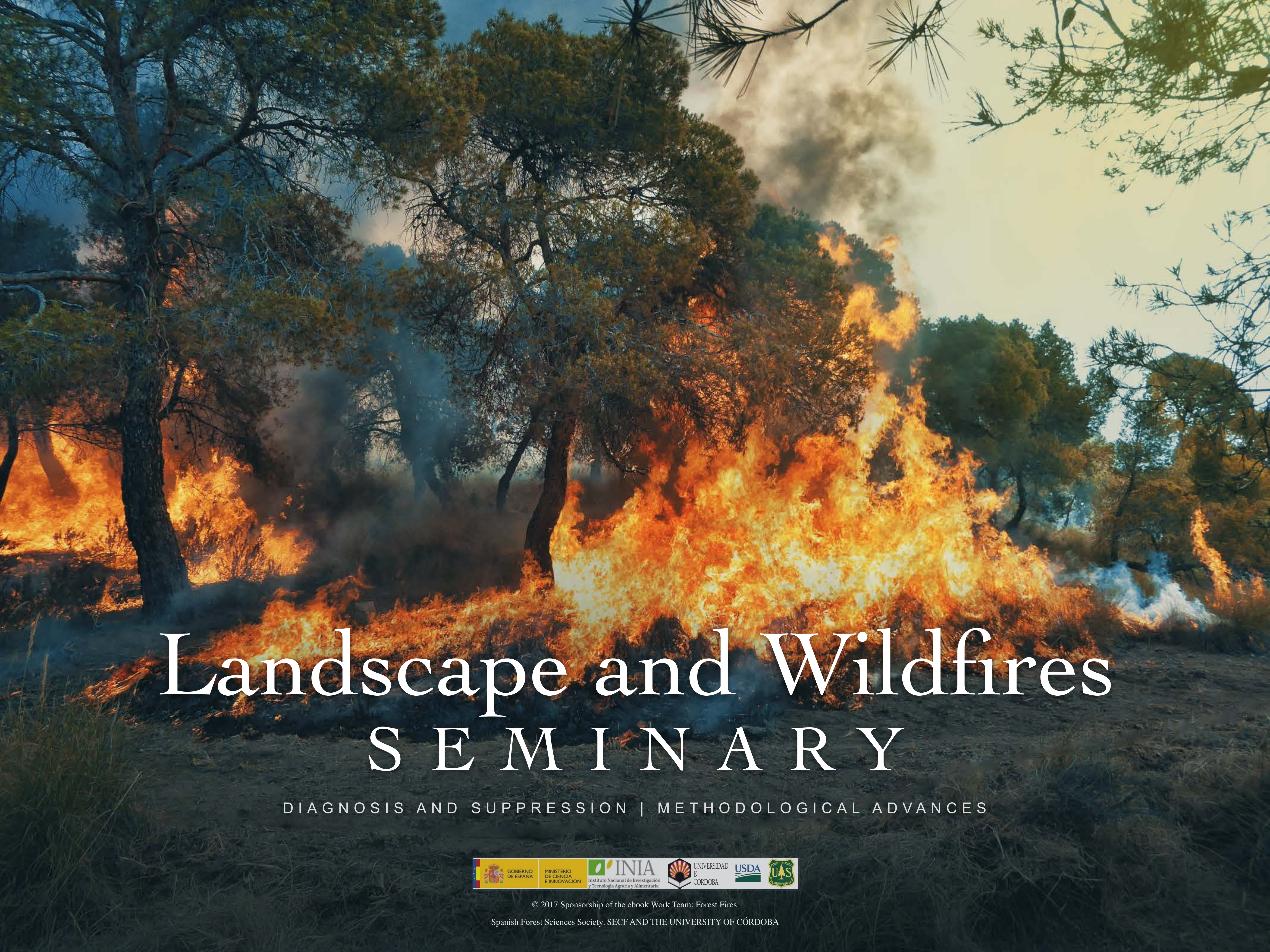

# Landscape and Wildfires SEMINARY

DIAGNOSIS AND SUPPRESSION | METHODOLOGICAL ADVANCES

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- Dr. David Calkin, USDA Forest Service
- Dr. Christopher (Kit) O'Connor, USDA Forest Service
- Dr. Matthew Thompson, USDA Forest Service

**Dr. Francisco Rodríguez y Silva**. Professor of Forest Fire Sciences and Management, University of Córdoba (Spain). Officier of the Forest Engineers Corps of Spain (1985). Director of the Program of Defense against Forest Fires in the Network of Natural Forests (National and Natural Parks) of Andalusia from 1986 up to 1994. Chief of the Department of Forest Fires of the Agency of Environment of the Andalusia Government (1989 to 1994). Chief of the Forest Fire Prevention and Forest Restoration Service of the Department of Environment (1994-1996). Associate Professor of the University of Córdoba, Forest Engineering Department (Agricultural and Forestry School) (1994 to 2001)). Full professor of Forest Fire Sciences and Management, University of Córdoba (Spain) (2001-present). Education: Forest Engineer, Polytechnic University of Madrid (1984). Fire Resource Management (Hinton Forest Technology, Alberta. Canada, 1993). Doctor of Engineering (Ph.D), Polytechnic University of Madrid (1998). Master of Applied Economics, National Distance Learning University of Spain, (2009). Master of Economic Research, National Distance Learning University of Spain (2017). Professor Rodríguez y Silva is head of the Forest Fire Laboratory (LABIF-UCO), Forest Engineering Department at the University of Córdoba (UCO). He specializes in forest fire risk management and decision making support, forest fire behavior, and fire economic planning. Since 1986, he has been involved with the Regional Forest Fire Fighting Plan of Andalusia «INFOCA», serving as head incident commander, director of the Regional Operations Center, and head of large fires. He has strong experience in forest fire operations, planning and coordination and is FAO assistant on Forest Fires and Forest Fires Coordinator for the Spanish Forest Sciences Society. Google Scholar profile. www.franciscorodriguezysilva.com

**Dave Calkin**, PhD, Supervisory Research Forester, Human Dimensions Program, US Forest Service Rocky Mountain Research Station, Missoula, Montana. Dave is the team lead of the Fire Management Science group (https://www.fs.fed.us/rmrs/groups/wildfire-risk-management-team) of the National Fire Decision Support Center working to improve risk based fire management decision making through improved science development, application, and delivery. Dave's research incorporates economics with risk and decision sciences to explore ways to evaluate and improve the efficiency and effectiveness of wildfire management programs. Dave received a BS in applied math from the University of Virginia, and MS in

# Researcher Biographies

effectiveness of wildfire management programs. Dave received a BS in applied math from the University of Virginia, and MS in natural resources conservation from the University of Montana, and his PhD in Economics from Oregon State University. Google Scholar profile.

**Kit O'Connor** , PhD, is an ecologist with the Human Dimension Program of the US Forest Service Rocky Mountain Research Station. His current work is focused on developing spatially explicit risk-based tools that support integrating operational fire response with sustainable landscape planning, fire responder safety, and efficient use of resources. Dr. O'Connor enjoys developing research products and translating them into tools that can be tested and adopted for use by land managers. His research background in disturbance ecology draws from forest ecology, fire science, entomology, dendrochronology, ecological risk assessment, and spatial analysis and modeling. He holds a Bachelor of Science from Penn State University, a Master of Science from the University of Quebec at Montreal, and a PhD from the University of Arizona. Away from the office, Kit enjoys trail running, skiing, biking, and backpacking adventures near his home in Missoula, Montana, USA. Google Scholar profile.

**Matthew P Thompson**, PhD, Research Forester, Human Dimensions Program, Rocky Mountain Research Station, U.S. Forest Service, Fort Collins, Colorado. Matthew P Thompson is a Research Forester with the Human Dimensions Program, which provides science-based innovation to help human societies develop sustainable relationships with their environment, and which seeks to better integrate social and economic sciences into natural resource planning and decision making. Matthew's research draws from risk, decision, and systems analysis to address complex challenges of contemporary forest and wildland fire management. Matthew received a BS in systems engineering from the University of Virginia, a MS in industrial engineering and operations research from the University of California, Berkeley, a MS in forest management from Oregon State University, and a PhD in forest engineering from Oregon State University, as well as a Certificate in Strategic Decision and Risk Management from Stanford University's Center for Professional Development. In 2016 Matthew received the Presidential Early Career Award for Scientists and Engineers at the White House. Google Scholar profile.

# Background

In 2015, researchers from the U.S. Department of Agriculture Forest Service, Rocky Mountain Research Station, Human Dimensions Program (hereafter U.S. Forest Service), and the University of Córdoba, Forest Engineering Department, Forest Fire Laboratory, Spain (hereafter University of Córdoba), entered into an official Memorandum of Understanding (MOU). The primary objective of the MOU is to jointly develop strategic fire planning models and decision support systems to promote cost-effective and efficient fuels and fire management. The broader goals of the research are to enhance firefighter and public safety, to reduce fire management costs, and improve adoption of risk management principles by the fire management community.

Since the creation of the MOU, the research team has shared data, gone on multiple field visits, prototyped several modeling frameworks, offered lectures for the Master Fuego program, presented seminars in Spain and the U.S., and published two peer-reviewed articles. In November of 2016, Dr. Francisco Rodríguez y Silva visited the Forestry Sciences Laboratory in Missoula, MT, where he participated in an expert workshop to discuss development of a fire responder exposure index. Later in February of 2017, Dr. David Calkin and Dr. Matthew Thompson visited the University of Córdoba, where they participated in a roundtable exercise involving participation from over one hundred fire managers from throughout southern Spain. In June of 2018, Dr. Rodriguez y Silva hosted Dr. Matthew Thompson and Dr. Kit O'Connor on a visit to the University of Córdoba that included several days of field visits to large fires (2017 Segura Fire, 2015 Quesada Fire) and natural areas, to discuss fire progression and incident response operations in Spain. This work culminated in the creation of a new generation of tools designed to characterize suppression difficulty index (SDI).

### eBook Objectives and Relevant Research

The purpose of this eBook is to summarize key findings and lessons learned from the workshop and roundtable exercises, and describe their relation to recent and ongoing research performed under the MOU. To begin we review two recent papers published by the research team that reflect our primary research objectives, and that will guide future research efforts.

# Background

*O'Connor, C. D., M. P. Thompson, and F. Rodríguez y Silva (2016), Getting Ahead of the Wildfire Problem: Quantifying and Mapping Management Challenges and Opportunities, Geosciences, 6(3), 35.*

This paper reviews the role of GIS-based assessment and planning to support operational wildfire management decisions. The authors focus on recent and emerging research that pre-identifies anthropogenic and biophysical landscape features that can be leveraged to increase the safety and effectiveness of wildfire management operations. Figure 1 identifies the three main areas of our research intended to support incident response decisions: wildfire risk assessment; spatial fire planning; and mapping responder safety. The responder exposure workshop held in Missoula focused on the third element, specifically on identifying potentially hazardous locations and safety zones to inform allocation of personnel and resources. Much of the discussion at the seminar in Córdoba, especially Dr. Rodríguez y Silva's presentation of the suppression difficulty index, and Dr. Thompson's discussion of potential control locations, focused on the ideas that were introduced in this paper.

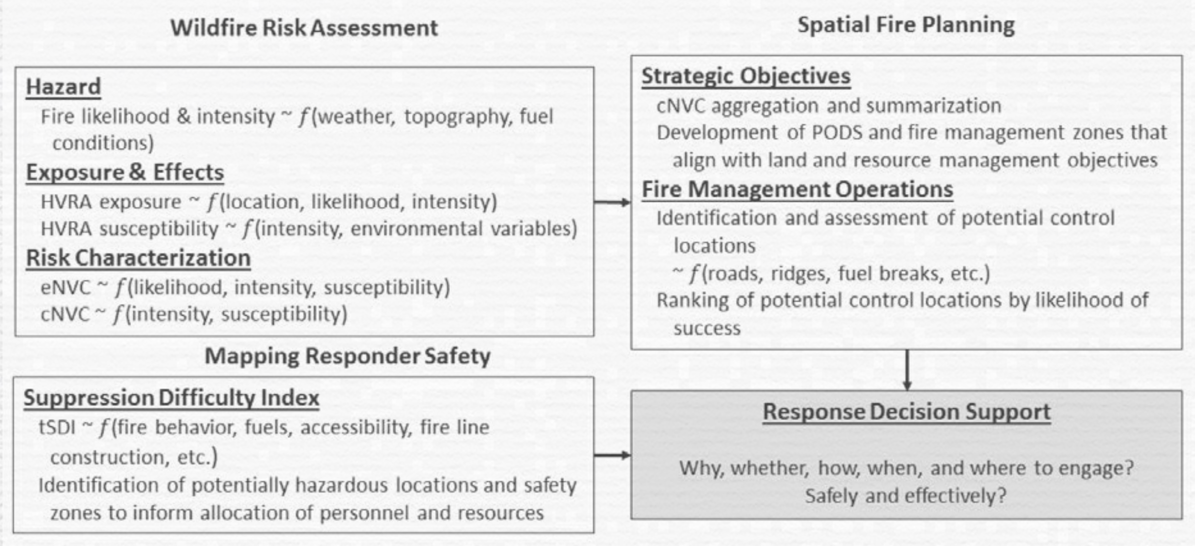


Figure 1: Flow diagram of pre-fire planning components that can be used to inform fire response decision support (O'Connor et al. 2016). The joint research described in this eBook focuses on these and related topics.

*Thompson, M.P., Rodríguez y Silva, F., Calkin, D.E., and M.S. Hand (2017), A review of challenges to determining and demonstrating efficiency of large fire management, International Journal of Wildland Fire, doi: 10.1071/WF16137*

This paper reviews challenges to determining and demonstrating efficiency of strategic approaches to managing low-probability, high-consequence large fire events. The review is organized around key decision factors such as context, complexity, alternatives, consequences, and uncertainty, and for illustration contrasts fire management in Andalusia, Spain, and Montana, USA. Despite differences in socioecological context (e.g., values-at-risk, fire regime, fire management policy), the analysis found

# Background

many common management and research questions, particularly those related to safe and effective suppression response.

Table 1 summarizes the key uncertainties highlighted in the analysis that challenge efficient management. Two of the primary challenges include quantifying the consequences of fire, and how they may change under alternative suppression strategies. Recommended avenues of research include: (1) empirical research to better characterize the productivity and effectiveness of suppression resources; (2) stronger incorporation of economic principles into ecosystem modeling; (3) stronger incorporation of principles from risk and decision analysis; and (4) improving and expanding the knowledge exchange across the global fire community. Much of Dr. Calkin's discussion at the seminar in Córdoba focused on challenges to determining efficient large fire strategies that were identified in this paper.

| Uncertainty | Issues and Considerations |
|---|---|
| **Fire Consequence Assessment** | |
| Fire effects | Data availability and sufficiency issues, impacts to ecological processes over space and time, gaps in basic and applied fire science |
| Non-market valuation | Limited utility of benefit transfer due to contextual specificity of existing willingness-to-pay studies |
| Fire spread potential | Landscape conditions, weather conditions, modeled fire behavior |
| **Incident Response and Suppression Consequence Assessment** | |
| Suppression expenditures | Sociopolitical pressures (e.g. community expectations, media coverage), managerial incentive structure, variability in decision maker behavior |
| Suppression resource productivity | Productivity of control efforts under different conditions and mixes of resources, intrinsic differences in crew capabilities and behaviors |
| Suppression resource effectiveness | Effectiveness of control efforts under different conditions and mixes of resources, probability of success, dispatch processes and resource arrival times |
| Counterfactual scenarios | How suppression efforts changed the fire behavior and outcomes that might have otherwise occurred |

Table 1: Uncertainties faced in large fire management (Thompson et al. 2017)

# Summary of Fire Responder Exposure Workshop, Missoula, USA
November 2016

# Fire responder exposure metrics and enhanced decision support to improve fire responder safety

*Dr. Kit O'Connor*

Dr. Kit O'Connor, Ecologist and analytics lead with the Rocky Mountain Research Station Wildfire Risk Management Science Team, organized an expert workshop to discuss development of improved fire responder exposure metrics and enhanced decision support to improve fire responder safety. The text below from Dr. O'Connor summarizes the main motivation and findings of the workshop.

While technological innovations over the past several decades have improved wildfire response capabilities, travel efficiency, communications, and spatial fire forecasting, they have not significantly reduced the number of fire responder fatalities (NIFC 2016). Firefighting is an inherently dangerous occupation, exposing fire responders to extreme environmental conditions while pushing the physical and mental limits of human exertion. Making the correct decisions under these conditions can mean the difference between safe, successful incident response, and unnecessary risk, exposure, and all-to-often, preventable fatalities. Extreme conditions during operational fire response are often interspersed with periods of reduced activity during an incident when responders and their commanding officers can become complacent even under continued exposure to a range of environmental and fatigue-related hazards.

The fire research community has stepped up efforts to address some of these concerns with higher quality dynamic weather

# Fire responder exposure metrics and enhanced decision support to improve fire responder safety

*Dr. Kit O'Connor*

(Jolly et al. 2019) and fire behavior forecasting (Finney et al. 2011), and spatial risk tools such as the hospital evacuation time model (WFDSS 2013). These tools are designed to reduce the risk of burn over incidents, to help with developing suppression strategies that consider all forms of injuries, and to explicitly recognize the increase in exposure to hazards with distance from medical facilities. To date there has been limited work to quantify and map out the challenges associated with wildfire response prior to fire ignition. In the first tool of its kind, Rodríguez y Silva et al. (2014) designed a method to quantify and integrate the suppression effort associated with physical landscape conditions, potential fire behavior, and available resources into a single index that can be mapped across a landscape.

This suppression difficulty index (SDI) provides a visual representation of the challenges faced by fire responders and can be used to prioritize treatment of fuels, creation of control features, and as a communication tool to discuss fire responder safety and suppression challenges and opportunities in advance of a fire season. SDI is the first fire risk metric that explicitly acknowledges the tradeoff between potential fire behavior and the availability of resources and strategies to mitigate fire hazards. The model has now been successfully applied to forests in Spain, Israel, Chile, and the western United States (RMRS Wildfire SDI 2018). An example of terrestrial SDI applied to the western United States can be seen here.

Advances in the calculation and application of suppression difficulty are ongoing and are being actively integrated into the forest and fire planning processes of fire managing agencies. In discussing the results from the SDI modeling process with fire management staff we heard from the field that they would like a similar type of tool that explicitly characterizes in situ hazards on any given landscape and under a range of potential fire weather conditions. These conversations were the impetus for the development of a new tool designed to address the specific factors most commonly associated with fire responder injury or death.In November of 2016, we convened a workshop with fire researchers, line officers, fuels specialists, and operational fire response staff to discuss the creation of a spatial fire responder exposure mapping tool. We wanted to emulate the methods used to create the SDI and apply them to the factors most likely to result in fire responder injury or fatality. We began with presentations detailing the application of SDI to forested

# Fire responder exposure metrics and enhanced decision support to improve fire responder safety

***Dr. Kit O'Connor***

landscapes of the Western United States and a review of additional tools currently under development that explicitly address the exposure of fire responders to hazardous conditions (Figure 2).


Figure 2. Dr. C.D. O'Connor presenting an overview of SDI applications and wildfire responder hazard research to date.

Some of the research areas where work has already been done include the hospital evacuation time algorithm (WFDSS 2013), wind-topography alignment index (Jolly et al. 2009), post-fire snag dynamics modeling (Dunn and Bailey 2012, Dunn et al. 2019), defining and identifying safety zones (Butler 2014, Butler et al. 2015), Accurately portraying mobility challenges (Campbell et al. 2019), and the severe fire danger index mapping tool (WFAS 2016, Jolly et al. 2019). This exercise was designed to stimulate thinking about the range of hazards, their prioritization, and how these might be quantified with spatial or temporal metrics that could be applied prior to a fire season to inform active incident response.

We then called on the expertise of the invited participants to develop a list of the highest priority hazards for wildfire incident response. Following much deliberation, an initial list of fifteen primary hazard conditions was summarized down to six top priorities (Figure 3).

# Fire responder exposure metrics and enhanced decision support to improve fire responder safety

*Dr. Kit O'Connor*

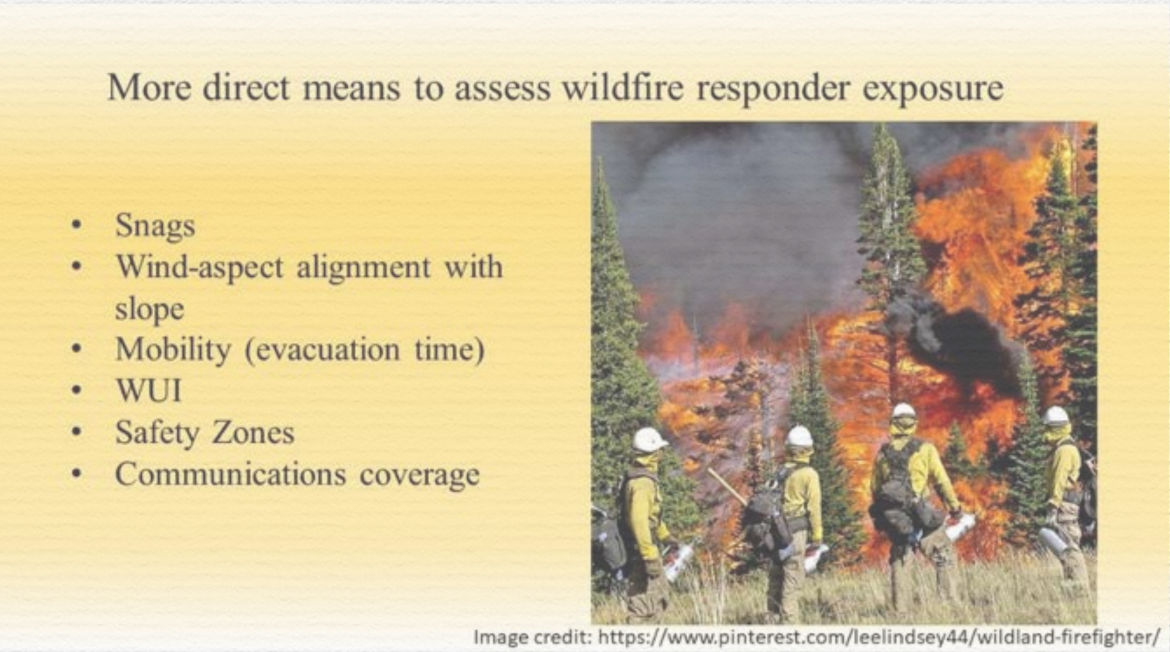


Figure 3. Fire Responder hazard conditions summarized to six top priorities.

**1. Topography and wind alignment** is attributed to burn over incidents resulting in the highest number of fire responder fatalities. The condition occurs when responders are caught in a location where the wind direction pushing a fire aligns with the topographic aspect, resulting in an acceleration of fire spread commensurate with slope steepness. An aspect-wind alignment index would use fire behavior modeling with upslope wind direction to identify locations with heightened risk of fire responder exposure as a function of terrain, fuel type, and potential weather conditions (Figure 4).

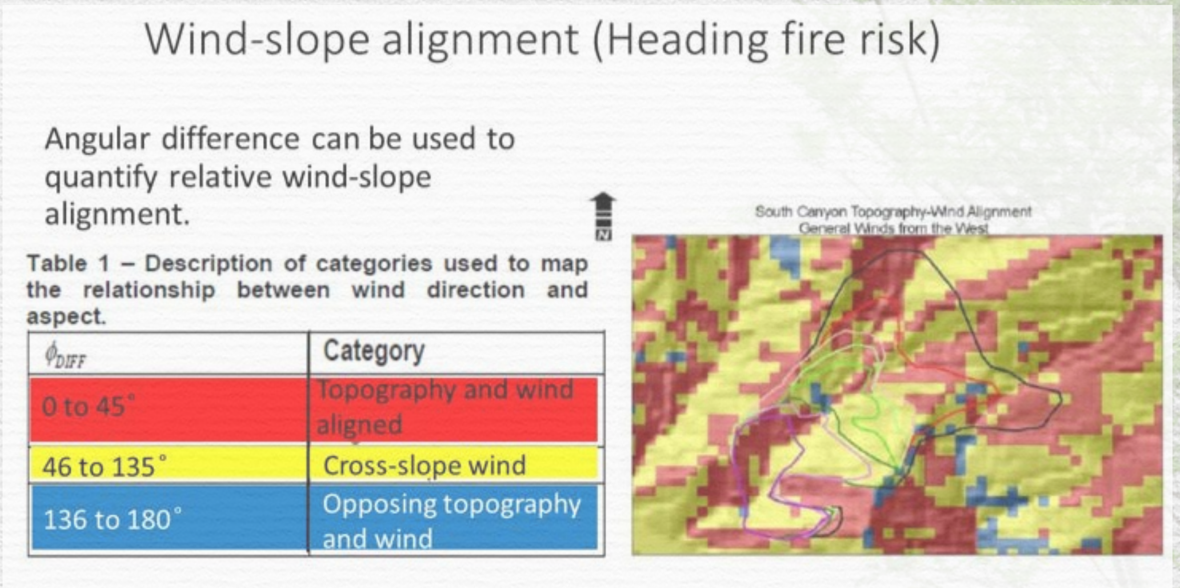


Figure 4. Jolly et al. (2009) Wind-slope alignment on the 1994 South Canyon Fire burn over.

# Fire responder exposure metrics and enhanced decision support to improve fire responder safety

*Dr. Kit O'Connor*

**2. Working in and around snag patches** results in the highest number of fire responder injuries. Injuries are generally associated with falling snags from chainsaw accidents or timbered stands with a high density of snags coupled with windy conditions. Development of a snag risk index would involve quantifying and mapping snag patches across a landscape, modeling snag dynamics through time to estimate current snag size and density, and modeling the growth of understory vegetation that can hinder mobility and contribute to time of exposure (Figure 5).

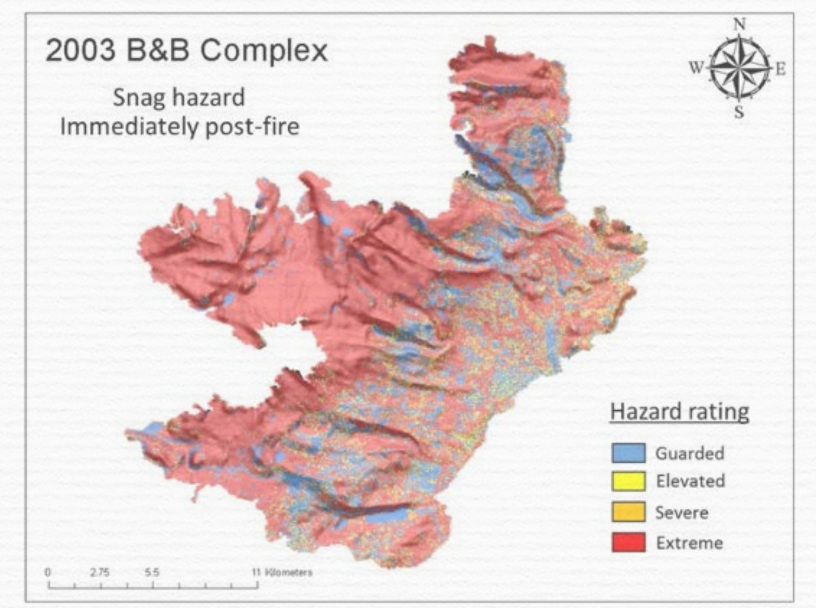


Figure 5. Dunn et al. 2019 Post-fire snag hazard modeling example. Courtesy of the authors. Link to additional information here: https://ars.els-cdn.com/content/image/1-s2.0-S0378112719302191-mmc2.mp4

**3. Mobility challenges**, both vehicular and on foot, result in a significant number of injuries and fatalities. Poor road or trail conditions, long driving times, steep slopes with loose rocks, and hazardous vegetation can significantly slow movement of personnel and resource and increase exposure to hazards. A spatial cost surface that incorporates each of these hazards could be used to calculate accumulated exposure with distance from a source location.

**4. Extraction and evacuation** challenges prolong exposure to extreme conditions during firing operations or following an injury. The Wildland Fire Decision Support System currently uses a hospital evacuation time algorithm to calculate ground travel time to the nearest health facility from a national database of hospitals in the United States (Figure 6). Additional functionality could be added for surface evacuation to a safety zone or evacuation to a suitable helicopter landing location.

# Fire responder exposure metrics and enhanced decision support to improve fire responder safety

*Dr. Kit O'Connor*

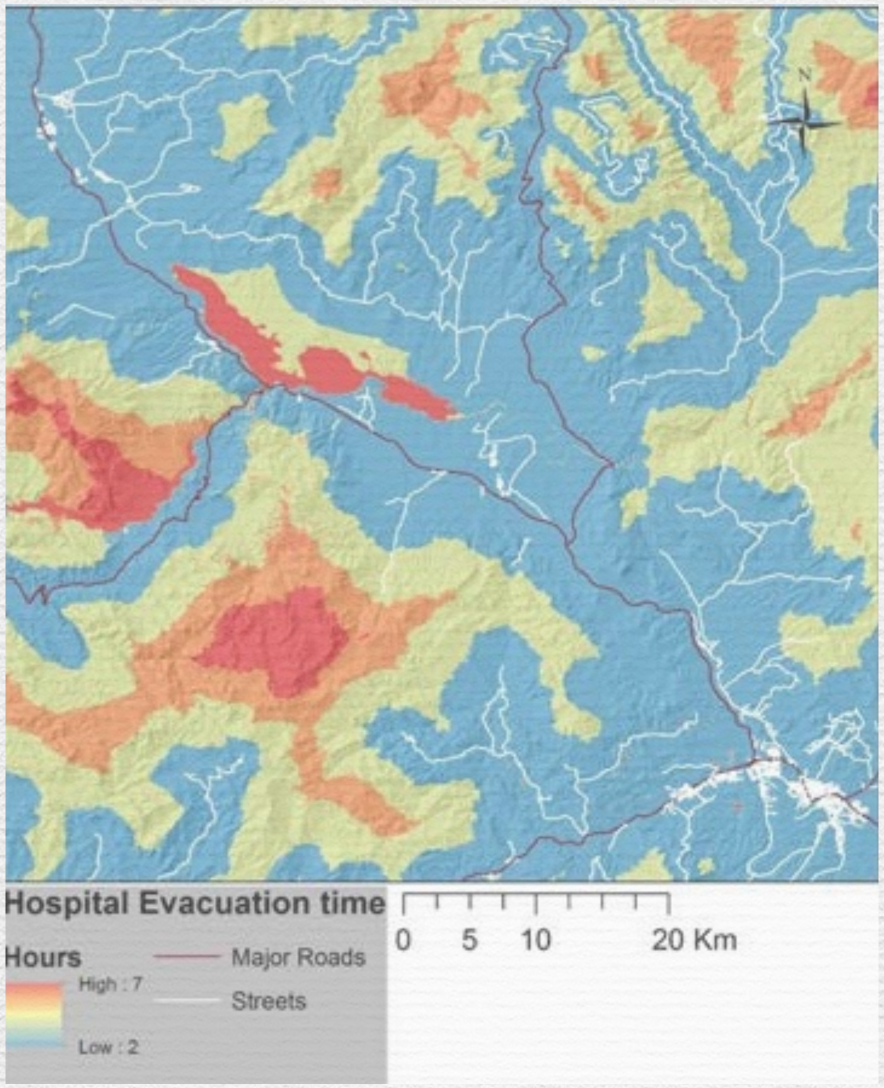


Figure 6. Fisher and Kirsch (2015) Estimated Ground Evacuation Time. Map products available in the Wildland Fire Decision Support System.

**5. Wildland urban interface** compounds typical fire responder hazards by increasing the complexity of fire response decisions and actions. Public expectations of structure protection, access and egress challenges for one-way or non-connected roads, evacuation of residents, and unpredictable fuel types increase uncertainties and elevate exposure hazards. Mapping of WUI locations from remote sensing products can help to inform response and avoid unnecessary exposure. Silvis Wildland Urban Interface change 1990-2010

**6. Lack of reliable, pre-defined safety zones.** Knowing the location, distance, and best travel routes to pre-identified safety zones can significantly reduce unnecessary exposure. Recent work modeling heat convection suggests that the general rule for estimating the safe separation distance (radius of a safety zone) of two times the flame length is inadequate, especially in steep terrain. A spatial model that conservatively identifies potential safety zones larger than at least four times the maximum potential flame length could be combined with a travel friction surface to identify least-cost travel paths between safety zones.

# Fire responder exposure metrics and enhanced decision support to improve fire responder safety

*Dr. Kit O'Connor*

Alternatively this model could be used to prioritize the creation of adequate safety zones on landscapes where they do not currently exist. Firefighter safety zone research

**7. Communication coverage gaps** and radio user error also contribute to fire responder injuries and fatalities. Especially in remote mountainous terrain, radio coverage is obscured in valleys, cellular coverage is limited by repeater proximity, and satellite phone coverage is hindered by canopy cover and the number of satellites within view. While no national communications coverage databases exist in North America, personnel on individual forests often maintain radio coverage maps that can be used to identify potential "dead zones" to avoid during fire response and to prioritize locations for mobile radio repeater deployment during an incident.

Environmental effects on limits to human performance and attrition fatigue were also considered important adjustment factors that needed to be taken into account with each of the above hazards.

Workshop participants identified existing data sources and additional information that would be necessary to develop spatial metrics for each of the above factors. The intention of this work was to involve local forests and other land managing agencies in the collection of information necessary to quantify cumulative levels of wildfire responder exposure depending upon ignition point location, weather conditions, and length of engagement.

Several of the highest priority hazards overlap spatially and would likely be correlated at some level. For example, fire responder mobility is often impeded within a snag patch, however this impediment is dynamic and changes with time since fire within a given vegetation type. Mobility and evacuation time share similar inputs and travel costs under different operating conditions. Mobility assumes movement toward a fire incident without time constraints and with the expectation of a high level of physical capacity, whereas evacuation is usually time constrained and may involve some level of physical incapacitation, making appropriate route selection all the more critical.

# Fire responder exposure metrics and enhanced decision support to improve fire responder safety

*Dr. Kit O'Connor*

We are in the process of developing spatial indices of accumulated fire responder exposure for each of the seven highest priority hazards. Ideally the methods used to produce these indices will be scalable and can be standardized to allow application on a range of landscapes and vegetation types. The majority of the spatial data are continuous for the whole of the United States, and many similar data products are being developed or are available for use in much of the global fire management community, making this approach potentially applicable to fire managing agencies worldwide.


Summary of Seminar and Roundtable,
Córdoba, Spain
February 2017

# Summary of Seminar and Roundtable, Córdoba, Spain, February 2017

Dr. Francisco Rodríguez y Silva organized a seminar and roundtable hosted at the University of Córdoba.

Title of seminar/roundtable:

**METHODOLOGICAL ADVANCES: LANDSCAPES AND FOREST FIRES, DIAGNOSYS AND SUPPRESION**

- Audience: 150 attendees from different fire prevention and suppression institutions in Spain
- Themes of the presentation:

## Presentations

Presentations from the University of Córdoba Seminar and Round Table Discussions

- ***Dr. Fco. Rodríguez y Silva***. Introduction. The management of large fires in the United States & Spain: Necessary changes and common strategies (safety, effectiveness and efficiency). Trends.
- ***Dr. Dave Calkin***. Background and advances in research on forest fire economics. Experiences from the Rocky Mountain Research Station (RMRS USDA Forest Service, Human Dimension Program, National Fire Decision Support Center)
- ***Dr. Matt Thompson***. Advances and new research lines on: Analysis, Evaluation and risk management
- ***Dr. Matt Thompson***. Landscape risk assessment and planning
- ***Dr. Dave Calkin***. Operational safety in suppression and effective operational response
- ***Dr. Fco. Rodríguez y Silva***. Applications and Future Work (Suppression Difficulty Index SDI, Surface Contraction Factor FCS, GI Management Index, Technical Efficiency and Uncertainty Assessment)
- ***Dr. Fco. Rodríguez y Silva***, Dr. Dave Calkin, Dr. Matt Thompson. Roundtable and conclusions

**Roundtable: 4 audience questions**

- Given that wildfires are dynamic and often unpredictable events do you see much value in pre-planning our fire response?
- What do you think are the primary challenges facing wildfire managers that were not discussed today?
- Which aspects of the presentations do you think hold the most promise to improve wildfire outcomes?
- What emerging or new factors do you think will challenge wildfire management the most in the future?

# Introduction. The management of large fires in the United States & Spain: Necessary changes and common strategies (safety, effectiveness and efficiency). Trends.

*Dr. Francisco Rodríguez y Silva*

Within the framework of this seminar, and with the approach directed towards the analysis of landscape and forest fires, their diagnosis and suppression, we conducted an analysis on the presence of large forest fires in both countries (United States and Spain). For this, the thematic content includes a historical perspective, a review of tools and knowledge, as well as references to the effects they generate, the current trends in the presence of this problem, the current scenarios and the opportunities they present, and finally the present challenges and research aimed at better knowledge of the problem and the search for solutions that minimize negative impacts.

Applied knowledge from ongoing research projects such as RTA2014-00011-C06 GEPRIF and RTA2017 VIS4FIRE, funded by the National Institute of Agricultural and Food Research and Technology through the Ministry of Science and Innovation of the Government of Spain, is supporting the primary objectives of "Reduction of Fire Severity Through New Tools and Integrated Technology of Protection against Forest Fires", allowing a greater focus on prevention and more efficient suppression of forest fires. Specifically, the objectives of the aforementioned project are aimed at:

- Development of new systems to quantify the volume of forest fuels.
- An integrated evaluation of preventive forest fuel treatments to reduce fire severity, including effectiveness, longevity and ecological effects on soil and vegetation.
- Estimation and evaluation of the difficulty of control and liquidation of fire and operational capabilities.

# Introduction. The management of large fires in the United States & Spain: Necessary changes and common strategies (safety, effectiveness and efficiency). Trends.

*Dr. Francisco Rodríguez y Silva*

- Prediction of the potential severity of forest fires and the effects of preventive treatments to determine priority areas of action, both preventive and post-fire rehabilitation.
- An evaluation of the economic efficiency of prevention, extinction and rehabilitation activities
- The dissemination of results.

The comparative references that are incorporated in this text are supported by the joint research agreement formalized by the University of Córdoba and RMRS USDA Forest Service, aimed at research on economic and strategic fire planning in forested landscapes, as well as operational suppression actions.

A national fire archive maintained by the United States Forest Service has a web platform (https://www.fs.fed.us/fire/), that allows access to fire data downloads through the "Fire & Aviation Management" page. The Forest Service offers links that allow:

- Following and monitoring the evolution of active fires
- Access to reports related to incident management
- Connection with the National Coordination Center (NIFC)
- Access to information generated in the different geographic areas of coordination
- Access to forest fire statistics
- Viewing satellite image information of the fires through MODIS

Once the section corresponding to the statistical reports of the registered fires is accessed, information on the historical evolution of the fires and their consequences can be consulted, including number of fires, frequency, area affected and costs among other options. As an example, a table that collects this information for the period between 1985 and 2015 is shown below (table 4).

# Introduction. The management of large fires in the United States & Spain: Necessary changes and common strategies (safety, effectiveness and efficiency). Trends.

***Dr. Francisco Rodríguez y Silva***

**Federal Firefighting Costs (Suppression Only)**

| Year | Fires | Acres | Forest Service | DOI Agencies | Total |
|---|---|---|---|---|---|
| 1985 | 82,591 | 2,896,147 | $161,505,000 | $78,438,000 | $239,943,000 |
| 1986 | 85,907 | 2,719,162 | $111,625,000 | $91,153,000 | $202,778,000 |
| 1987 | 71,300 | 2,447,296 | $253,657,000 | $81,452,000 | $335,109,000 |
| 1988 | 72,750 | 5,009,290 | $429,609,000 | $149,317,000 | $578,926,000 |
| 1989 | 48,949 | 1,827,310 | $331,672,000 | $168,115,000 | $499,787,000 |
| 1990 | 66,481 | 4,621,621 | $253,700,000 | $144,252,000 | $397,952,000 |
| 1991 | 75,754 | 2,953,578 | $132,300,000 | $73,820,000 | $206,120,000 |
| 1992 | 87,394 | 2,069,929 | $290,300,000 | $87,166,000 | $377,466,000 |
| 1993 | 58,810 | 1,797,574 | $184,000,000 | $56,436,000 | $240,436,000 |
| 1994 | 79,107 | 4,073,579 | $757,200,000 | $161,135,000 | $918,335,000 |
| 1995 | 82,234 | 1,840,546 | $367,000,000 | $110,126,000 | $477,126,000 |
| 1996 | 96,363 | 6,065,998 | $547,500,000 | $153,683,000 | $701,183,000 |
| 1997 | 66,196 | 2,856,959 | $179,100,000 | $105,048,000 | $284,148,000 |
| 1998 | 81,043 | 1,329,704 | $306,800,000 | $109,904,000 | $416,704,000 |
| 1999 | 92,487 | 5,626,093 | $361,100,000 | $154,416,000 | $515,516,000 |
| 2000 | 92,250 | 7,383,493 | $1,076,000,000 | $334,802,000 | $1,410,802,000 |
| 2001 | 84,079 | 3,570,911 | $683,122,000 | $269,574,000 | $952,696,000 |
| 2002 | 73,457 | 7,184,712 | $1,279,000,000 | $395,040,000 | $1,674,040,000 |
| 2003 | 63,629 | 3,960,842 | $1,023,500,000 | $303,638,000 | $1,327,138,000 |
| 2004 | 65,461 | 8,097,880 | $726,000,000 | $281,244,000 | $1,007,244,000 |
| 2005 | 66,753 | 8,689,389 | $524,900,000 | $294,054,000 | $818,954,000 |
| 2006 | 96,385 | 9,873,745 | $1,280,419,000 | $424,058,000 | $1,704,477,000 |
| 2007 | 85,705 | 9,328,045 | $1,149,654,000 | $470,491,000 | $1,620,145,000 |
| 2008 | 78,979 | 5,292,468 | $1,193,073,000 | $392,783,000 | $1,585,856,000 |
| 2009 | 78,792 | 5,921,786 | $702,111,000 | $218,418,000 | $920,529,000 |
| 2010 | 71,971 | 3,422,724 | $578,285,000 | $231,214,000 | $809,499,000 |
| 2011 | 74,126 | 8,711,367 | $1,055,736,000 | $318,789,000 | $1,374,525,000 |
| 2012 | 67,774 | 9,326,238 | $1,436,614,000 | $465,832,000 | $1,902,446,000 |
| 2013 | 47,579 | 4,319,546 | $1,341,735,000 | $399,199,000 | $1,740,934,000 |
| 2014 | 63,212 | 3,595,613 | $1,195,955,000 | $326,194,000 | $1,522,149,000 |
| 2015 | 68,151 | 10,125,149 | $1,713,000,000 | $417,543,000 | $2,130,543,000 |

*Source: National Interagency Fire Center*

Table 4. Historical fire occurrence of forest fires en US. 1985-2015

In relation to the continued increase in the costs of suppression operations that has been observed in recent years in the US, two graphs are included below that allow us to observe the interannual trend (Figures 10 and 11).

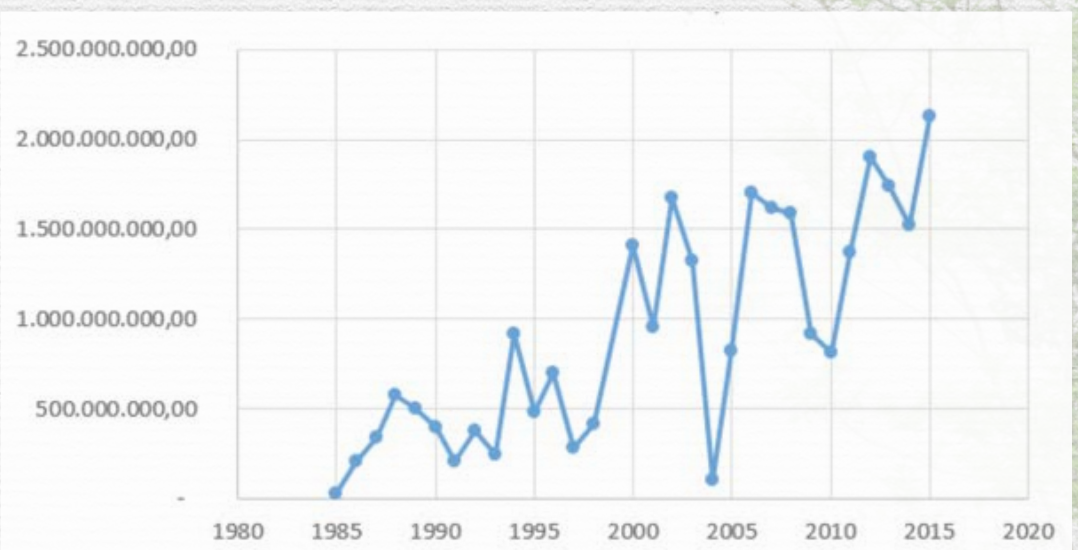


Figure 10. Suppression costs of large fires in US. (large fire, size > 121 ha). 1980-2015

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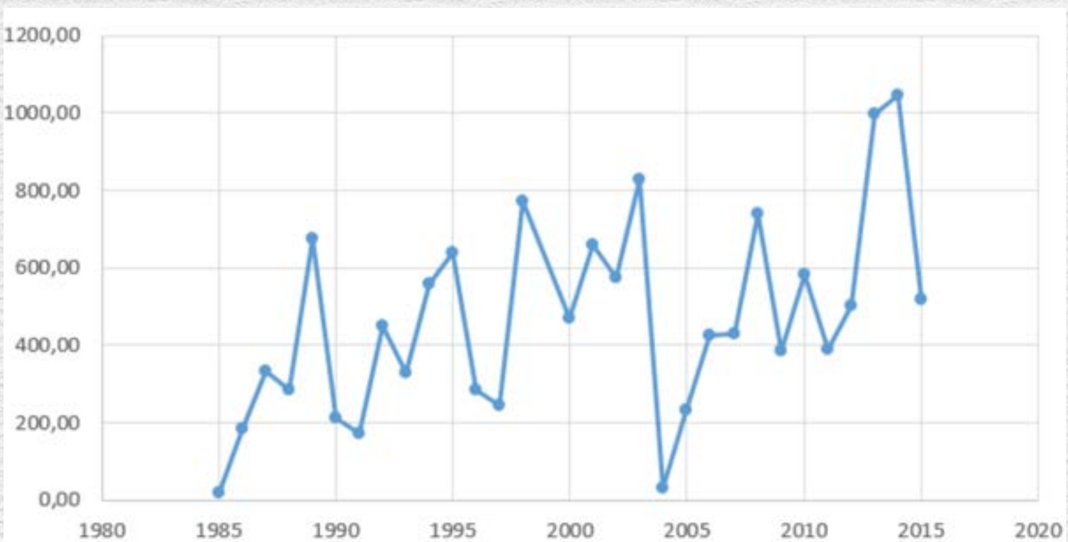


Figur11 2. Suppression costs/ha of large fires in US. (large fire, size > 121 ha). 1980-2015

As can be seen in Figure 10, the continued growth in extinction costs has exceeded two billion dollars. There are records of past fires affecting large areas and generating extraordinary ecological, economic and social impacts. Among others, the "Great Burn" recorded in 1910, affected an area of 1,214,000 ha with a total of 87 fatalities from fire propagation.

The information provided by the National Coordination Center (NICC) indicates that the annual average area affected in the last ten years is 6.9 million acres (2.8 million ha) . The complexity that has been observed in firefighting operations obviously has an impact on the increase in mobilizations of aerial resources and in the suppression cost. Specifically, for the years 2013, 2014 and 2015, the dispatch of airtankers reached the values of 1,057, 1,197 and 1,347, with an average dispatch over five years of 883. The past five years show a trend of increasing area affected by large fires in relation to all fires across the western United States. . During the 1970s, the average area of large fires in national forests was around 180,000 acres (72,800 ha); in this decade average area of large fires is around 1,500,000 acres (607,000 ha).

Another important feature that highlights the size of the problem of large fires in the US is the earlier date of the first major fire, as well as the later calendar date for the last major fire. This change in the seasonality of the occurrence of the forest fires can be observed on the USDA Forest Service fire statistics data archive maintained by by "Climate Central", http://www.climatecentral.org/.In the 1970s, available data indicate that the average Julian date of the first major fire was125, while at

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present, the average Julian date is75. Similarly, the last record of a major fire in the 1970s was day 285, while at present it is around day 315. In national forests managed by the USDA Forest Service, the annual average number of large fires  in the 1970s was 25, while at present the number is approaching 150. In relation to the area affected by a large fire, in the 70s typical large fires did not exceed 10,000 acres, currently large fires average approximately 40,000 acres.(Figure 12).

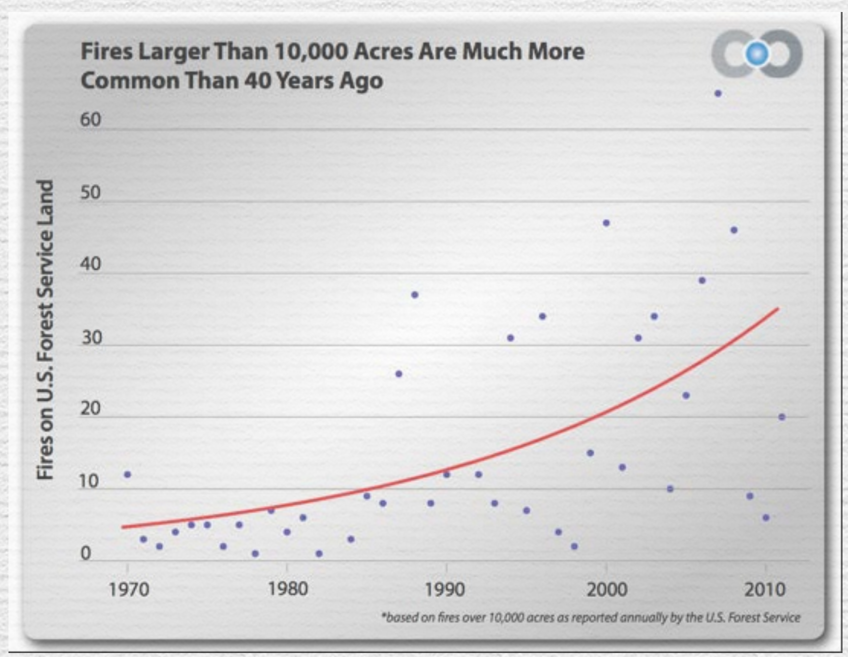


Figure 12. Fires larger than 10,000 Acres along 1970 - 2010
(Source: http://www.climatecentral.org/)

Other information of interest, shows that the years in which the average temperature has been higher, the record of large forest fires has increased compared to the years of milder thermal conditions (fFigure 13).

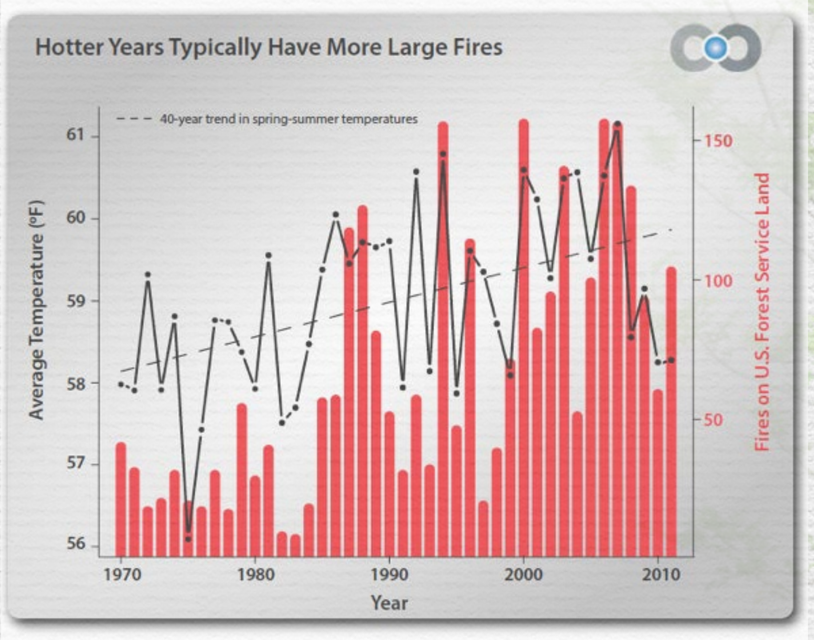


Figure 13. Hotter years typically have more large fires 1970 - 2010.
(Source: http://www.climatecentral.org/)

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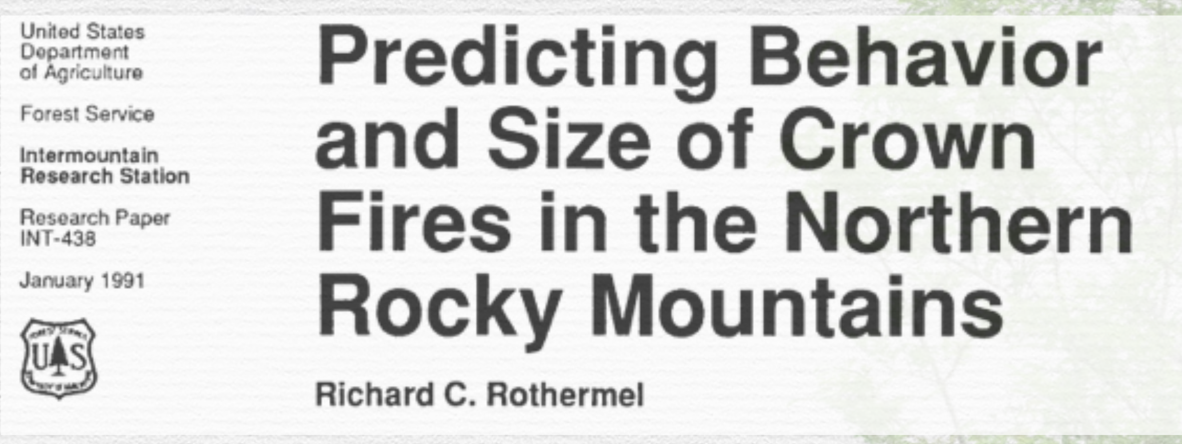
The impact of large fires have also increased in relation to the energy emissions generated by them. In October 2003, the “Cedar Fire” originated in the Cleveland National Forest in San Diego County, affected 275,000 acres, damaging more than 2,400 houses, 15 people lost their lives, including a wildland fire fighter.

Based on the evidence of changing conditions noted above, it is clear that addressing this change in the complexity of fire management will require input from wildland fire management professionals as well as science-based observations and analytical assessment to document changes and develop new models and approaches to fire management.

A prime example of this synergy between experience, observations, and analytics is demonstrated in the crown fire models developed from the 1988 Yellowstone fires(Figure 14).



United States
Department
of Agriculture

Forest Service

Intermountain
Research Station

Research Paper
INT-438

January 1991

**Predicting Behavior and Size of Crown Fires in the Northern Rocky Mountains**

Richard C. Rothermel

Figure 14. Research paper INT-438, about the crown fire model

This model serves as a foundation for several additional improved models developed over the last 29 years that account for additional complexity in fire canopy transition informed by additional laboratory and field observations. A summary of the advances of knowledge in crown fire modelling can be found in the USDA Forest Service publication "Fire Management Today" (Vol. 73, no .: 4, 2014) (Figure 15).

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Figure 15. Fire Management Today" (Vol. 73, nº: 4, 2014)

In Spain, the statistical data base of forest fires, whose management officially corresponds from 1968 to present. Consulting both databases and annual publications prepared from the Area of Defense against Forest Fires, the trends in large fire size and frequency in Spain are overall similar to those observed in the United States, however with greater variability from year to year. Some of this variability can be explained by inconsistent staffing and resources available for firefighting in the 1980s and 1990s.

With an increase in operational capacity of firefighting crews in the Autonomous Communities and institutional support of the National Administration, the number of large fires in relation to the total number of fires has decreased over the last two decades, however the total area burned has remained consistent or in some years even increased, suggesting that while the number of large fires is lower, the typical size of these fires is larger than in the past. Fires such as "Minas de Río Tinto (Huelva, 2004)" with more than 30,000 ha, affected or "Quesada (Jaén, 2015)" with more than 9,500 ha, are examples of this trend (Figure 16).

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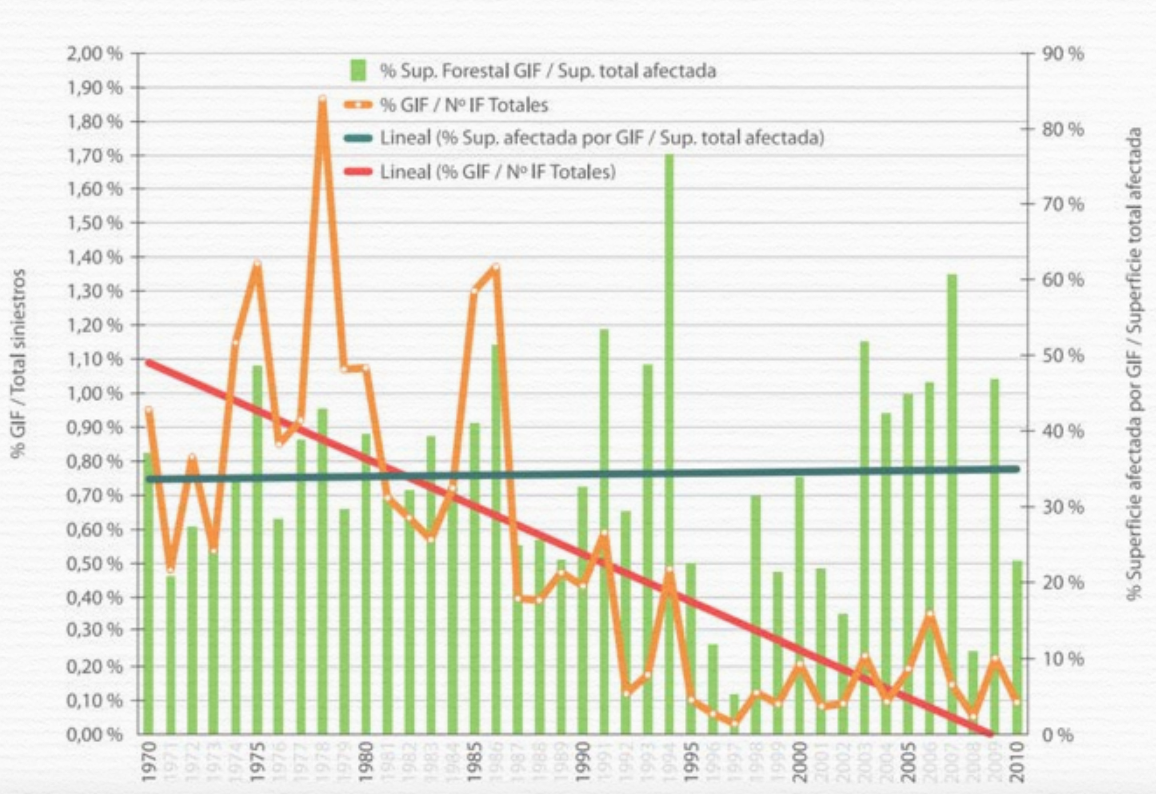


Figura 16. % Large fires to total fires in Spain (1970-2010)
(Fuente: https://www.mapa.gob.es/es/desarrollo-rural/estadisticas/Incendios_default.aspx)

In 2014, the total of the large forest fires registered, represented 21% of the total area affected, and 0.07% of the total number of fires. In 2015, these figures increased to 38.76% of the proportion of surface affected by large fires in relation to the total area, and 0.12% of the proportion of the number of large fires in relation to the total number of fires.

A recent paper published in Forests (MDPI), titled “Potential Effects of Climate Change on Fire Behavior, Economic Susceptibility and Suppression Costs in Mediterranean Ecosystems: Córdoba Province, Spain”, conducted a study of suppression costs for the period 1993-2015. This study, based on the information available from five large fires in Andalusia, shows a similar trend to that seen in the United States; a significant increase in the cost per hectare of suppression operations (Table 5) (Molina et al. 2019).

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| Forest Fire | A | B | C | D | E | F | G | H |
|---|---|---|---|---|---|---|---|---|
| Burned area (ha) | 6176.00 | 2258.00 | 1207.00 | 2295.98 | 1704.50 | 8226.00 | 4979.15 | 9760.42 |
| Control time * (h) | 57.00 | 53.00 | 51.00 | 36.00 | 36.00 | 42.00 | 72.00 | 233.00 |
| Burned area/hour (ha/h) | 108.35 | 42.60 | 23.67 | 63.78 | 47.35 | 195.86 | 69.15 | 41.89 |
| Terrestrial resources (€) | 115,749.44 | 118,489.00 | 123,940.72 | 373,646.69 | 103,654.72 | 134,659.26 | 198,837.06 | 240,775.86 |
| Aerial resources (€) | 64,909.31 | 176,912.48 | 111,863.98 | 89,138.28 | 239,222.10 | 375,357.87 | 748,162.17 | 1,910,652.73 |
| Total suppression costs (€) | 180,658.75 | 295,401.48 | 235,804.70 | 462,784.97 | 342,876.82 | 510,017.13 | 946,999.23 | 2,151,428.59 |
| Cost per unit area (€/ha) | 29.25 | 130.82 | 195.36 | 201.56 | 201.16 | 62.00 | 190.19 | 220.42 |
| Cost per unit time (€/h) | 3169.45 | 5573.61 | 4,623.62 | 12,855.14 | 9524.36 | 12,143.26 | 13,152.77 | 9233.6 |

(A) Beas fire: 6176 ha in 1993, (B) Cázulas-Otívar fire: 2258 ha in 1999, (C) Sierra de Lújar fire: 1207 ha in 2000, (D) Mijas fire: 2295.98 ha in 2001, (E) Obejo fire: 4979.15 ha in 2007, (F) Mijas fire: 1704.5 ha in 2011, (G) Coín fire: 8226 ha in 2012 and (H) Quesada fire: 9760.42 ha in 2015. * Control time: is the time of reducing the heat output of a fire, extinguishing the fire by the completion of a control line around the perimeter.

Table 5. Suppression costs of large fires (1993-2015)
(source: Forests 2019, 10, 679; doi:10.3390/f10080679)

The differences that can be found in the suppresion costs between the US and Spain, can be explained in relation to the following influential factors:

- Geographical dimensions (size)
- Differences in population density, (Spain 92 inhabitants per km2, US 33 inhabitants per km2)
- Policy differences (complete fires exclusion in Spain in contrast to some acceptance of natural fires, with free evolution up to certain limits and according to certain cases in the U.S.).
- Differences in the amount and types of resources dispatched to fires.

In relation to suppression resources, a recent comparative investigation carried out by Rodríguez y Silva, (2017) found the following differences in resource allocation between Spain and the US on average (table 6):

| Types of resources | Average nº of resources dispatched in Spain | Average nº of resources dispatched in US |
|---|---|---|
| Fire crew | 1.98 | 7.99 |
| Fire brigades | 18.18 | - |
| Engine | 7.68 | 9.98 |
| Airplane (Airtankers and helicopters) | 8.49 | 4.66 |
| Dozers | 0.49 | 1.35 |

Table 6. Average of number of resources dispatched to fires, Spain and USA.

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Finally and as a summary, below are a set of ideas that highlight the complexity of operational management of forest fires and the problems in with decision making in the context of large forest fires:

- State of increasing uncertainty
- Absence of informative feedback with adequate speed
- Concern about the consequences
- Continuous incidence of decision making with lack of contrast information
- Lack of prior knowledge of suppression opportunities on the landscape
- Immediacy of decisions
- Pressure by external conditions (outside of the fire zone)
- Lack of productivity that can be developed by the combination of types and numbers of resources
- Preference for the massive presence of suppression resources (ground and aerial resources)
- Operational inefficiency
- Decisions in relation to the movements and positions of resources without adequate information on potential fire behavior
- Actions taken out of immediacy (a need to do something) without strategic consideration of results in terms of suppression operations.

# Applications and Future Work (Suppression Difficulty Index SDI, Surface Contraction Factor FCS, GI Management Index, Technical Efficiency and Uncertainty Assessment)

*Dr. Francisco Rodríguez y Silva*

Landscape analysis is complex from the point of view of forest fires. To have a better understanding of what suppression actions imply, it is necessary to have methodologies and procedures. In this sense, the methodology for determining operational priorities for the prevention and suppression of forest fires based on the evaluation of the difficulty of extinction (Rodríguez and Silva, et al. 2014) provides information on the characteristics of fire behavior and of the opportunities that the landscape offers for the development of the suppression operations (density of roads, fuel breaks, capability to open fire line, water reserves for the aerial means) (Figure 17).

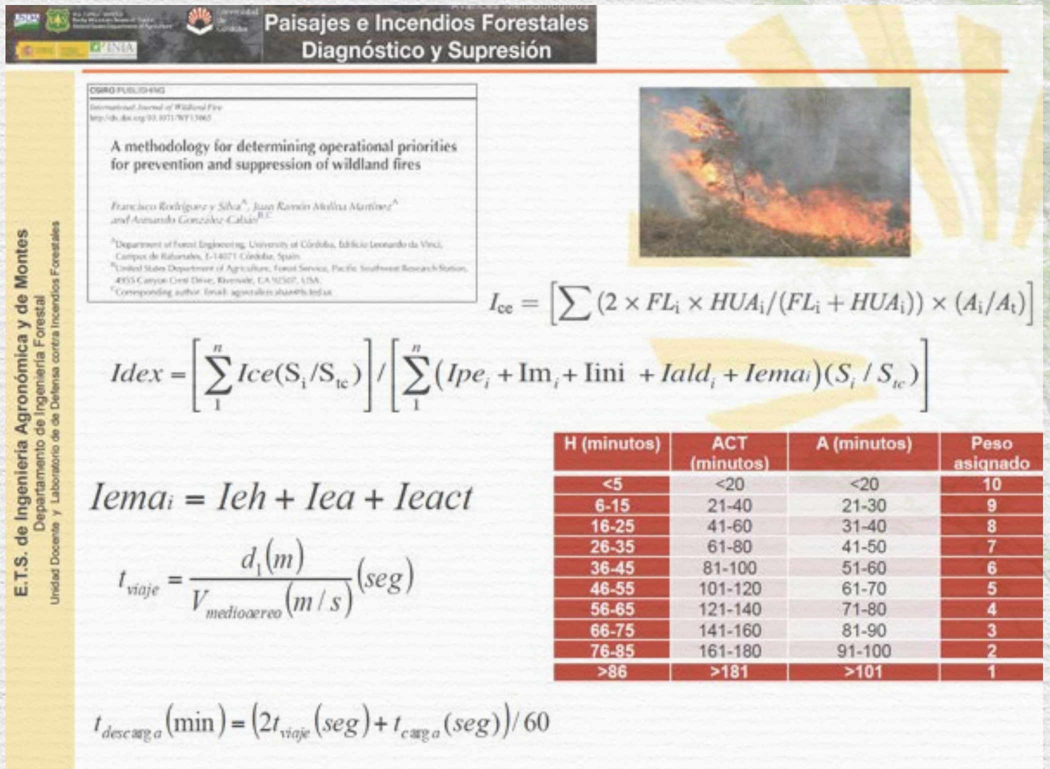


Figure 17. Suppression Difficulty Index SDI.

# Applications and Future Work (Suppression Difficulty Index SDI, Surface Contraction Factor FCS, GI Management Index, Technical Efficiency and Uncertainty Assessment)

***Dr. Francisco Rodríguez y Silva***

Models for evaluating the economic impacts of forest fires, based on the direct effects of fire behavior on natural resources, (both market and nonmarket), and economic depreciation, provide a valuable framework for decision making. The SEVEIF model, integrated in the Visual-SEVEIF simulator, calculates economic losses in two possible situations, in the case of forest fires that have occurred, and on landscape with potential for fire to occur (Rodríguez and Silva et al. 2009, 2013, 2014). This model is an important tool for interpreting the impacts of fires on the forested landscapes (Figure 18).

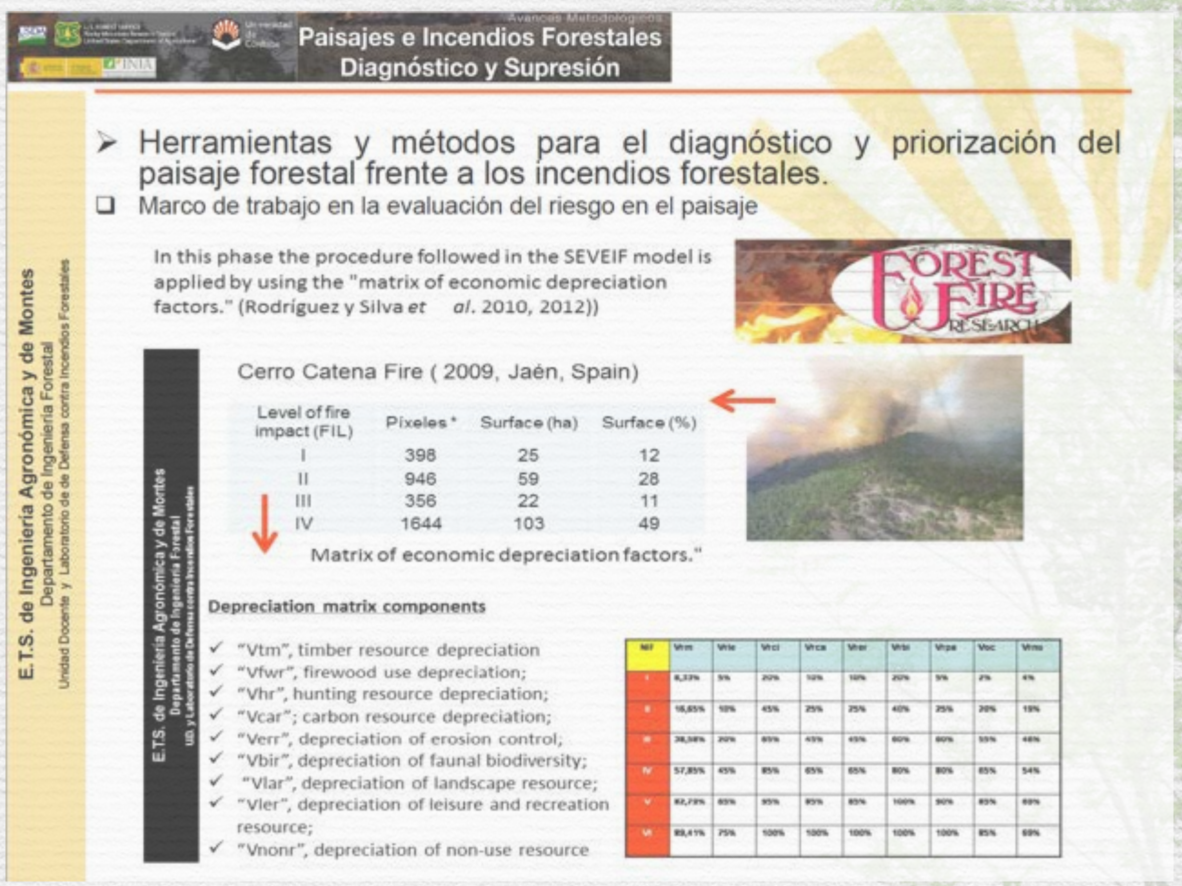


Figure 18. SEVEIF model (table of economic value depreciation of the natural resources)

# Applications and Future Work (Suppression Difficulty Index SDI, Surface Contraction Factor FCS, GI Management Index, Technical Efficiency and Uncertainty Assessment)

***Dr. Francisco Rodríguez y Silva***

Among the first results of joint research between the Forest Fire Laboratory of the University of Córdoba (LABIF-UCO) and the RMRS USDA Forest Service (Forestry Sciences Lab., "Human Dimension Program"), has been the integration of related variables with the suppression difficulty and the risk of the fire control operations, in relation to safety. The work published in the journal Geosciences (MDPI), entitled: Getting Ahead of the Wildfire Problem: Quantifying and Mapping Management Challenges and Opportunities, includes in addition to a review an advance of the ongoing investigations (Figure 19).

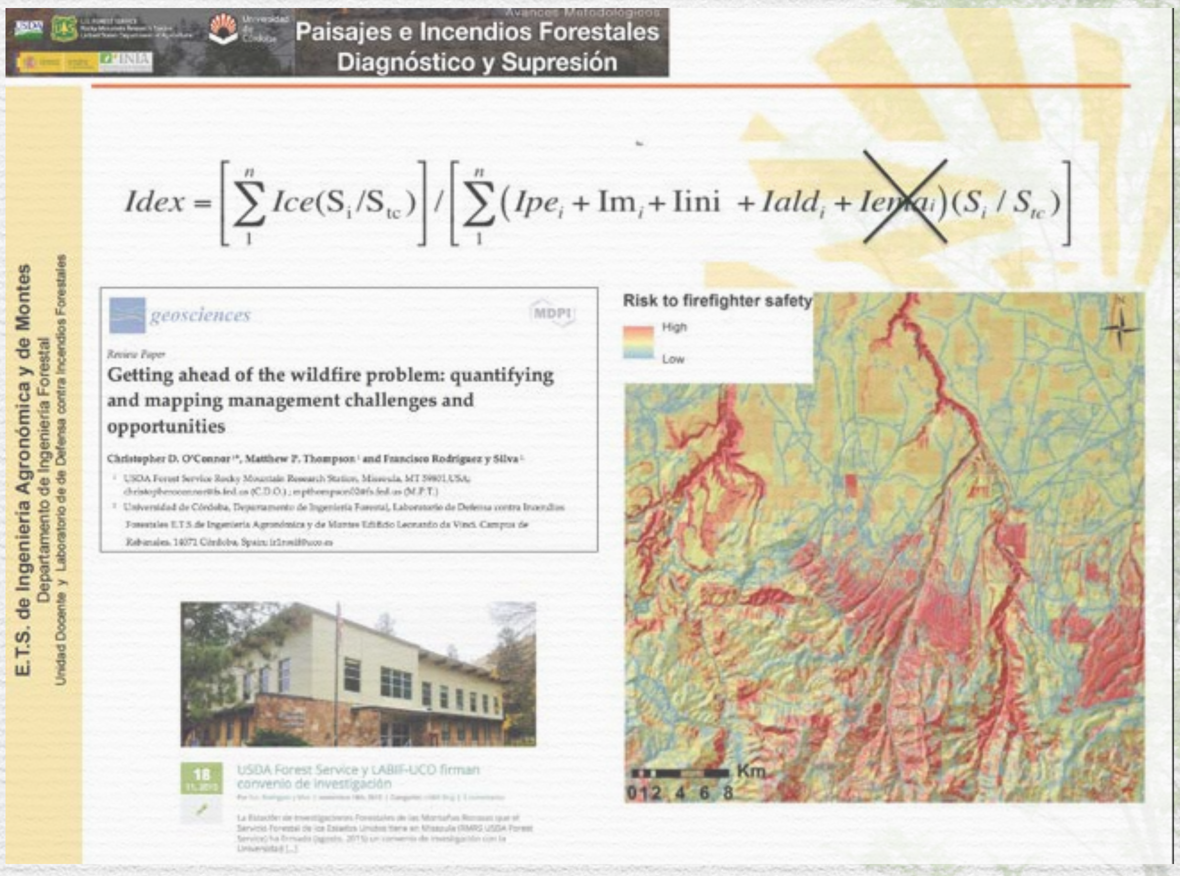


Figure 19. Suppression difficulty and risk of control fire operations

# Applications and Future Work (Suppression Difficulty Index SDI, Surface Contraction Factor FCS, GI Management Index, Technical Efficiency and Uncertainty Assessment)

***Dr. Francisco Rodríguez y Silva***

The spread of fires that showed extreme behavior with crown fire propagation, even with phenomena of eruptive propagation in the canyons (Quesada Fire, 2015, Spain) (Segura Fire, 2017, Spain) have provided relevant information to carry out research that has helped to differentiate multiple drivers of complex propagation. Research in this area has produced a new and more advanced version of the suppression difficulty index. This new version incorporates surface, crown and eruptive canyon spreading components into the index of energetic behavior.

In the determination of crown fire propagation, a recent modeling has been included that provides a prediction of spread adjusted to the observations available from crown fire propagation in Mediterranean ecosystems (Rodríguez y Silva et al. 2017) (Figure 20).

This research resulted in the development of an improved version of suppression difficulty index that incorporates observations of complex fire behavior. This new model helps to efficiently identify operational areas that represent situations of special risk for the fire exposure of ground forces. This tool is being progressively determined and adapted to the operational achievements of Spain and the United States (Figure 21).


Figure 20. Crown fire behavior in Mediterranean ecosystems

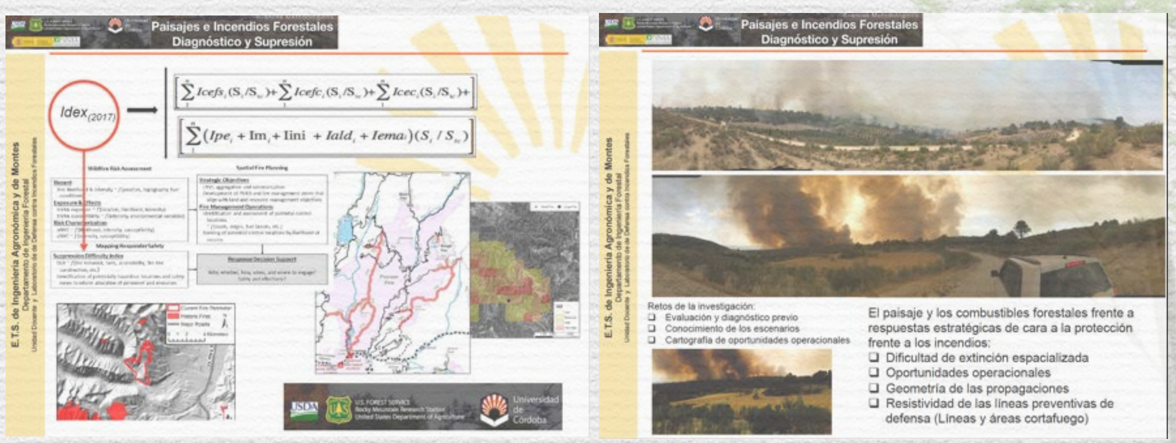


Figure 21. New version of Suppression Difficulty Index (SDI) and images of Quesada Fire (2015, Spain)

# Applications and Future Work (Suppression Difficulty Index SDI, Surface Contraction Factor FCS, GI Management Index, Technical Efficiency and Uncertainty Assessment)

***Dr. Francisco Rodríguez y Silva***

Another of the tools that provides an important evaluation of suppression resource productivity is the surface contraction factor (Rodríguez and Silva and Gonzalez-Cabán, 2016). This tool makes the comparison between the perimeter of the fire without containment and suppression actions with the perimeter of the fire in which suppression actions have been taken. The surface contraction considering the time elapsed since the ignition until the fire has been controlled, is a ratio of the overall productivity of the extinguishing operations applied to control the fire (Figure 22). The opportunities offered by this tool to capitalize on the experiences of lessons learned in predicting productivity in extinction operations are among the most important:

- The analysis of yields
- Measurement of production capacity in extinction operations
- The evaluation of efficiency
- The comparison of results obtained in the suppression actions between different combinations and extinguishing equipment

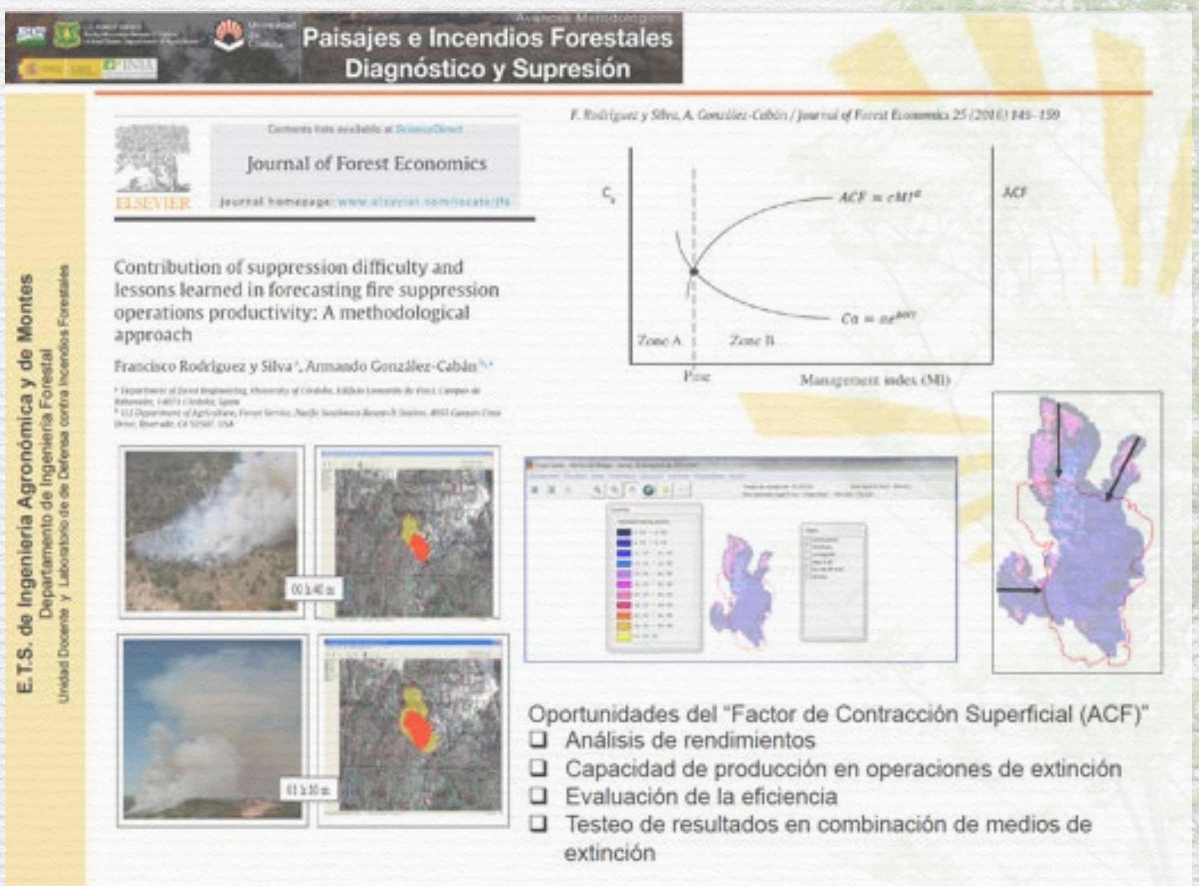


Figure 22. Surface Contraction Factor (SCF)

# Applications and Future Work (Suppression Difficulty Index SDI, Surface Contraction Factor FCS, GI Management Index, Technical Efficiency and Uncertainty Assessment)

*Dr. Francisco Rodríguez y Silva*

One of the main problems of assessing the landscape in forest fire defense programs, is the difficulty of correctly interpreting the variables that affect the movement of fire under different scenarios, and the expected results after the extinction actions, in terms of achievements possible in the control of the different sectors of the perimeter of the fire. In this sense, uncertainty in decision making is a complex problem, not resolved. The line of work, consisting of recovering the experiences and lessons learned after fire suppression operations, is undoubtedly an important and very necessary activity to reduce uncertainty.

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 that increase the difficulty of carrying out 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 distribution of fuels over the landscape and in management of an emergency given an action plan.

On the other hand, the selection of solutions in an uncertain environment (as characteristic of fire suppression actions) frequently are separate from decision models based on optimized economic and fire effects outcomes. 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 to wildland fire management that include uncertainty. The selection of solutions continues to be anchored in the actor's empirical experience (Rodríguez y Silva, 2019). The selection of strategic solutions for wildfire response under uncertainty scenarios correspond to a process integrating a structured assessment of the assumptions facilitating a potential reduction in uncertainty (Figure 23).

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.

# Applications and Future Work (Suppression Difficulty Index SDI, Surface Contraction Factor FCS, GI Management Index, Technical Efficiency and Uncertainty Assessment)

*Dr. Francisco Rodríguez y Silva*

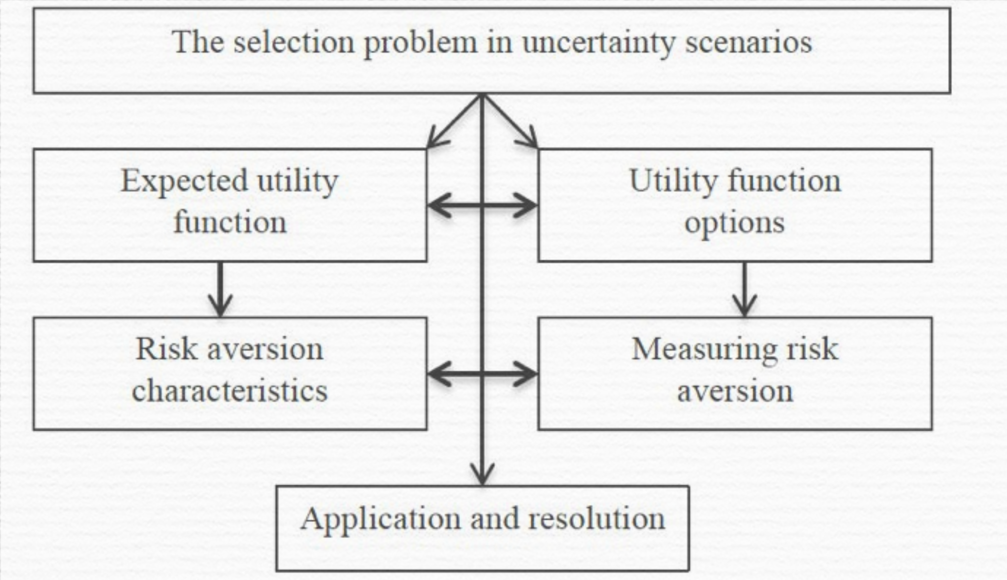


Figure 23. Integration of thematic blocks that facilitates uncertainty reduction in the selection of strategic solutions.

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, then subject to the comparative preferences conditions, we can determine the expected utility of being able to develop the selected contingent plan (Rodríguez y Silva, 2019).

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 based on economic analysis of risk and choice under uncertainty 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.

Through better knowledge of the landscape and its implications in the planning of suppression operations and the capitalization of experiences in extinction actions, progress in efficiency can be made. In this sense, recent work in the evaluation of the technical

# Applications and Future Work (Suppression Difficulty Index SDI, Surface Contraction Factor FCS, GI Management Index, Technical Efficiency and Uncertainty Assessment)

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efficiency of extinction operations, based on the fundamentals of productivity, has allowed the development of evaluation tools based on the integration of fire behavior, the net change in the value of resources affected by fire and extinction costs (Figure 24). With this methodology, the efficiency achieved in fire suppression operations can be evaluated (Rodríguez and Silva et al. 2014), (Rodríguez and Silva, and Gonzalez-Cabán, 2016).

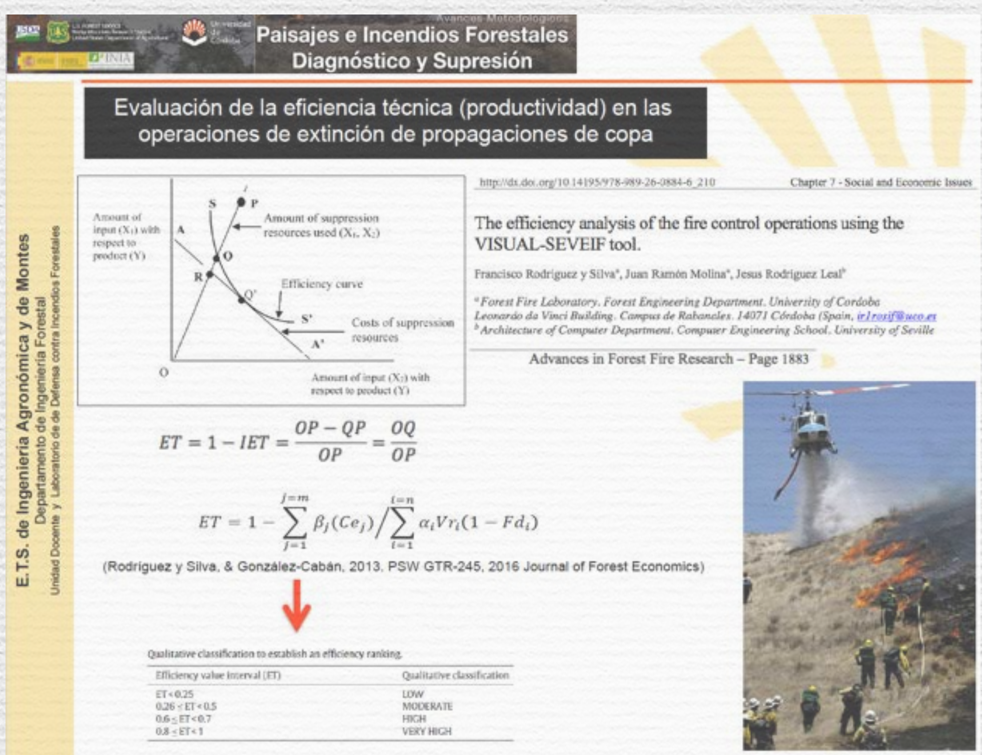


Figure 24. The efficiency analysis of the fire control operations

The current possibilities of economic analysis supporting studies on the potential danger of forest ecosystems and the suppression difficulty operations based on fire behavior, represents an important advance in decision making tools for fire management. Undoubtedly the incorporation of modern econometric tools based on efficiency and productivity concepts, as well as in the development of utility functions, can help to carry out guidelines for the budgetary definition to support protection of ecosystems, considering the value of natural resources and the suppression costs. From the generation of the database obtained through the capitalization of the fire suppression operations, it is necessary to select the variables and parameters that will allow analyzing and evaluating the productivity of suppression operations. The following should be considered:

- Fire perimeter controlled by time unit (production rate) (m / min)
- Surface contraction factor ACF, (calculated as the the difference between one and the quotient between observed fire growth with suppression resources and the modelled fire growth without suppression, subject to the time elapsed since the detection until the fire is controlled (Rodríguez y Silva, and González Cabán, 2016)
- Average surface affected by each forest fire registered (ha / fire)

# Applications and Future Work (Suppression Difficulty Index SDI, Surface Contraction Factor FCS, GI Management Index, Technical Efficiency and Uncertainty Assessment)

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- Average extinction costs per affected area, (€ / ha)
- Unitary costs of the different resources to fires suppression
- Production rates of each different resource
- Quotient between suppression cost and net change value of the natural resources
- List of the total resources dispatched to fires, including the proportion of individual operational periods in relation to the total sum of operational periods of all resources involved in a fire.

In table 7, a series of independent variables are used in a deterministic function of suppression operational productivity. This function allows for the assessment of a series of econometric production functions such as the perimeter length controlled per unit of time (m/min) (Rodríguez y Silva, and Hand, 2018).

| Aerial resources suppression effect Rp MAR | Ground resources suppression effect Rp MT | Suppression Difficulty Index (Idex) | Fire weather index IPMIF |
|---|---|---|---|

Table 7 - Variables considered to develop the deterministic models

One of the most significant contributions of the work presented thus far is the ongoing determination of "strategic management points", identified as areas in which conditions are appropriate for safe and effective suppression actions. Determination of these locations requires the integration of complex variables related to fire behavior, the geometry of fire spread , the type of fire contact with fuel breaks and fuel break networks, knowledge of the productivity and efficiency of the different types of resources, and inclusion of tactical experience to inform modeling outcomes. These inputs are all directly related to the research and advances of knowledge mentioned in the ongoing research and presentations included in this electronic publication.

# Applications and Future Work (Suppression Difficulty Index SDI, Surface Contraction Factor FCS, GI Management Index, Technical Efficiency and Uncertainty Assessment)

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## Literature Cited & Recommended Reading

- Butler, B. W. 2014. Wildland firefighter safety zones: A review of past science and summary of future needs. International Journal of Wildland Fire. 23(3): 295-308.
- Butler, B., Parsons, R. and Mell, W., 2015. Recent findings relating to firefighter safety zones. In In: Keane, Robert E.; Jolly, Matt; Parsons, Russell; Riley, Karin. Proceedings of the large wildland fires conference; May 19-23, 2014; Missoula, MT. Proc. RMRS-P-73. Fort Collins, CO: US Department of Agriculture, Forest Service, Rocky Mountain Research Station. p. 30-34. (Vol. 73, pp. 30-34).
- Campbell, M. J., W. G. Page, P. E. Dennison, and B. W. Butler. 2019. Escape Route Index: A Spatially-Explicit Measure of Wildland Firefighter Egress Capacity. Fire 2:40.
- Dunn CJ, Bailey JD (2012) Temporal dynamics and decay of coarse wood in early seral habitats of dry-mixed conifer forests in Oregon's Eastern Cascades. Forest Ecology and Management 276, 71-81.
- Dunn, C. J., C. D. O'Connor, M. J. Reilly, D. E. Calkin, and M. P. Thompson. 2019. Spatial and temporal assessment of responder exposure to snag hazards in post-fire environments. Forest Ecology and Management 441:202-214.
- Butler 2014
- Butler at al 2015
- Finney MA, Grenfell IC, McHugh CW, Seli RC, Trethewey D, Stratton RD, Brittain S (2011) A method for ensemble wildland fire simulation. Environmental Modeling & Assessment 16, 153-167.
- Fisher and Kirsch (2015)
- Jolly WM, Butler BW, Forthofer J (2009) Assessing topography and wind alignment for firefighter safety. In 'Eighth Symposium on Fire and Forest Meteorology. Kalispell, MT', October 13-15, 2009. pp. 4.
- Jolly, W. M., P. H. Freeborn, W. G. Page, and B. W. Butler. 2019. Severe fire danger index: A forecastable metric to inform firefighter and community wildfire risk management. Fire 2:47.Katuwal, H., D. E. Calkin, and M. S. Hand (2016), Production and efficiency of large wildland fire suppression effort: A stochastic frontier analysis, Journal of Environmental Management, 166, 227-236.
- Molina J.R., González-Cabán A., Rodríguez y Silva, Fco. (2019). "Potential Effects of Climate Change on Fire Behavior, Economic Susceptibility and Suppression Costs in Mediterranean Ecosystems: Córdoba Province, Spain". Forests 2019, 10, 679; doi:10.3390/f10080679.
- NIFC (2016) 'Serious Accident Investigations.' Available at https://www.nifc.gov/safety/safety_reprtsInvest.html [Accessed April 4].

# Applications and Future Work (Suppression Difficulty Index SDI, Surface Contraction Factor FCS, GI Management Index, Technical Efficiency and Uncertainty Assessment)

*Dr. Francisco Rodríguez y Silva*


- O'Connor, C.D., Calkin, D.E., and M.P. Thompson (2017), An empirical learning method for predicting potential fire control locations for pre-fire planning and operational fire management, International Journal of Wildland Fire, doi: 10.1071/WF16135
- RMRS Wildfire SDI (2018) Terrestrial Suppression Difficulty Index of the western United States.Interactive map: http://www.arcgis.com/home/webmap/viewer.html?url=https%3A%2F%2Fapps.fs.usda.gov%2Ffsgisx02%2Frest%2Fservices%2FRDW_Wildfire%2FRMRS_WildfireSuppressionDifficultyIndex%2FMapServer&source=sd
- Most recent version here : https://www.fs.usda.gov/rmrs/suppression-difficulty-index Rodríguez y Silva f.; Molina J.R.; Herrera M.A.; Zamora R. (2009). The impact of fire and the socioeconomic vulnerability of forest ecosystems: A methodological approach using remote sensing and geographical information systems. Genral Technical Report PSW-GTR-227. Pacific Southwest Research Station. Forest Service, U.S. Department of Agriculture; 151 - 168.
- Rodríguez y Silva, F., and A. González-Cabán (2010), 'SINAMI': a tool for the economic evaluation of forest fire management programs in Mediterranean ecosystems, International Journal of Wildland Fire, 19(7), 927-936.
- Rodríguez y Silva, F., Molina J., Herrera M., Rodríguez J. (2013). VISUAL-SEVEIF, a Tool for Integrating Fire Behavior Simulation and Economic Evaluation of the Impact of Wildfires. General Technical Report PSW-GTR-245. Pacific Southwest Research Station. Forest Service, U.S. Department of Agriculture; 163 - 178
- Rodríguez y Silva, F., Molina J., Rodríguez J. (2014). The efficiency analysis of the fire control operations using the VISUAL-SEVEIF tool. Advances in Forest Fire Research- page 1883. Chapter 7, Social and Economics Issues. http://dx.doi.org/10.14195/978-989-26-0884-6_210
- Rodríguez y Silva, F., J. R. M. Martínez, and A. González-Cabán (2014), A methodology for determining operational priorities for prevention and suppression of wildland fires, International Journal of Wildland Fire, 23(4), 544-554.
- Rodríguez y Silva, F., and A. González-Cabán (2016), Contribution of suppression difficulty and lessons learned in forecasting fire suppression operations productivity: A methodological approach, Journal of Forest Economics, 25, 149-159.
- Rodríguez y Silva, F. (2017). Modelización econométrica de la productividad de las operaciones de extinción de incendios forestales en ecosistemas mediterráneos. Tesis de master en Investigación en Economía. Universidad Nacional de Educación a Distancia. Facultad de Ciencias Económicas y Empresariales. España.
- Rodríguez y Silva, F., and Hand M. (2018). Advances in Forest Fire Research 2018- page 1146. Chapter 6, Social and Economics Issues. https://doi.org/10.14195/978-989-26-16-506_128

# Applications and Future Work (Suppression Difficulty Index SDI, Surface Contraction Factor FCS, GI Management Index, Technical Efficiency and Uncertainty Assessment)

*Dr. Francisco Rodríguez y Silva*


- Rodríguez y Silva, F. (2019). Economic Analysis of Risk and Choice under Uncertainty in Landscape Planning in Relation to Wildfires. General Technical Report PSW-GTR-261. Pacific Southwest Research Station. Forest Service, U.S. Department of Agriculture; 98 - 113
- Scott, J. H., M. P. Thompson, and D. E. Calkin (2013), A wildfire risk assessment framework for land and resource management, Gen. Tech. Rep. RMRS-GTR-315. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 83 p..
- Thompson, M. P., J. R. Haas, J. W. Gilbertson-Day, J. H. Scott, P. Langowski, E. Bowne, and D. E. Calkin (2015), Development and application of a geospatial wildfire exposure and risk calculation tool, Environmental Modelling & Software, 63, 61-72.
- Thompson, M. P., P. Bowden, A. Brough, J. H. Scott, J. Gilbertson-Day, A. Taylor, J. Anderson, and J. R. Haas (2016), Application of Wildfire Risk Assessment Results to Wildfire Response Planning in the Southern Sierra Nevada, California, USA, Forests, 7(3), 64.
- WFAS (2016) 'Wildland Fire Assessment System Severe Fire Weather Potential Mapping Tool.' Available at http://www.wfas.net/ [Accessed March 8].
- WFDSS 2013

# 1. Background and advances in research on forest fire economics. Experiences from the Rocky Mountain Research Station (RMRS USDA Forest Service, Human Dimension Program, National Fire Decision Support Center)

# 2. Operational safety in suppression and effective operational response

***Dr. David Calkin***

Dr. Calkin opened his discussion by providing some historical context on the U.S. Forest Service and its current fire management challenges. The U.S. Forest Service manages approximately 78 million ha of public land and maintains the largest wildland fire management organization in the world. The history of wildfire management in the U.S. Forest Service is a complicated and evolving story. The Great Burn of 1910 where 1.2 million ha of land burned in Idaho and Montana and killed 87 people helped to galvanize the need for active fire and land management and increased public support for the U.S. Forest Service. At the time the Agency had just been formed and was under threat from private interests looking to transfer the recently established national forests into private ownership. The Great Burn also helped to establish the primacy of wildfire suppression as the dominant management paradigm despite active debate regarding the need for wildfire on the landscape. This debate is fundamental to fire management in the U.S. and continues to this day. Given the ecological need for wildfire as a restorative agent of change in many western U.S. forests we are faced with a complicated challenge. How do we achieve increased wildfire on the landscape while ensuring important natural and human developed resources are not damaged by wildfire? This conflict forms the basis of wildfire risk management and economic analyses in the modern context.

Dr. Calkin then presented an overview of the US fire management system and introduced some of the challenges to advancing economic analyses to the US fire context. Key knowledge gaps regarding the consequences of wildfire to highly valued resources

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*Dr. David Calkin*

and assets and our ability to measure how we alter fire outcomes through suppression actions currently limit the application of economic concepts and models to wildfire management. These limitations have significant influence on our ability to ensure that current management responses are both effective (that is achieving the best outcome) and efficient (at the least cost). Specific topics of uncertainty that our joint research efforts look to explore include uncertainty around fire spread potential, wildfire effects on natural and human developed resources, valuing change to resources affected by fire, and organizational factors that influence fire management strategy selection. Much of the US team's research has focused on application of economic and decision science to better understand management of the largest most complex wildfire events. Although there are many interesting management challenges associated with the initial attack of wildfire, most of the losses, cost and opportunities for improved long term results are associated with the larger, longer duration events.

Conceptually, what we attempt to accomplish in the application of economic science to wildfire management is to determine the management structure and strategies that minimize expected net value change from wildfire management. As stated in the previous paragraph there are numerous uncertainties that challenge our ability to definitively determine economic efficiency of our fire management system and associated response. Within the western US the Forest Service manages large contiguous areas of wild lands with limited human development. Large wildfire events can last several weeks to months and on some events the fire is allowed to spread to achieve resource benefit objectives. Within Andalusia, Spain, private ownership is far more likely to be interspersed within natural areas and fire events are typically of shorter duration with a single management objective of suppressing the fire in the most efficient way. Table 3 below demonstrates some of the primary ways in which economics is considered in our two regions, Andalusia, Spain and Montana, USA.

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## 2. Operational safety in suppression and effective operational response

***Dr. David Calkin***

Both the U.S. and Spain share many challenges in improving our fire management outcomes however objectives and strategies frequently differ, thus our research approach and areas of emphasis are not identical. Despite these differences we have much to learn through our integrated research efforts.

| Location | Andalusia, Spain | Montana, USA |
|---|---|---|
| **Context** | Applied to specific fire scenarios, typically small fire and short duration | Applied to thousands of possible fire scenarios, typically large fire and long duration |
| **Fire simulation approach** | Deterministic | Probabilistic |
| **Economic model** | Cost–benefit analysis, net value change monetised | Cost-effectiveness analysis, net value change not monetised |
| **Fire effects analysis** | Expert judgement, depreciation matrix | Expert judgement, response function |
| **Non-market valuation** | Asset- and resource-specific equations from various peer-reviewed studies | Multi-criteria decision analysis to assign relative importance weights to assets and resources |
| **Key omissions** | Limited inclusion of smoke impacts, responder safety and other health concerns; limited temporal horizons | Limited inclusion of smoke impacts, responder safety and other health concerns; limited temporal horizons |

Table 3: Comparison of net value change estimation approaches used in existing decision support tools (Thompson et al. 2017)

# 1. Advances and new research lines on: Analysis, Evaluation and risk management

## 2. Landscape risk assessment and planning

***Dr. Matthew Thompson***

Dr. Thompson used the framework from Figure 7 as the principal themes to guide his discussion. He first addressed spatial wildfire risk assessment, describing the primary elements of an assessment framework (Figure 1) and emphasizing the importance of spatial context and landscape conditions as driving factors of risk. The presentation highlighted several examples of real-world risk assessments from the western U.S. that spanned planning scales ranging from local to national, and that informed decision processes including fuel treatment planning and budgetary prioritization (Thompson et al. 2015). A key similarity between the assessments performed in the U.S. and those in Spain is the use of response functions and depreciation matrices that estimate resource- and asset-specific fire consequences as a function of fire intensity.


**Figure 7**: Basic elements of wildfire risk assessment include the likelihood of fire, the intensity of fire, and the susceptibility of resources and assets to fire (Scott et al. 2013).

# 1. Advances and new research lines on: Analysis, Evaluation and risk management

# 2. Landscape risk assessment and planning

***Dr. Matthew Thompson***

Dr. Thompson then transitioned into a discussion focused largely on spatial fire planning, in particular the concept of Potential wildland fire Operational Delineations (PODs) and their application to National Forest System lands in the U.S. (Thompson et al. 2016). PODs are the fundamental spatial unit of analysis for synthesizing risk assessment results, and can facilitate zoning up landscapes according to broad strategic response objectives. Figure 8 presents an example network of PODs in the Sierra National Forest, California, U.S., along with corresponding strategic response categories. The categories range from "protect" where high losses from fire are expected, to "restore" where losses are low and ecosystem benefits from fire are expected. On this specific landscape, the spatial mosaic of POD response assignments tends to follow an easterly progression from "protect" to "restore" to "maintain." This largely reflects the proximity to the wildland-urban interface along the western flank of the National Forest, as well as the presence of vegetation types that can benefit from fire located furthest from development.

The creation of POD boundaries is intended to align with features that are meaningful to operational fire management, leveraging for example ridgetops, waterbodies, roads, barren areas, elevation changes, or major fuel changes. Developing PODs is ideally an interdisciplinary exercise infused with local knowledge, including input from fire specialists, fire and fuel planners, GIS specialists, and resource specialists, along with managers. Using POD categories can help inform decisions related to incident suppression as well as preventative fuels management. Fuel treatment strategies within PODs would tie to land and fire management objectives, for example in "protect" zones mechanical fuel treatments could be used to yield desired fire behavior conducive to more effective fire suppression. Fuels management could also be used to actually create POD boundaries, for instance through strategically placing fuel breaks.

Lastly, Dr. Thompson summarized recent research on identifying potential control locations (O'Connor et al. 2017). These potential control locations can form the basis for creating PODs, and more broadly can be used to support incident response decisions of where and when to construct fire line. A key aim of the recent analysis is to develop transparent, repeatable methods for developing potential control line maps that are objective and

# 1. Advances and new research lines on: Analysis, Evaluation and risk management

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***Dr. Matthew Thompson***

quantifiable. Although these maps will never be a substitute for local knowledge and expertise, the idea is that they could enhance pre-fire response planning and help managers identify areas on the landscape where suppression actions are more likely to be safe and effective. The basic spatial analysis is built from the intersection of historical fire perimeters with measured landscape features such as topography, fuels, and roads, along with compound fire indices such as fire rate of spread, resistance to control, and suppression difficulty indices (Rodríguez y Silva et al. 2014). Figure 9 illustrates a modeled probability of control surface for a landscape including the Tonto National Forest in Arizona, U.S. The local forest team used this map of suppression opportunities to develop a POD network, and further summarized wildfire risk assessment outputs to integrate forest plan management objectives with operational fire management opportunities and constraints.

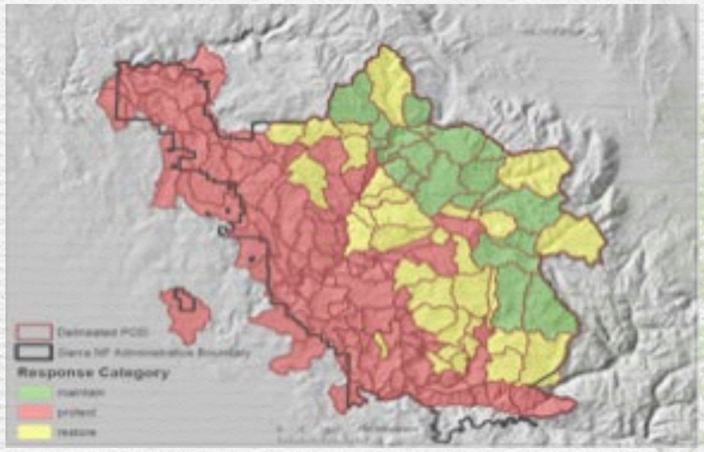

**Figure 8:** Example POD map along with strategic response categories assigned on the basis of a comprehensive spatial risk assessment (Thompson et al. 2016).

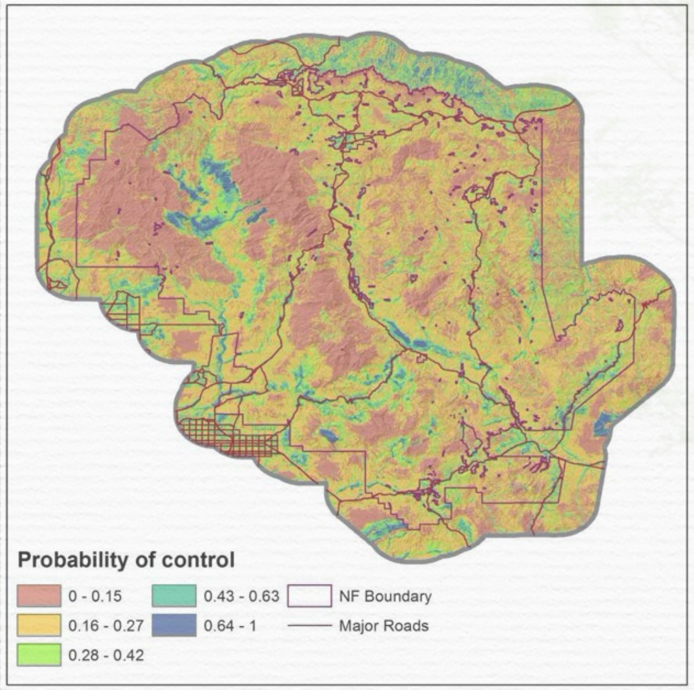


**Figure 9:** Example results showing modeled probability of control surface (Figure produced by Dr. O'Connor).

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