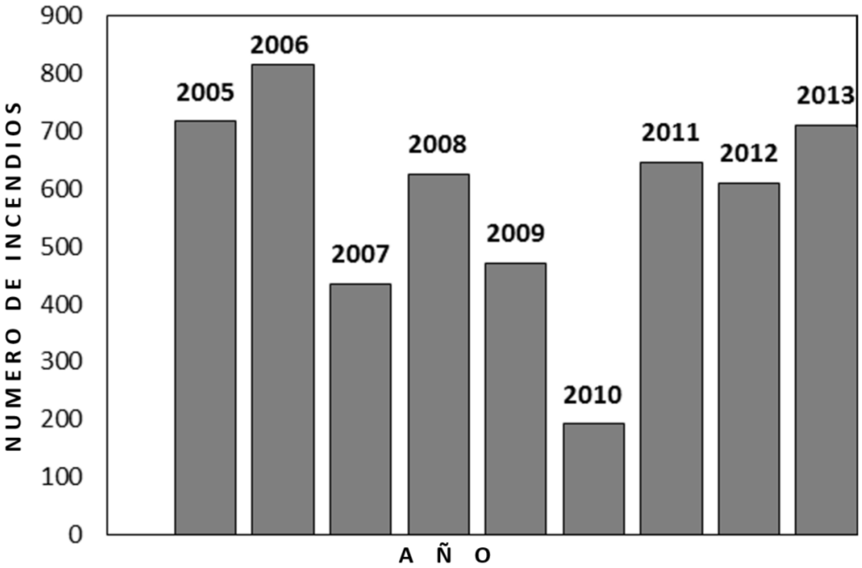

Figure 2— Number of fires per year in the state of Jalisco, from 2005 to 2013 (CONAFOR, 2015).

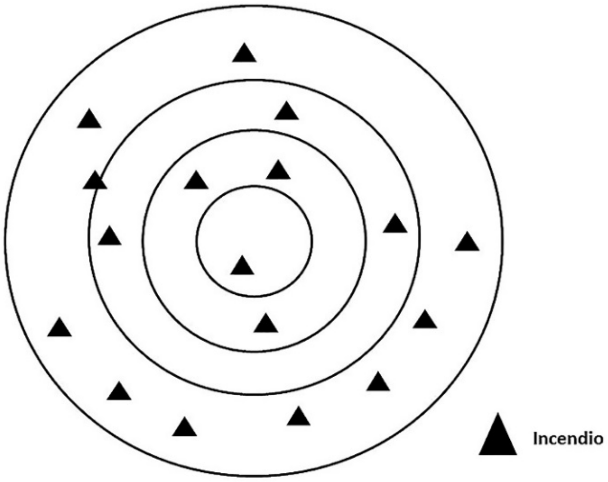

Figure 3— Theoretical schematization of the location of wildfires in reference to the variation in areas analyzed.

Analysis of variability

Considering each one of the four sampling intensities indicated, the number of fires in each of the corresponding RSs was determined. Based on this, descriptive statistics were generated in relation to the number of fires for each of the twelve areas analyzed. On the other hand, through analysis of variance and Tukey's range test, we determined whether the difference between the number of fires per area was significant. Subsequently, to define the RS area that captures the variability in the number of fires, the variation in this variability (coefficient of variation) in relation to the 12 RS sizes was plotted. As a criterion of variability, the coefficient of variation was used, since it describes the amount of variability (in relation to the mean) without being based on the units. Therefore, unlike standard deviation, the dispersion of the different sampling intensities used in this study can be compared, regardless of the difference in their means. These graphs were generated independently for each of the four sampling intensities tested. In these graphs the RS area where the variability trend initiates an asymptotic behavior was determined. This, in turn, enabled determining the Risk Factor, which means the number of fires that are located within this area (RS).

Results and discussion

RS statistics

Based on the four sampling intensities tested (100, 300, 500 and 1000 sites), the statistics corresponding to the different site sizes evaluated were calculated (*table* 1). Regardless of site size, the minimum value was zero fires, while the maximum number of fires per site was from 8 (in 1 km^2) to 276 (in 200 km^2). On the other hand, according to the means and modes, it can be deduced that in most of the sampled RSs there was no fire. As for the variability, considering the coefficient of variation, it begins to stabilize from the 70 km^2 site size.

Table 1— *Statistics on the number of sites that are located by site size, in relation to the sampling intensities*.

	Intensidad de	**Tamaño del sitio (km^2)**											
Estadístico	**muestreo**	**1**	**2**	**4**	**8**	**10**	**15**	**30**	**50**	**70**	**100**	**150**	**200**
Media	100	0.01	0.06	0.16	0.37	0.49	0.74	1.5	2.44	3.33	4.66	6.75	8.97
	300	0.05	0.09	0.23	0.47	0.55	0.8	1.48	2.45	3.32	4.62	7	9.41
	500	0.05	0.11	0.21	0.42	0.53	0.77	1.41	2.36	3.31	4.73	7.36	9.89
	1000	0.04	0.08	0.15	0.3	0.38	0.61	1.26	2.11	2.92	4.18	6.31	8.53
Error típico	100	0.01	0.03	0.05	0.12	0.16	0.21	0.37	0.57	0.76	0.94	1.22	1.57
	300	0.02	0.03	0.09	0.15	0.16	0.2	0.3	0.45	0.56	0.7	0.96	1.19
	500	0.01	0.03	0.05	0.09	0.11	0.15	0.24	0.36	0.44	0.58	0.83	1.06
	1000	0.01	0.01	0.02	0.04	0.04	0.06	0.12	0.18	0.22	0.3	0.41	0.53
Desviación estándar	100	0.1	0.28	0.53	1.24	1.6	2.14	3.67	5.72	7.55	9.41	12.24	15.7
	300	0.34	0.55	1.51	2.59	2.74	3.5	5.25	7.8	9.67	12.21	16.61	20.62
	500	0.25	0.77	1.23	2.09	2.55	3.45	5.47	8.14	9.89	12.88	18.48	23.83
	1000	0.31	0.43	0.69	1.15	1.41	1.96	3.66	5.62	7.1	9.39	13.09	16.82
Varianza de la muestra	100	0.01	0.08	0.28	1.55	2.56	4.6	13.46	32.73	57.07	88.49	149.8	246.5
	300	0.12	0.3	2.28	6.68	7.51	12.24	27.53	60.8	93.48	149.1	275.9	425.1
	500	0.06	0.6	1.51	4.37	6.49	11.89	29.96	66.22	97.89	166	341.5	567.8
	1000	0.1	0.19	0.47	1.33	1.99	3.84	13.43	31.53	50.44	88.26	171.5	283
Coeficiente de variación	100	10	4.63	3.29	3.36	3.26	2.9	2.45	2.34	2.27	2.02	1.81	1.75
	300	6.43	6.12	6.66	5.46	4.95	4.35	3.55	3.18	2.91	2.64	2.37	2.19
	500	5.19	7.19	5.87	5.03	4.83	4.5	3.89	3.45	2.99	2.72	2.51	2.41
	1000	8.36	5.74	4.62	3.86	3.73	3.22	2.91	2.67	2.43	2.25	2.07	1.97

Risk Factor (RF)

Figure 4 defines the variability, based on the coefficient of variation, in relation to site size, where it can be seen that the variability in the number of fires decreases as the RS size increases. This occurs at all sampling intensities, until reaching an asymptote, where the coefficient of variation values tend to stabilize. In the case of the sampling intensity of 100 sites, the coefficient of variation (CV) begins to stabilize at a site size of 40 km^2, reaching an asymptotic behavior when the RS area is between 80 and 100 km^2. For the sampling intensity of 200, the asymptote of the curve starts at the 100 km^2 RS. On the other hand, the sampling intensities of 300 and 500 sites defined similar trends in the CV decrease, with the CV beginning to decrease, approximately, at a site size of 80 km^2, while CV stabilization is defined between the RSs of 120 and 140 km^2. Finally, the variability trend in the 1000-site sampling intensity starts an asymptotic behavior between 60 and 80 km^2, approximately reaching the lowest CV at a RS size of 100 km^2.

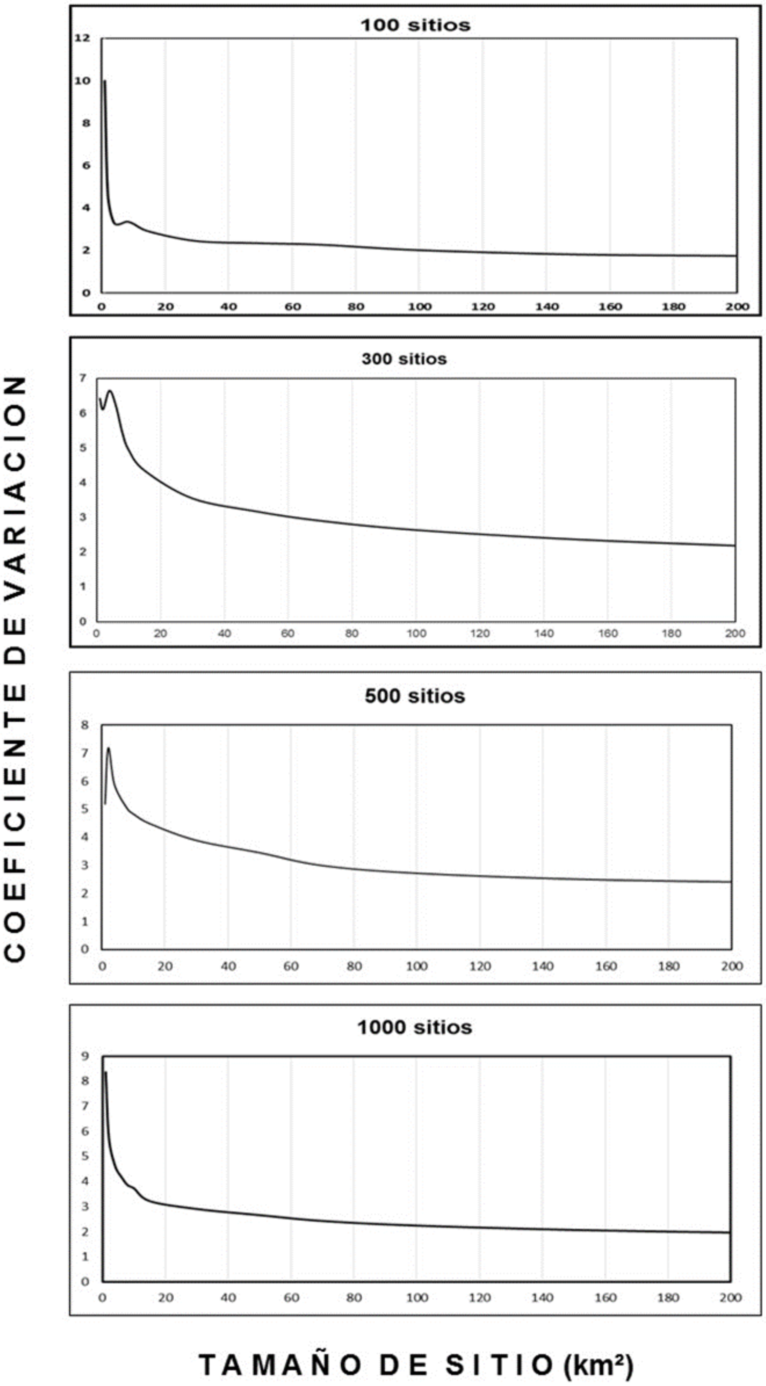

Figure 4—Coefficient of variation trend in relation to site size, for different sampling intensities.

According to the above, it is considered that, in general, the asymptotic behavior of the CV occurs at a RS size of approximately 100 km^2; therefore, this area was used to define the Risk Factor. Although, in the cases of the sampling intensities of 300 and 500 sites, the asymptotic behavior is more clearly defined in between the RSs of 120 and 140 km^2, the reduction of the CV that is achieved, in relation to the 100 km^2 RS, is not significant. This is corroborated by comparing the CV values that are determined at each of the sampling intensities tested (*table* 1); the CV values are very similar among the different sampling intensities, considering a RS of 100 km^2, being 2.01864, 2.64275, 2.72100 and 2.24920 respectively for 100, 300, 500 and 1000 sites sampled. Based on all this information, the risk factor is conceptualized as the number of fires that are located in a circular 100 km^2 area.

Number of fires per hectare

The Risk Factor (number of fires in 100 km^2) can also be referred to as the number of fires per hectare (NFH). *Figure 5* shows the NFH trend, estimated based on the number of fires located on average in each of the site sizes tested, which, in turn, are differentiated by each of the sampling intensities tested. NFH values ranged from 0.00010 to 0.00060. As can be seen, there is a high variability in the number of fires per hectare in the RSs of less than 30 km^2, even when considering the different sampling intensities. On the other hand, after the 30 km^2 RS size, the NFH average stabilizes between 0.00040 and 0.00050. The sampling intensity that showed the greatest variability was that of 100 sites, while the intensities of 500 and 1000 sites showed a more constant trend. Finally, the RS size of 100 km^2 defines a stabilization in the number of fires per hectare.

Considering the above, analyses of variance were performed for the sampling intensities of 500 and 1000 sites. In both cases the differences were significant (p= 0.0001). This implies that there is a difference between the numbers of forest fires that are located in each of the 12 site sizes. *Figure* 6 shows the comparative relationships resulting from the Tukey test, with which each site size was compared to all others. It is noteworthy that, for the sampling intensities of both 500 and 1000 sites, the means of the RSs of 100, 150 and 200 km^2 turned out to be different in comparison to the rest of the RSs.

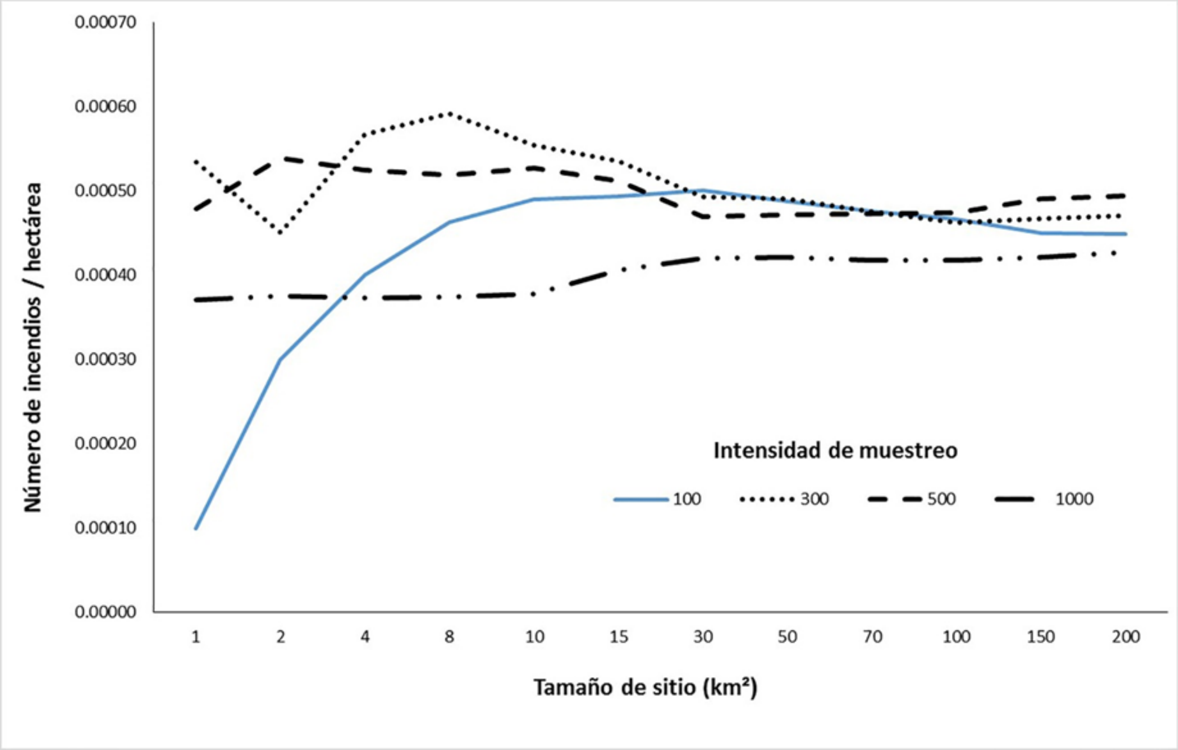

Figure 5—Behavior of the mean number of wildfires per hectare, by site size and sampling intensity.

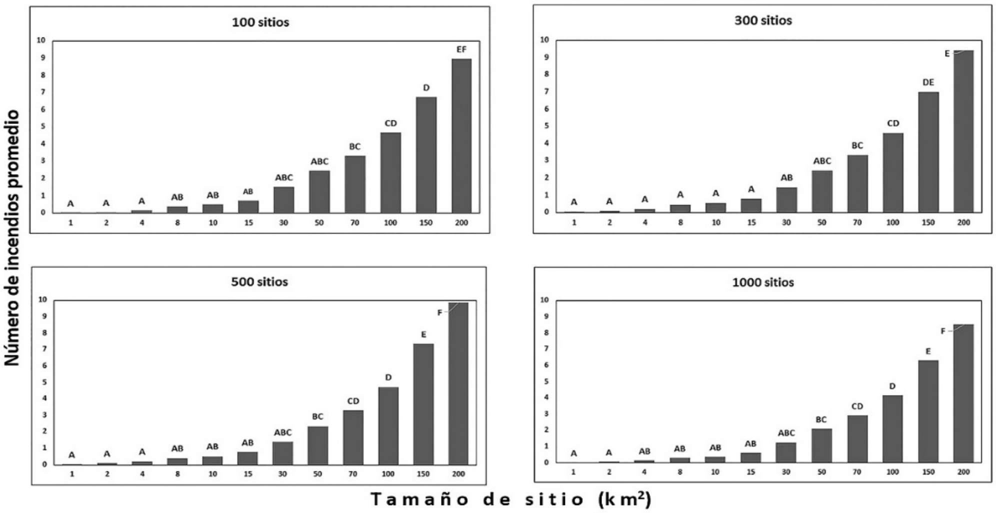

Figure 6—Results of the comparison of means (Tukey's test) of the different site sizes in relation to the sampling intensities

Conclusions

Based on the results of this study the following conclusions are defined:

1) The variation in the number of fires begins to stabilize, approximately, at a RS size of 100 km^2.

2) The different sampling intensities defined similar trends in terms of the variability of the number of fires.

3) The Risk Factor (RF) is conceptualized as the number of fires detected within a circular 100 km^2 area.

4) There is a significant difference in the number of fires located in the different RS sizes.

5) Although it is possible to define the number of fires per hectare (NFH), its estimate is based on the RF definition. Therefore, it should only be used for comparative purposes when the area to be analyzed is less than 100 km^2.

6) The RF can be used to support the definition of a standardized validation strategy in the definition of wildfire risk areas.

7) Based on the RF, the number of wildfires in a number of sampling sites can be determined. Therefore, one can not only make comparisons, but also share information between different areas.

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Valuation of the Economic Impact of Wildland Fires on Landscape and Recreation Resources: A Proposal to Incorporate them on Damages Valuation[1]

Juan Ramón Molina[2], Francisco Rodríguez y Silva[2]

Abstract

Even when they account for a large part of damages caused by forest fires on environmental and landscape services they are seldom included in the valuation of damage assessments. Some fires within natural parks have caused significantly larger impacts on these environmental and landscape services (nonmarket) than on market services.

The economic valuation of forest fires impacts on environmental and landscape services requires indirect valuation techniques like the travel cost or contingent valuation methods. There are differences on welfare estimates depending on the geographic zone analyzed; In the Natural Park de Aracena y Picos de Arrocho, for example, varying between 25-91 €/visitor. For the same area the recreation and leisure valuation reaches upwards of 21€ million.

The methodological process goes beyond a simple economic valuation because it includes the resources net-value-change depending on fire intensity level. Using an inventory of 14 fires and a survey we developed a resource depreciation net-value-change matrix of environmental services values or depreciation based on fire intensity levels, which is directly related to flame length. Geographic Information Systems (GIS) smooth the integration of fire behavior information and the economic valuation providing a tool for the analysis of the territory economic vulnerability. This allows for the methodological procedure to be used in a prevention mode (through the fire potential behavior) or in a post-fire mode (through a field inventory). With the objective to identify the relative importance of the leisure recreation and landscape services resources within a burned area we provide an economic valuation of fire economic impact for four fires (Obejo, Cerro Vertice, Cerro Catena, and Alhama).

Keywords*:* depreciation rate, socioeconomic vulnerability, travel cost valuation

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[1] An abbreviated version of this work was presented at the Fifth International Symposium on Fire Economics, Policy, and Planning: Environmental; Services and Wildfires, Tegucigalpa, Honduras; 14-18 Nov 2016.

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Introduction

Occurrence of a forest fire implies economic impacts not only on nonmarket values, but also on landscape and environmental services resources (Kerkviet y Novell 2000). Given its valuation difficulty, these values are generally left out of post-fire expert valuations. However, socioeconomic changes have lead a resurgence in the value of second or recreation homes located in forest areas, mostly on protected natural spaces (Navarrete and González 2003).

Valuation of landscape values requires using indirect methods like travel cost, contingent valuation or hedonic prices (Christie y otros 2006, Lasanta y otros 2006). Use of any of these methodologies create some controversy as they are conditioned by the sample. In this application we will use the travel cost method that uses the consumer's willingness-to-pay as an indicator. Consumer surplus represents the difference between what the consumer is willing to pay for a good or service and the actual amount paid. Considering different cost types imply important differences in the demand curve, and consequently, in consumer's surplus (Azqueta 1996). Travel costs can be divided in two categories, fixed cost (fuel, time, depreciation, etc.) and variable costs (food, lodging, etc.).

The use of Geographic Information Systems (GIS) allows us to measure natural resources values by fire intensity and vegetation class (Zamora et al. 2010, Molina et al. 2009). The georeferenced valuation of natural resource improves not only post-fire economic valuation, but also provides a preventive tool facilitating budget allocation and land management planning (Rodríguez y Silva and González-Cabán 2010). By identifying the location of recreation activities, based on each activity demand, GIS permits the estimation of its economic potential. Therefore, the georeferenced valuation of landscape or recreation services becomes a useful tool for the optimization of prevention activities or damages or impacts mitigation by including resources not generally considered, even though they represent an important component of the ecosystem total value.

The main objective of this work is to propose a methodological procedure for the economic valuation of losses in recreation resources caused by wildfires. This proposal is more than just an economic valuation, because it includes fire behavior components (intensity), and vegetation resiliency, which is a measurement of the landscape vulnerability pre or post fire. As examples, we include preventive applications (Natural Park de Aracena y Picos de Aroche), and post fire application (de Obejo, Cerro Vertice, Cerro Catena, y Alhama fires. We performed an analysis of each zone relative values to test for significant differences between the studied fires.

Materials and Methods

Study Area

In this study we use two scales, one for preventive measures application at landscape level, the other a fire scale for post-fire application. The preventive measure application was used in the Aracena y Picos de Aroche Natural Park in Huelva Province, southwestern Spain (figure 1). The Park total area is a little over 186,000 hectares and changing landscape depending on sun exposure and altitudinal gradient. The rural economy depends on tourism and production of the Iberian swine. The vegetation is dominated by oak species used in an extensive agro-pastoral (dehesa) system, with extensive areas of chestnut trees; also pine plantations, and also scrub zones.

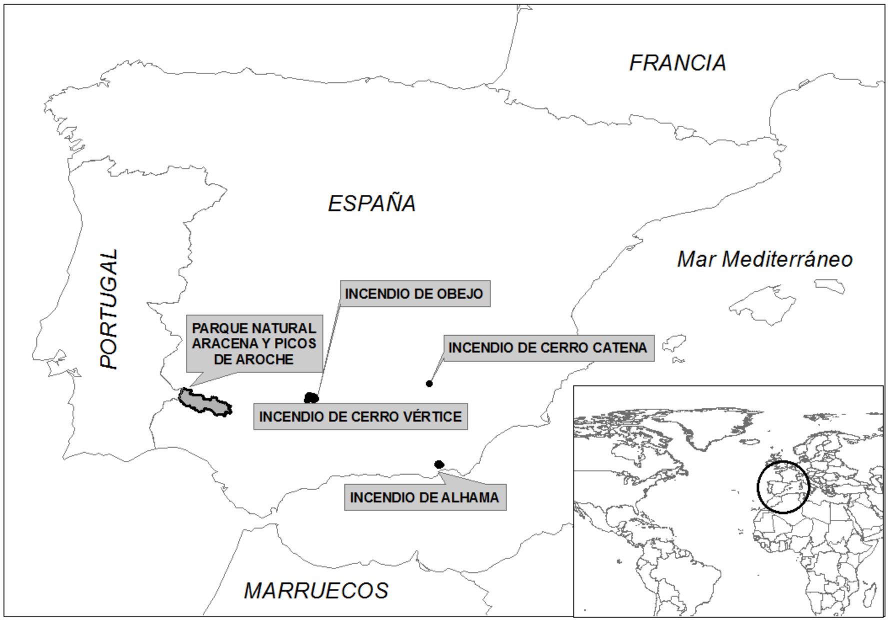

Figure 1- Study area showing fires evaluated and natural park location.

The post-fire application was done for four fire with different vegetation (Figure 1). The Obejo fire affected almost 5,000 hectares, and Cerro Vertice fire almost 150 hectares of private, unsuitable for tourism and lack of infrastructure lands. Though not in a protected area, the Alhama fire (3,260 hectares) was included because it had potential for greater damages due to its location close to urban centers and high presence of hikers and bikers. Finally, the Cerro Catena fire (209 ha) occurred within one of the largest natural spaces in Iberian Peninsula subject to a tourism demand.

Economic valuation: travel cost method

Using the travel cost method (TCM) to value recreation resources requires implementing a survey questionnaire to identify visitors' characteristics and incurred expenses to a recreation area from different zones. The survey questionnaire consisted of three related sections: the first contains information related to basic fixed costs incurred (point of origin, transportation mode, gasoline expenses, etc.), the second contains information on incidental expenses to the trip (lodging and meals costs, etc.), and the last one inquiring about the type of activities performed during the visit and how a fire would affect their visitation to the area.

The demand function can be estimated by individual visitors or by demand zones based on trip point of origin (Haab and McConnel 2002). In our case we used a zone demand model. Consumer surplus was estimated considering the fixed and incidental costs based on four distinct zones: <75 km; 75-150 km; 150-250 km; and >250 km, given the cost differences between the visitors from surrounding towns and those coming from large cities (Figure 2). Transportation costs are estimated based on a mean fuel cost of 1.1 €/liter (mean value for the period 2014-2016) and an average fuel consumption of 11-17 km/liter. In Spain the cost of time is estimated as 8 €/h (Gutiérrez 2008) or 4.85 €/h (Riera et al. 1994). Though the general trend is to use one third of the average wage as the cost of time, more recent studies are suggesting using 50% of the average wage (Wolff 2014). Given that in Spain the average wage is 15.7 €/h (2014), the cost of time would vary from 5.24 €/h y 7.85 €/h whether we use one third or half of the average wage. Because we do not have updated information on the true cost of time in Spain, we chose to use the average of the one third and one half of the average wage or 6.54 €/h.

The mean consumer surplus is then the product of the consumer surplus for each defined zone times its visitation rate from each zone. The annual recreation value is the product of the mean consumer surplus and the number of visitors (from official Natural Spaces visitation statistics and by estimating the direct number of visits or the expert opinion of environmental offices present in the zones). We can also use a proportional apportionment based on the zones landscape qualitative value similar to the proposed by Molina et al. (2016) for the Aracena y Picos de Aroche Natural Park.

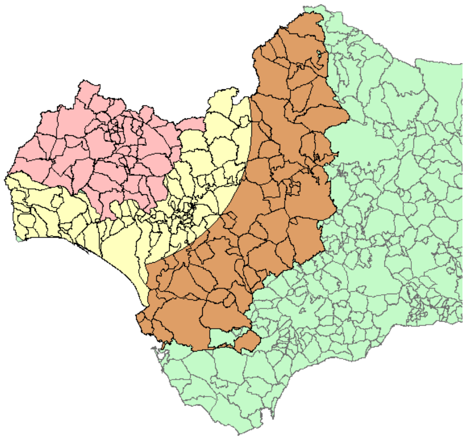

Figure 2-Demand zones identified for the travel cost model valuation of the Aracena y Picos de Aroche Natural Park.

Economic valuation of the fire impact on the recreation resource

To value a fire's economic impact on a zone requires identifying the mean recovery or a resiliency period. Measured as the landscape adaptation and recovery after a fire, the fire intensity and the floristic composition determines an ecosystem resiliency. Therefore, losses are directly proportional to the time of recovery or updating of the economic losses; though there are cases, like areas of pastures without trees where the fire effect can be positive. Damages can be estimated by the following formula:

$$P = V \frac{(1+t)^{\wedge n - 1}}{t(1+t)^{\wedge n}} \tag{1}$$

where P are losses in an area completely affected (€/ha), V is the annual value estimated using the travel cost method (€/ha), t is the annual interest rate, and n is the landscape recovery time (in years) to a pre-fire condition. For the study area we use a recovery period between zero (0) years (for pastures without trees and cattle ranching where fire effect is positive) to 70 years for densely populated chestnut tress areas.

As noted, equation 1 estimate the losses for an area completely affected, that is with a maximum flame severity. However, the fire behavior is not homogenous depending on fuels present, topography and weather conditions. Therefore, it is necessary to perform an analysis of the potential fire behavior in the area evaluated using spatial simulators, and a field inventory or satellite imagery for post-fire valuation. The final valuation of the fire's impact is the product of the total valuation and the resource depreciation value, which depends on the flame's intensity (equation

2). Therefore, the proposed tools is more than just economic valuation for it reflects the landscape vulnerability of an ecosystem to fire.

$$I = P * (RD) \qquad (2)$$

Where P is defined as before (€/ha), and RD is the resource depreciation rate. The resource depreciation rate is an x amount of one unit of the original landscape depreciation value.

Determining the depreciation rate for a nonmarket resource, such as the use value of an open space, is complicated requiring the use of indirect valuations. For our case we used average depreciation values as a function of the fire intensity that is directly related to flame length (Alexander and Cruz 2012). We determine the values after visiting 14 fires in Andalusia and recreation association's opinion, and the rooms (lodging) demand based on average seasonal occupation rate in relation to the number of pre-fire years.

Results

Economic vulnerability of the recreation resource

A little over 600 in-person interviews were conducted in the valuation of the resource recreation at Aracena y Picos de Aroche Natural Park. After accounting for bad responses, passing by visits, and decline to participate, a total of 500 useable surveys were obtained, for an effective response rate of about 82%; highest response rates were obtained at hotels interviews. The estimated consumer surplus by the four zones identified ranged between 25 and 91 euros. Based on these estimates and a visitation rate of 130,000 annually, the total annual recreation value of the Natural Park ranges between 3.3 and 11.9 million €.

The total recreation value was then proportionally distributed over the landscape based on the zone recreation and tourism infrastructure, and its landscape value (Molina et al. 2016). The two most highly rated activities for the area were hiking and picnicking. As economic theory asserts, the areas closest to the Park provide the greatest visitation rates. We distributed the total recreation value estimate over the landscape by pixels considering the quality of the landscape and the preventive infrastructure. Likewise we assigned an average resiliency period and average fire behavior based on flame length. Using the different fire intensities and social preferences in the 14 fires analyzed we developed a logarithmic function between the depreciation rate (%) and flame length (equation 3).

$$RD= 0.265 \ln(x) + 0.0837 \qquad R^2 = 87 \qquad (3)$$

Where RD is as previously defined and x is the mean flame length in meters.

Using the economic relationships developed in the methodology, and assuming a potential mean fire behavior, the total economic impact of fire on the Arecena y Picos de Aroche Natural Park is between 21 to 76 million €; this is 7 times more than the annual recreation value of the area.

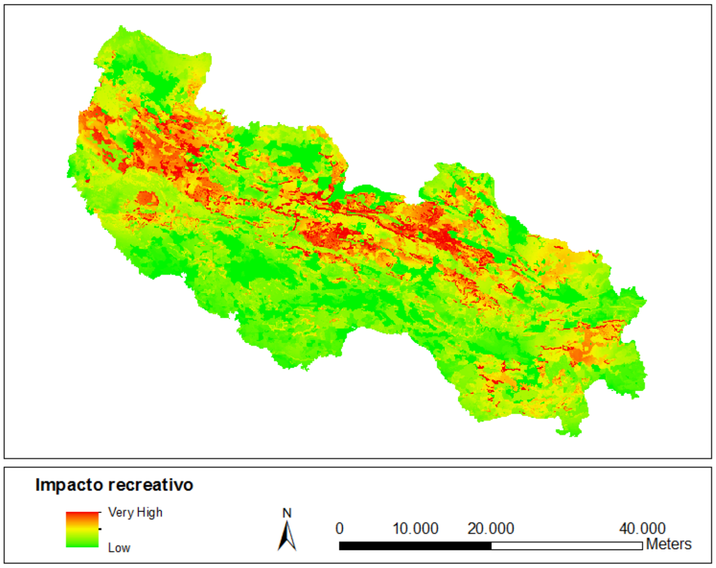

Figure 3- Potential economic impact of qualitative valuation of the recreation use in the Aracena y Picos de Aroche Natural Park.

Economic impact of fire on the recreation resource

As in the previous case, we had to value the recreation resource, using a similar methodology, and an inventory of fire intensity levels to determine the economic impact of fire on the recreation resource. Having collected this information and using a fire severity vegetation map, and all 14 analyzed fires we determine and assign a resiliency period for each vegetation grouping. Because we had georeferenced information for each of the fires were able to prioritize the restoration actions (Figure 4).

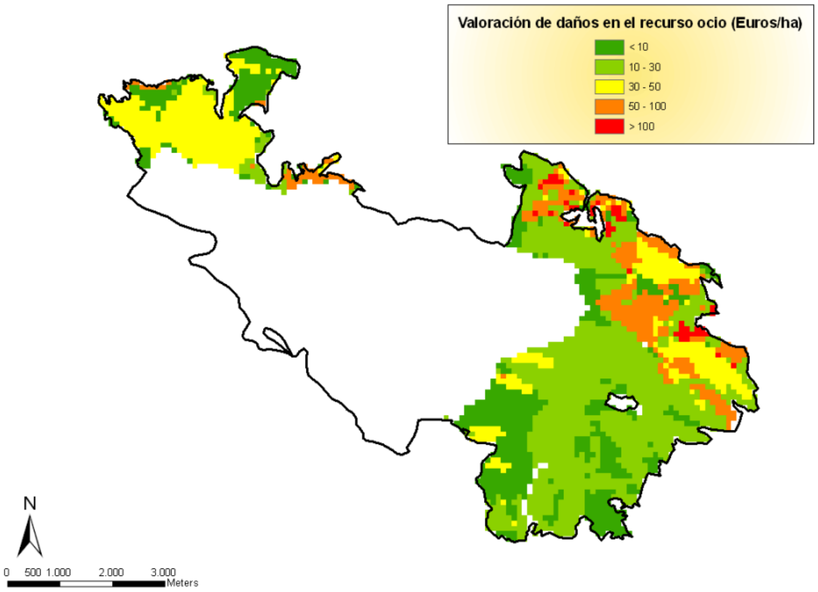

Figure 4- Georeferenced valuation of the economic impact of the Obejo fire on the recreation resources.

Based on the fire burned zones characteristics the economic impact on the recreation resource ranged between 27.78 and 175.72 €/ha (Table 1). In terms of the resource relative importance within the valuation had a range between 3.9 to 13.98%. The importance of the recreation resources close to natural protected areas was the highest at 13.98%, while in places close to urban centers was 11.78%. In the most remote locations the economic impact of fires was 5.31% (±1.99).

Table 1-*Recreation resource valuation for the four fires considered.*

Fire	Mean impact (€/ha)	Relative importance (%)
Obejo	27.78	3.9
Cerro Vertice	36.55	6.72
Alhama	23.75	11.78
Cerro Catena	175.72	13.98

Discussion

Even though the application of TCM to value the economic impact of forest fires has not been applied in Spain, the use of this methodology for recreation resources valuation is an alternative (Riera et al. 1994, Navarrete and González 2003). Not using this tool usually results in an undervaluation of economic impacts from forest fires (Molina et al. 2009). Though the methodology could be subject to criticism because of the sample design and selection we believe, as stated by the United

Nations Food and Agriculture Organization (FAO) (1997): *the economic valuation of natural resources is relevant and useful up to the point that helps managers to make informed decisions. It is possible, even before we have enough information to obtain an exact value, to reform institutions and policies, and stimulate a more sustainable land management, and discourage natural resources depletion.*

Because of the high differences (upward of 8 million euros) in the annual recreation values in the two methodological approaches, it is necessary to caution the need to consider an uncertainty threshold in the valuation of the recreation resources. However, given the importance of tourism for the area's rural development in the study area, we believe necessary incorporation of the incidental costs as a fire could potentially cause the a reduction of the recreation activity itself, even closing the recreation infrastructure analogous to other Andalusian protected spaces (Molina et al. 2009). Although in the short run the recreation vulnerability is high, the recovery periods are not long given the Mediterranean species adaptation to fire and the presence of large swath of lands in the *dehesa* agro-pastoral system (Molina et al. 2011). In this regard, the total recreation vulnerability of the Natural Park is multiply by 7; that is, there is a recovery period of only 7-8 years in the whole Park area.

We included the depreciation rate based on the flame length average value and its direct relationship to fire intensity (Alexander and Cruz 2012) because the simplicity and dynamism required by forest managers making the post-fire valuations. Flame length is the easier parameter to identify in-situ (Zamora et al. 2010) for adjusting the depreciation or damage rate. This equation allows the use of the methodological approach in the preventive mode (determining potential behavior through simulations) and for the post-fire valuation. The methodology application in a preventive mode is a useful tool for landscape scale planning level and budget allocation to mitigate flame caused damages. Its use on valuation of large forest fires can be complemented with satellites imagery (Rodrigues y Silva et al. 2013)

The importance of the recreation resource in the protected natural spaces (Cierra Catena fire) is reflected on the recreation impact analysis of the four fires considered here, as well as in areas around urban centers (Alhama fire). In these two cases its importance is >10% of the total impact, even though there is serious under valuation of damages because they are not normally valued.

Though the relative importance of the recreation resource in the Catena fire does not represent a proportional increase at only 13.98%, the value by unit of area burned of the fire is very high compared to the other fires (175.72 €). This can be due to the importance of the timber resource, carbon dioxide sequestration, and erosion protection in protected natural spaces. In the Alhama fire recreation and leisure represent a high relative importance due in part to the absence of important timber species (no timber values or carbon dioxide sequestration), to the present infrastructure, and the closeness to urban centers. Finally, in the Cerro Vertice fire the largest resource weight respond to greater number of tree species and their closeness to a national road.

Conclusions

The abandonment of rural areas is due in part to the low economic value of Mediterranean forests; therefore, it is fundamental to perform an integrated valuation of natural resources. Forest fires managers should be responsible for knowing the need to incorporate all fire impacts to the valuation process, especially when they affect directly local communities. Their importance is greater in protected natural spaces or close to urban centers representing more than 10% of all total losses. We should not forget the contribution of preventive mapping to operational capabilities for decision making and budget allocation.

Acknowledgements

Funding for this project was provided by Spain Ministry of Science and Innovation through project GEPRIF (RTA2014-00011-C06-01).

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Participatory Workshops with Experts on Fire Environments in Mexico to Generate Information on Forest Fuel Beds[1]

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Abstract

Generation of information about fire environments and forest fuel beds is essential to know the behavior of wildfires. Developing experimental models in laboratories can be costly and time-consuming. One alternative is to take advantage of the empirical knowledge of people with experience in fire management and wildfire fighting. In order to collect empirical information on the fire environment to evaluate and describe forest fuel beds in different ecosystems in Mexico, four participatory workshops were held. These workshops were held in four venues covering the North, Central, West and South regions of Mexico in August, 2016. Fire management experts, mainly wildfire fighters with several years of experience, were invited. During the workshops, a theoretical proposal for a forest fuel bed (FFB) map for Mexico was presented. Based on this FFB map, the experts answered, in working groups of three to seven people, a questionnaire that sought to describe FFBs, fire behavior, an empirical fire behavior index, topography and weather. The four workshops were attended by a total of 108 experts in fire management and fighting, with a combined 1385 years of experience in the subject. The participants were mainly wildfire fighters belonging to federal government agencies. There were also representatives from universities and research centers, civil society organizations and private companies. The participants provided information for 55 forest fuel beds and identified forest fire risk and hazard polygons in 30 states of the country. At the moment, the workshop results are being systematized and analyzed; afterwards, it will be useful to compare them with the results generated by theoretical fire behavior models and risk and hazard models.

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[1] An abbreviated version of this paper was presented at the Fifth International Symposium on Fire Economics, Policy, and Planning: Ecosystem Services and Wildfires, November 14-18, 2016, Tegucigalpa, Honduras. Abstract only available.

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Influence of Climate Change on Tree Vegetation: A Case Study of "Cerro Azul" Meambar National Park (PANACAM), Honduras[1]

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Abstract

Tree vegetation was evaluated through the establishment of 14 Permanent Monitoring Plots (PMP) in "Cerro Azul" Meambar National Park (PANACAM), located in central Honduras. The plots were distributed in four elevational ranges (900 - 1,200, 1,200 - 1,500; 1,500 - 1,800 and 1,800 - 2,080 m), where a total of 1,896 individuals belonging to 231 species, 135 genera and 69 families were recorded. No significant differences were found for richness, diversity and structure between the elevational ranges; however, there is a low similarity in species composition between ranges, where those that showed the greatest similarity share only 29% of the same species. Correlation tests showed that species composition is mostly correlated to mean annual precipitation followed by the temperature of the coldest month and elevation. On the other hand, no correlations were found with the precipitation of the driest month, slope and geographic coordinates. The modeling projected to 2050 using emission scenarios, one optimistic (B1) and one pessimistic (A2) of the Intergovernmental Panel on Climate Change (IPCC), showed that there is a high probability of reduced plant populations due to the projected change in the climatic variables under study. The A2 scenario is the one that has the greatest impact on the change in areas with species presence, which shows a loss of 300 of 9,200 modeled ha, with the areas with the highest elevation being the most affected. Although there was no significant difference for structure, richness and diversity along the elevational gradient, elevation is considered to be a determining factor in composition since the elevational ranges that presented the greatest similarity were those that were in continuous form, but not those with a greater elevational difference. Continuous ranges shared up to 29% of the same species, whereas the ranges with the highest elevational difference shared only 7% of the species.

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[1] An abbreviated version of this paper was presented at the Fourth International Symposium on Fire Economics, Planning, and Policy: Ecosystem Services and Wildfires, November 14-18 2016, Tegucigalpa, Honduras. Only abstract available.

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The Role of Native Peoples in Managing Natural Disasters[1]

Arnaldo Bueso[2]

Abstract

The leading role of native peoples in natural disaster management within the framework of the *Promotion of Food Security and Social Inclusion in the Lempa Region of Western Honduras Program* (PROSADE LEMPA) involves:

- Actions aimed at reducing the imminent risk to remnant forests and the most vulnerable populations due to "Natural Disaster" caused by fires and pests.
- The participation of key actors such as indigenous peoples, government, civil society, private enterprise and international cooperation in fire management.
- Systematization of PROSADE LEMPA's experience with vulnerable populations most affected by natural disasters.

Brief description of the Program

The program is run by CARE International, benefiting around 40 thousand people living in the 4 municipal groupings of the Lempa Region of Honduras.

Among these municipal groupings, the following are represented and prioritized: Association of municipalities of the Frontera de Intibucá (ANFI), and the grouping of the municipalities of San Andrés, San Francisco, Erandique and Gualcince Lempira (CAFEG, MOCLEMPA and MANCOSOL).

The main objective of this new project, PROSADE-LEMPA, is to eradicate the exclusion, vulnerability and extreme poverty conditions in Honduras. Therefore, interventions will focus on small-scale women farmers who do not benefit equitably from the economic growth of societies, as well as the Lenca indigenous peoples.

In total, 252 communities, 23 municipalities, two departments and 7,560 families, equivalent to approximately 40,000 people, are directly benefited.

The components of this innovative new program include: food availability and access, improved health with good hygiene and sanitation practices, food security governance, a drought early warning system and humanitarian aid.

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[1] An abbreviated version of this paper was presented at the Fourth International Symposium on Fire Economics, Planning, and Policy: Ecosystem Services and Wildfires, November 14-18 2016, Tegucigalpa, Honduras. Only abstract available.

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This publication is available online at www.fs.fed.us/psw/.

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