Towards Integrated Fire Management. Outcomes of the European Project Fire Paradox

Joaquim Sande Silva, Francisco C. Rego, Paulo Fernandes, Eric Rigolot

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EUROPEAN FOREST INSTITUTE

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To José Moreira da Silva, Pau Costa, and all those
who dedicated their lives to fire management.

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Foreword

One of the most important challenges for European forests, especially in Southern Europe, is fire. Fire has been affecting on average half a million hectares of forests, shrublands and crops every year. The European Forest Institute is committed to support initiatives which help generation and dissemination of scientific knowledge on forest fires. This knowledge is fundamental to support adequate political decisions and to implement the most appropriate technical solutions in order to mitigate the problem. This was the justification for the establishment in 2005 of the EFI Project Centre PHOENIX concentrating on fire ecology and post-fire management.

Another cornerstone addressing the importance of the fire issues in the EFI's activities was the EFI Discussion Paper 15 "Living with wildfires: what science can tell us". This publication by Dr. Yves Birot and his co-authors from the Regional Office EFIMED, provided the perspective that societies should learn to live with wildfires by controlling the circumstances causing forest fires. This general concept of Fire Management was also the leading principle of the EC-funded project "Fire Paradox", 2006–2010, in which EFI was part of the consortium.

In terms of knowledge dissemination, key researches in the Fire Paradox project have been compiled into a report, with the aim of gathering the main results achieved by the project in one publication.

The result of this effort is the present EFI Research Report. Besides the necessary acknowledgements to all experts involved, I would also like to thank the European Commission for supporting this publication through Fire Paradox. I am convinced that it will be a useful contribution to the implementation of fire management policies and measures in Europe.

Risto Päivinen
Director, European Forest Institute

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The editors are also grateful to all authors who accepted the challenge to participate in this Research Report. Finally we would like to thank the whole Fire Paradox Consortium, since this book is the direct result of the work developed during the four years duration of the project.

The Editors
Joensuu, January 2010

1. Introducing the Fire Paradox

1. Introducing the Fire Paradox

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The Fire Paradox project (2006–2010) was funded by the European Commission Research and Development program. The main objective of the Fire Paradox project was to produce and use science to inform decisions, practices and policies under integrated fire management in Europe. The project included 30 partners from eleven European countries and six partners from Africa, South America and Asia, with close support from ten specialists from the USA, Canada and Australia which formed the International Advisory Committee. Fire problems and solutions are found all over the world, and we see the knowledge exchange and benefits of Fire Paradox will extend far beyond Europe.

The approach taken by Fire Paradox includes the development of the science to inform the use of fire as a main component of the fire management solutions proposed, and the development of strategies for their implementation at the regional, national, and European levels.

The Wildland Fire Management Terminology produced by the Global Fire Monitoring Centre for the FAO[1] defines Fire Management as including "all activities required for the protection of burnable forest and other vegetation values from fire and the use of fire to meet land management goals and objectives", involving "the strategic integration of such factors as knowledge of fire regimes, probable fire effects, values-at-risk, level of forest protection required, cost of fire-related activities, and prescribed fire technology".

Integrated Fire Management involves further integrating the different components of fire management (fire prevention, detection, suppression, and use) with consideration of fire ecology relationships, being defined by FAO/GFMC as "fire management systems". These include one or both of the following concepts of integration:

1. Integration of natural or human-caused wildfires within prescription and/or planned application of fire in forestry and other land-use systems in accordance with the objectives of prescribed burning;
2. Integration of the activities and the use of the capabilities of the rural populations (communities, individual land users) to meet the overall objectives of land management, vegetation (forest) protection, and smoke management (community-based fire management).

1 1999 Wildland Fire Management Terminology produced by the Global Fire Monitoring Centre for the FAO

In other documents, such as those produced by the Global Fire Initiative, integrated fire management is viewed as “an approach to addressing the problems and issues posed by both detrimental and beneficial fires”, by “evaluating and balancing the relative risks posed by fire with the beneficial or necessary ecological or economical roles that it may play”, and by facilitating the implementation of “cost-effective approaches of preventing detrimental fires and maintaining desirable fire regimes”, recognizing that “managing beneficial aspects of fires may involve various forms of fire use”.

The concept of integrated fire management was never intended for Europe, and the philosophy of Fire Paradox offers an innovate approach for its implementation. In fact, Fire Paradox proposes the full integration of fire use in the prevention and suppression strategies by promoting the possibilities of the beneficial use of fire by prescribed burning, and the traditional fire use; and by using fire to suppress wildfires (see Figure 1).

When compared to other less populated parts of the world, the European situation offers a very special context to the use of the Fire Paradox philosophy, as in many regions of Europe fire has been traditionally used and continues to be used in rural practices whereas, at the same time, the vast majority of damaging wildfires have human causes. This apparent paradox is more evident in Europe than in many other regions of the world; because of this, there may also be more potential solutions to solve the paradox.

The approach taken in Fire Paradox was based on the paradox that fire can be “a bad master but a good servant”, thus requiring the consideration of the negative impacts of current wildfire regimes (understanding initiation and propagation) and the beneficial impacts of managed fires in vegetation management and as a planned mitigation practice (prescribed burning together with some traditional fire uses) and for combating wildfires (suppression fire). These were the four integration pillars of the project.

This Research Report reflects the structure of the project, corresponding to its integration pillars – initiation, propagation, prescribed burning and suppression fires – and including a closing chapter which synthesizes and combines the main project outcomes. The book provides science based knowledge that can assist policy makers to develop the necessary ‘common strategies’ to elaborate and implement integrated fire management policies. It makes extensive use of the science and technology findings from the Fire Paradox project, focusing on policies and best management practices, as well as providing guidelines for the future.

The chapters were written by leading authors recruited from key researchers from Fire Paradox Modules and Work Packages. Within each chapter there are a number of text boxes, many of which describe specific project activities, and outputs in order to illustrate key messages and recommendations.

In order to complement the information provided in the different chapters, the present publication includes a CD containing the deliverables and the internal reports from Fire Paradox Modules and Work Packages. These documents are directly or indirectly referred to in the chapters and were included in order to provide the outputs of the project on which the conclusions and recommendations were essentially based.

The book has four different topic sections, containing 15 chapters:

Section 1. Wildfire initiation: understanding and managing ignitions. In this section authors present the current knowledge and the project findings on fire

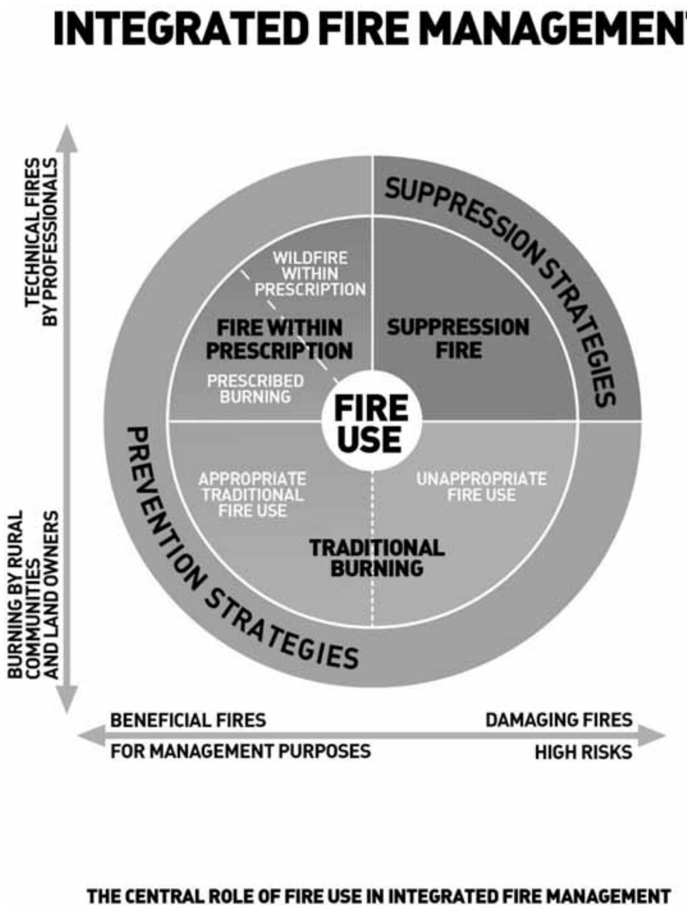

Figure 1. Integrated Fire Management, from a fire use perspective.

ignitions related to human activities, fuel flammability and fire occurrence, and an assessment of policies and practices related to fire ignitions.

Section 2. Wildfire Propagation: knowledge and search for solutions. This section addresses issues related with different factors influencing European fire regimes, fire modelling and simulation, wildland urban interfaces, fire economics, the knowledge on fire behaviour for fire fighting operations and the use of wildfire scenarios for fire suppression purposes.

Section 3. Prescribed burning: preventing wildfires and more. This section reviews recent developments to evaluate prescribed burning policies and practices in Europe and other regions, the scientific knowledge and operational tools to support prescribed burning, and discusses the learning and the training on the use of prescribed burning.

Section 4. Suppression fire: a tool to control wildfires. This section presents a review on the policies and practices of suppression fire in Europe and other regions, the application and practice of suppression fire as an operational tool in Europe and discusses the requirements of training for improving suppression fire capacity.

As a concluding text, there is a standalone chapter presenting some of the project developments which may contribute to solve the Fire Paradox in the context of integrated fire management.

Overall, the present Research Report provides a comprehensive synopsis of science, technology, products and services resulting from the Fire Paradox project. In addition, this book presents science-based knowledge and recommendations for changing the paradigm of fire management in Europe and elsewhere.

2. Wildfire Initiation: Understanding and Managing Ignitions

2.1 Fire Starts and Human Activities

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2.1.1 Introduction

The knowledge about where, when and why do fires start is essential to assure appropriate fire policy and management. The ability to understand and predict the patterns of fire ignitions will help managers and decision makers to improve the effectiveness of fire prevention, detection and fire fighting resources allocation.

This chapter starts by giving an overview of the patterns of fire occurrence in Europe. Then we present a more detailed analysis of key factors driving fire ignitions based on some case studies, and we conclude by making some remarks concerning implications for management.

2.1.2 Overview of fire ignitions occurrence in Europe

Unless otherwise specified the information presented in this introductory section results from the analysis of data extracted from the European Forest Fire Information System (EFFIS) wildfire database concerning the period 1998–2007 (21 countries – not all the countries have data for the whole period). The EFFIS database only includes wildfires that affected, at least partially, forest and other wooded land areas.

Anthropogenic and natural causes
There is evidence that the earliest use of fire by hominids occurred more than one million years ago (Pausas and Keeley 2009), although solid evidence date from less than 300 000 to 400 000 years (Weiner et al. 1998). Natural fire regimes have been increasingly altered by humans for many thousands of years at least, so that in most regions of the world, human activities have become much more important than natural sources of ignition (Goldammer and Crutzen 1993). This is especially true for Europe and particularly for the Mediterranean Region with its long history of human intervention in the ecosystems (Thirgood 1981).

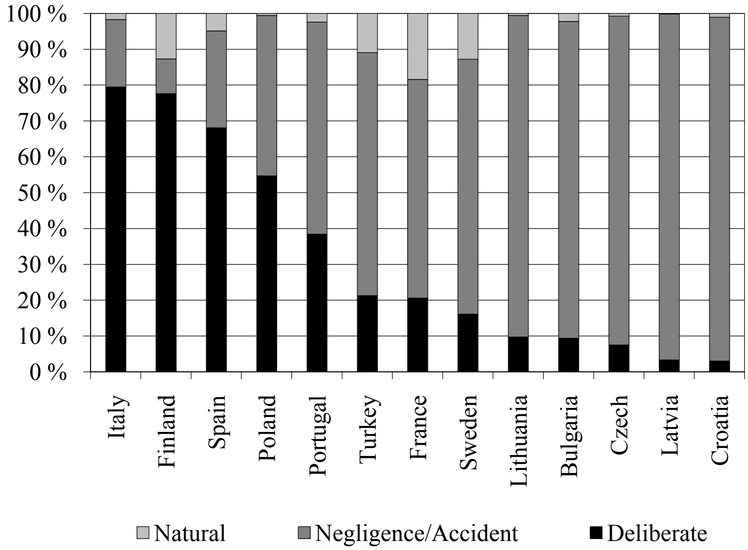


Figure 1. Main general causes of wildfires in Europe. Data extracted from the fire database of the European Forest Fire Information System (EFFIS) (Period 1998–2007; only countries with a minimum of 500 fires successfully investigated are included; countries are ordered by decreasing proportion of deliberately caused fires).

Currently, 95% of the fires in Europe are directly or indirectly caused by human behaviour and activities. Among the fires with known causes, 51% were intentionally caused, 44% started by negligence or accident, and only 5% had natural causes (mainly lightning). However, there are enormous differences between countries, with intentional causes representing 2% to 79% of all fires, negligent and accidental causes representing 10% to 98%, and natural causes representing 0% to 32%. Figure 1 shows the main general causes of wildfires for the 13 countries that had at least 500 fires that were successfully investigated.

Independently of the general designations (intentional, negligent, accident), which can vary among countries, there are some common aspects which characterize the human behaviour and activities which result in fire starts. Some of the major anthropogenic causes of wildfires in Europe are associated with land management, such as the burning of agricultural and forestry residues, land burning for pasture renovation or the use of machinery. However, there are many other factors that are also known to cause fires, including arson, accidents with electric power lines and railways or the fire use associated with forest recreation (e.g. Bassi and Kettunen 2008; Vélez 2009).

Concerning the question of how do fires start, the investigation of ignition causes is crucial if we want to understand the important role of humans in fire regimes. As we saw there are big differences among countries with regard to what are the main fire causes. However there is a considerable difference among the different

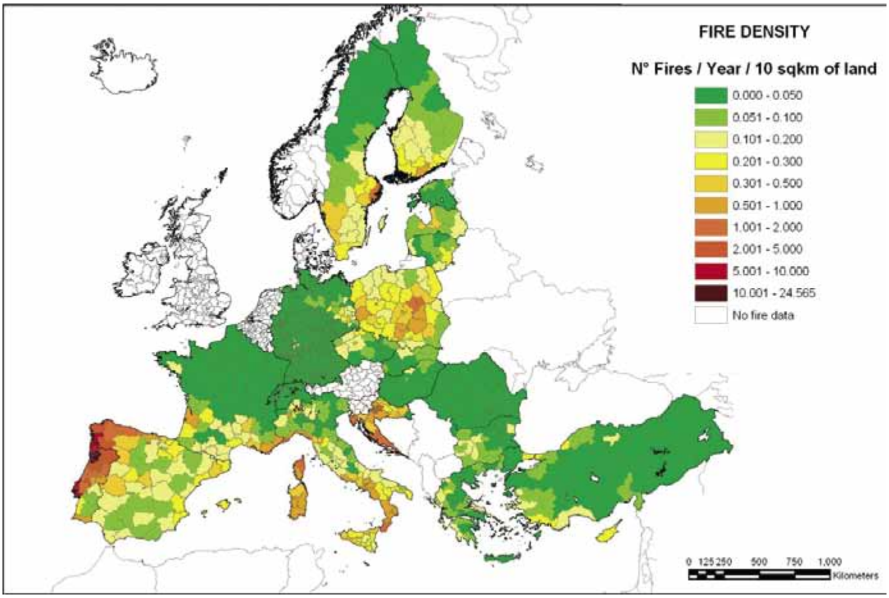


Figure 2. Fire density (number of fires/year/10 km^2) in Europe: average annual distribution in the period 1998–2007; based on province-level data (NUTS 3).

European countries with respect to the percentage of fires for which the cause of the fire is determined. These percentages range from nearly 100% in Latvia to only 5% in Portugal. Moreover the criteria for investigating and classifying the cause of a fire are not uniform among European countries, precluding the possibility of reliable comparisons. Although the distinction between natural and human-caused fires may be more or less straightforward, it is much more difficult to classify the different human activities responsible for a fire ignition. Even at the very coarse level of classification which only separates negligent/accidental from intentional (arson) causes, the different countries have not used the same criteria, making international comparisons difficult. For example, in Portugal uncontrolled agricultural burnings are classified as negligence, whereas in Spain this cause for fire starts is classified as intentional (APAS 2004).

Spatial and temporal patterns of fire ignitions

The higher densities of wildfires in Europe are mainly concentrated in the southern regions with the Mediterranean countries accounting for most of the fires reported. However in some central and northern countries fires are also frequent (Figure 2). There are several factors that can potentially explain the spatial variation of ignition density, such as climate, population density, main economic activities and land use.

Several studies worldwide have identified numerous factors influencing the spatial patterns of fire ignitions (e.g. Mercer and Prestemon 2005; Loboda and Csiszar

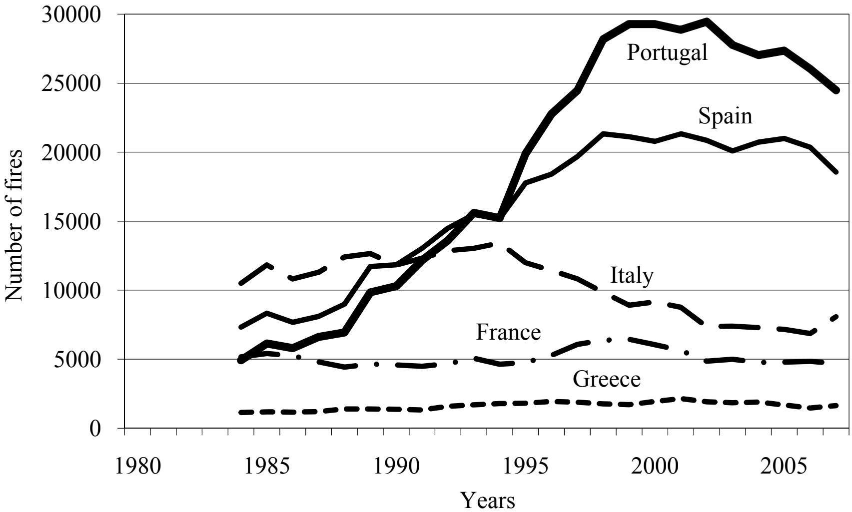
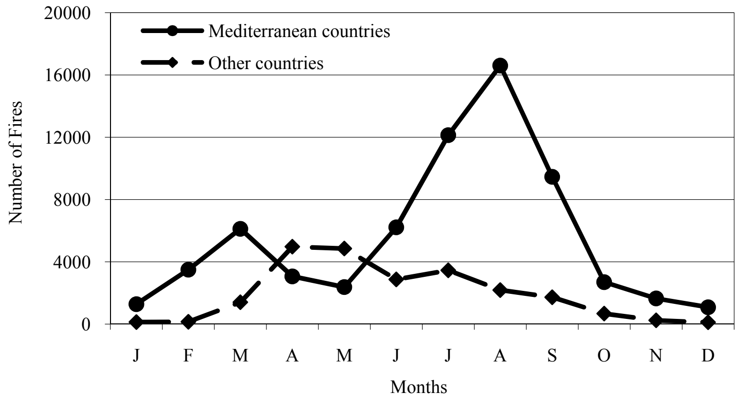


Figure 3. Evolution of the number of fires in five southern European countries in the period 1980–2007, using moving averages (n = 5 years) (based on country-level data; source: EC 2008).

2007). However, the effects of different factors on fire ignition occurrence can vary a lot among ecosystems and across spatial scales (e.g. Yang et al. 2007), and until recent years scarce information was available for Europe. Some additional information is presented in this chapter (see sections 2.1.3 and 2.1.4).

The number of wildfires in Europe has been increasing in recent decades (UN 2002; EC 2008). UN (2002) reported an increase from about 40 000 fires in the 1970s to 95 000 in the 1990s (decade averages for a group of 31 European countries). Several socio-economic factors, including the increasing recreational use of forests and land accessibility contribute to this trend. However, the improvements on fire detection methods and in the communication/reporting systems are likely to have also contributed to the detection and reporting of more fires, and we do not know to what extent each factor has influenced the observed trend.

In the last decade, despite the large annual variability, the number of fires has apparently stabilized or is even beginning to decrease. For example the EFFIS database shows an annual average of 89 000 fires in the last decade (1998–2007) which is lower than the average reported for the 1990s in a UN report (UN 2002); however the EFFIS database refers to a group of 21 European countries, while the UN report refers to 31 European countries, thus limiting direct comparisons. On the other hand, looking at the trends of the five largest EU Mediterranean countries (those having a longer time-series fire database), and even if they present very different situations, we can also see that the overall tendency in the current decade is towards a stabilization or to a decrease in the number of fires (Figure 3), but some more time is necessary to clearly confirm this trend.



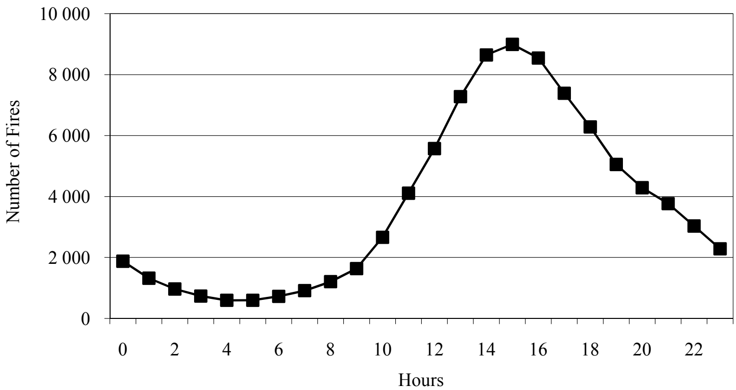


Figure 4. Average monthly (top) and hourly (bottom) distribution of wildfires in Europe. Data extracted from the fire database of the European Forest Fire Information System (EFFIS) (Period 1998–2007; 21 countries).

Fire occurrence in the European region is mostly concentrated in summer and spring (see Figure 4). The majority (51%) of all wildfires occurs during the third trimester of the year, corresponding to the summer months (July to September). On average, 27% of the wildfires occur during the spring months (April to June), 14% occur during winter (January to March), and only 7% in autumn (October to December). However the monthly distribution of wildfires is not the same for all the countries. In the Mediterranean countries the majority of fires occur during the summer, while in most of the remaining countries the majority of fires occur in spring.

On average the hourly distribution of wildfires peaks between 14.00h and 17.00h, with 30% of all fires starting in this period (Figure 4). The majority of fires start between 13.00h and 19.00h (53% of all ignitions), and the period of the day when fewest fire starts is between 03.00h and 07.00h (only 3%). There are few differences among European countries with regard to the distribution of fire ignitions during the day.

Fire ignitions and resulting burned area
In the European region, the vast majority of wildfires are small, and only a few have major consequences. On average 70% of all European wildfires burn less than 1 ha and 95% burn less than 10 ha. In total, less than 1% of all fires are larger than 100 ha, and less than 0.2% are considered to be large fires (more than 500 ha). Although in general these patterns are quite similar in all countries, the larger fires are almost exclusively concentrated in the Mediterranean countries.

The Mediterranean countries have the highest number of fires and the largest area burned in Europe. On average about 500 000 ha are burned every year in these countries.

2.1.3 Analysis of key factors driving fire ignitions

The Portuguese case study

Portugal is the European country with the highest density of wildfires, both in terms of ignitions and of burned area, and thus it was selected as a case study for a more detailed analysis. Recently a research team studied about 130 000 fires that occurred in Portugal during a five-year period (Catry et al. 2007, 2008, 2009). The work was focused on characterizing and identifying the main factors driving the spatial occurrence of wildfire ignitions. Several socio-economic and environmental variables hypothesized to be related to the spatial distribution of fire ignitions were selected and analyzed. Several logistical models were developed and an ignition risk map was produced for the entire Portuguese mainland, demonstrating that it is possible to predict the likelihood of ignition occurrence with good accuracy and using a small number of easily obtainable variables.

Modelling fire ignitions
Human presence and activity are the key drivers of fire ignitions in Portugal. The selected explanatory variables were all highly significantly related with the spatial distribution of ignitions.

Population density was found to be the most important variable in the multivariate models. This variable was positively correlated with ignition occurrence, meaning a higher probability of ignition in the more populated areas. In several other studies worldwide population density was also found to be positively related to wildfire ignitions (e.g. Cardille et al. 2001). In Portugal, 70% of all fire ignitions occurred in municipalities with more than 100 persons/km^2 although they only represent 21% of the territory.

Land cover was also hypothesized to be a determinant factor causing ignitions because different kinds of human activities (land uses) lead to different levels of risk, like those implicating an active of fire (e.g. traditional burning to eliminate agricultural residues), and because different land covers have different fuel characteristics (e.g. moisture, flammability), which can determine fire ignition and initial spread. In our studies land cover showed a strong influence on the probability of fire ignition, similar to other author's findings (e.g. Cardille et al. 2001). The vast majority of fires started in agricultural and mixed urban-rural areas (85%), and only 15% started in forested or uncultivated areas although they cover 50% of the country. Results indicate that agriculture is a very important factor influencing fire starts. This is in accordance with previous investigations of fire causes, which concluded that a large proportion of wildfires is due to agricultural activities (e.g. MMA 2007). Also contributing to this high ignition incidence are the higher population densities usually present in these areas (in comparison to forested and uncultivated areas), and that the herbaceous vegetation in many Mediterranean agricultural areas is easier to ignite and the fires propagate more easily than in other fuel types, especially during the summer when fuel moisture is very low. The high ignition incidence in urban-rural areas may also be explained by the co-occurrence of agricultural activities and a high human presence. Forests, shrublands and sparsely vegetated areas also showed a positive influence on the multivariate models, but their influence was considerably lower.

Probability of fire ignition occurrence decreased with increasing distance to main roads; this result has also been found in other studies (e.g. Vega-Garcia et al. 1996). According to our results, 98% of all ignitions occurred at less than 2 km from the nearest road and 85% were within a distance of 500 m.

Elevation positively influenced ignition distribution. This effect may be because some human activities are more likely to occur at higher elevations, such as the renovation of pastures for livestock using traditional burnings, which are known to cause frequent wildfires in the Iberian Peninsula (see Box 1). Badia-Perpinyà and Pallares-Barbera (2006) also found a higher ignition frequency at higher elevations in a rural area of north-eastern Spain. Additionally, lightning-caused ignitions have been described to be more likely to occur at higher elevations (e.g. Vazquez and Moreno 1998).

Fire ignitions and resulting burned area

The spatial patterns of ignition are not the same for all fire sizes (Catry et al. 2008). This conclusion is based on both the comparisons between the frequency of ignitions resulting in fires of different sizes, and the modelling work performed taking into account the final burned area.

Although most fires start in areas of higher population density, there are important differences in the origin of ignitions that resulted in smaller versus larger burned areas, with most larger fires starting in areas with comparatively lower population density (see Figure 5). The strong positive influence of population density observed in the global multivariate predictive models rapidly decreases for increasing fire sizes, becoming negative when predicting the occurrence of fires larger than 500 ha.

The influence of land cover type is different for ignitions resulting in small or large fires. Considering all fire sizes, the class of mixed urban-rural areas had nine times more ignitions than would be expected if they occurred randomly in the territory. Forests and shrublands registered three times less fire ignitions than if they were randomly distributed. However, results also show that the probability of large fire occurrence is significantly higher in woodlands and lower in urban-rural areas, when compared to small fires.

The frequency of ignitions also depends on distance to roads, and ignitions are more likely to occur closer to the main roads independent of the resulting fire size. However we verified that the frequency of larger fires starting at longer distances

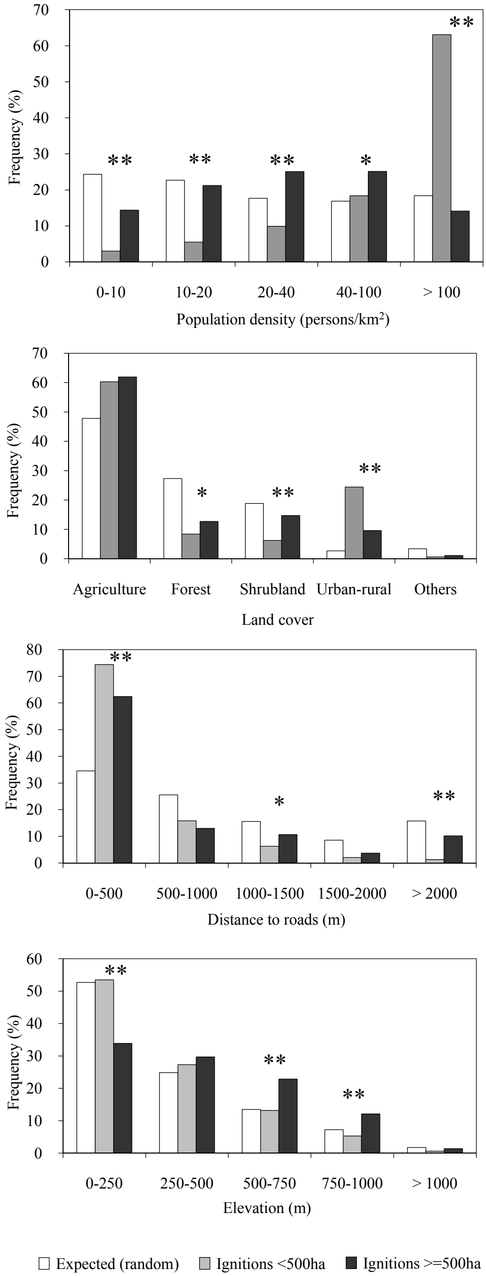


Figure 5. Comparison between fire ignitions that resulted in burned areas smaller or larger than 500 ha (significant differences * p<0.05, ** p<0.001) in relation to population density, land cover, distance to roads and elevation. Expected fire frequencies (corresponding to a random occurrence) are shown as reference (adapted from Catry et al. 2008).

is significantly higher than for smaller fires. Concerning elevation, larger fires are significantly more likely to start at higher elevations than smaller fires (Figure 5).

Results of this study clearly showed that fire ignitions are strongly related with human presence and activity, but also that the spatial patterns of ignitions are different for larger or smaller wildfires. The models produced had reasonable to good predictive ability, with ROC (Receiver Operating Characteristics) analysis indicating 74% to 87% agreement between predicted probabilities and observed outcomes. Models built for different years performed similarly, which indicates little spatial variability in a five-year period.

2.1.4 European comparisons – Relationships between ignitions and land cover

Due to increasing anthropogenic fire activity, understanding the role of land cover in shaping coarse-scale wildfire regimes has become a major concern. This is because human presence and impact (e.g. population density, agricultural practices, grazing pressure) together with the amount of fuel and its spatial distribution are basic factors in explaining fire ignition and propagation (Lloret et al. 2002). Land cover and fuel characteristics are characteristics that are often closely related (Turner and Romme 1994), such that the probability of fire ignition will be affected to a large extent by the nature of the different land cover types.

In a different study a research team quantified coarse-scale patterns of fire ignition in three selected European study areas in order to determine to what extent ignition occurrence is dependent on land cover in different European regions (see Bajocco and Ricotta 2007). Authors identified land cover types where fire ignition probability is higher or lower than expected by a random null model assuming that, if several land cover types were equally fire-prone, fires would occur randomly in the landscape.

Methods

The analyzed data sets are composed of (i) 13 377 fire records in Sardinia (Italy) during the period 2000–2004, (ii) 3023 fire records in the Coimbra district (Portugal) during the period 2001–2005, and (iii) 1331 fire records in the Cantons of Ticino, Graubuenden and Uri (Switzerland) during the period 1982–2005. Land cover maps with a common legend were used for all selected study sites derived from CORINE Land Cover data, where the original classes were aggregated into 12 coarser macro-classes, the composition of which slightly varies across the study areas (see Table 1). The urban class includes mixed urban-rural areas, as stated in the Portuguese study case.

To determine whether the number of fires in the examined cover classes is significantly different from random, Monte Carlo simulations were used. The null hypothesis is that fires occur randomly across the landscape so no differences between the relative abundance of fires in each land cover class and the relative extent of each class within the analyzed region are expected. At each study site, the actual number of fires in each land cover class was compared with the results of 999 random simulations.

Table 1. Results of the analysis on fire ignitions occurrence by land cover class in different European regions (Italy, Portugal and Switzerland). The symbols + and – indicate, respectively, whether fire ignition occurrence probability is higher or lower than expected by a random null model on a given land cover class at $p < 0.01$. () = not significant at $p = 0.05$; NP = the land cover class is not present in the study area.

Land Cover Types	Italy (Sardinia)	Portugal (Coimbra)	Switzerland (TI- GR-UR)
Urban surfaces	+	+	+
Non-irrigated arable land	+	+	(-)
Irrigated arable land	(+)	-	NP
Vineyards	+	-	+
Fruit trees and olive groves	+	+	+
Heterogeneous agricultural areas	+	+	+
Broad-leaved forests	-	-	+
Coniferous forests	-	-	-
Mixed forests	-	-	+
Pastures	-	NP	(+)
Natural grasslands	-	-	-
Transitional woodland-shrub and/or sclerophyllous vegetation	-	-	-

Results

The results of the analysis on fire ignitions in selected European study areas are shown in Table 1. According to the Monte-Carlo simulations, fire incidence in terms of number of fires by land cover class is not random ($p < 0.01$).

Overall, though the results obtained slightly vary across the study sites, there is a clear positive association between the number of fires and urban and agricultural land cover types. More specifically, in Sardinia, the number of fires is higher than expected by a random null model in urban areas and in all agricultural classes. By contrast, the number of fires is lower than expected in forests, grasslands and shrublands. A similar result is obtained for Portugal, where, apart from 'irrigated arable land' and 'vineyards', all land cover types with high human pressure are characterized by very high fire ignition probabilities. Forests, natural grasslands and shrublands exhibit the opposite behavior, all being characterized by low ignition probabilities.

In Switzerland, the situation is slightly more complex, due to the presence of two different fire seasons (spring and summer). Most artificial and agricultural land cover classes are characterized by high ignition probabilities. This is also the case for two forest classes, 'broad-leaved forests' and 'mixed forests' that are strongly affected by anthropogenic induced fires because of their proximity to settlements. On the other hand, in grasslands, shrublands and coniferous forests, the number of fires is lower than expected by chance alone.

From a statistical viewpoint, this analysis is easy to conduct at any spatial scale and with any meaningful land-use classification scheme providing valuable information for the development of strategies for fire risk assessment and fire prevention.

2.1.5 Conclusions – Implications for management

The ignition risk (the chance of a fire starting as determined by the presence and activity of any causative agent, also defined as 'fire risk'; FAO 1986; NWCG 2006) is an essential element in assessing fire danger (e.g. Finney 2005; Vasilakos et al. 2007). Nowadays, many fire management decisions are still exclusively based on the factors influencing the fire spread and suppression difficulty. However, as resources are limited, it is important to define priorities among areas. Under similar fuel, topographic or weather conditions, the areas with higher ignition risk should be given priority for surveillance (e.g. Vasconcelos et al. 2001; Chuvieco et al. 2003). The ability to understand and predict the patterns of fire ignitions is essential for managers. It will help improve the effectiveness of fire prevention, detection and allocation of fire fighting resources. Knowledge about where, when and why do fires start improve that ability.

Fire incidence varies greatly among land cover types. Some types of land cover burn far more often than would be the case if fires occurred randomly. Further, fire ignition probability is usually connected to social, economic and cultural drivers. The disproportionately high fire occurrence in the urban and agricultural classes is largely due to the high human presence that represents the major source of fire ignition in most European regions. Population density, distance to roads and elevation were also found to be important predictors of the occurrence of fire ignitions. The present results may strongly contribute to solving the Fire Paradox by providing to the managers information on priority areas with high fire hazard and risk. In these areas, optimizing prescribed burning applications and the ecological benefits of the wise use of fire may be very effective in achieving the wildfire reduction goals.

The temporal patterns of fire starts seem to be mostly related with the meteorological conditions, which affects the fire ignition and initial spread (e.g. affecting fuel moisture and flammability). The knowledge of these patterns can also have important consequences for fire management, namely in terms of vigilance and fire fighting preparedness.

The knowledge on fire causes is also of crucial importance and should have a high priority in terms of investing resources for minimizing the wildfire problem. Nevertheless, there are important differences among European countries concerning the process of fire cause investigation. These differences result in different rates of investigated fires and especially in different classification systems, which preclude reliable, quantitative comparisons between countries. Given these discrepancies, the European Commission through its Joint Research Centre has recently launched a call for proposals concerning the "Determination of forest fire causes and harmonisation of methods for reporting them". However it is necessary that results coming from this initiative are translated into policies aimed at harmonizing the different methods and criteria for fire investigation and fire cause classification. Although local actions targeted at well identified groups are an essential strategy for preventing fire ignitions, Europe should have common initiatives and support mechanisms on this topic. The existence of common criteria will help identify which countries and regions need the most attention and where resources should be preferably allocated to prevent fire ignitions. On the other hand, we also saw

Box 1. Wildfires and pastoralism – the Portuguese case study

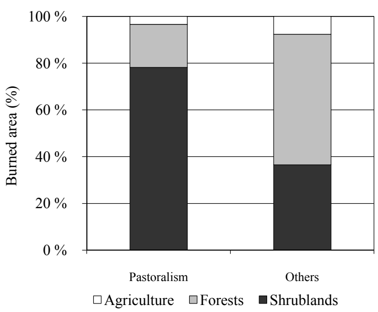
The relationships between wildfires and pastoralism were studied in Portugal using a national database of about 135 000 fires that occurred during a six-year period (2002–2007). A sample of 7337 fires with a known cause was used to investigate the particular characteristics that differentiate the fires that were caused by shepherds (renovation of pastures for livestock) from all the other causes.

On average, pastoral activity was responsible for 20% of all wildfires and for 11% of the area burned. Shepherd-caused fires burned mainly shrublands (78%) and forests (18%). In contrast the other fires burned more forests (56%) than shrublands (37%).

Logistic regression methods were used to analyze the relative importance of 26 potential explanatory variables and to develop fire ignition predictive models. The factors having the greatest influence on the probability of pastoral fire occurrence were the presence of forest, active population, recurrence of fires in the past, altitude and slope. Presence of forests and active population had a negative influence and the remaining variables had a positive influence. The tests performed to evaluate the models showed good accuracy on predicting fire occurrence (82–85%, *ROC*).

Concerning topography, results showed that fires associated with pastoral activity occurred at higher elevation and in more irregular terrain than the other fires. These fires also started more often in areas with lower human population density/activity, more distant to the major roads and where fires burned more frequently in the past. They were also more frequent in areas with more shrublands and less forests when compared to the other fires.

Fires due to pastoral activities also showed a different temporal pattern, occurring mostly from mid-summer to mid-autumn (Figure 6). However large annual variations in the fire season were observed, possibly being related with the annual meteorological conditions and food availability for cattle.



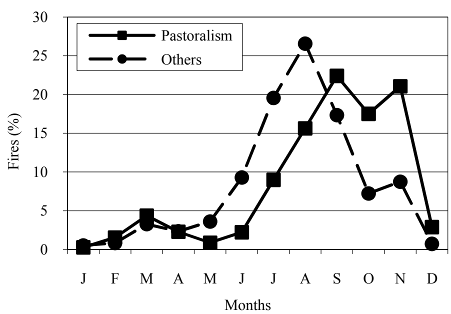


Figure 6. Comparison between fires that were started for pastures renovation (6-year averages): main land cover classes affected (left); and annual distribution of fires (right). Reproduced from Catry and Rego (2008); (EU Forest Focus Programme: UTAD, AFN).

that fires of different causes can have different spatial and temporal patterns. Thus having more information about fires investigated (with known causes) and analysing them separately by cause type (e.g. as we did for shepherd-caused fires), will also contribute to improving existing knowledge.

Further important research topics should also include measures of temporal fire activity, such as predictions on number of fires per day in relation to natural and anthropogenic variables. Additionally, as only a low proportion of ignitions result in large burned areas, from a management perspective it would be important to further understand the characteristics of ignitions that result in large fires, as these should become a priority for initial attack and suppression. This was addressed in the case of Portugal, but more research is needed on this important topic.

References

APAS 2004. Estado del Conocimiento sobre las Causas de los Incendios Forestales en España. Asociación para Promoción de actividades Socioculturales, Madrid. 54 p.

Badia-Perpinyà, A. and Pallares-Barbera, M. 2006. Spatial distribution of ignitions in Mediterranean periurban and rural areas: the case of Catalonia. International Journal of Wildland Fire 15: 187–196.

Bassi, S. and Kettunen, M. 2008. Forest Fires: Causes and Contributing Factors in Europe. European Parliament, Brussels. 56 p.

Cardille, J.A. and Ventura, S.J., Turner, M.G. 2001. Environmental and social factors influencing wildfires in the Upper Midwest, USA. Ecological Applications 11(1): 111–127.

Catry, F.X., Damasceno, P., Silva, J.S., Galante, M. and Moreira, F. 2007. Spatial distribution patterns of wildfire ignitions in Portugal. Proceedings of the 4th International Wildland Fire Conference. CD. Seville, Spain.

Catry, F.X., Rego, F.C., Bação, F.L. and Moreira, F. 2009. Modelling and mapping the occurrence of wildfire ignitions in Portugal. International Journal of Wildland Fire 18: 921–931.

Catry, F.X., Rego, F.C., Moreira, F. and Bação, F. 2008. Characterizing and modelling the spatial patterns of wildfire ignitions in Portugal: fire initiation and resulting burned area. In: de las Heras J., Brebbia C.A., Viegas D. and Leone V. (eds.). International Conference on Modelling, Monitoring and Management of Forest Fires. WIT Press, Vol. 119: 213–221, Toledo, Spain.

Catry, F.X. and Rego, F.C. 2008. Caracterização e análise dos padrões temporais e espaciais dos fogos relacionados com o pastoreio. In: Botelho, H.S., Bento, J.M., Manso, F.T. (Co-ords.) A relação entre o pastoreio e os incêndios florestais. UE Forest Focus Programme. UTAD, AFN.

Chuvieco, E., Allgöwer, B. and Salas, J. 2003. Integration of physical and human factors in fire danger assessment. In 'Wildland Fire Danger Estimation and Mapping. The Role of Remote Sensing Data'. Chuvieco, E. (ed.) Vol. 4: 197–218.

EC 2008. Forest fires in Europe 2007. Report No 8. European Commission, Joint Research Centre, Institute for Environment and Sustainability. Ispra, Italy. 80 p.

FAO 1986. Wildland fire management terminology. FAO Forestry Paper 70, Food and Agriculture Organization of the United Nations.

Finney, M.A. 2005. The challenge of quantitative risk analysis for wildland fire. Forest Ecology and Management 211: 97–108.

Goldammer, J.G. and Crutzen, P.J. 1993. Fire in the environment: Scientific rationale and summary of results of the Dahlem Workshop. In: Goldammer, J.G. and Crutzen, P.J. (eds.). Fire in the environment: The ecological, atmospheric and climatic importance of vegetation fire. John Wiley & Sons, Toronto. Pp. 1–14.

Lloret, F., Calvo, E., Pons, X. and Dìaz-Delgado, R. 2002. Wildfires and landscape patterns in the Eastern Iberian Peninsula. Landscape Ecology 17: 745–759.

Loboda, T.V. and Csiszar, I.A. 2007. Assessing the risk of ignition in the Russian Far East within a modelling framework of fire threat. Ecological Applications 17 (3): 791–805.

Mazzoleni, S. 2007. Spatial and temporal statistics on wildfire regimes across Europe. Deliverable D4.1-1a of the Integrated Project "Fire Paradox", Project no. FP6-018505. European Commission. 14 p.

Mercer, D.E. and Prestemon, J.P. 2005. Comparing production function models for wildfire risk analysis in the wildland–urban interface. Forest Policy and Economics 7: 782–795.

MMA 2007. Los incendios forestales en España. Decenio 1996–2005. Ministerio de Medio Ambiente, Centro de Coordinación de la Información Nacional sobre Incendios Forestales. Madrid, Spain. 106 p.

NWCG 2006. Glossary of wildland fire terminology. National Wildfire Coordinating Group, PMS 205 (Boise, ID).

Pausas, J. and Keeley, J. 2009. A Burning Story: The Role of Fire in the History of Life. BioScience 59: 593–601.

Thirgood, J.V. 1981. Man and the Mediterranean Forest a History of Resource Depletion. Academic Press, San Diego 194 p.

Turner, M.G. and Romme, W.H. 1994. Landscape dynamics in crown fire ecosystems. Landscape Ecology 9: 59–77.

UN 2002. Forest fires in Europe 1961–1998. International Forest Fire News 27: 76–80. FAO/UNECE, United Nations (UN). Available at: www.fire.uni-freiburg.de/iffn/iffn_27/content27.htm

Vasconcelos, M.J.P., Silva, S., Tomé, M., Alvim, M. and Pereira, J.M.C. 2001. Spatial prediction of fire ignition probabilities: comparing logistic regression and neural networks. Photogrametric Engineering & Remote Sensing 67(1): 73–81.

Vasilakos, C., Kalabokidis, K., Hatzopoulos, J., Kallos, G. and Matsinos, Y. 2007. Integrating new methods and tools in fire danger rating. International Journal of Wildland Fire 16(3): 306–316.

Vazquez, A., Moreno, J.M. 1998. Patterns of lightning- and human-caused fires in peninsular Spain. International Journal of Wildland Fire 8(2): 103–115.

Vega-Garcia, C., Woodard, P.M., Titus, S.J., Adamowicz, W.L. and Lee, B.S. 1995. A logit model for predicting the daily occurrence of human caused forest fires. International Journal of Wildland Fire 5 (2): 101–111.

Vélez, R. 2009. The causing factors: a focus on economic and social driving forces. In: Birot, Y. (ed.). Living with wildfires: what science can tell us. EFI Discussion paper 15. European Forest Institute, Joensuu. Pp. 21–25.

Weiner, S., Xu, Q.Q., Goldberg, P., Liu, J.Y. and Bar-Yosef, O. 1998. Evidence for the use of fire at Zhoukoudian, China. Science 281: 251–253.

Yang, J., Healy, H.S., Shifley, S.R. and Gustafson, E.J. 2007. Spatial patterns of modern period human-caused fire occurrence in the Missouri Ozark Highlands. Forest Science 53 (1): 1–15.

2.2 Flammability: Influence of Fuel on Fire Initiation

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2.2.1 The fire initiation phase

Fire initiation consists of two phases in a wildfire growing process: (i) fire ignition and (ii) fire initial extension (until the arrival of the fire fighters).

Fire ignition regroups fuel reaction to energy inputs (drying and thermal degradation as endothermic phases, and combustion of flammable gases and charcoal as an exothermic phase); energy is input either by conduction (contact), radiation and convection.

Fire initial extension is piloted, step-by-step, by the combustion of the fuel particles located close to the ignition point. During this initial phase, if the burning conditions are stable and if the fuel is homogeneous, the pattern of the propagation of the fire front is circular; the centre of the circle is the ignition point and the radius of the circle is related to the spread rate of the fire. The front shape will be modified by changes in the burning conditions (gusts of winds, local relief) and local fuel heterogeneities.

The initial phase is common to all fires whatever the final size of the burned area, whatever the problems and difficulties faced by the fire fighters to control and finally to extinguish it, and whatever the loss of human life and the associated damage. Each catastrophic wildfire is always a fire, ignited at a given point or on a given small area, which grows in accordance with its own dynamic during the initial phase and may continue to spread despite the existing prevention means and the fighting means used to reduce its intensity and its rate of spread.

Ignition is the consequence of the mix of fuel particles, oxygen and heat input at a given location and at a given moment.

The phase of the thermal degradation of a fuel particle is endothermic (i.e. absorbing energy), the combustion phase either of flammable gases or of charcoals is exothermic (i.e. releasing energy). The basic phenomenon can be split into three sequential steps:

1. water is vaporised from the fuel particle;
2. (phase of pyrolysis) flammable gases associated with the oxygen of the air produce carbon-monoxide and carbon-dioxide and water;
3. charcoals and oxygen produce ashes and carbon-monoxide and carbon-dioxide.

In general, industrial and structural fires ignite in closed spaces, where the first step of the combustion phase consumes the available oxygen very rapidly and produces large amounts of black and toxic smoke. Wildfires are open fires where oxygen is not the limiting factor; nevertheless, such smoke can also be produced during large and intense wildfires.

Consequently, fire fighters and wildland managers cannot act directly on these combustion phases and must act on other parameters to limit the energy released and to reduce the fire extension.

2.2.2 The role of fuel particles characteristics

2.2.2.1 Chemical, thermal and physical characteristics

Given their role in the basic mechanisms, chemical, thermal and physical characteristics of fuel particles have been largely studied specifically to provide input data to the models predicting the behaviour of fires. Eufirelab teams promoted common methods to determine these characteristics (Allgöwer et al. 2007, Fernandes et al. 2006), and Fire Paradox partners have improved the cone calorimeter method for these types of fuel particles (Rein et al. 2008).

Wildland and forest fuel is basically constituted of living material (needles and leaves, twigs of various diameters, branches, trunks, and parts of the root system) and of dead material, partially decomposed (litter and duff) whose characteristics are altered during the decomposition process.

Fuel material is essentially composed of carbon, nitrogen, oxygen and hydrogen. In addition, and depending on the species, their environment, their stage of development, and their physiological state, this material also contained oligo-elements which intervene in the photosynthesis and growth processes but which very rarely plays a role in the initiation processes of a fire. Fuel material, particularly issued from Mediterranean tree and shrubs species, is rich in organic oils and in organic volatile compounds and terpenes (*Pinaceae* and *Cupressaceae*) whose flash points are low; this characteristic largely contributes to the ignition and spread of fire (Alessio et al. 2008).

Heat capacity (the amount of energy needed for heating the material) and heat content (the amount of energy released by the combustion of the material) are two important parameters for characterising wildland and forest fuel. Heat capacity varies between 0.4 and 1.4 kJ/kg/K and heat content of most Mediterranean species, either shrubs and trees, varies from 18 500 kJ/kg (oak leaves) to 24 000 kJ/kg (pine needles and *Ericacea* foliage) (Dimitrakopoulos and Panov 2001): these species are considered as highly energetic. Heat content depends on the richness in organic oils and in other organic volatile compounds. Baker (1983) indicates a heat content from 18 600 kJ/kg to 23 200 kJ/kg for cellulose and hemicelluloses, and 25 600 kJ/kg for lignin; consequently, heat content of wildland and forest fuel decreases with the richness of the tissues in cellulose and increases with their richness in lignin.

Szczygieł et al. (1992) established the relationships between heat and ash contents and flammability parameters and confirmed that ash content is fairly stable and does not significantly intervene in the combustion process as long as it remains lower than 5%.

Physical characteristics of the wildland and forest fuel contribute to the ignition and initial propagation processes. The larger the surface exposed to heat, the easier the heat will be intercepted; this heat is released by the initial source or by the combustion of fuel particles and transmitted either by radiation or by convection. Surface-to-volume and mass-to-volume ratios are two of the most important parameters for characterising the fuel particles. Surface and volume of leaves, needles and twigs can be determined through geometrical approximations detailed by Eufirelab members (Allgöwer et al. 2007; Fernandes et al. 2006). For more complicated shapes, Fernandes and Rego (1998) proposed to evaluate the surface by water immersion and weighing the mass of water which constitutes a film around the fuel particle. This water immersion method also allows the user to determine the volume of the fuel particle by adapting the pycnometer method to the specificities of the fuel particles.

Fuel particles have been classified according to their thickness (leaves, bark) or their diameter (twigs and branches). Eufirelab members proposed to classify Mediterranean fuel particles in four classes: coarse (>25 mm), medium (>6 mm to 25 mm), fine(>2 mm to 6 mm), and very fine (≤2 mm). The limits of the three first classes are the same as the American standards. The subdivision of the finest class in two classes (more than 2 mm and less than 2 mm) allows the user to separate leaves, needles and fine twigs from larger fuel particles and to determine more accurately the mass of the fuel consumed at the fire front of a prescribed burning, given that very fine, fine and medium fuels are generally consumed at the fire front of a wildfire.

2.2.2.2 Fuel moisture content

Fuel moisture content (FMC) also plays a paramount role in the reaction of wildland and forest fuel to heat exposure. Water vaporisation uses an important amount of energy due to the high heat capacity of water. It increases the concentration of non-flammable gases in the mixture of gases of combustion, and reduces their ability to initiate and sustain the combustion process by increasing the endothermic part of the combustion reaction.

For live fuels, a given FMC is the balance between the water inputs throughout foliage and roots system and the water outputs by plant evapo-transpiration. Each species adopts specific strategies to resist drought, and to limit its own water reserves at a level which permits the survival of the plant, or at least part of it. In contrast, dead material is not regulated by physiological mechanisms; its moisture content depends only on the water exchanges regulated by physical laws.

The moisture content of a given fuel is obtained by drying the fuel and calculated with the commonly used formula $FMC = 100\ (Mi - Mf) / Mf$

where Mi is the initial mass or wet mass of fuel and Mf is the final mass or its dry mass.

Unfortunately, some end-users prefer to express the moisture content using a different formula:

WFMC = 100 (Mi – Mf) / Mi

FMC can easily be deduced from WFMC by this third formula

FMC = 100 WFMC / (100 – WFMC)

It is assumed that the mass loss (Mi-Mf) is exclusively the mass of water which was inside the material and vaporised during the drying period. The international standard drying temperature is 105°C, applied for inert materials like sand, cement or plaster. Using this temperature level for drying wildland and forest fuel over-estimates the mass loss, and consequently the moisture content, because at this high temperature proteins are destroyed and oils and other organic compounds are either decomposed or volatilised. Therefore, many Mediterranean, and more broadly European, teams adopt a lower drying temperature. Eufirelab members proposed and adopted 60°C for live and dead fuels; this temperature threshold respects the proteins and limits the vaporisation of the largest part of the organic compounds. This lower temperature induces a longer duration of exposure to reach the stabilised mass. This duration depends on the type of oven, the structure of the fuel, the mass of the sample, the size of the containers: in order to be sure to reach the oven-dry mass and for simplifying the manipulation, Eufirelab members recommended a duration of 24 hours.

Other teams prefer to use a moisture "analyser" or "determination balance" constituted by an infra-red dryer placed above the plate of the electronic balance: this analyser displays the initial current and final weights during the drying process and determines in real time the FMC. This device provides quicker results but does not allow the users to carry out simultaneous replications or to compare simultaneously several fuel types, or several species.

Because these two methods cannot be easily applied outside, Australian teams have designed and developed a device based on the measurement of the electric resistance of a pellet of a pellet made from ground-up fuel (Chatoo and Tolhurst 1997). Through calibration tables, the FMC is directly displayed on the screen of the device. Fire managers may adapt immediately their tactics and strategies as soon as the value is displayed, for example the practitioners may stop the prescribed burning when the moisture content of the litter or of the duff falls below the prescription range.

In general, Fire Danger Systems are based on fuel characteristics and on topographical (slope and aspects) and meteorological data (local or regional temperature, rainfall and wind regime). They combine their monitoring with the monitoring of the moisture content of dead fuels (litter) and/or of living fuels (leaves of shrubs and trees). Meteorological data can be continuously monitored, and data are displayed as frequently as required. Moisture content of 1 hour, and more commonly, 10 hour time-lag fuels might be acquired at a "high" frequency, but generally only during the driest and hottest period of the day in order to catch the relative minimum which corresponds to the peak of the daily fire danger. Depending on the use of the parameter, and of the density of the network of plots where the fuel is collected, FMC can be available daily or every two or three days.

Szczygieł et al. (2009) and Ubysz and Szczygieł (2009) present, as an example, the Polish network of observation sites and the deduced map of fire danger (Figures 1 and 2).

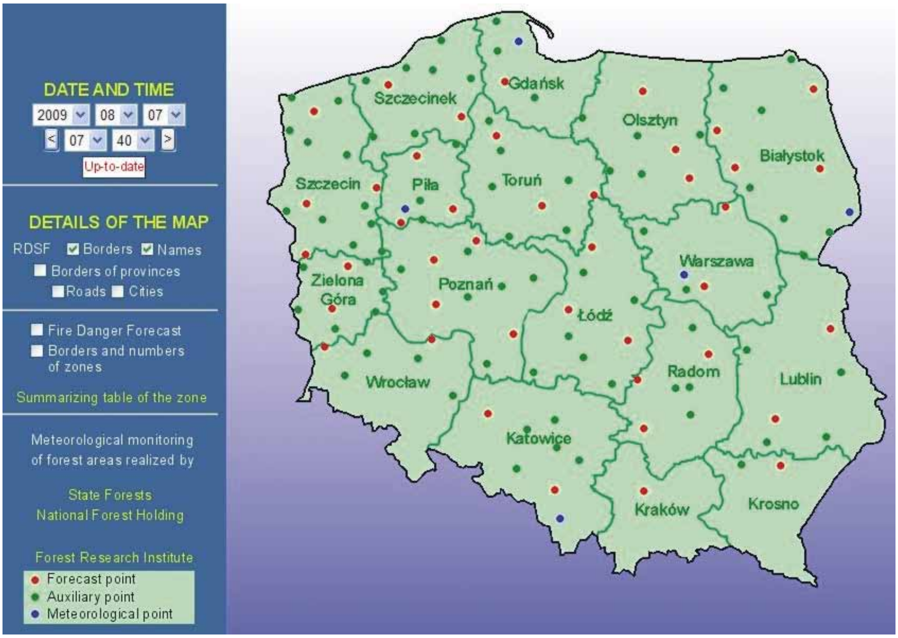

Figure 1. Polish network of fuel moisture content measurements.

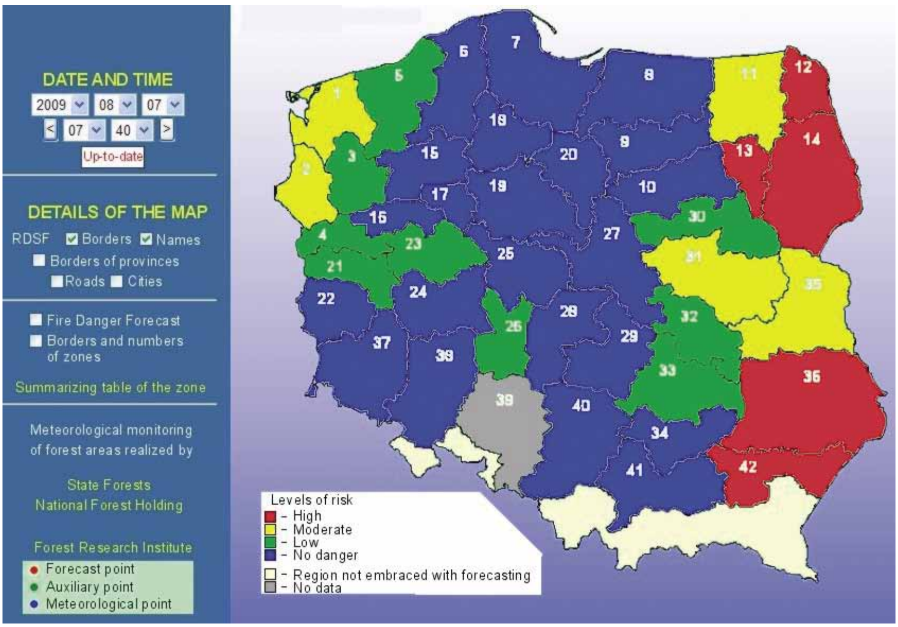

Figure 2. Polish deduced fire danger information map.

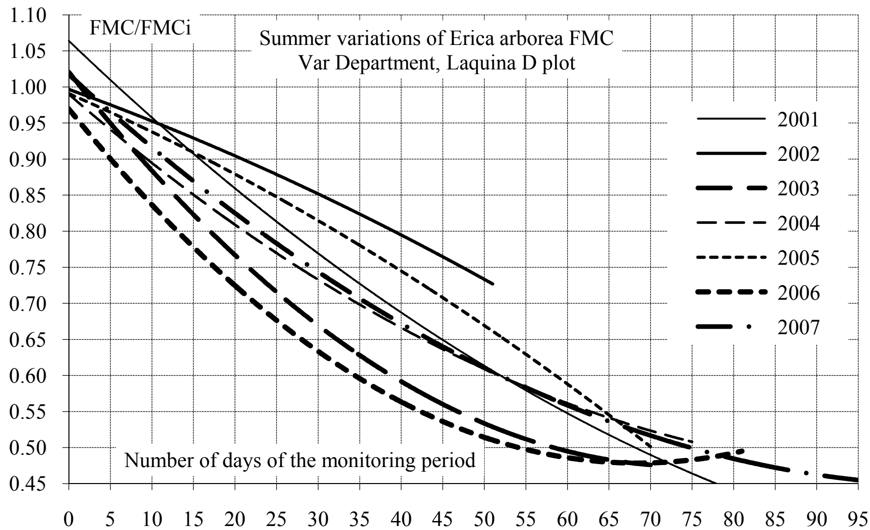

Figure 3. Summer variations of *Erica arborea* FMC, 2001–2006.

Figure 3 synthesises the evolution of the FMC of *Erica arborea* samples collected during six dry summer periods (2001 to 2006) on one plot of the French network which covers the French Mediterranean region (Forest Focus project).

During the summers 2002 and 2005, the drought was not too severe and *Erica arborea* was able to limit the decrease of its FMC: the first third of the variation was reached after 25 days in 2005 and 30 days in 2002, and the first half after 40 days in 2005 and 47 days in 2002.

During the other summer periods, these thresholds were respectively reached after 8 to 17 days and 17 to 28 days.

This kind of monitoring of several species in a given plot and several plots at a given date improves the accuracy of the fire danger prediction by including biological data. In a recent synthesis paper, Chuvieco et al. (2009) demonstrate that live fuel moisture content can be used to predict the behaviour and the occurrences of wildfires in specific Mediterranean ecosystems.

2.2.2.3 Fuel flammability

To update maps of fire hazard, the maps need to be deduced from meteorological and fuel moisture content data. This is generally based on the knowledge acquired through previous events, logical evolutions and also flammability data.

Methods and main results of other studies on the flammability of wildland and forest fuel have been described (Valette and Moro 1990; Moro 2006). Weise et al. (2005) in preliminary tests indicate that the cone calorimeter can also be used for

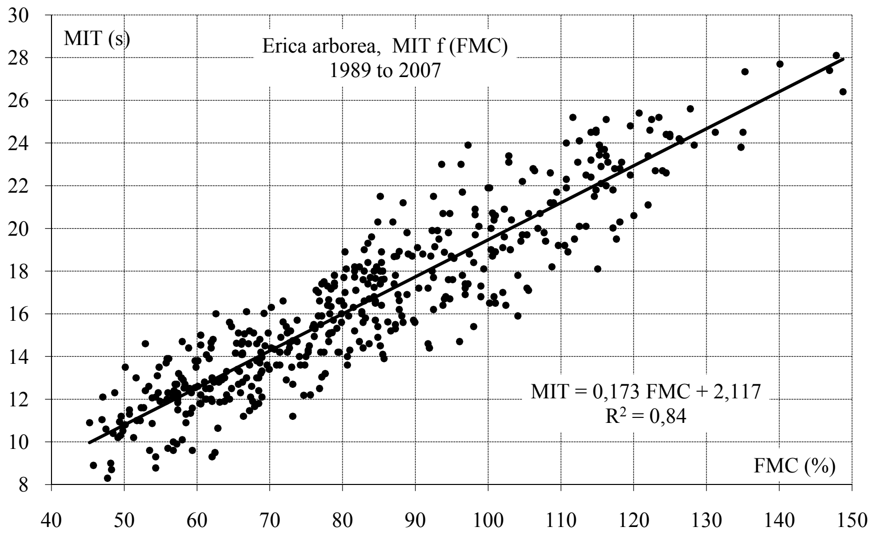

Figure 4. Mean Ignition Time of *Erica arborea* versus Fuel Moisture Content.

relating time to ignition and moisture content. Dibble et al. (2007) indicate that the cone calorimeter provides data that enable comparison of combustion properties among many species. Fire Paradox partners improved the procedure in order to characterise wildland and forest fuel and to provide the fire behaviour modellers with accurate values of required input (Rein et al. 2008; Madrigal et al. 2009).

Guijarro et al. (2002) described an adapted method for fuel beds and concluded that an increase of moisture content and of bulk density of litters implies an increase of the time to ignition. It also implies a decrease of the rates of initial fire spread and of combustion, and of the resulting flame height and fuel consumption ratio. Finally, it implies a decrease of the risk of fire initiation. Jappiot et al. (2007) proposed a classification of wildland urban interface areas, based on the flammability of the dead litter fuels.

On www.eufirelab.org/specific.php, Moro offers results on *Erica arborea;* measurements have been carried out during the summers from 1989 to 2007; the graphs illustrate how fuel flammability is largely dependent on fuel moisture content. Figure 4 summarises these results and a general equation, either linear or exponential, linking FMC to the Mean Ignition Time (MIT):

$$MIT = 0.173*FMC + 2.117 \qquad R^2 = 0.84 \qquad MIT = 6.767*e^{0.010FMC} \qquad R^2 = 0.82$$

Measurements of flammability parameters permit the classification of species, which is of highest interest during the fires seasons. The following table summarises the classification proposed by Valette and Moro (1990), Velez (1990) and Dimitrakopoulos (2001). Even though the approaches and methods are different, the common species are classed at the same level of flammability.

Flammability	France	Greece	Spain
Extremely flammable	*Pinus halepensis, Quercus ilex, Erica arborea*	*Pinus halepensis, Pinus brutia, Quercus ilex*	*Pinus halepensis Quercus ilex*
Highly flammable	*Arbutus unedo, Quercus coccifera, Pistacia lentiscus*	*Arbutus unedo, Quercus coccifera, Pistacia lentiscus*	*Arbutus unedo, Quercus coccifera*
Moderately flammable	*Cistus salvaefolius*	*Phlomis fruticosa, Cistus salvaefolius.*	*Cistus salvaefolius*

Many teams have studied in laboratory conditions the mechanisms of wildland initiation by incandescent objects like sparks and cigarettes. Xanthopoulos et al. (2006) demonstrate that the probability that fire may be initiated by a cigarette thrown from a car window is very small but not null, particularly when the car speed is low and the road is narrow; this is the case for many European roads crossing wildland areas and forests.

2.2.2.4 Conclusions

The above overview illustrates the role of the chemical, thermal and physical characteristics of the particles of wildland and forest fuel on fire initiation. It underlines the paramount role of the variations of fuel moisture content on the variations of their flammability and consequently on the fire hazard they present, at least during the driest and hottest seasons.

It is quite impossible to modify the chemical, thermal and physical characteristics of the fuel particles of the wildland and forest fuel at a reasonable cost. However, concerning the fuel bed, many treatments can reduce the fuel load and the fuel porosity.

Likewise, fuel moisture content cannot be easily maintained at a low risk level over large areas; the existing means are dedicated for very local application.

So, the recommendations towards wildland areas and forests managers, fire fighters, end-users, owners, local or regional authorities that can be deduced, will concern only limited areas, mainly wildland urban interfaces and vicinities of structures (houses, workshops, factories, etc.) located in or close to wildland areas and forests (Vélez 2009).

These recommendations will be related to the identified wildfire causes. Martin et al. (2005) describe the existing databases, analyse the content of three of them (from France, Italy and Spain) and summarise the procedure followed by the Spanish Nature Protection Service SEPRONA for wildfire investigation and prosecution. Alexandrian (2008) analyses the wildfire causes following the new classification used by the French Prométhée system.

2.2.3 Coping with fuel flammability – practical recommendations

Except the areas concerned by volcanism which are well known, monitored and managed, lightning wildfires occur during dry storms. Their frequency seems to increase (Alexandrian 2008); this might be a consequence of the global warming. This type of wildfire is typically ignited at a given point, where an enormous amount of energy is released and the initiation phase is very dynamic. Recommendations should be in the sense of:

- reinforcing research to identify the conditions under which such phenomenon occur;
- associating the remote monitoring of lightning impacts to the radar monitoring of rain to predict the localisation of fire initiation;
- using historical data to identify lightning-prone areas, develop a lightning detection system and improve the accuracy of the predictive model of lightning fires;
- reinforcing fire monitoring on lightning-prone areas and when the weather conditions are favourable to lightning and dry storms.

Many fire initiations are related to works carried out in wildland areas and forests during the periods of high fire danger (drought, wind). Generally, the initial energy released is very weak and the initial phase is long. At that step, if the weather conditions are not too severe, the extinction is easy as soon as the workers have some tools and equipments to control and extinguish the fire. But, this fire can smoulder for a long time and be detectable later after the departure of the workers. To reduce the number of fire initiations related to "forest" activities, recommendations should be in the sense of:

- equipping professional workers with fire fighting tools;
- integrating the prevention of fire initiations in the work organisation and schedule;
- making aware the workers to the specific fire risks of the area;
- excluding burnings during the summer period;
- including the days or periods of high fire danger in the "bad weather" clause of the working contracts and, consequently, to exclude any penalty in case of absence;
- forbidding any activity in wildland areas and forests during days or periods of high fire danger, except for fire prevention and fighting.

Other fire initiations are related to unintentional and imprudent acts committed either by local inhabitants or by tourists coming mainly from regions or countries where the fire danger is generally low. In both cases, local or regional authorities have to make them aware of the risk and to encourage them to change their personal behaviour. In general the initial energy is weak and the fire initiation is detected early. Recommendations should be in the sense of:

- reinforcing information on fire danger;
- improving information to common citizens;
- managing recreation areas to minimise the fire initiations (no car parks in shrub or herbaceous strata, efficient ash trays, active information panels with clear and simple recommendations towards the visitors, presence of specialised personnel);

- prohibiting any introduction of "hotspots" in these areas like barbecues or ovens;
- installing garbage bins and encouraging visitors to take the garbage back with them;
- closing and suppressing refuse areas, and in a first step to banish any access to them, and develop adapted refuse centres.

Other wildfire initiations are related to accidents or events which occur along or at the vicinities of equipments like electric power lines, highways, roads and opened paths, railways. Initial energy can either be very weak (a spark from an engine, a cigarette discarded from a car) or larger in case of car, van or lorry crashes. To limit the risk of fire initiation, recommendations should be in the sense of:

- managing along the highways a physical barrier to maintain cigarettes discarded from vehicles;
- promoting on both sides of the highway the planting of native shrubs and tree species with low flammability;
- making the highways users aware of the local fire danger through active luminous signs;
- managing the borders of open roads and paths by reducing the existing live and dead fuels;
- encouraging railway companies to implement brakes that do not emit sparks and windows that prevent passengers throwing cigarettes outside;
- managing the borders of the railways by reducing the existing live and dead fuels;
- encouraging the burying of electric power lines (high, medium and low voltage) in order to reduce the risks of power discharges between the line and the ground vegetation;
- reinforcing the efforts to reduce the amount of fuels below the electric power lines which can not be buried.

Some management measures can be recommended in wildland urban interfaces and in the vicinities of structures built in or close to wildland areas or forests, such as:

- promoting the selection, development or introduction of shrub and tree species presenting lower flammability;
- encourage the reduction of fuels on the interface and in the vicinities of the structures;
- making the inhabitants aware of the specific risks they will face during the high danger period;
- encouraging the inhabitants to clean the immediate border of the houses, including roof, rain gutters and woody shutters;
- collecting rain water and store it in a tank for fire fighting purposes;
- promoting less flammable building materials for houses.

Finally, the last category of wildland initiation causes is related to the acts of pyromaniacs and arsonists. The first sub-category concerns persons who need psychiatric treatments. On the contrary, arsonists are completely responsible of their acts; all the above recommendations are inefficient.

These acts may be based on neighbours' disputes or related to hunting dissensions; mediator's interventions may be efficient to solve problems.

When the arsonists' acts are based on soil occupation, a dissuasive decision is to prohibit the building of houses or any other structures into wildland areas or forests, which have been partially or totally burned; this prohibition can be applied during the following ten, twenty or thirty years. In Mediterranean areas where the pressure of the landed property is important, such a regulation must be strongly supported by the population and the public authorities at local, regional and national levels.

References

Alessio, G.A., Peñuelas, J., Llusià, J., Ogaya, R., Estiarte, M. and De Lillis, M. 2008. Influence of water and terpenes on flammability in some dominant Mediterranean species. International Journal of Wildland Fire 17: 274–286.

Alexandrian, D. 2008. Les statistiques "feux de forêt" de ces trente dernières années. Forêt Méditerranéenne XXIX(4): 377–384.

Allgöwer, B., Calogine, D., Camia, A., Cuiñas, P., Fernandes, P., Francesetti, A., Hernando, C., Koetz, B., Koutsias, N., Lindberg, H., Marzano, R., Molina, D., Morsdorf, F., Ribeiro, LM., Rigolot, E. and Séro-Guillaume, O. 2007. Eufirelab: Methods for Wildland Fuel Description and Modelling: Final Version of the State of the Art. Deliverable D-02-06. 57 p.

Baker, A.J. 1983. Wood fuel properties and fuel products from woods. In: Proc. Fuel Wood Management and Utilization Seminar, Nov. 9–11, 1982, Michigan State Univ., East Lansing, MI. Pp 14–25.

Chatto, K. and Tolhurst, K. 1997. The development and Testing of the Willtronics T-H Fine Fuel Moisture Meter. CFTT, Centre for Forest Tree Technology, Fire Management Branch, Department of Natural Resources and Environment, Research Report No. 46. 44 p.

Chuvieco, E., González, I., Verdú, F., Aguado, I. and Yebra, M. 2009. Prediction of fire occurrence from live fuel moisture content measurements in a Mediterranean ecosystem. International Journal of Wildland Fire 18: 430–441.

Dibble, A.C., White, R.H. and Lebow, P.K. 2007. Combustion characteristics of north-eastern USA vegetation tested in the cone calorimeter: invasive versus non-invasive plants. International Journal of Wildland Fire 16: 426–443.

Dimitrakopoulos, A.P. 2001. A statistical classification of Mediterranean species based on their flammability components. International Journal of Wildland Fire 10: 113–118.

Dimitrakopoulos, A.P and Panov, P.I. 2001. Pyric properties of some dominant Mediterranean vegetation species. International Journal of Wildland Fire 10: 23–27.

Fernandes, P.M. and Rego, F.C. 1998. A New Method to Estimate Fuel Surface Area-to-Volume Ratio Using Water Immersion.. International Journal of Wildland Fire 8: 121–128.

Fernandes, P., Allgöwer, B., Guijarro, M., Cuiñas, P., Hernando, C., Mendes-Lopes, J., Morsdorf, F., Ribeiro, L.M. and Valette, J.C. 2006. Eufirelab: Methods for wildland fuel description and modelling: Commonly used methods. Deliverable D-02-05. 7p

Guijarro, M., Hernando, C., Díez, C., Martínez, E., Madrigal, J., Lampin-Cabaret, C., Blanc, L., Colin, P.Y., Pérez-Gorostiaga, P., Vega, J.A. and Fonturbel, M.T. 2002. Flammability of some fuel beds common in the South-European ecosystems. IV International Conference Forest Fire Research; Luso; 18–23 November 2002

Jappiot, M., Curt, T., Lampin, C., Borgniet, L., Vinet, O., Luois, S., Chandioux, O. and Estève, R. 2007. Characteristics and Flammability of French Mediterranean Dead Litter Fuels. Poster at the International Wildland Fire Conference, Seville, Spain, 13–17 May 2007.

Madrigal, J., Hernando, C., Guijarro, M., Diez, C., Marino, E. and De Castro, A.J. 2009. Evaluation of forest fuel flammability and combustion properties with an adapted mass loss calorimeter device. Journal of Fire Sciences 27:323–342.

Martin, P., Bonora, L., Conese, C., Lampin, C., Martinez, J., Molina, D. and Salas, J. 2005. Eufirelab: Towards methods for investigating on wildland fire causes. Deliverable D-05-02. 54 p

Moro, C. 2006. Méthode de mesure de l'inflammabilité du combustible forestier Méditerranéen. Internal technical report. 14 p.

Rein, G., Torero, J., Guijarro, M., Esko, M. and de Castro, A. 2008. Methods for the experimental study and recommendations for the modelling of pyrolysis and combustion of forest fuels. Deliverable D2.1-1 of the Integrated Project "Fire Paradox", Project no. FP6-018505. European Commission. 83 p.

Szczygieł, R., Valette, J.C. and Moro, C. 1992. Teneur en cendres et pouvoir calorifique supérieur d'espèces forestières méditerranéennes : relations avec les paramètres d'inflammabilité. PIF1992-01. 15 p + annexes.

Szczygieł, R., Ubysz, B., Piwnicki, J. and Kwiatkowski, M. 2009. Fire flammability of forest plant formations in Poland. Deliverable D4.2-3 of the Integrated Project "Fire Paradox", Project no. FP6-018505. European Commission. 94 p.

Ubysz, B. and Szczygieł, R. 2009. Fire Situation in Poland. Instytut Badawczy Lesnictwa, Internal Report. 34 p.

Velez, R. 1990. Preventing forest fires through silviculture. Unasylva 41.

Vélez, R. 2009. The causing factors: a focus on economic and social driving forces. In: Birot, Y. (ed.). Living with wildfires: what science can tell us. EFI Discussion paper 15. European Forest Institute, Joensuu. Pp. 21–25.

Valette, J.C. and Moro, C. 1990. Inflammabilités des espèces forestières méditerranéenne, conséquences sur la combustibilité des formations forestières. Revue Forestière Française XLII numéro spécial 1990. Pp. 76–92

Weise, D.R., White, R.H., Beall, F.C. and Etlinger, M. 2005. Use of the cone calorimeter to detect seasonal differences in selected combustion characteristics of ornamental vegetation. International Journal of Wildland Fire 14: 321–338.

Xanthopoulos, G., Ghosn, D. and Kazakis, G. 2006. Investigation of the wind speed threshold above which discarded cigarettes are likely to be moved by the wind. International Journal of Wildland Fire 15: 567–576.

2.3 An Overview of Policies and Practices Related to Fire Ignitions at the European Union Level

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2.3.1 Introduction

Recent socio-economic changes, some forest management actions and other policy measures outside the forest sector (e.g., environmental and nature protection policies) have contributed to change the structure of some ecosystems enabling the build-up of fuels, which makes ecosystems more fire prone and increases the associated risk of large wildfires. Thus, the forest sector is facing new realities that are causing changes in the European wildfire context.

Until now, the process to induce changes in wildfire policies or the adoption of new political measures has been a fast ad hoc reaction to a past catastrophic situation, rather than proactive mitigation before an emergency arises (FAO 1999). This situation requires a shift in paradigm from a short-term fire policy, based mainly on technological investments for emergency suppression measures, to a longer-term preventive policy of removing the structural causes of wildfires and reducing, as much as possible, potential damage (Birot 2009).

However, the shift from suppression-oriented policies to preventive and integrative policies requires also an investigation of the human causes contributing to wildfires in Europe[1]. Established fire policies provide the framework for social prevention actions, including new governance methods and pre-extinction measures (Aguilar and Montiel 2009a).

This holistic and proactive approach to wildfire management (Morugera and Cirelli 2009) needs different formulations in Europe. In fact, wildfire issues receive different consideration within the national policy instruments depending on the risk severity of wildfires in the national contexts and the different political and administrative systems existing in each country. In countries along the northern rim of the Mediterranean Basin, wildfires are a subject of growing concern; in Northern and Central European countries wildfires have been historically far less serious.

In general, the wildfire problem has become worse during the second half of the 20th century. For example, land-use change dynamics have aggravated fire hazards and disaster potential, especially in Southern Europe, in part because the abandonment of rural areas, the prolonged protection of forest lands (and consequently fire exclusion from the ecosystem), and the expansion of wildland

1 Workshop on Forest Fires in the Mediterranean Region: Prevention and Regional Cooperation. Report. Corpo Forestale dello Stato, Rome, Italy – Joint Research Centre, European Commission – FAO. Sabaudia, Italy, 13–15 May 2008

urban interface areas (Galiana et al. 2009; Martínez 2004; Vélez 2002, Vilar del Hoyo et al. 2008).

The best instruments to introduce innovative approaches and recommendations for the necessary paradigm shift towards a solution to the current wildfire problem are a combination of legislation together with policy measures. However, the pattern and spatial distribution of the fire problem in Europe are different in the different regions and countries, and should be tackled differently at the regional and national levels, taking into account wildfire incidence and socio-economic conditions.

2.3.2 Description and characterization of policy instruments

Depending on the decentralization level of European countries, issues of wildfire management are handled principally within forest and civil protection policies at the national and regional level. National and Regional Forest Plans usually include preventive and curative actions to mitigate wildfire hazard, while civil protection policies aim to protect human lives and goods.

The European Union (EU) has also considered the wildfires problem in their political agenda since the 1980s through various regulations[2] that have encouraged the Member States (MS) to reinforce prevention of wildfires. Recently, the European Commission (EC) has adopted a Communication on the prevention of natural and man-made disasters (COM(2009)82) that focuses on subjects where a common approach is more effective than separate national approaches; for example, developing knowledge, linking actors and policies, and efficient targeting of community funds to prevention.

In agreement with national administrations, the main initiatives undertaken by the EC regarding fire prevention include:

- The European Forest Fire Information System (EFFIS) that collects information on forest fires (e.g. causes, risk levels) to create a common EU Fire Database.
- Financial provisions to MS. Regarding support to the national prevention policies, the LIFE+ instrument[3] co-finance communication and awareness campaigns for fire prevention; while the Rural Development Regulation constitutes the main source of investment in infrastructure for wildfire prevention.
- Support for scientific research on various wildfire topics.

Information derived from the EFFIS database suggests that the pattern of wildfires is not related only to climatic conditions, but also to socio-economic causes that affect fire ignitions (Vélez 2009). In Europe, about 95% of wildfires are directly or indirectly human caused.

2 Regulation EEC Nº 3529/86 on forest protection against fire; EEC Nº 2158/92 on protection of the Community´s forests against fires; Forest Focus Regulation EC Nº 2152/2003 concerning monitoring of forests and environmental interactions in the Community.

3 The LIFE+ Regulation (EC) No 614/2007 is the new EU financial instrument for the environment for the period 2007–2013 and includes provisions for funding forest fire prevention projects.

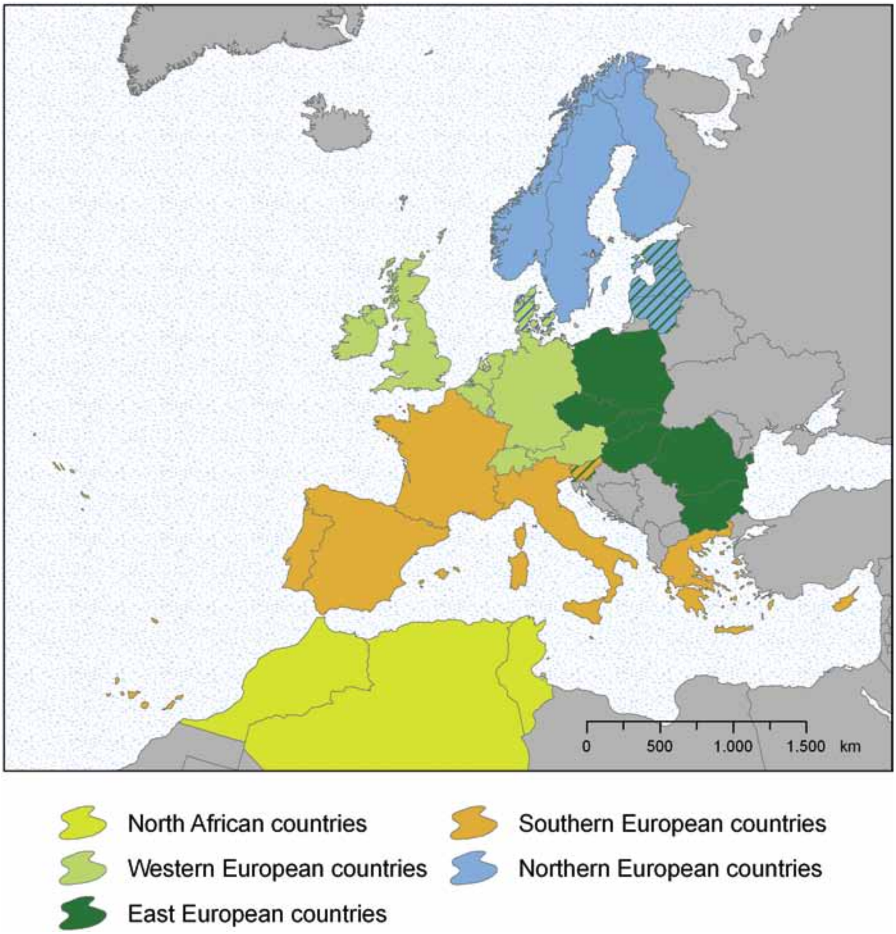

Figure 1. Wildfire legislation and zoning policy in Europe (by Montiel, C., UCM).

Policy measures in each country are influenced by the perceived level of threat, which varies with the intensity and scale of fire-related problems. The Mediterranean Basin countries have by far the most and significant policies, and implementation of regulations about fire prevention. In the rest of Europe (especially in Northern countries) forest production goals are more important than forest fires in forestry management. Fire occurrence and incidence are different from region to region; therefore, national legal and policy frameworks should be adapted to existing ecological and socio-economic characteristics of each European region (see Figure 1).

Regulations are complemented and translated through planning instruments outlining specific actions. To prevent and reduce fire ignitions, the key issues considered within the national and regional policy frameworks are the following:

- *Causes investigation:* although the investigation of wildfire causes needs further development in many countries, it is an essential activity to reduce fire ignitions, and it is becoming a more important priority in the Mediterranean region.
- *Detection systems:* detection also plays an important role in reducing fire ignitions and fire propagation.
- *Fire risk zoning:* this means the demarcation of areas that are potentially hazardous and where there is an increased fire risk. These areas normally receive a special legal status (e.g. restrictions, special measures). In determining fire risk zones new fire prone areas, like the wildland urban interface, require special attention because specific preventive measures might be needed.
- *Determination of a 'high-risk' season:* the declaration of high-risk fire seasons is a decision taken by individual Member States. The duration of a high-risk fire risk season differs from country to country and is a function of the climate and the seasonality of fire causes. Mediterranean countries define longer high-risk fire seasons than Northern regions.
- *Regulation of hazardous activities:* in countries where these kinds of measures are established, it is common to prohibit the use of fire in agro-silvo-pastoral and leisure activities outside of the designated areas, and/or to prohibit the use of fire at specific times of the year. Likewise, to avoid fire starts there are measures that regulate existing hazardous installations or their location.
- *Placement of silvicultural treatments:* (removal of brush, thinning or pruning) are carried out adjacent to hazardous infrastructures areas either to prevent fire ignitions in the area, or to prevent wildfires spreading from these areas.
- *Use of fire as a tool:* when used for achieving prevention objectives, prescribed burning is directly related with the strategic reduction of fuel accumulation and the avoidance of fire starts because of uncontrolled rural burnings.
- *Existence of a legal framework for burning:* the legal frameworks in the Mediterranean Basin range from countries that do not contemplate the use of fire and even prohibit it (e.g. Greece) to those that have developed regulations and basic criteria and conditions for the use of fire (e.g. France, Portugal and some regions in Spain and in Italy).
- *Fire prevention campaigns:* although public information and social awareness about fire prevention receives relatively little attention in national legislation, it is a common and relevant issue in national fire plans.

In addition to forest and civil protection policies, there are also other public policies – spatial planning, agricultural and rural development policies, energy policy and environmental policy – that influence the structural causes affecting the wildfire problem (Lázaro et al. 2009).

- Spatial planning has the potential to adequately coordinate all interventions needed to respond to natural hazards (floods, wildfires, etc.) to achieve a more sensible use of the territory. However, alongside urban policies, this policy may affect one of the most important causes increasing wildfire risk: the scattered settlements in forest areas.
- The evolution of the Common Agricultural Policy towards a real Rural Development Policy brings about significant opportunities for intervention on wildfire management such as: (i) the linking of wildfire prevention objectives to local development processes; (ii) the recognition of agriculture's territorial

role in wildfire prevention; and (iii) the possibility to take advantage of the new energy priorities to increase the use of forest biomass as a source of energy.

- The growing perception of wildfires as one of the main environmental problems for Europe, especially in the Mediterranean area, favours its consideration as a priority for environmental management.

2.3.3 Territorial policies and underlying wildfire causes

Wildfires, especially in the Mediterranean region, are more than just a consequence of periods of drought; they can also be considered an indicator of the socio-economic differences between areas and their respective levels of development. Some of the factors influencing fire regimes in recent decades are closely related to changing socioeconomic conditions. The most relevant are[4]:

- Rural depopulation, leading to the abandonment of rural areas and changes in landscape because the invasion by natural and pioneering vegetation, which may lead to increases in build-up of fuels, and therefore in fire risk. A subset of this factor is the aging of rural population, which also increases wildfire risk because of the loss of know-how in traditional burning practices.
- Concentration of population in urban areas, which increases the wildland urban interface. The construction of new residences (first or second homes) near surrounding vegetation increases fire risk.
- Shifts in forestry policy priorities from the production of wood and other raw materials to focusing on nature conservation, landscape management and recreation.

Other factors influencing the temporal variation of fire regimes during recent decades, such as climate change, changes in landscape configuration, changes in ignition causes and the success of predominant fire suppression policies should be also considered. Therefore, an important segment of the causes contributing to the wildfire problem is left out of the traditional policy domains related to wildfire management (Forest and Civil Protection policies) and must be supported by other sectoral policies, which address the multiple dimensions of forest ecosystems such as those related to the economy, natural resources and the environment (see Figure 2)

2.3.4 Risk practices in new fire scenarios: the need of social prevention adapted measures

The main components of the wildfire problem in Europe – fire and territory – have substantially evolved in the last decades, increasing vulnerability to wildfires. Fire behaviour is evolving because there are new fuel patterns, which are the result of

4 Self Assessment, conclusions and recommendations of the Regional Session: Europe, Southeast Europe, Mediterranean North Africa and Caucasus, held in 4th International Wildland Fire Conference (Seville, Spain. 2007).

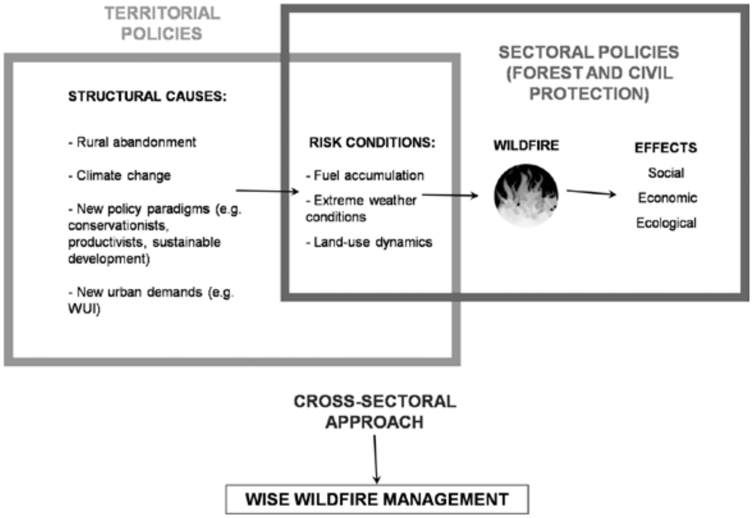

Figure 2. Territorial policies in wildfire management (by Lázaro, A., UCM).

uncontrolled development and biomass accumulation. Spatial and human concerns are also defining new territorial models, which create emerging fire prone areas and new territories at risk (Vélez and Montiel 2003). The multiple combinations of fuel patterns, new trends in spatial-planning and new social realities, have resulted in new fire scenarios, which require new approaches to fire management.

At the regional scale, it is possible to recognize three territorial scenarios (see Figures 3 and 4), showing different fire ignition patterns and different vulnerability to wildfires, and therefore needing different fire management strategies:

- *Scenario 1: Disadvantaged rural areas.* These are rural areas in crisis, suffering from rural abandonment, decline or abandonment of agrarian activities, and without significant increase in new urban pressures, in which forests have reclaimed the abandoned lands. The aging and declining population has also meant the loss of the fire culture, hence turning its use into a risk factor. Today the use of fire in traditional rural activities is set in different spatial conditions in which continuity of woodlands and fuel load results in an increase in wildfire risk. However, the use of fire by a neo-rural population or by users of wildland recreational areas becomes a new ignition risk factor because they are not able to guarantee fire control.
- *Scenario 2: Dynamic rural areas.* These areas are characterized by a consolidated socio-economic context and productive forests, with no significant problems of rural abandonment. The use of fire as a management tool in rural activities has been generally maintained. Furthermore, the existing fire culture can determine a type of ‘fire-dependent rural communities’, where fire use regulation and governance mechanisms for fire management are strongly needed.

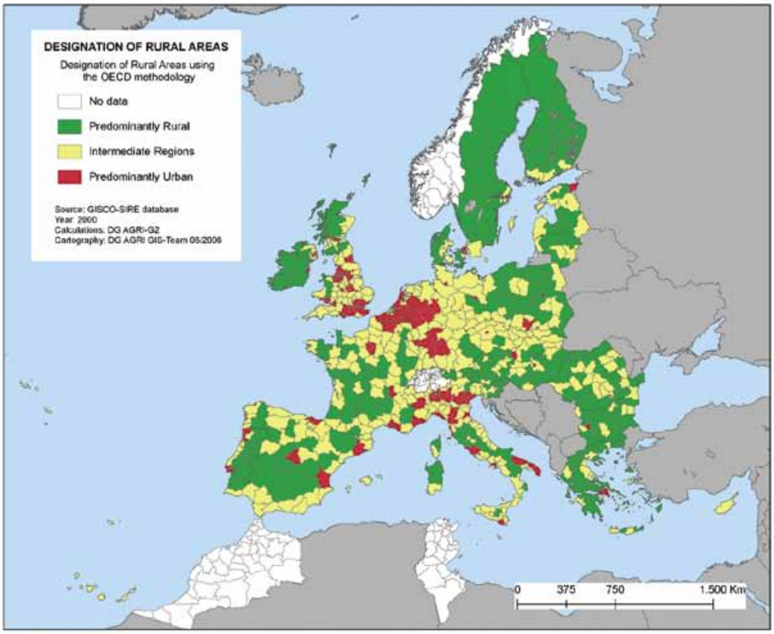

Figure 3. Regional distribution of rural and urban areas in Europe (by Lázaro, A., UCM). ND: no data; IR: intermediate rural areas; PR: predominantly rural areas; PU: predominantly urban areas.

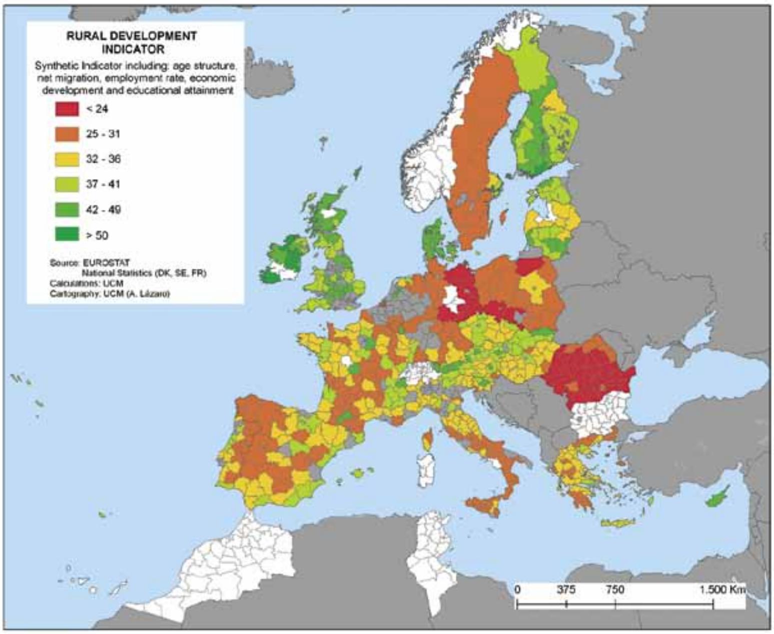

Figure 4. Rural development index in European regions (by Lázaro, A., UCM).

- *Scenario 3: Suburban rural areas and wildland urban interfaces.* These are areas with a predominance of urban developments, where agrarian activities have been abandoned. The transitional areas between wildlands and urbanized spaces – the wildland urban interface – represents an increasing fire risk factor and are highly vulnerable.

The effectiveness of interventions on structural causes affecting wildfires depends, to a large extent, on their adaptation to the spatial and socio-economic characteristics of the area under consideration. The three different types of fire territorial scenarios demand different policy and management measures regarding the biophysical and social components of the fire problem.

Adapting the national and regional programmes of social prevention measures to the fire territorial scenarios is very effective for reducing fire ignitions (Vélez 2010). Social preventive measures refers to public information, social awareness and new governance mechanisms allowing the existing stakeholders in each scenario to participate in the integrated fire management scheme.

In the disadvantaged rural areas territorial scenario, the use of prescribed burning techniques by professional teams to carry out fuel management tasks is advisable. This strategy permits facing the main challenge of fuels management at lower costs, and also adapting to the situation of low population levels and scarce human resources. Nevertheless, in the dynamic rural areas scenario, it is convenient to incentivize the culture of fire in rural communities by the enhancement of best practices of fire use and, most importantly, to promote regulations and new governance mechanisms to resolve conflicts that are at the origin of fire ignitions. Finally, raising awareness of wildfire risk should be a priority in metropolitan rural areas and wildland urban interfaces.

2.3.5 New demands and challenges for wildfire management

Fire has always been present in Europe. It has been widely used as a tool in rural practices. Nevertheless the wildfire policies adopted by most European countries over the last century have been based on total fire exclusion. In the context of global change and new policy paradigms, the negative effects of these national policies and the loss of traditional fire use knowledge has become evident by analyzing fire ignition frequency. At present, the main political challenges to overcome are the adoption of long-term prevention actions, the development of new governance mechanisms and the improvement of decision support tools, always guaranteeing the safety of fire fighters and the inhabitants of burned areas.

Governance in wildfire management needs to be participatory at all stages of the process including agenda setting and problem definition, elaboration and formulation, implementation and enforcement, and evaluation and proposal of policy changes. In addition, learning processes related to the appropriate use of fire by rural populations and the reduction of human-caused wildfires can effectively contribute to reducing fire occurrence through the management of social conflicts and the development of new cooperation opportunities. Alongside the need for empowerment of local groups, measures should be taken with the intent to improve, first, accountability when adopting preventive and remedial actions, and, secondly, multi-sectoral coordination and the multi-level implementation of wildfire management programs, especially in decentralized countries.

All stakeholders in the different fire scenarios should have the opportunity to participate in the different stages of fire management, from information and planning to cooperation in pre-extinction measures, according to their knowledge, interests and concerns (Morguera and Cirelli 2009). Governments should define and implement the corresponding legal frameworks and platforms to make public participation in fire management possible and effective.

Further, conflict resolution systems concerning fire use in the Mediterranean countries are greatly needed. Recognizing the benefits of some traditional fire uses and accepting them instead of systematically suppressing them, would contribute to effective fuel management strategies and to sustainable fuels load control. This approach would most likely result in wildfire management cost reductions; for example, by reducing the need for some silviculture treatments and in fighting fires caused by rural activities. In fact, prescribed burning is an effective tool for fuels management, at least in the defined territorial scenarios 1 and 2. However, this technique, as well as the use of suppression fire, entails a social, policy and technical challenge, which is the social acceptance and regularization of traditional fire use, as well as cooperation between stakeholders and public administrations.

Therefore, participatory mechanisms, learning and lessons-drawing, know-how transfer and training schemes are greatly needed. We need to move from a one-dimensional perception of the negative impacts of fire to a more sophisticated one that also stresses its positive effects (Aguilar and Montiel 2009b). In addition, interagency and multi-level coordination is essential for wildfire management, considering the complexity of the fire problem in Europe, where different physical and human factors are interacting at different socio-spatial and temporal scales. Finally, considerations must be given to the emergence of new fire prone areas in Eastern, Central and Northern countries, and to development of new decision support tools to evaluate new fire scenarios, namely the large and continuous areas with fuel models of high risk and the wildland urban interface territories (Galiana et al., 2009).

2.3.6 Conclusions and recommendations

The national and regional wildfire policies in Europe should consider all aspects of wildfire management as a whole and with a long-term view. An integrated approach through the connection of the wildfires policies and the territorial policies (e.g. spatial planning, rural development, energy policy) is needed to address the structural causes of wildfire events. In fact, the starting point to set proactive and effective wildfire management policies is the identification of the factors driving fire ignitions, framed within their territorial contexts. The success of the fire risk reduction actions adopted depends, to a large extent, on this preliminary identification of causes.

Preventive measures should also be given more emphasis in fire policies as the only way to avoid emergency situations and costly suppression actions. However, although prevention is slowly gaining importance within national wildfire legislation

Box 1. Wildland urban interface (WUI) as new fire prone areas – the Spanish study case

Fire risk is higher in the WUI zone, where human presence and its related activities near forest fuels could ignite fires. In Spain, WUI areas spread over more than 2% of the national surface and account for around 1 100 000 hectares.

Galicia (9.1%), Asturias (8.9%), Canarias (7.3%) and Madrid (6.4%) have the highest proportion of WUI areas; while the proportion is lowest in Castilla-La Mancha (0.5%) and Aragón (0.6%).

During the last decade, there has been a growing concern about the WUI in the context of wildfire management due to the rapid expansion of houses near or inside forest areas and several catastrophic fire events.

Based on the Corine Land Cover data, during the period 1987–2000, the WUI surface in Spain grew 6.8 %, resulting in 55 100 hectares of new interface areas.

Spatial data on WUI extent, location and their evolution over time provide key information to develop effective fire planning in order to both avoid fire initiation and prevent negative impacts for the population.

The WUI zone is considered in the Spanish forest and fire regulations, but its consideration in planning documents is still very scarce. The general measures considered towards the prevention of ignitions and possible propagation of fires from urbanized areas to the forest masses include: fuel treatments around the structures, awareness and information campaigns to WUI residents, and the regulation of potential fire risk activities in urban areas.

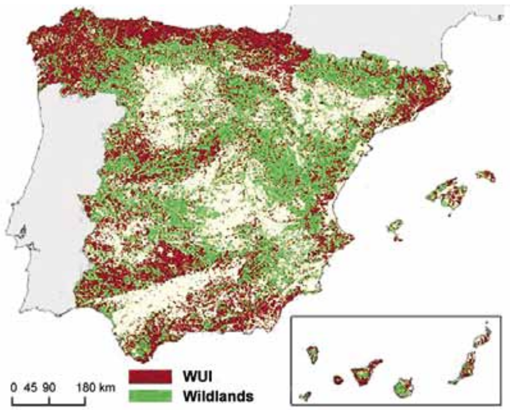

Figure 5. Distribution of the WUI in Spain, in 2000. Source: G. Herrero Doctoral Thesis, in progress.

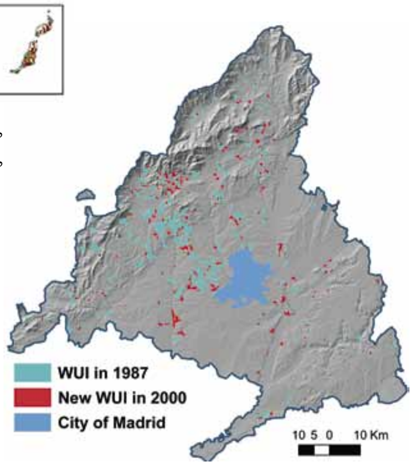

Figure 6. WUI spread in Madrid from 1987 to 2000.

and policies, it is still undervalued when compared to fire extinction. One of the reasons for this unbalanced situation is that preventive actions are a constant task over the year that does not have the same visibility as extinction investments and that receives less public recognition.

On the other hand, wildfire prevention covers various fields of action (forest fuel management, public awareness and education campaigns, fire risk analysis, conciliation of interests, detection, etc.) and concerns different stakeholders (forest land owners, building enterprises, town councils, etc.). Basic prevention regulations should address the following aspects: (a) forest management to avoid fires; (b) preventive silviculture measures in defensive and preventive infrastructures; (c) risk zoning to delimit areas regarding their fire risk and regulated land uses and activities according to fixed levels of risk; (d) establishment of risk periods in each country; (e) basic regulation on traditional and prescribed burnings; (f) social prevention measures (public awareness, governance mechanisms, etc.). New territories at risk, such as wildland urban interfaces, deserve special attention and specific preventive measures should be considered as well.

Furthermore, prevention strategies should evolve according to spatial, socio-economic and natural changes, and they should also adapt to different socio-economic and territorial contexts, considering influencing factors like spatial planning issues.

More coordination at the national, Mediterranean, and European level is also needed to face the new fire scenarios. To do that, new governance mechanisms, adapted to the diverse regional and local conditions, should develop participatory and community-based tools for integrated fire management, based on a dialogue between the different stakeholders and the public authorities.

Legal aspects should also be clarified and enhanced through the development of incentives and obligations concerning preventive actions. The regulation of fire use practices for different land management purposes should be promoted through the national and regional legal systems, in order to prevent and reduce fire ignitions as a consequence of negligence, or arson related to grazing and agricultural activities. In fact, prescribed burning could be an alternative or complementary technique for fuel management, but carefully adapted to the different contexts and according to the existing territorial patterns (rural abandoned areas, wildland urban interface, productive rural regions, etc.).

Finally, existing EU funds provide basic financial support for national, sub-regional and regional prevention measures, and must therefore be made available for integrated wildfire management, particularly in Mediterranean countries, including non-EU states.

References

Aguilar, S. and Montiel, C. 2009a. Pays méditerranéens. Prévenir les feux de forêt. Courrier de la Planète 88: 19.

Aguilar, S. and Montiel, C. 2009b. New governance strategies for wildland fire management in Mediterranean countries. In: Buttoud, G. (ed.): Change in Governance as Collective Learning Process: Management, Politics and Ethics in Forestry, International Symposium. Nancy, France, 21–24 June 2009. Pre-conference Proceedings. Pp. 9–18.

Birot, Y. 2009. Living with wildfires: what science can tell us. EFI Discussion Paper 15. European Forest Institute. 82 p.

FAO 1999. Report of meeting on public policies affecting forest fires, 14th session, Rome, Italy, 28–30 October 1998, I. Part 1.

Galiana, L., Herrero, G. and Solana, J. 2009. A wildland-urban interface typology for forest fire risk management in Mediterranean areas. Landscape Research Journal (under review).

Herrero, G. Las interfaces urbano-forestales como nuevos territorios de riesgo: análisis y caracterización regional en España. Doctoral Thesis, in progress.

Lázaro, A., Galiana, L., Aguilar, S. and Sesbou, A. 2009. Assessment document on the main strengths and weaknesses of the legislation and spatial policy instruments concerning wildfire integrated management in the EU, in European member states and in North African countries. Deliverable D7.3-1of the Integrated Project "Fire Paradox", Project no. FP6-018505. European Commission. 81 p.

Martínez, J. 2004. Análisis, estimación y cartografía del riesgo humano en incendios forestales. Doctorate Thesis, Departament of Geography, University of Alcalá, Madrid.

Morguera, E. and Cirelli, M.T. 2009. Forest fires and the law. A guide for national drafters based on the Fire Management Voluntary Guidelines, FAO Legislative Study 99, Rome.

Vilar del Hoyo, L., Martín, Mª P. and Martínez, J. 2008. Empleo de técnicas de regresión logística para la obtención de modelos de riesgo humano de incendio forestal a escala regional. Boletín de la AGE 47: 5–29.

Vélez, R. 2002. Causes of forest fires in the Mediterranean Basin. In: Arbez, M., Birot, Y. and Carnus, J.M. (eds). Risk management and sustainable forestry. EFI Proceedings 42. European Forest Institute. Pp. 35–42

Vélez, R. and Montiel, C. 2003. La problemática del monte mediterráneo. Investigaciones Geográficas 31: 121–137.

Vélez, R. 2009. The causing factors: a focus on economic and social driving forces. In: Birot, Y. (ed.). Living with wildfires: what science can tell us. EFI Discussion Paper 15. European Forest Institute. Pp. 21–25.

Vélez, R. 2010. Prescribed burning for grazing improvement and fire social prevention: the Spanish EPRIF Programme. In: Montiel, C. (ed.): Best Practices of fire use. Prescribed burning and suppression fire programmes in selected case studies regions. EFI Research Report 24. European Forest Institute. In press.

3. Wildfire Propagation: Knowledge and Search for Solutions

3.1 Humans, Climate and Land Cover as Controls on European Fire Regimes

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3.1.1 The driving factors of fire regimes

The expression 'fire regime' has become a rather loosely used term since it was first introduced by A.M. Gill more than three decades ago. Gill proposed a description of a fire regime as including: the time between fires, the time since last fire, the intensity of the fire, the type of fuel burned, and the season of occurrence (Gill (1975). Since then, the expression has been widely used, and other authors have proposed modifications to the original definition (e.g. Bond and Keeley 2005). Some authors have used the expression to describe a particular fire, but more commonly the expression has been used to summarize the characteristics of the fires that typically occur at a site (Whelan 1995). Within the present text, 'fire regime' is used in the latter sense, without particular regard to the precise set of fire characteristics to be included.

Both climate and fuel characteristics influence fire regimes, and there has been considerable debate about which is the most important driving factor influencing the fire regime of a specific region (Minnich et al. 1993; Keeley and Fotheringham 2001; Gillett et al. 2004; Archibald et al. 2009). It is not a straightforward exercise to assess whether one factor or another factor is the most important, since that depends on the type of fuels and climate (Bessie and Johnson 1995; Agee 1997). In many regions this assessment is even less straightforward because of the influence of humans (Pausas and Keeley 2009); this raises another unsettled issue of whether humans or natural factors are more important in determining fire patterns (Bowman et al. 2009). Humans influence fire regimes in three basic ways: by starting new ignitions, by changing fuel characteristics, and by actively suppressing fires. Given its long history of human occupation, including the traditional use of fire for agriculture and slash and burn practices, these aspects have assumed a particular importance in Europe as reported by different local studies (e.g. Carrion 2002; Andric and Willis 2003; Tinner et al. 2005).

Therefore, in order to understand the mechanisms responsible for fire regimes it is important to look at historical data. Charcoal preserved in lake or bog sedimentary sequences provides a long-term record of changing fire regimes at a catchment scale. The Global Palaeofire Working Group (Power et al. 2008) has compiled nearly 800 such records from around the world, and analyzed these to examine changes in fire regimes on decadal to millennial timescales. Fire regimes show a strong response to temperature changes on centennial to millennial time scales. During the last glacial (ca 80 000–20 000 years ago), fire increased during the repeated abrupt warming events registered in the Greenland ice core and decreased during the following cool periods (Daniau et al. in press). This trend is also seen during the last 21 000 years (Power et al. 2008). Because of the increased number of sites available, it has been possible to show that there have been opposing trends in temperature changes between the northern and southern hemisphere (with warming in the southern hemisphere corresponding to cooling in the northern hemisphere and vice versa); this has resulted in asynchronous changes in fire regimes between the two hemispheres. Records for the past 2000 years also show strong correspondence between temperature changes and fire, both at global and regional scales (Marlon et al. 2008). Temperature changes influence fire regimes primarily through vegetation productivity and hence fuel availability. In addition, cold climates are characterized by a reduction in the vigour of the hydrological cycle, and thus by reduced lightning and thus reduced ignitions. Temperature changes may also be important through influencing the rate of curing of fuels. Marlon et al. (2008) also examined the potential role of humans on recent fire regimes, and have argued that the major role of humans in global fire regimes during the past 2000 years has been to suppress fires during the twentieth century. The timing of the downturn in fire in several regions, most obviously in the Americas, Australia and Asia, pre-dates the introduction of active fire fighting, but corresponds with the expansion of large-scale agriculture and ranching (Bowman et al. 2009). In regions that have not experienced a recent expansion of large-scale agriculture and ranching, such as the northern hemisphere boreal zone or Europe, there is no downturn in fire during the last century. Thus, Marlon et al. (2008) argue that the decrease of fire activity was an accidental consequence of human activities and resulted mainly from landscape fragmentation and/or the reduction of fuel loads in intensively managed landscapes. The downturn in fire activity in Europe during the first part of the twentieth century has been seen, though expressed less strongly, in inventory data (see e.g. Mouillot and Field 2005) and is incorporated in the representative concentration pathway (RCP) scenarios developed for the next International Panel on Climate Change assessment.

In this chapter we discuss the factors determining the fire regime in Europe, and in particular the relationship between fire occurrence and land cover, by presenting recent studies developed in different European regions: island of Sardinia (Italy); Macedonia (Greece); Portugal; Ticino (Switzerland); and Poland (Figure 1).

3.1.2 Factors determining the fire regime in different European regions

In many areas of Europe, and particularly in the Mediterranean Region, the last decades have been characterized by drastic changes in land cover, especially grazing pattern and land abandonment, combined with reforestation. This recent development emphasized the need of addressing the problem of fire proneness, in order to understand which land cover types are ‘preferred’ by wildfires. Fire proneness assessment of land cover types has received recent attention from

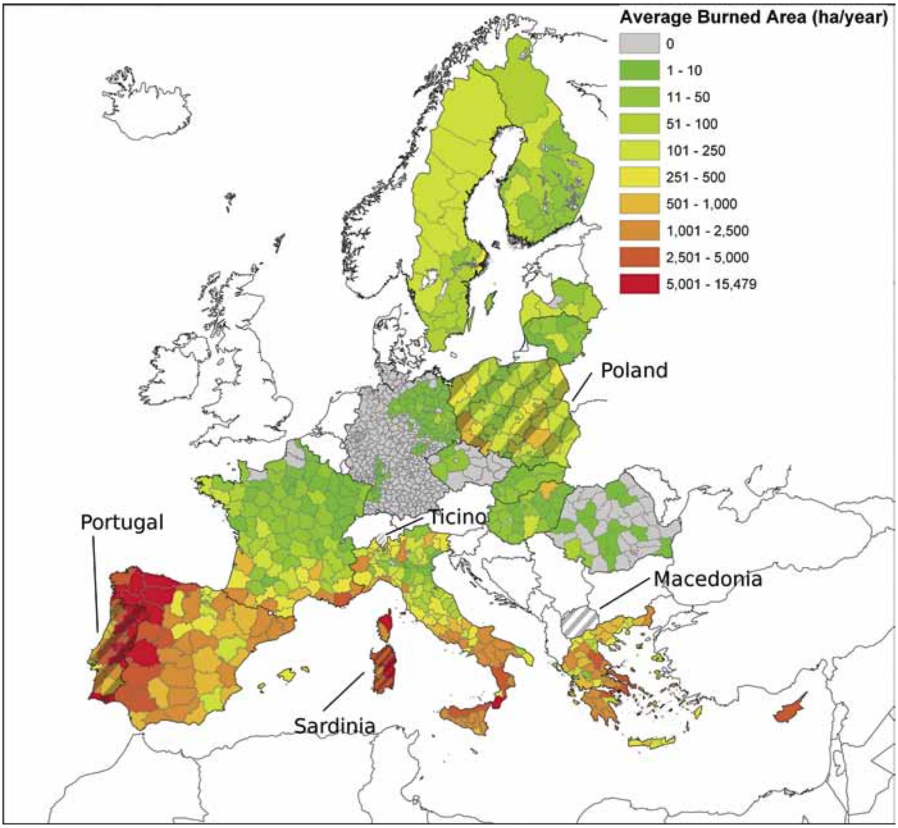

Figure 1. Map of burned areas in the European Union by region (NUTS3) and location of the study regions. Adapted from San-Miguel and Camia (2009).

researchers (e.g. Cumming 2001; Nunes et al. 2005; Moreira et al. 2009). The analysis of fire proneness within a certain region depends on the method used and on the available data sets. In this context we must have in mind that typically, data sets are short and may not necessarily capture a comprehensive range of land use types and patterns. On the other hand, it is very important to have a sufficient number of geo-referenced fire perimeters in order to allocate the burned areas to the different land cover types. This is not always possible because not all countries and regions have gathered this information over the years. The use of ignition points instead of burned areas may be a way to overcome this difficulty, although it has to be taken into account that in the European context, the mechanisms influencing the start of a fire are strongly correlated with human activities leading to ignitions (Catry et al. 2009), whereas the mechanisms responsible for the distribution of burned areas across the landscape, are essentially climate and fuel-driven.

Recent studies were developed aiming at assessing the influence of these factors on fire regime. The methodologies varied according to the data available, but also to the approach chosen by each research team. Besides the basic aspect of fire proneness, other aspects like fire seasonality and fire size were addressed by the different studies, aimed at characterizing the fire regime according to different types of land cover.

Sardinia (Italy)

On the basis of the available fire history data for Sardinia for the period 2000–2004, Bajocco and Ricotta (2007) analyzed the fire proneness of given land cover classes both in terms of fire frequency and mean fire size, but keeping both variables separate. The results obtained from the analysis of 13 377 fires showed that for most land cover classes, fire behaved selectively, in terms of both fire frequency and fire size. Fire frequency was higher than expected by chance alone in urban and agricultural areas whereas in forests, grasslands, and shrublands, fire frequency was lower than expected. In grasslands and shrublands mean fire size was significantly larger than expected from a random null model whereas in urban areas, permanent crops, and heterogeneous agricultural areas, there was a significant resistance to fire spread. Additionally, in terms of the mean fire size, forests and arable land did not appear to be particularly fire prone, since both land use classes burned in proportion to their availability.

A complementary study by Bajocco et al. (2009) was performed, aiming at assessing the seasonality of wildfires for each land cover class. More specifically, the aim of the study was to analyze the temporal patterns of fire occurrence in Sardinia during the period 2000–2006, in order to identify land cover classes where wildfires occur earlier or later than expected from a random null model. The results showed that the timing of fire ignition was selective for all land cover classes analyzed, with very high significance levels. Wildfires occurred earlier than expected from a random null model, in urban areas and in all agricultural classes. By contrast, wildfires occurred later than expected, in forests, grasslands, and shrublands. There was also a strong association between land cover classes and the Climatic Regions of Sardinia. Therefore the study highlighted a close relationship between the timing of fire occurrence and land cover, governed by two complementary factors: climatic factors that determine the spatial distribution of land cover classes according to climatic regions; and the human population that directly influences fire ignition.

Using the same wildfire data set, Bajocco et al. (2008) have evaluated the remotely-sensed phenological uniqueness of the Sardinian phytoclimatic regions (Mediterranean, Transitional Mediterranean, and Transitional Temperate) following the classification by Blasi et al. (2000) and to what extent these regions differed in the temporal properties of their wildfire time series. The results obtained provided a clear and coherent segregation of the major phytoclimatic units in terms of phenological dynamics and temporal characteristics of wildfire regimes. The results also emphasized a gradient in the mean starting Julian day of fires. For instance, the earliest mean time of wildfire occurrence was usually related to the Mediterranean phytoclimatic region, which was also the region that experienced the highest number of fires, while the latest mean time of wildifre occurrence was associated with the Transitional Temperate region. The authors concluded that there was a strong climatic control on the temporal characteristics of wildfires, even in regions of high human pressure.

Macedonia (Greece)

Bajocco et al. (2008) assessed fire proneness by using fire ignition locations across the region of Macedonia in northern Greece over a period of 13 years (1985–1997). The resource selection ratio (Manly et al. 1993; Moreira et al. 2001) was used to derive a ranking of land cover classes in terms of fire proneness. This ranking was further analyzed across vegetation zones. The results were discussed in relation to the moisture and temperature regime of vegetation zones (*Quercion ilicis, Ostryo-Carpinion, Quercion confertae, Fagion-Abietion cephalonicae, Pinetalia nigrae, Vaccinio Picetalia*) across the elevation gradient, population density and the relative abundance of different land cover classes. It appeared that fire frequency was conditioned by two opposing trends. On the one hand fire frequency decreased in higher elevations where climate becomes cool and moist. On the other hand, human population density is higher in lowlands and in warmer, drier zones where agriculture is the dominant land cover. Here climate conditions were more conducive to fire ignition but the landscape was characterized by land cover classes which are generally less fire prone. Especially, in the *Ostryo-Carpinion* vegetation zone, semi-natural land cover classes were so scarce that, overall, this zone had fewer fires than expected by its area, indicating that fires have a lower likelihood of starting in intensively managed agricultural landscapes, where fuel load is kept at low levels. The authors mention the existence of a dynamic 'tension zone' corresponding to a higher fire incidence. This zone was characterized by a gradual shift from warm and dry conditions to cool and humid conditions, but also a gradual shift from intensively managed landscapes (relatively abundant, fire-resistant, predominantly agricultural land cover classes) to less densely populated landscapes (flammable semi-natural and forest land cover classes).

Portugal

Patterns of wildfire occurrence at the landscape level were characterized by Moreira et al. (2009) during the period 1990–1994 in Portugal. Based on land cover information within 5591 burned patches (larger than 5 ha) and in the surrounding landscape, resource selection ratios were used to measure fire proneness for different land cover classes in 12 regions of the country. Shrublands were the most fire-prone land cover, whereas annual crops, permanent crops and agro-forestry systems were the least fire-prone. In terms of forest types, conifer plantations were more fire-prone than eucalyptus plantations, and broadleaved forests were the least fire-prone. There were regional variations in susceptibility of land cover classes to fire, which were discussed on the basis of differences in climate, management, ignition patterns, fire fighting strategies, and the regional availability of each land cover class. A cluster analysis of regional variations in selection ratios for all land cover classes, allowed the identification of three main geographical areas with similar fire selection patterns. The study also showed a significant positive correlation between land cover availability and the resource selection ratio.

Based on the study by Moreira et al. (2009), Silva et al. (2009) restricted the assessment of fire proneness to the main forest types in Portugal classified according to the main species, using three different approaches: the use of resource selection ratios applied to burned patches; the proportion of randomly located plots that were burned; and the proportion of burned National Forest Inventory plots. The results allowed ranking fire proneness according to the following decreasing order: maritime pine (*Pinus pinaster*) forests, eucalyptus (*Eucalyptus globulus*) forests, unspecified broadleaf forests, unspecified conifer forests, cork oak (Quercus suber) forests, chestnut (*Castanea sativa*) forests, holm oak (*Quercus rotundifolia*) forests and stone pine (*Pinus pinea*) forests. Silva et al. (2009) also used a different data set (1998–2005 fire maps) to explore the influence of structural variables plus stand composition on fire probability, by using univariate logistic models. From all variables, stand composition was the most important for explaining fire probability. Stepwise regression procedures were used to build a multivariate logistic model which showed that stand structure plays a different role for different types of forest, in terms of fire probability (see text box).

Ticino (Switzerland)

Fire proneness of given forest vegetation classes was analyzed both in terms of fire frequency and fire size (mean and median) for the period 1982–2005 in Canton Ticino (southern Switzerland), by Bajocco et al. (2008). With this purpose, the authors investigated the data set in four fire groupings (all fires, anthropogenic winter fires, anthropogenic summer fires, and natural summer fires) and performed 1000 random Monte Carlo simulations on frequency and size. Anthropogenic winter and summer fires occurred mostly at low elevation in chestnut (*Castanea sativa*) stands, broadleaved forests and in the first 50 m from the forest edge. In winter, half of the fires in chestnut stands were significantly larger than 1.0 ha and the average burned area in some coniferous forests tended to be high. Lightning fires seemed to prefer spruce (*Picea abies*) stands and to avoid the summer-humid chestnut and beech (*Fagus sylvatica*) stands and the 50 to 100 m buffer area. In beech forests, in mixed forests and in the spruce stands hit by natural fire in summer, the fire size tended to be small. The obtained fire occurrence pattern and especially the occurrence of anthropogenic fires in terms of fire frequency, seemed to be also related with geographical parameters such as altitude and aspect, and to anthropogenic characteristics such as the closeness of roads or buildings.

Poland

A database of the fires that occurred between 1996–2006 in Poland was used by Szczygieł et al. (2009) to analyze the relationship between fire frequency and land cover. This study revealed that the vast majority of fires occurred in non-forest lands. Using the Corine land cover classification (Büttner et al. 2004), the study concluded that 31.9% of fires occurred in non-irrigated arable land (37.3% of burned area); 16.2% occurred in continuous urban fabric (8.6% of burned area); 11.2% occurred in complex cultivation patterns (8.5% of surface area); 9.5% occurred in land principally occupied by agriculture (17.4% of burned area); 8.8% occurred

Box 1. Case study of fire proneness: Portugal

Fire proneness was studied in Portugal by using 1998–2005 fire maps. These maps were overlapped with the locations of the 1997–1998 Forest Inventory plots, in order to relate forest characteristics (composition and vegetation density) with fire occurrence. With this data it was possible to build a fire probability model using logistic regression procedures (Figure 2). Results suggest that fire probability is higher in eucalyptus, maritime pine and unspecified broadleaf stands, whereas it is lower in holm oak and cork oak stands. Moreover it seems that fire probability increases for higher vegetation density (given by a Cover Index) for all species, except for unspecified broadleaf stands (a decreasing trend) and for eucalyptus (a mixed trend).

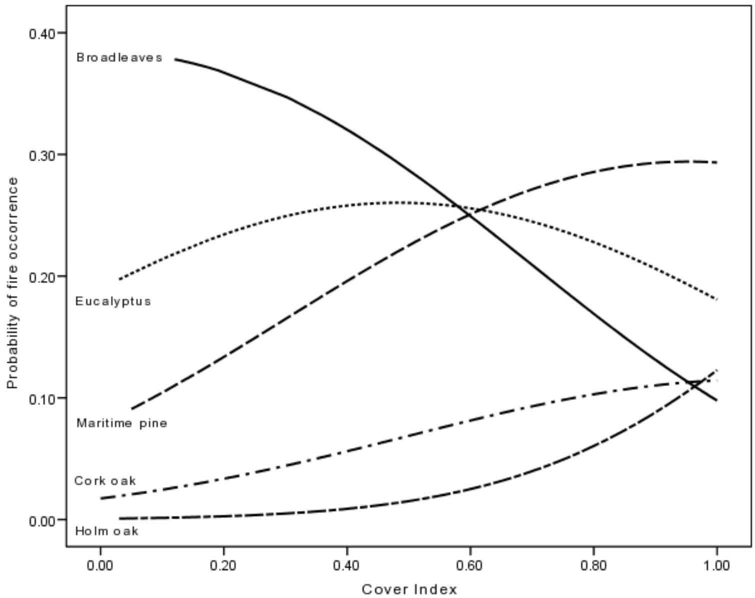

Figure 2. Probability of fire occurrence during years 1998–2005 as a function of a cover index, for five types of forest according to a logistic regression model. Adapted from Silva et al. (2009).

in coniferous forests (5.8% of burned area), 6.6% occurred in broadleaved forests (8.3% of burned area) and 3.6% occurred in mixed forests (2.9% of burned area).

The authors refined the results for the Polish State Forests, using data from 2002–2008, including a total of 30 494 fires. The analysis covered the relationship between the number of fires and the forest site types, the dominant species and the stand age classes, using the resource selection ratio. The analysis confirmed the existence of different levels of fire proneness according to site and stand conditions. The sites with higher fire proneness were conifer forests, starting from the driest sites to the moister ones. The lowest values (less than 1) corresponded to broadleaf forests and to mountain forests. In terms of dominant stand species, the highest value was obtained by Scots pine (*Pinus sylvestris*) stands (more than 1). All other stands had values less than 1, the lowest values being obtained by broadleaf species and fir (*Abies* spp.) stands. Finally, in terms of age classes, the results showed that fire proneness generally decreased for older stands, with resource selection ratio values greater than 1 only for stands younger than 40-years-old. The exception to this trend was class V, corresponding to stands older than 80-years-old, which showed higher values than class IV (60–80-years-old).

3.1.3 Conclusions

Despite the wide range of methodologies used in the reported studies, and the differences in spatial and temporal scales, some coherent conclusions emerge that have practical consequences for management policies.

There is a fundamental distinction to be drawn between number of fire starts and the impact, as measured by area burned, of fires. Individual case studies show that the number of fires is strongly influenced by human activities, being higher in agricultural areas and wildland urban interfaces. However, many of these fires are small. Although the importance of controlling human-caused ignitions should not be underestimated, climate factors and vegetation type appear to be more important drivers of large fires, as seen during the extreme weather conditions occurred in 2003 in Europe (Trigo et al. 2006). The palaeo-record of biomass burning essentially confirms these conclusions, showing a strong response of burned area from decadal to millennial-scale climate changes over most of the last 21 000 years with significant increases in fire during warmer intervals.

The individual case studies indicate that land cover, which is partially influenced by climate but also a consequence of human management, is important in determining the availability of fuel and hence fire regimes. Humans can play an important role in deliberately or inadvertently modifying the land cover and therefore the fuel characteristics of a given region. The results on fire proneness at local scales clearly emphasize the importance of adequate land cover planning and proper fuel management for wildfire prevention. These analyses suggest that policies on land-use planning should be driven to minimize fire hazard, taking into consideration the high costs of fire suppression and fire prevention. Societies should reflect on the models of land-use transformation, which have been followed in the last century, namely that which concerns the generalized abandonment of agricultural fields and the establishment of forest plantations (Nunes et al. 2005; Vélez 2009). In this latter case, prescribed burning as a fuel management technique has been suggested to be an economically and ecologically advisable solution (De Ronde et al. 1990; Fernandes and Rigolot 2007). Therefore, new solutions for land-use planning and management should be envisaged, if societies are really committed to minimize the problems caused by wildfires.

The difficulties reported in some of the above described research points to a clear need for European countries to use common criteria for wildfire statistics, as well as a common data set on land cover occupation. Specifically, to improve fire prevention, fire managers need information concerning the spatial and temporal distribution of fires across the landscape. In this framework, ecologically meaningful landscape classifications may provide geographical units with great potential for the development of strategies for fire risk assessment and fire prevention. While land cover directly controls what is actually burned by fires in terms of fuel load and fuel continuity, it also influences the seasonality of fires through its strong association with the bioclimatic characteristics of the landscape. Therefore, ecologically suitable land cover maps may be helpful for the development of strategies for fire hazard assessment – for example, for optimizing the location of water points and fire brigades, thus rendering fire fighting strategies more effective. On the other hand, it is of paramount importance that individual fire reports include both a map of the burned area and the corresponding ignition point location. This would provide valuable information which can be used to better understand the different role of humans, fuel and climate as controls on fire regimes. At the European level, the European Commission Joint Research Centre, which manages the European Forest Fire Information System, would be the right agency to support and lead this task, aiming at achieving a sound, coherent and comprehensive fire database.

References

Agee, J.K. 1997. The severe weather wildfire – Too hot to handle? Northwest Science 71:153–156.

Andric, M. and Willis, K.J. 2003. The phytogeographical regions of Slovenia: a consequence of natural environmental variation or prehistoric human activity? Journal of Ecology 91:807–821.

Archibald, S.A., Roy, D.P., Van Wilgen, B.W. and Scholes, R.J. 2009. What limits fire? An examination of drivers of burnt area in Southern Africa. Global Change Biology 2008:1–18.

Bajocco, S., Angelis, A.D., Rosati, L., Ricotta, C., Mouflis, G.D., Gitas, I.Z., Silva, J.S., Moreira, F., Vaz, P., Catry, F., Ferreira, P.G., Pezzatti, G.B., Torriani, D. and Conedera, M. 2008. Publication describing wildfire regimes distribution in selected European study areas. Deliverable D4.1-1b of the Integrated Project “Fire Paradox”, Project no. FP6-018505. European Commission. 79 p.

Bajocco, S., Ricotta, C., Pezzatti, G.B. and Mazzoleni, S. 2009. Quantitative evaluation of fire proneness of different land use classes. Internal Report IR4.1-2a of the Integrated Project “Fire Paradox”, Project no. FP6-018505. European Commission. 33 p.

Bajocco, S. and Ricotta, C. 2007. Evidence of selective burning in Sardinia (Italy): which land-cover classes do wildfires prefer? Landscape Ecology. Pp. 557–567.

Bessie, W.C. and Johnson, E.A. 1995. The relative importance of fuels and weather on fire behaviour in Subalpine forests. Ecology 76:747–762.

Blasi, C., Carranza, M.L., Frondoni, R. and Rosati, L. 2000. Ecosystem classification and mapping: a proposal for Italian landscapes. Applied Vegetation Science 3:233–242.

Bond, W.J. and Keeley, J.E. 2005. Fire as a global ‘herbivore’: the ecology and evolution of flammable ecosystems. Trends in Ecology & Evolution 20:387–394.

Bowman, D., Balch, J.K., Artaxo, P., Bond, W.J., Carlson, J.M., Cochrane, M.A., D'Antonio, C.M., DeFries, R.S., Doyle, J.C., Harrison, S.P. and others 2009. Fire in the Earth System. Science 324:481–484.

Büttner, G., Feranec, J., Jaffrain, G., Mari, L., Maucha, G. and Soukup, T. 2004. The Corine Land Cover 2000 project. EARSeL eProc 3:331–346.

Carrion, J.S. 2002. Patterns and processes of Late Quaternary environmental change in a montane region of southwestern Europe. Quaternary Science Reviews 21:2047–2066.

Catry, F.X., Rego, F.C., Bação, F.L. and Moreira, F. 2009. Modeling and mapping wildfire ignition risk in Portugal. International Journal of Wildland Fire 18:921–931.

Cumming, S.G. 2001. Forest type and wildfire in the Alberta boreal mixedwood: what do fires burn? Ecological Applications 11:97–110.

Daniau, A.-L., Harrison, S.P. and Bartlein, P.J. Fire regimes during the last glacial. Quaternary Science Reviews. In press.

De Ronde, C., Goldammer, J.G., Wade, D.D. and Soares, R.V. 1990. Prescribed fire in industrial pine plantations. Ecological Studies Analysis and Synthesis 84:216–272.

Fernandes, P.M. and Rigolot, E. 2007. The fire ecology and management of maritime pine (Pinus pinaster Ait.). Forest Ecology and Management 241:1–13.

Gill, A.M. 1975. Fire and the Australian flora: a review. Australian Forestry 38:4–25.

Gillett, N.P., Weaver, A.J., Zwiers, F.W. and Flannigan, M.D. 2004. Detecting the effect of climate change on Canadian forest fires. Geophysical Research Letters 31:1–4.

Keeley, J.E. and Fotheringham, C.J. 2001. History and management of crown-fire ecosystems: a summary and response. Conservation Biology 15:1561–1567.

Manly, B., McDonald, L.L. and Thomas, D.L. 1993. Resource selection by animals: statistical design and analysis for field studies. Chapman and Hall, London.

Marlon, J.R., Bartlein, P.J., Carcaillet, C., Gavin, D.G., Harrison, S.P., Higuera, P.E., Joos, F., Power, M.J. and Prentice, I.C. 2008. Climate and human influences on global biomass burning over the past two millennia. Nature Geoscience 1:697–702.

Minnich, R.A., Vizcaino, E.F., Sosaramirez, J. and Chou, Y.H. 1993. Lightning detection rates and wildland fire in the mountains of Northern Baja-California, Mexico. Atmosfera 6:235–253.

Moreira, F., Rego, F.C. and Ferreira, P.G. 2001. Temporal (1958–1995) pattern of change in a cultural landscape of northwestern Portugal: implications for fire occurrence. Landscape Ecology 16:557–567.

Moreira, F., Vaz, P., Catry, F. and Silva, J.S. 2009. Regional variations in wildfire preference for land cover types in Portugal: implications for landscape management to minimize fire hazard. International Journal of Wildland Fire 18:563–574.

Mouillot, F. and Field, C.B. 2005. Fire history and the global carbon budget: a 1° ×1° fire history reconstruction for the 20th century. Global Change Biology 11:398–420.

Nunes, M.C.S., Vasconcelos, M.J., Pereira, J.M.C., Dasgupta, N., Alldredge, R.J. and Rego, F.C. 2005. Land cover type and fire in Portugal: do fires burn land cover selectively? Landscape Ecology 20:661–673.

Pausas, J. and Keeley, J. 2009. A burning Sstory: the role of fire in the history of life. BioScience 59:593–601.

Power, M.J., Ortiz, N., Marlon, J., Bartlein, P.J., Harrison, S.P., Mayle, F., Ballouche, A., Bradshaw, R., Carcaillet, C., Cordova, C. and others 2008. Changes in fire regimes since the Last Glacial Maximum: an assessment based on a global synthesis and analysis of charcoal data. Climate Dynamics 30:887–907.

San-Miguel, J. and Camia, A. 2009. Forest Fires at a Glance: Facts, Figures and Trends in the EU. In: Birot, Y. (ed.). Living with Wildfires: what science can tell us. EFI Discussion Paper 15. European Forest Institute. Pp. 11–18.

Silva, J.S., Moreira, F., Vaz, P., Catry, F. and Godinho-Ferreira, P. 2009. Assessing the relative fire proneness of different fores types in Portugal. Plant Biosystems 143:597–608.

Szczygieł, R., Ubysz, B., Piwnicki, J. and Kwiatkowski, M. 2009. Fire flammability of forest plant formations in Poland. Deliverable D4.2-3 of the Integrated Project “Fire Paradox”, Project no. FP6-018505. European Commission. 91 p.

Tinner, W., Conedera, M., Ammann, B. and Lotter, A.F. 2005. Fire ecology north and south of the Alps since the last ice age. Holocene 15:1214–1226.

Trigo, R.M., Pereira, J.M.C., Pereira, M.G., Mota, B., Calado, T.J., Dacamara, C.C. and Santo, F.E. 2006. Atmospheric conditions associated with the exceptional fire season of 2003 in Portugal. International Journal of Climatology 26:1741–1757.
Vélez, R. 2009. The causing factors: a focus on economic and social driving forces. In: Birot, Y. (ed.). Living with wildfires: what science can tell us. EFI Discussion Paper 15. European Forest Institute. Pp. 21–25.
Whelan, R.J. 1995. The ecology of fire. Cambridge University Press, Cambridge.

3.2 Fire Modelling and Simulation Tools

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3.2.1 Introduction

The scientific observation of fires in natural conditions is a difficult task. As for many environmental phenomena, fire modelling has been a way to reduce the amount of observations necessary for understanding and predicting fire behaviour. Modelling approaches can be reduced to two: empirical and physically-based.

Empirical fire behaviour models are established on the basis of a reasonable number of fire observations and predict the rate of spread or flame size of a fire (Sullivan 2009b). Usually, simple equations give the fire rate of fire spread as a function of a small number of parameters (wind speed, fuel characteristics, fuel moisture, and slope). There are well-known empirical models developed in the Australia, Canada, and the United States, and scientists have recently developed similar models in Spain and Portugal.

Physically-based models are based on the principles of combustion and they attempt to quantify the basic fire mechanisms (Sullivan 2009a). It has only been in the last decade, however, that a full representation of wildfire physics has been able to give predictions of fire spread. The so-called full physical models enable three-dimensional (3D) simulations of fire spread at the scale of a forest stand (<20 ha), but usually on super-computers. These models solve the transport equations of physics over time on a spatial grid, and predict many fire characteristics.

Despite the fast development of computer resources, it is not practical – so far and in the near future – to use this new generation of physically-based models to simulate fire at larger scales (10 km^2) with resolutions on the order of meters or smaller. The other aspects of these types of model, which limit their applicability is the accessibility of the large amounts of vegetation and atmospheric data that they require. Two-dimensional (2D) fire simulators have been developed in parallel to provide decision-makers with powerful tools capable of predicting and mapping fire behaviour in real conditions. Currently, GIS-based fire simulators can automatically compute fire growth under heterogeneous conditions of terrain, fuels and weather. However, because the results of the simulation have to be obtained in almost or faster than real time, fire simulators can only use simplified models (empirical or semi-physical). A way – and one of the objectives of the Fire Paradox project – to fill the gap between 3D physical models and 2D fire simulators is to use, as the "engine" of a fire simulator, parametric laws fitted to the output of 3D physical models (see Box 1).

Box 1. Vesta

Vesta is the Large Scale Wildfire Simulator developed in the frame of the Fire Paradox project. The basic idea of the software is to fill the gap between time consuming 3D physical models and existing semi-empirical 2D fire simulators.

The physical model used to establish parametric laws is Firetec, thanks to an agreement with the LANL (Los Alamos National Laboratory).

Besides the basic usual functions of a 2D-Fire simulator, its main features are the following:

- it is able to work on various vector and raster GIS file formats (import and export);
- as a ‘platform’, it is able to use various propagation models;
- it may be run with or without spotting models (namely the probabilistic model developed in the frame of the Saltus project);
- it includes a wind simulator to assess the local variations of wind direction and speed on the terrain;
- it allows fuel types description with the best accuracy available;
- it allows the user to simulate in an interactive way some human intervention as fuel breaks, aerial dropping, etc.
- it enables launching a series of simulations on a given area to calculate hazard maps;
- it enables the user to compare fire simulated with real wildfires to validate the results obtained;
- maps and fires can be visualized in 2D and 3D.

3.2.2 Pyrolysis, heat transfer and combustion

The ignition and spread of fire are governed by the physico-chemical processes of pyrolysis, heat transfer and combustion (Albini 1992).

Fire ignition, which is the initiation step of fuel combustion, can occur only when a heat source, fuel and an oxidizer are all present at the same time in the same physical space at high enough temperature to react. In the particular case of woody fuels heat transferred to the vegetation makes the temperature of the fuel rise. Beyond some threshold ‘ignition’ temperature (about 300°C), the vegetation releases flammable gaseous fuel at a high rate: this is the pyrolysis process. The gaseous fuels react with oxygen, this is the flaming combustion process releasing heat. Basically, fire spread is possible after fire ignition and when the amount of heat transferred from the pre-existing fire to neighbouring fuel is high enough to cause its ignition.

The rate of fire spread – i.e. the speed of the fire – depends on the strength of the heat source, on the efficiency of the heat transfer processes, and on the energy required to raise the temperature of the fuel to the ignition temperature. In wildfires, fine fuels such as grasses, twigs, and foliage are largely responsible for fire spread due to their large surface area per unit volume, which increases their vulnerability to ignition. The dominant heat transfer processes between these fuels are radiation and convection.

Fire spread is not only the propagation of fire on the terrain slope, but also the transition of fire from surface fuels (litter, grasses, shrubs) to crown fuels (tree canopy foliage). A fire that burns only the surface fuels is called a surface fire and a fire burning also the tree canopy is called a crown fire.

Fire spread may be enhanced by the transport of firebrands some distance ahead of the fire. These firebrands may ignite the fuel at their landing point and a secondary fire – called a fire spot – develops. Spotting can occur up to kilometers from the main fire front. Crown fires are the most likely to produce fire brands causing spotting. Empirical or physically-based models have also been developed for fire spotting.

3.2.3 Physical processes and factors influencing fire spread

Understanding how woodlands burn amounts to understanding how the basic processes of pyrolysis, combustion and heat transfer are affected by the different environmental factors and the nature of the complex coupling between them.

Knowledge of these effects, their relationships, and their quantification has been the purpose of many studies based on observations, experiments and modelling.

Forest fuel moisture and wind are probably the most obvious factors affecting fire spread. Because water content of the fuel must be evaporated before ignition can occur and because the boiling of water requires a huge amount of energy, fuel moisture content is the most important parameter influencing fire start. Moisture content also influences fire spread and how much of the existing fuel can burn. This is why so many efforts have been dedicated to measure or predict the moisture content of vegetation as influenced by meteorological conditions and biological cycles. In natural fires, wind has mainly the effect to bend the flames towards the unburned vegetation and convect heat to its surface. This enhances heat transfer to the unburned fuel and it has been observed that fire rate of spread is more or less proportional to wind speed at least for low to moderate wind speeds and for surface fires.

The terrain slope also affects fire spread and a steep slope is known to represent very dangerous situations for fire fighters.

The amount of forest fuel and how it is distributed in the different vegetation layers is also a factor affecting fire spread. In addition, fire intensity (also known as fire power) is directly influenced by the amount of fuel available to burn.

3.2.4 3D-Fire modelling

Fire modelling is a powerful technology for the simulation and prediction of fire spread, even if only average fire behaviour is predictable.

Fire behaviour research has established significant correlations between the fire environment – wind, fuel properties, slope – and fire rate of spread. This is why empirical models succeed operationally in predicting fire spread within the range of environmental conditions under which they have been developed. Fire is, of course, governed by the laws of physics and as such is not a completely random process. These facts mean that some aspects of fire are predictable at some scales and this is essential to decide strategies of fire prevention and mitigation.

The question of fire behaviour predictability however remains important. Fire observations by experts of wind flows and recent advances in coupled fire-atmosphere modelling have revealed that wind turbulence plays a dominant role in erratic fire behaviour often observed in the field. In addition, the turbulence level, which measures the amount of local wind fluctuations, is increased by buoyancy effects. Hot gases in a fire plume are less dense than ambient air and rise vertically in the atmosphere due to the Archimedes' principle; the driving force is called the buoyancy force and the upward vertical motion of hot gases is accompanied by downward vertical motion of fresh air. This physical situation is very unstable and explains why high-intensity fires are likely to exhibit very erratic and dangerous behaviour. A simple physical criterion based on the relative force of wind and buoyancy has been proposed to identify such unstable situations, but the prediction of the criterion itself remains delicate.

It is well known in the field of fluid mechanics that turbulence effects are only predictable on average. That means that one must expect great variations in fire behaviour from one moment to another and from one point to another. Fire practitioners or fire fighters operating on the ground must be aware of and account for this variability, which is significant mainly at local scales (<1 km).

The natural heterogeneity of vegetation and mechanism of spotting are additional sources of fire behaviour variability.

Physical models, and in particular coupled atmosphere-fire models that solve the transport equations of physics to represent the fire, are powerful tools to explore the effects of turbulence (and more generally non-linear effects) on fire behaviour, provided that they use adequate computation and modelling approaches. Other models, by their nature, cannot properly render the effects of turbulence. The fact that the fuel is spatially-distributed in these models also enables the variability caused by the non-uniform distribution of vegetation biomass to be accounted for. Examples of use of full physical models in the field of research are given in Box 2.

Global change is expected to cause important changes in the environmental factors that influence fire start and spread. In particular, changes in vegetation characteristics are expected. The first consequences have been observed with the decline of some conifer forests in the south of Europe: an immediate consequence is the sudden reduction of moisture content of the vegetation. One can also expect that some species not yet adapted to heat and dryness will adapt to new climate conditions by reducing their plant moisture content or more likely by producing dead biomass, as some Mediterranean species already do. Tree species are known to have a large capacity for adaptation. One can eventually expect that by migration new mixtures of plant species will take the place of species no longer adapted to their environment. In order to assess the consequences of these changes on fire behaviour, empirical models will be of small value since they are based on fire observations made in existing vegetation types. In contrast recent physically-based models are powerful tools to explore new environmental scenarios.

3.2.5 2D-Fire simulators

A two-dimensional fire simulator predicts fire growth over a map. In a real situation, local conditions (i.e. topography, fuel and weather in each map pixel) change over the map. Using spatial information along with weather and wind files, the simulator thus requires the support of a geographic information system (GIS).

Fire simulators can potentially be used by land management agencies and fire fighting organisations for:

- wildfire training and educational sessions by conducting all kinds of 'what-if' scenarios;
- prevention and pre-suppression activities by assessing the effectiveness of fuel treatments, testing the location of potential access roads, identifying opportunities for the use of prescribed burning;
- operational purposes by supporting fire suppression activities and predicting wildfire behaviour;
- making decisions by producing hazard maps and risk maps, economic assessment.

The two North-American fire simulators Farsite (Finney 1998) and Prometheus – the most used worldwide – have the same functionalities. Using deterministic models (i.e. they produce output directly related to the input used by the user), they:

- can use point, line or polygon ignitions;
- can automatically compute wildfire growth and behaviour for long time periods;
- produce output that are GIS compatible;
- are based on existing fire behaviour models widely used (e.g. Behave, CFFDRS);
- enable some interactivity with the user (e.g. modification of fuel types, simulation of aerial and ground fire suppression actions).

3.2.6 Linkage between 3D-fire models and 2D-fire simulators

The scale of prediction of physically-based models resolving transport equations on a three-dimensional grid is still far from the landscape scale, and even in a long-term perspective, the operational use of such models will be limited by the computational resources, especially when a number of simulations are requested. This is the reason why such models cannot be a direct component of a fire simulator at a landscape scale.

So, since such 3D-fire models have a limited use for operational purposes, one way to overcome this limitation is to incorporate their results as the 'engine' of 2D-fire simulators.

As a first step, the 3D physically-based model is used to provide local fire behaviour characteristics like rate of spread or fire intensity, by making simulations over distances up to several hundreds of meters in the direction of propagation. The model serves to implement a database of fire characteristics for various fuel types, topographies and weather conditions. As a second step, the library of simulated conditions is used to fit parametric laws that yield the rate of spread as a function of wind, slope, fuel load, moisture content, and so on. Finally, these laws are applied to local input data to predict fire spread over the terrain map using a contagion process.

Box 2. 3D-modelling of fire behaviour and effects

Three-dimensional physically-based modelling of fire has been extensively used in Fire Paradox in the frame of research studies on the understanding of fire behaviour and effects mechanisms. Three different models have been used: (i) FDS, the Fire Dynamics Simulator developed by the NIST (mainly devoted to building or structural fires); (ii) WFDS (the FDS version for wildland fire simulation); and (iii) Higrad-Firetec, a coupled atmosphere-fire model for fire behaviour simulation developed by the LANL (Los Alamos National Laboratory) and the INRA (Institut National de la Recherche Agronomique).

Many questions arise from forest and fire managers about the efficiency of surface fuel reduction on tree survival, about the size and location of fuel breaks in a forest landscape, or about the effect of fuel removal or modification on fire intensity. Simulations of the effects of vegetation heterogeneity on fire behaviour have been run with Higrad-Firetec, in the context of the evaluation of fuel break efficiency. A simulation of fire spreading over a fuel-break is shown as an illustration in Figure 1. Similar simulations have been done in a pine (*Pinus halepensis*) stand using varied vegetation patterns on the fuel break. These simulations revealed that: (i) a 25% cover of trees on the fuel break decreases significantly fire intensity as compared to the untreated pine stand (75% cover fraction), but 50% is not efficient; (ii) the size of the tree clumps does not affect significantly the fire behaviour, except if very dense trees (unrealistic for pines) are used to run the simulations.

The impact of a surface fire on tree crowns is usually measured through the percentage of crown scorched in length or volume. A description of crown injury is often used as an input to statistical models predicting tree mortality after fire. Empirical models for the prediction of crown scorch height have been developed in the past, based on a simple formulation derived from the plume theory. The most representative of such models is the Van Wagner model for scorch height. Higrad-Firetec, as well as a two-dimensional CFD (Computational Fluid Dynamics) code, has been used to explore the relevance and implications of plume theory in the context of crown scorch height prediction: the assumptions of the plume theory were found to be inadequate. This conclusion could be extended to some models for crown fire initiation that also rely on plume theory.

Fire also impacts tree trunks, and tree mortality models often also account for this effect. In an attempt to examine flow and thermal conditions on a tree trunk, when a surface fire spreads around it, and so to understand the mechanisms of fire impact, both computer simulations (WFDS) and laboratory experiments were conducted as complementary approaches to the same problem. The results obtained by both approaches were, in general terms, very similar, showing an increase in flame residence time and on flame height in the leeward (near-wake) side of the trunk.

Wildfires also have specific impacts in the wildland urban interface, in particular on houses. FDS was used to simulate the thermal impact of a fire on a house and also the transport of firebrands around a house. Indeed firebrands are often the cause of house ignition at roof level. Regarding the thermal impact it was shown that two-dimensional simulations can give useful results in terms order of magnitude, but that three-dimensional simulations are required for deeper investigations. These simulations coupled with ignition models for building materials (also developed in Fire Paradox) should give an evaluation of the thermal risk in the future. Regarding firebrands, three-dimensional simulations give indication of the risk they represent by monitoring of brands at different positions around the house, but the effects of flow instability and unsteadiness on results should be further investigated before considering the operational use of such approach to fire impact measurement.

Box 2. Continued

Suppression fire is one possible use of fire against wildfires and as such could help solving the fire paradox. 3D-modelling using Higrad-Firetec was one approach followed to assess the feasibility and efficiency of suppression fire. Field experiments have also been conducted for the same purpose in Fire Paradox. Although it is difficult for the model to strictly reproduce the experiments, both approaches indicate that it is very difficult to find proper conditions for a safe and efficient use of backfires, when a wildfire spreads over a flat terrain under the influence of even moderate winds: the backfire is expected to be "sucked" by the wildfire, but this was observed only under weak wind conditions. As already known by fire managers, however, topography can help the development of such a "sucking" phenomenon.

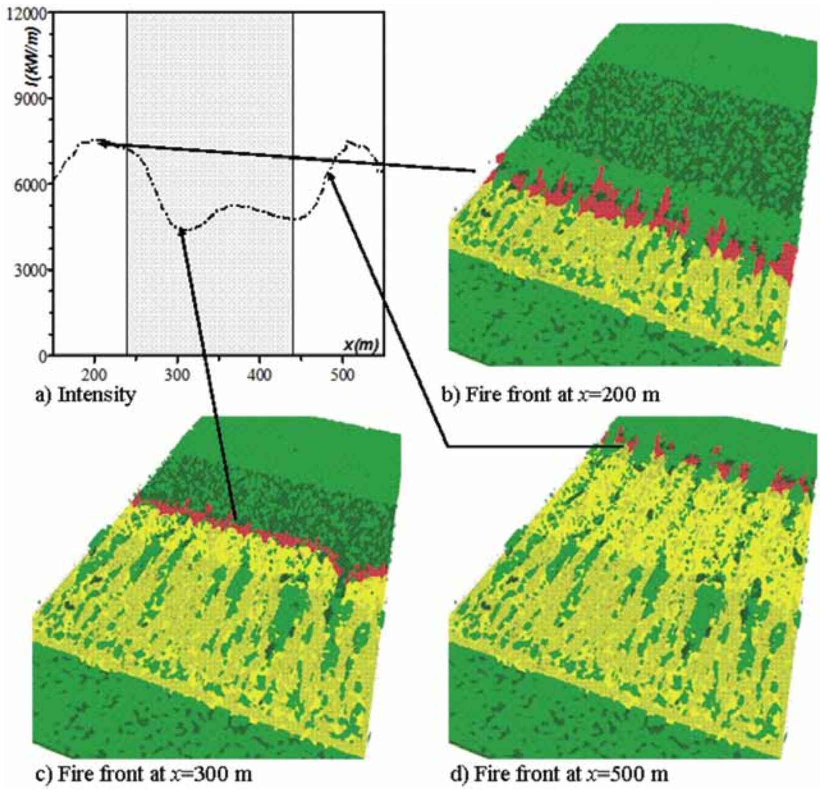

Figure 1. Numerical simulation of a fire spreading over a fuel break in a *Pinus halepensis* stand, using the coupled fire-atmosphere model FIRETEC (INRA – LANL joint work). Cover proportion of trees on the fuel break is 25%. The fire spreads along the x-axis and the fuel-break extends from x=240 m to x=440 m. Flame contours in red are deduced from computed isotherms. Green and yellow colour contours are used respectively for tree canopy and surface fuels (shrubs, grasses) representations (iso-contours of computed biomass density). Adapted from Pimont (2008).

Box 3. Fuel editor

The Fire Paradox Fuel Manager (Lecomte et al 2009) is a piece of computer software integrated in the data processing chain between the European data and knowledge base on fuels and the 3D physically-based fire propagation models. The scientific objective was the representation of vegetation scenes and their transformation into fuel complexes including all the necessary parameters to run a fire behaviour model. The technological objectives are to implement a user friendly platform to generate fuel complexes in 3D, to provide tools for managing the European database on fuels, to visualize fire effects on trees and simulate post fire vegetation successions.

A survey of available simulation platform technologies has led us to join the Capsis project, dedicated to hosting a wide range of models for forest dynamics and stand growth. A new CAPSIS module – "FireParadox" – has been developed which implements data structure and functionalities of the Fire Paradox Fuel Manager.

A 3D vegetation scenes' editor has been implemented allowing interactive manipulative functionalities on vegetation scenes (e.g. zoom, rotation, etc) as well as on vegetation objects (selecting, adding, updating) through a graphical user interface. Several renderers are available to display 3D vegetation objects. Fire damage on vegetation objects have been mainly focused on fire-induced tree mortality. Several fire impacts on tree crown and trunk have been defined and can be visualized at the scene scale. Moreover, several tools are available to display information (descriptive statistics, indicators) on the vegetation scene content or on the current selection.

Several creation modes of vegetation scenes are available including loading of a pre-existing inventory file or the automatic generation of a new scene respecting a set of constraints on species distribution.

The application is connected through the Internet to the European database on fuels and manages the user's rights.

An export module has been developed to prepare the set of files necessary to run the fire propagation model. Export files describe the composition and the structure of the fuel complexes taking into account the physical properties of various components of the different vegetation layers (trees, shrubs, herbs and litter) composing the vegetation scene. Further details can be found at http://fireintuition.efi.int/fuel-manager.fire.

References

Albini, F.A. 1992. Dynamics and modelling of vegetation fires: observations. In: Crutzen, P.J. and Goldammer, J.G. (eds.).Fire in the environment: the ecological, atmospheric, and climatic importance of vegetation fires. Report of the Dahlem Workshop held in Berlin, 15–20 March 1992. 400 p.

Finney, M. A. 1998. FARSITE: Fire Area Simulator-model development and evaluation. Res. Pap. RMRS-RP-4, Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 47 p.

Lecomte, I., de Coligny, F., Griffon, S., Pimont, F., Rigaud, E., Rigolot, E. and Vigy, O. 2009. Fire Paradox fuel manager: software and user's manual. Product P6.1-6 of the Integrated Project "Fire Paradox", Project no. FP6-018505. European Commission. 85 p.

Pimont, F. 2008. Modélisation physique de la propagation des feux de forêts: effets des caractéristiques physiques du combustible et de son hétérogénéité. Université de la Méditerranée, Aix Marseille II. Doctoral Thesis. 323 p.
Sullivan, A.L. 2009a. Wildland surface fire spread modelling, 1990–2007. 1: Physical and quasi-physical models. International Journal of Wildland Fire 18: 349–368.
Sullivan, A.L. 2009b. Wildland surface fire spread modelling, 1990–2007. 2: Empirical and quasi-empirical models. International Journal of Wildland Fire 18: 369–386.

3.3 Wildland Urban Interfaces, Fire Behaviour and Vulnerability: Characterization, Mapping and Assessment

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3.3.1 Introduction

Large areas initially consisted of contiguous forests, particularly in Europe, were influenced by human activities to a large extent. This influence contributed to the fragmentation of the rural landscape and forested areas were found surrounded by or intermixed with urban development. Urban and economic development in or near wildland vegetation poses a major threat to the environment (Johnson 2001, Radeloff et al. 2005a). They are areas of human-environment conflicts, such as the destruction of homes by wildfires, natural habitat fragmentation, introduction of exotic species, and biodiversity decline (Radeloff et al. 2005a). These areas that are characterized by increased human activities and land use conversion make up the wildland urban interfaces (WUIs).

The significance of WUIs has grown in recent years mainly because WUIs, as landscape units, have grown worldwide (Steward et al. 2003). Essentially in USA, Canada and Australia interest in study of WUIs increased after the huge fires of 1985 (Davis 1990). Since 2000 in Europe the WUI becomes involved in the forest fire environment. Residential areas are increasingly affected by wildfires with damage on goods and people. Extreme fires affected Portugal, France and Spain in 2003, Spain in 2005, Portugal and Spain in 2006, and Greece in 2007. More crown fires involve WUI zones, mainly during heat waves, destroying houses (Lampin-Maillet 2008).

So large efforts, aiming at the identification and mapping of existing or potential WUI areas have been recorded in North America and to a lesser extent, in Europe. The aim was to assess fire risk in WUIs and particularly their vulnerability in order to improve the efficiency of prevention actions for the protection of WUIs from wildfire propagation.

Wildfire risk can be defined as the expected loss due to wildfires on a certain area and period of time. Many definitions of wildfire risk exist (Hardy 2005, Camia et al. 2004). The most common corresponds to the combination of hazard with vulnerability: risk = hazard*vulnerability, establishing relationships between

Table 1. Fire risk definition with detailed elements.

FIRE RISK					
Hazard				Vulnerability	
Occurrence		Intensity			
Ignition Probability	Wildfire Probability	Threatened area	Wildfire Intensity	Stake	Reply Response

theses three concepts (Chen et al. 2003). So fire risk encompasses two different components: (i) the probability that a wildfire affects the area during that period of time – fire hazard; and (ii) the potential damage that the fire will cause once it occurs – vulnerability (Blanchi et al. 2002, Jappiot et al. 2009). Blanchi et al. (2002) proposed to define each component of fire risk as composed of different overlapping elements (Table 1).

But we also find other fire risk definitions where intensity is considered as part of vulnerability (Jappiot et al. 2009, Wilson et al. 2005).

The assessment of forest fire risk is generally recognized as an indispensable component of fire prevention and suppression systems. As fire fighting resources and fire prevention infrastructures are not infinite, the need for predicting a wildfire incident and its consequences becomes apparent. Resources need to be allocated wisely, in space and time, for the sake of operation and cost effectiveness. Usually fire risk assessment consists of a combination of fire hazard assessment and vulnerability assessment.

- Various authors in risk-related issues have used the term fire hazard, in different and contradicting ways (Camia et al. 2004). In the present work, we consider fire hazard as the combined outcome of the probability of fire occurrence and the potential intensity of the resulting fire, similarly to the definition used by Blanchi et al. (2002). We consider the probability of fire occurrence as the likelihood of a fire to happen in an area. Finally, fire intensity is considered as the potential energy release per unit length of fire front, in the case of a fire incident (Byram 1959). Fire hazard is generally computed as an index (San Miguel-Ayanz et al. 2003). Assessment methodologies are categorized by their temporal scales (Marzano et al. 2004). If the assessment is based upon factors, that change very slowly over time (e.g. vegetation, topography), then the outcome would be a structural (static or long-term) index (Jappiot et al. 2009). On the other hand, if the assessment is based upon factors that are likely to change frequently (daily or even hourly, e.g. fuel moisture, weather) then the outcome would be a dynamic (short-term) index.
- Concerning the other component vulnerability, there are many different concepts of vulnerability across disciplines and topics (Gallopin 2006). According to natural risks, vulnerability can be considered in three ways: as a consequence, as a state or characteristic, or as a cause (Mantzavelas et al. 2008).

In the first case vulnerability is the value that could be lost when hazard occurs. According to Coburn et al. (1994), vulnerability is defined as the degree of loss to a given element (or set of elements), resulting from a given hazard at a given severity level. Caballero et al. (2004) stated that vulnerability can be expressed through the calculation of the potential damage when a single unit is exposed to a certain level of danger.

In the second case vulnerability can be the propensity of an element or a set of elements to suffer damage, when a hazard occurs (D'Ercole 1998). Commonly, vulnerability may encompass the degree of fragility of men, organized societies, economic structures, built environments and ecosystems to the negative consequences resulting from the exposure to hazardous events. According to Blaikie et al. (1994), vulnerability expresses the capacity of a person or group to anticipate, cope with, resist to and recover from the impact of natural hazards.

Finally, in the third case vulnerability corresponds to a "system which considers a lot of variables (natural and human). Their spatial and temporal dynamic can produce situations which can be more or less dangerous for exposed society" (D'Ercole 1996). In this case the aim is to identify the factors (variables) that are the source of vulnerability.

In short, it is obvious that the definition of the vulnerability refers mainly to the impacts of a catastrophic event. The vulnerability of an element is usually expressed as a percentage loss (or as a value between 0 and 1) for a given hazard severity level (Blanchi et al. 2002).

The great challenge is to express vulnerability in measurable units or indices in order to be used for further estimation of the total fire risk. Furthermore, most of disaster mitigation work is focused on reducing vulnerability, and in order to do it, there is a need to understand which elements or units are the most exposed at risk, from the principal hazards which have been identified (Coburn et al. 1994).

The concern of this chapter is the wildland urban interface and fire risk assessment. It supposes to define precisely this term. In geography, interface is defined as the contact plan or contact line between two different systems (Brunet et al. 1993). It constitutes a privileged zone to exchange, to interact between two systems, specifically human and wildland systems (Carroue et al. 2002). In the literature, definitions present WUI as the line, area, or zone where structures and other human developments meet or intermingle with undeveloped wildland or vegetative fuels. The term of WUI community exists with the following definition "the urban-wildland interface community exists where humans and their development meet or intermix with wildland fuel", where houses meet or intermingle with undeveloped wildland vegetation (USDA-USDI 2001). Nowadays and more generally, the WUI commonly described as the area where urban areas meet and interact with rural lands (Vince et al. 2005), includes the edges of large cities and small communities, areas where homes and other structures are intermixed with forests and other land uses, and islands of undeveloped lands within urban areas (Alavalapati et al. 2005, McGee 2005, Caballero et al. 2004). In these WUI increased human influence and land use conversion are chancing natural resource goods, services and management (Macie and Hermansen 2002).

The issue of the chapter is to map the location of WUIs on the territory and to determine which WUIs are at the greatest risk. For that several objectives are

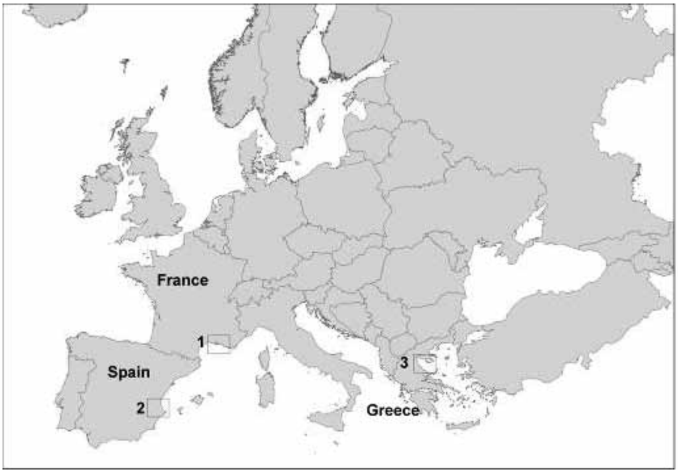

Figure 1. Location of the three European study cases.

developed. The first objective is to present a method to characterize and to map WUIs at a local scale with a view to improve fire prevention, and at a landscape scale with a view to analyse their territorial development in the landscape. The second objective is to propose a fire hazard calculation and mapping process taking into account structural and daily factors. The third objective is to propose a method to assess vulnerability levels. The fourth and last objective is to present a specific approach developed with a view to assess and to map fire risk in WUIs through a total fire risk index. Tools have been developed as the result of scientific research.

In order to develop the previous objectives, three study cases have been defined in three European countries: France, Spain and Greece. The first one is located in southeastern France in the Metropolitan area between Aix-en-Provence and Marseille (site 1 in Figure 1). The second one is located in southeastern Spain in Sierra Calderona (site 2 in Figure 1). The third one is located in northeastern Greece in the western part of the prefecture of Thessaloniki (site 3 in Figure 1).

3.3.2 Identification, characterization and mapping of WUIs in European Mediterranean countries

In order to map WUIs on the territory, a precise definition of the WUI has been proposed as follows (Lampin-Maillet et al. 2010):

- WUIs are composed of residential houses, which are inhabited permanently, temporarily or seasonally (agricultural, industrial, commercial and public buildings were not taken into consideration);
- Houses are located at 200 m from forests or shrubland to consider area where brush-clearing is partially required or spot fires occur (Colin et al. 2002);

- WUI are delineated by a radius of 100 m around the houses. This distance takes into account the perimeter wherein fuel reduction operations can be imposed on home owners.

These different distances are particularly adapted to the European context but they also could be changed according the specific local context of the country (vegetation clearance regulation or urban organization).

3.3.2.1 At local level (Lampin-Maillet et al. 2010)

Considering the above definition, the WUI area is located up to 300 m from forests, garrigues (200 m + 100 m) so it is also significantly exposed to firebrands from vegetation in the case of fire. Therefore, in France, WUIs are the subject of the French Forest Orientation Law of July 9, 2002 which makes brush clearing obligatory within a 50 m perimeter around each house located at a distance of less than 200 m from forests or shrublands. In other European countries, the effective fuel treatments are required only within a 10-30 m radius.

We considered WUI as two intermixed elements: the first concerned the spatial organization of residential houses, and the second concerned the structure of fuel vegetation. Spatial criteria had to be developed to specify the structure of dwellings in contact with the different vegetation structures. Concerning the structure of dwellings, after first approaches developed with housing density calculation (Lampin et al. 2007a,b,c), we proposed a real and quantitative definition of terms corresponding to isolated, scattered, dense (or very dense) clustered dwelling types, usually used by land managers and geographers. Their distinction is based on quantitative criteria described in Lampin-Maillet et al. (2009) such as housing density. Concerning the structure of vegetation, only the horizontal structure of vegetation that can be spatially recognized has been characterized (no vegetation, sparse vegetation and continuous vegetation). Then the combination of different types of dwellings and different classes of horizontal structures of vegetation produced a WUI typology. The method used to characterize and to map WUIs is based on three steps.

The first step is to characterize and map the housing configuration. The houses considered as located in WUIs are selected. Then according to the definition of the dwelling types established in Lampin-Maillet et al. (2009) and through the process of buffering and house counting described in the same paper, each house was classified as belonging to one of the four configurations of houses: isolated, scattered, dense clustered, and very dense clustered housings. These classes take into account the distance between houses and the density of houses located within a 100 m radius around houses.

The second step is to characterize and map the structure of vegetation. The structure of vegetation reveals its horizontal continuity which is designed for the measurement of aggregation levels of spatial patterns within the vegetation class in a land-cover map. Among the different existing metrics in landscape ecology (McGarigal 2002), the most appropriate index to measure aggregation of spatial patterns is the aggregation index (AI) (Lampin-Maillet et al. 2010). This aggregation index has a spatial representation. Calculated on vegetation class, the aggregation

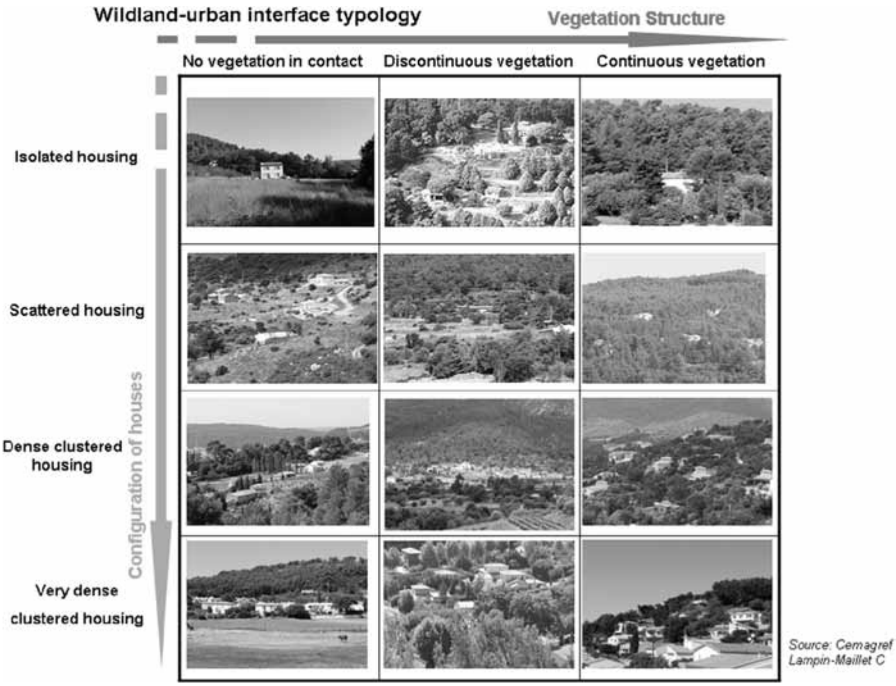

Figure 2. Typology of wildland urban interfaces (Lampin-Maillet et al. 2010).

index enhances spatial organization of forests and scrublands. Vegetation is defined as wildland forests (coniferous, deciduous, and mixed forest), scrublands, transitional lands (mostly clear-cuts). Excluded from vegetation are low- and high-intensity residential, commercial/industrial buildings, orchards/vineyards, pasture/hay, arable land (e.g., row crops) and pasture, small grains, fallow, urban/recreational grasses, bare rock/sand/clay, quarries, open water, and perennial ice/snow (Steward et al. 2003, Radeloff et al. 2005b, Lampin et al. 2006). Aggregation metrics calculations were made within a moving window with a radius of 20 m and a map of aggregation index values was also drawn up including three classes of AI values. The first class concerned values equal to zero, and the two other classes were determined by sharing the numbers of value equally into two groups or by setting a threshold value equal to 95%: the first distribution of numbers were considered as low values of aggregation, the second one as high values.

The third step is combining the two previous criteria through a geographical information system (GIS). The calculation allowed mapping of the WUIs according to 12 types (Figure 2) by crossing four classes of dwelling types and three classes of vegetation aggregation indices in a raster format. The WUI method has been applied in different areas in France and Spain. Figure 3 is an illustration of the WUI map carried out on French site, site 1 of Figure 1.

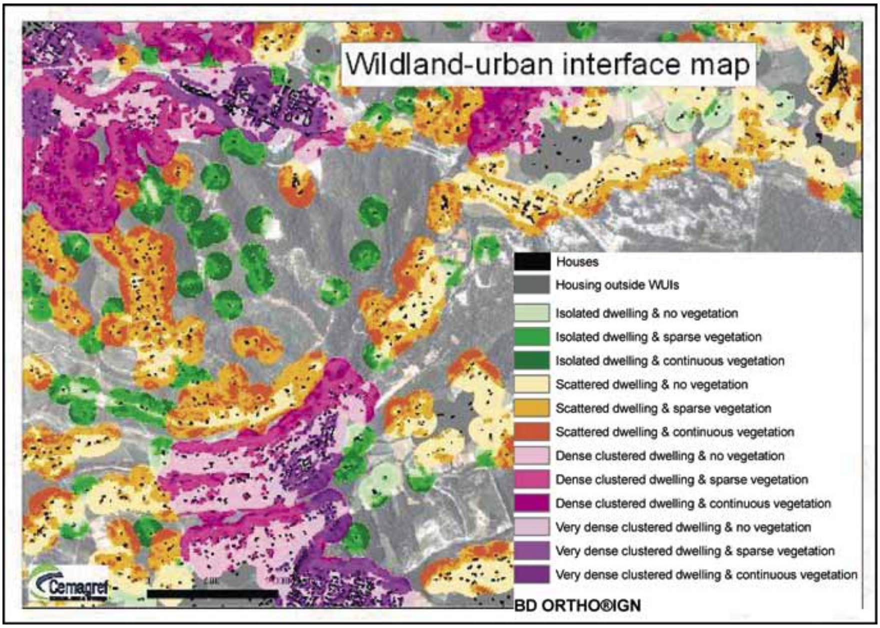

Figure 3. Map of wildland urban interfaces in study site 1 (Lampin-Maillet et al. 2010).

3.3.2.2 At landscape level (Galiana et al. 2007)

The local scale of analysis must be complemented by a more general approach. On one hand, WUI expansion processes are associated with counter-urbanization and development of second home dynamics which respond to spatial organizational models on an urban–regional scale (Antrop 2004). On the other hand, the existing landscape pattern exerts an influence on the land cover and land use trajectory, and ultimately on the pattern of new residential development. Also, fire behaviour is largely dependent on the landscape pattern. These are two major reasons to apply the landscape character assessment method developed as an intermediate scale between local and regional levels (Bürgi et al. 2004).

The WUI characterization developed results from the analysis at different scales (regional, landscape, local), and the interactions between them, i.e. multiscale analysis.

At the regional level, the objective of analysis is the establishment of a descriptive model of the main territorial dynamics influencing the area (suburbanization, abandonment and transformation of the rural areas, wildfires) and definition of its main spatial patterns. The results from this method improve the landscape character assessment. The model is based on the analysis of structural (distribution of land uses) and functional elements.

Table 2. WUI characterization. Relation matrix from the combination between the morphology of the settlements and the type of landscape (Specific case: Sierra Calderona)

Type of landscape/ Morphology of settlements	Towns	Urbanizations	Scattered rural settlements
I, Western flat topped peaks III, Wildland mountain with lower bunter sandstones and cultivated gullies	I, Compact towns II, Compact towns with extensions	III, Spontaneous urbanizations (not planned) on wildland terrain IV, Urbanizations planned on wildland terrain	IX, Scattered settlements on terraced slopes X, Scattered settlements on wildland terrain
IV, Agroforestal slopes V, Small agricultural valleys	-	V, Spontaneous urbanizations (not planned) VI, Urbanizations planned on wildland terrain	XI, Scattered settlements on cultivated slopes
II, Agricultural foothill plains	-	VII, Spontaneous urbanizations (not planned) VIII, Urbanizations planned	XII, Scattered rural settlements

At the landscape level, the multiscale analysis consists in the Landscape Character Assessment (LCA), based on the natural and cultural features present in the landscape and on evaluation of functional dynamics and uses. Landscape description established a hierarchical typology composed of two levels: landscape units and types (Countryside Agency and Scottish Natural Heritage 2002). The LCA provides the territorial context of the WUI studied in order to correlate urbanization processes with the type of landscape in which they occur and with the foreseeable risk evolution in these areas.

At the local scale, the WUI characterization process consisted of identifying the different morphologies defined by urbanization processes, examining them in the context of the landscape type of the area in which they occur and characterizing them according to fire behaviour.

Figure 4 is an illustration of the WUI map at landscape level located in site 2 of Figure 1.

3.3.3 Fire hazard assessment in WUIs (Lampin et al. 2009)

3.3.3.1 Steps for fire hazard mapping

The work presented hereafter is aiming at the definition of a standard workflow for obtaining a fire hazard map that will take into account structural and dynamic factors within a GIS. The map can be updated on a daily basis.

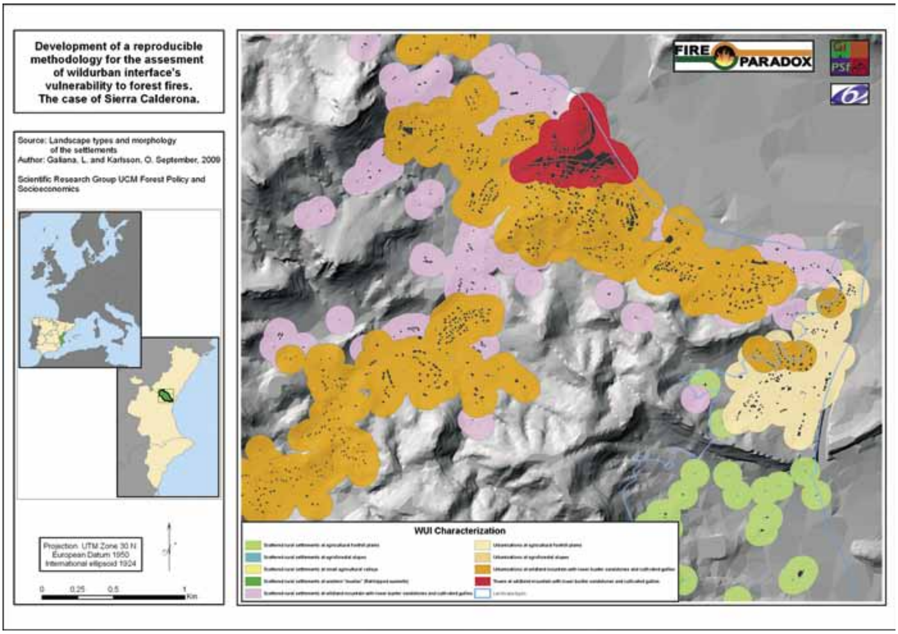

Figure 4. WUI map at landscape level in Spanish study site, site 2.

Calculation of a structural index (Probability of occurrence)

There are several approaches attempting to assess the combined impact of structural factors on fire hazard. Factors that are usually taken into account usually are:

- Human presence (population, distance from settlements, distance from roads etc.);
- Vegetation (type, biomass, structure);
- Topography (slope, elevation, aspect).

Factors are integrated into equations, each one weighted according to the author's opinion on its relative importance, to produce hazard indices. To overcome the subjectivity in weighting of the contributing factors, new techniques have been elaborated like principal component analysis (Xu et al. 2006), logistic regression (Chou and Minnich1993, Martinez et al. 2009) and neural networks (Vasilakos et al. 2007). These techniques seek to establish a relationship between those factors and fire history. Among those new techniques, logistic regression has been extensively used as it provides a probability of occurrence as an output. The accuracy of the assessment can be easily estimated by the observed fire incidents.

In a first step, a group of potentially significant variables for the prediction of fire occurrence must be defined (for example: fuel types, elevation, aspect, distance from nearest road, average annual rainfall, etc.). These variables should be regressed against a data set containing the perimeters of historic fire incidents.

In a second step, an exploratory analysis (e.g. Chi^2 significance test) should be performed, in order to identify if any of the variables in consideration are not related to fire occurrence. Further, weights are assigned to each of the remaining variables according to its significance, which is calculated by means of logistic regression. The logistic model of fire occurrence probability can be expressed as:

$$PFO_i = \frac{\exp(Z_i)}{1+\exp(Z_i)} \qquad (1)$$

Where PFO_i is the probability of a fire to occur in the ith geographic unit (pixel) and Z_i can be calculated as:

$$Z_i = b_0 + b_1X_{1i} + b_2X_{2i} + \ldots + b_jX_{ji} + e \quad (2)$$

Where X_{ji} is the value of the *jth* variable in consideration in the *ith* geographic unit (pixel or polygon), b_j is the weight of the *jth* variable and *e* is an error term.

As implied by equation 1, when Zi approaches positive infinity, the value of the index approaches 1, indicating that the *ith* geographic unit is definitely going to burn in the next period. Similarly, when Zi approaches negative infinity, the value of the index approaches 0, indicating that the *ith* geographic unit is not going to burn.

Value range for the PFO: PFO, being a probability, ranging between 0 and 1.

Calculation of a daily (dynamic) index

Considering the short-term component, different strategies have been applied. Most of them consist of trying to assess the effect of fuel water content on fuel flammability. The Canadian Fire Weather Index (FWI) is generally considered as one of the most efficient in defining the daily risk, as it has been globally applied and evaluated in very diverse ecosystems besides Canada (Marzano et al. 2004, Viegas et al. 1994). For these reasons the FWI is the dynamic index proposed also here. A schematic presentation of the FWI structure is shown in Figure 5.

The values of the required variables for the calculation of the FWI (temperature, relative humidity, wind and rainfall) are usually derived from meteorological stations or sensors. In order to calculate an FWI surface (map), there is a need to obtain a surface of values for each one of the above-mentioned variables. Thus, the point source values of those variables have to be interpolated, before the final calculation of the FWI (Mantzavelas et al. 2007).

Value ranges for the FWI: FWI is open-ended with ranges from 0 to 100+. Values from 0 to 8 are considered as low values, values from 8 to 17 are considered as moderate values, values from 17 to 32 are considered as high values, and values greater than 32 are considered as extreme values (Raínha and Fernandes 2002, Alexander 2008).

Combination of structural and daily indices; the Composite Index (CI)

As discussed above, the structural index PFO is calculated by considering all factors (human, topography, vegetation, weather, etc.) that contribute to the occurrence of the wildfire phenomenon. But, as implied by the calculation method, the structural index is a long-term predictor of fire occurrence and can only be considered as an average probability, because it does not take into account the current status of fuel, which is thought to be a very significant factor in the occurrence of wildfires. For instance, a heavy rain incident can reduce the chance of fire to zero, even in a place where the (long-term) occurrence probability is thought to be high. On the other hand, a meteorological index like the FWI, represents the ignition risk that

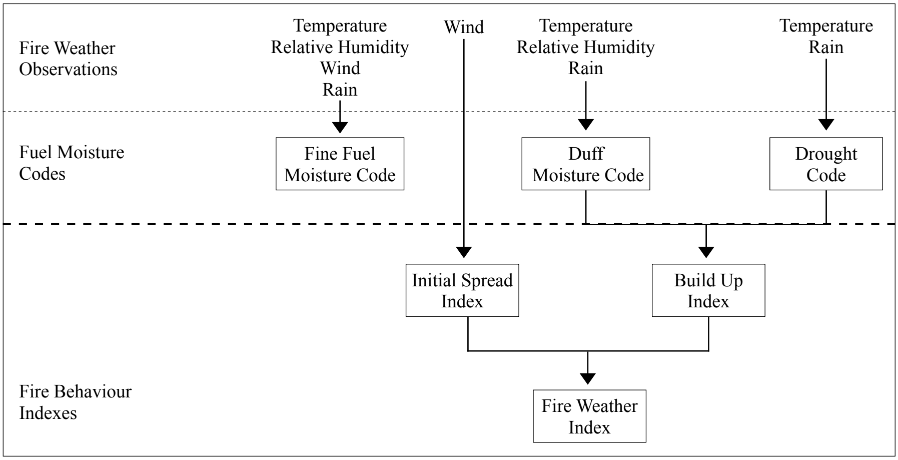

Figure 5. Simplified structure diagram for the Fire Weather Index (after Van Wagner 1987).

is contributed upon the daily fluctuations of the weather and their impact on fuel moisture status. Although the FWI is considered as quite efficient in defining the daily ignition risk, it is reasonable to think that: (a) all ignitions cannot be explained by a low fuel moisture level; and (b) not all ignitions develop into fires (e.g. in the case of a lack of fuel).

Thus, it becomes apparent, that an integrated approach is needed, in order to better understand and define the wildfire hazard issue. We propose, for that reason, the calculation of a Composite Index (CI), which is the product of the Structural Index (PFO) and the Fire Weather Index (FWI), such as:

$$CI_i = PFO_i * FWI_i \qquad (3)$$

where: CI_i is the value of the Composite Index for the *ith* geographic unit,
PFO_i is the value of the Structural Index for the *ith* geographic unit, and
FWI_i is the value of the FWI for the *ith* geographic unit.

The CI can be considered as the 'valid' portion of the FWI calculation. That is, provided that the calculation of the probability of fire occurrence in PFO is correct, then the CI is the part of the FWI value that remains meaningful under the combined influence of structural factors and fire history. In other words, we may say that CI is the part of the FWI value that is validated by structural factors and fire history (if the PFO value is 0 then the CI value becomes 0, whereas if the PFO value is 1 then the CI value is 100% of the FWI value).

Value ranges for the CI: CI, being the product of the PFO and the FWI has the same value range as the FWI (0 to 100+).

The Potential Fireline Intensity (PFI)

Until now, we have only dealt with the issue of fire occurrence. In order to have a broader view on the issue of fire hazard, we have to explore the possible

Table 3. Calculation of the Hazard Index.

CI\PFI	Low	Moderate	High	Very high	Extreme
Low	Low	Low	Moderate	Moderate	High
Moderate	Low	Moderate	Moderate	High	Very high
High	Moderate	Moderate	High	Very high	Extreme
Extreme	Moderate	High	Very high	Extreme	Extreme

consequences from a certain fire incident (Alexander 2008). A way to do so is to calculate the potential fireline intensity, which is the potential energy release per unit length of the fire front in the case of a fire incident. The calculation of fireline intensity is significant in fire suppression and the study of the ecological effects of fire. The fireline intensity is calculated as a function of fuel mass, the rate of spread and a 'constant' number, usually taken to be equal to 18 000 kJ/kg (Byram 1959):

$PFI_i = 18\,000 * W_i * ROS_i$ (4)

Where: PFL_i is the fireline intensity for the *ith* geographic unit (kW/m),
W_i is the available fuel mass in the *ith* geographic unit (kg/m^2), and
ROS_i is rate of fire spread in the *ith* geographic unit (m/sec).

Provided that fuel types are mapped according to the classification scheme introduced by Anderson (1982), or another classification scheme resulting in the description of fuel, mean values for Wi and ROSi are normally incorporated in the description of fuel types.

Value ranges for the PFI: PFI values range between 0 and 100 000 kW/m. Intensity values from 0 to 350 kW/m are considered as the low values, from 350 to 1700 kW/m are considered as moderate values, from 1700 to 3500 kW/m are considered as high values, from 3500 to 7000 kW/m are considered as very high values, and values greater than 7000 kW/m are considered as extreme values (Lampin et al. 2002).

3.3.3.2 The Hazard Index (HI) building and mapping

Finally the Hazard Index (HI) can be seen as a combination between the Composite Index and the Potential Fire Intensity. We propose the relationship defined in Table 2 for the calculation of HI.

The idea that stands behind the HI calculation is to integrate into one single index, the issues of fire ignition, fire spread, and the potential to cause damage. The HI embodies the different aspects of the indices that this index is calculated from. On the one hand, the CI indicates the effects of current weather conditions and fire history upon fire occurrence, while the PFI indicates the severity of the fire should an ignition occur.

For example, if current weather conditions do not favor ignition or spread and this is also validated by the fire history ('Low' CI value), and the potential fireline intensity is low ('Low' PFI value), then we should expect a low intensity fire, or

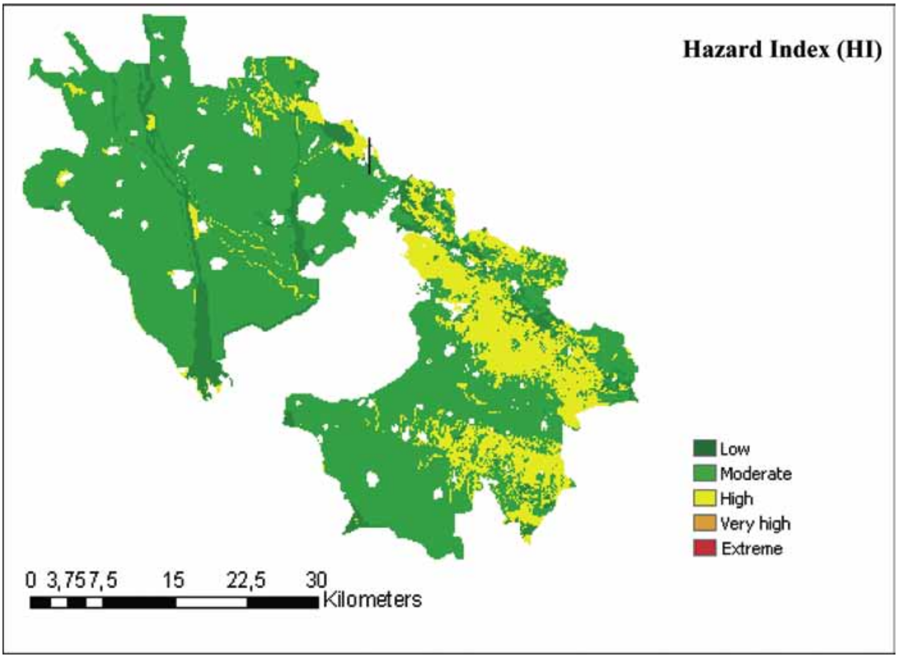

Figure 6. Example of calculation of the HI in the Greek study site 3 for 14/04/2007.

no fire at all ('Low' HI value). If current weather and fire history indicate that fire occurrence is very likely ('Extreme' CI value), and the potential fireline intensity is 'Extreme', then we should expect a very intense fire that may cause extensive damage ('Extreme' HI value). Intermediate classes of the HI ('Moderate', 'High' and 'Very High') can be explained, similarly, as the kind of fire behaviour and intensity that is expected at a given place and time. Figure 6 illustrates the map of this HI.

3.3.4 Vulnerability assessment in WUIs

The main objective is to develop a set of processes for mapping a synthetic index of the WUIs vulnerability to forest fires. Vulnerability assessment comes from its threefold consideration (a consequence, a state or characteristic, and a cause) as it is considered in the different definitions used above. In consequence vulnerability is formed by an internal component, related to the effects of the fire caused on the value of the affected goods and its capacity for recovery, and by an external component, related to the fire characteristics and by the ability developed by society to face the danger of wildfire.

Based on this approach, a wide variety of factors influencing vulnerability of the territory to forest fires have been identified and methods to obtain parameters

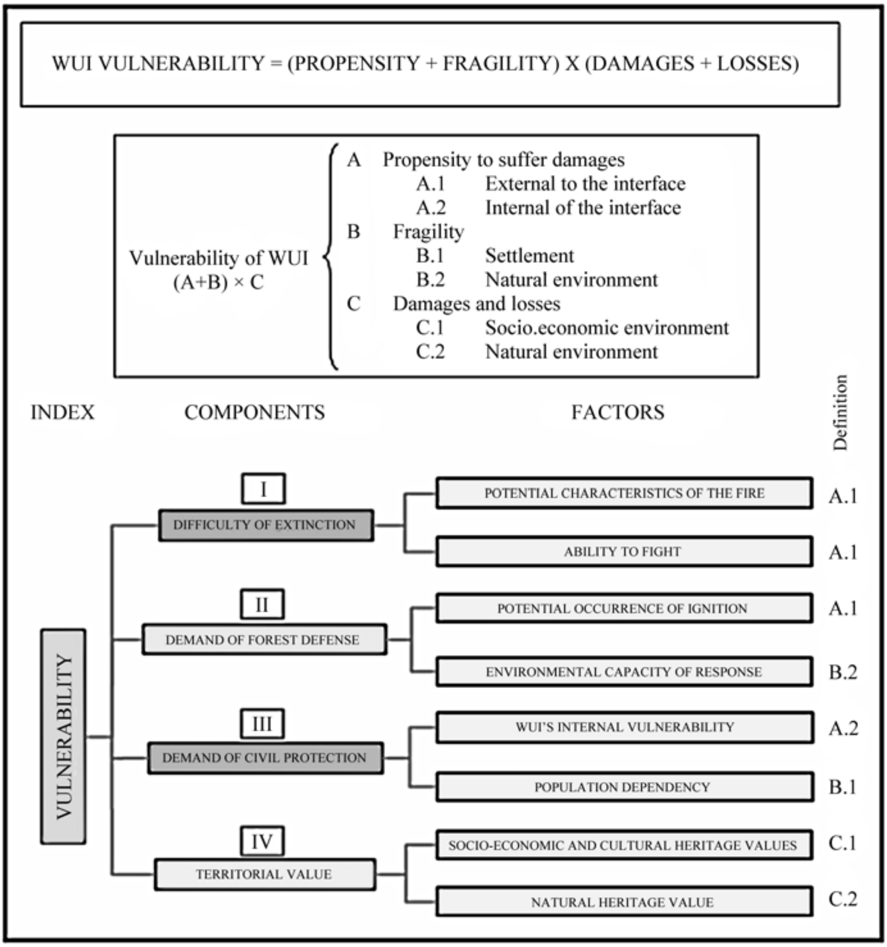

Figure 7. Flow chart illustrating the elements involved in assessing vulnerability index.

and its cartography at local level for the calculation of these factors have been proposed (Figure 7). Each factor will be further subcategorized into parameters. These parameters are the basic units that have to be mapped and standardized into a common, simple quantitative scale in order to allow them to be aggregated through a process based on multicriteria evaluation, where each variable is given a particular weight. The aggregation process can be repeated until all the hierarchical structure is aggregated into one single indicator, the vulnerability index and it will show whether a particular area is susceptible to suffer damage from wildfire. When all the components are calculated, the vulnerability index can be determined and will show whether a particular area is susceptible to suffer damage from wildfire.

In the task of obtaining these parameters, the modelling of potential high risk situations and the historical analysis of wildfires have played a very important role; also the conclusions obtained from the tasks of WUI characterization have been

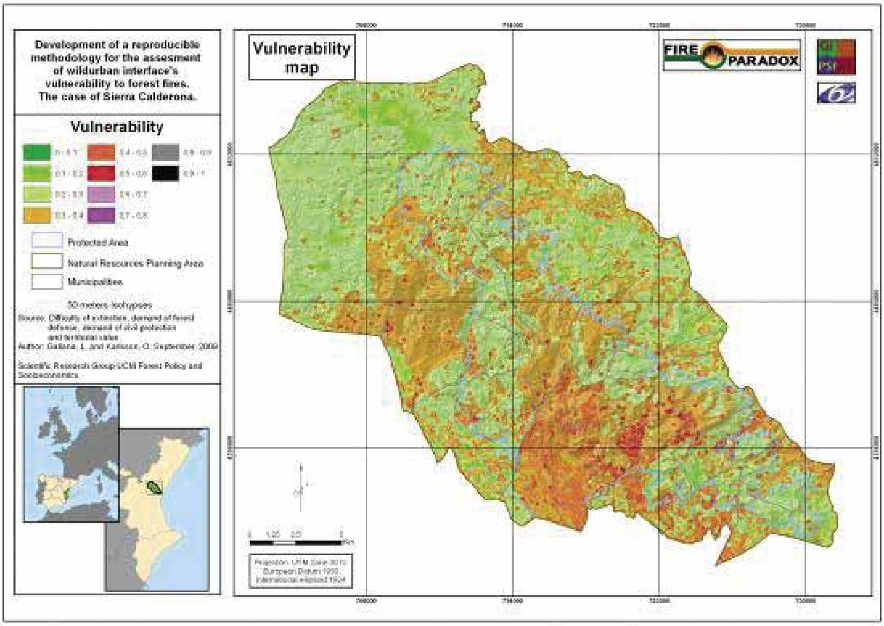

Figure 8. Map of vulnerability levels on Spanish study site (site 2 in Figure 1).

incorporated. Finally, the factors have been grouped into four synthetic components (difficulty of extinction, demand for forest defense, demand of civil protection and territorial value) which are integrated into a global index. Consultations with forest management and fire fighting experts of the experimental area (Sierra Calderona, Valencia, España) by applying a DELPHI methodology have been fundamental for the determining the weights given to the factors that make up each of the indices.

The final index which can be mapped (Figure 8) and the intermediate components, factors and parameters, are useful for the managers of territorial planning, emergencies and forest fire prevention and fighting.

3.3.5 A specific approach of fire risk assessment in WUIs through a total risk index (Lampin-Maillet 2009)

The work presented hereafter is aiming at the definition of a process for obtaining a fire risk map through the calculation of a total fire risk index based on a WUI map. The map can be updated on a basis depending on the territory WUI extension.

Considering the WUI map, a new perception of the territory is possible: WUI area, and outside WUI area. Because of their high vulnerability, ignition probability and combustibility, it is important and efficient to focus risk assessment in the WUIs. The method developed allows assessment and mapping of fire risk levels.

A spatial analysis on the studied territory was performed in order to establish relationships between the distribution of fire ignition points and burned areas and different land cover data, WUI types, environmental data. For that, a digitalized database of fire ignition points created by the French National Forest Institute (ONF) was used. It comprised fire ignition points during the 1997–2007 period for which the fire area was more than one hectare. Around 565 fire ignition points were located in the study area. A digitalized database of burned area produced by the Administration of Agriculture and Forest of Bouches-du-Rhône was used. It comprised 109 wildfires recorded study area during the 1990–2007 period. At last, a thematic land cover layer obtained from the Spot Thema database elaborated in 2004 by CNES, Provence-Alpes-Côte-d'Azur Region and a Spot Image from Spot 5 satellite imagery on the study area were used. The detailed level describes the territory (urban, agricultural and natural components) at the 1:10 000 scale.

As a result of the relationships established between WUIs and fire indicators calculated with past fire data (fire ignition density and burned area ratio), it is possible to identify specific WUIs which present a high level of fire risk. Figure 9 shows that WUIs corresponding to isolated dwellings present a high level of fire risk due to high levels of ignition density and burned area ratio. WUIs corresponding to very dense clustered dwellings present also a high level of ignition density linked with human activities but a low burned area ratio (high urban component and low vegetation component) (Lampin-Maillet et al. 2010).

The spatial analysis also allowed identification of a set of conditions that correspond with high fire risk in WUIs: housing density, road density, vegetation more or less continuous. Results of this analysis are expressed through three main functions (or fire risk indicators) based on statistical multiple regressions with R^2 more or less high:

- Fire Ignition Density FID = Exponential function (territory type, land cover type, housing density) with $R^2 = 51\%$;
- Wildfire Density WD = Exponential function (territory type, land cover type, housing density, coniferous forests, exposure to very warm temperatures) with $R^2 = 57\%$;
- Burned Area Ratio BAR = Polynomial function (territory type, land cover type, housing density, road density, country road density, garrigues, altitude, low aggregation of vegetation) with $R^2 = 36\%$.

A total index of wildfire risk was developed combining the three previous indicators (Lampin-Maillet 2009). In reference to fire risk definition, each of the three indicators includes information about hazard and/or vulnerability: Fire Ignition Density FID and Wildfire Density WD are particularly concerned by fire occurrence (ignition probability and wildfire probability) and Burned Area Ratio BAR is related to hazard and vulnerability through the intensity element. Their combination can contribute to a pertinent and efficient assessment of fire risk. So a Fire risk total index RI has been built corresponding to a linear combination of the three indicators having the same weight but corrected by their explanation level (R^2 value). In the case of the study area the equation is:

Fire risk total index RI = 0.89 FID + WD + 0.63 BAR

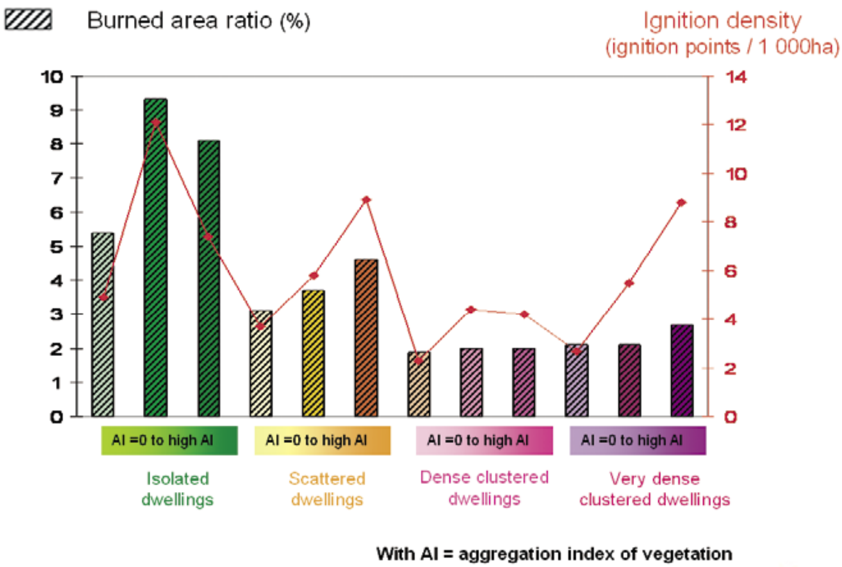

Figure 9. Fire ignition density and burned area ratio according to WUI types in Lampin-Maillet (2009).

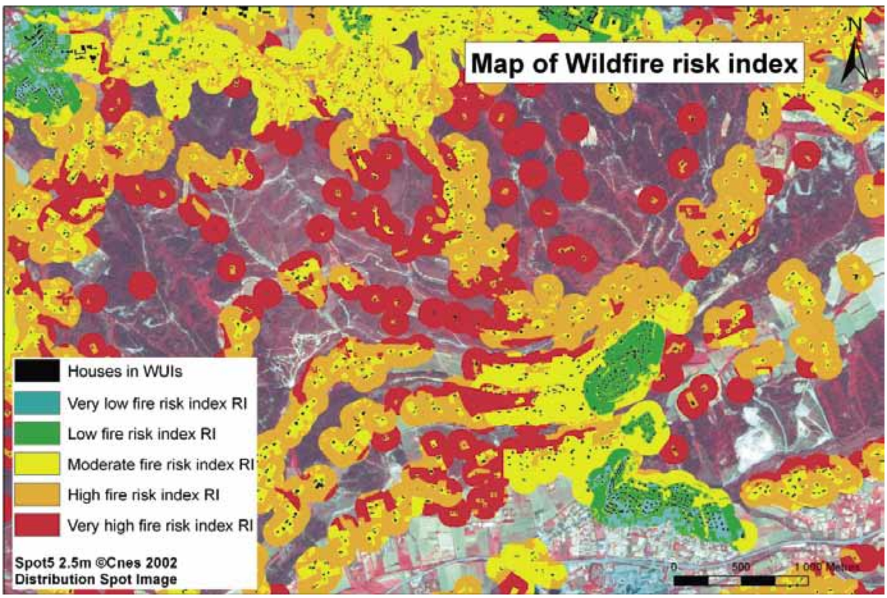

Figure 10. Map of wildfire risk global index in WUIs in the French study site (site 1 in Figure 1).

With respectively a correction of 0.89 corresponding to the ratio 51% / 57% for FID, a value of 1 (the best R^2 value) corresponding to the ratio 57% / 57% for WD, and a correction of 0.63 corresponding to the ratio 36% / 57% for BAR.

A map of this fire risk total index can be produced as illustrated at Figure 10 in the South of France.

Certain types of WUIs represent a high level of fire risk in terms of fire ignition density, wildfire density and burned area ratio. Regarding fire ignition density and burned area ratio, isolated WUIs with low and high aggregation indices of vegetation presented the highest values. Scattered WUIs with both low and high aggregation indices of vegetation also represented a high level of fire ignition density and burned area ratio even if these values were lower than those for isolated WUIs (Lampin-Maillet et al. 2010). Results also highlighted the fact that the burned area ratio generally decreased from isolated WUIs to dense and very dense clustered WUIs, and also decreased from a high aggregation index to a zero aggregation index (Lampin-Maillet et al. 2010).

3.3.6 Conclusions

In this chapter we proposed reproducible methods for characterizing and mapping WUIs at large scales and over large areas (Lampin-Maillet et al. 2010) and at landscape scale (Galiana et al. 2007). We also proposed on the one hand a method for fire hazard assessment and mapping (Lampin et al. 2009), and on the other hand a method for vulnerability assessment and mapping (Galiana et al. 2009). These two processes contribute to assessment of fire risk, combining fire hazard and vulnerability assessments. A specific approach has also been developed to calculate and to assess a total index of wildfire risk in WUIs (Lampin-Maillet 2009).

The WUI is often a location which is particularly appreciated as an area in which to live. However, in our European Mediterranean context this lifestyle carries a certain risk: people should always be aware of the existing fire risk in such WUI and should respect and apply efficient recommendations to insure against risky situations.

These results could have interesting implications for fire prevention and land management. Introducing the risk of wildfire with such maps, and particularly the vulnerability of the territory, is a way to make the inhabitants becoming aware of fire risk in WUIs. The WUI map is key information to identify locations where vegetation has to be reduced in order to protect the houses and their inhabitants in case of wildfire and where careful behaviour are essential to avoid fire ignition. This will globally decrease the risk of fire either by reducing fire propagation through biomass removal and/or by reducing fire ignition probability together with less carelessness. Accomplishing this goal is strictly related to the designation of suitable prevention messages and preventive actions which can be different according to WUI types.

WUIs have increased considerably all over the world in recent decades and this trend will certainly continue in the coming years due to the continuing trend of land abandonment combined with urbanization. The method we developed for mapping

WUIs is an appropriate tool for the assessment of WUI dynamics and associated fire risk dynamics in the context of ongoing changes in climate, urbanization and vegetation.

References

Alexander, M.E. 2008. Proposed revision of fire danger class criteria for forest and rural areas in New Zealand. 2nd Ed. National Rural Fire Authority, Wellington, in association with Scion, Rural Fire Research Group, Christchurch. 62 p.

Anderson, H.E. 1982. Aids to determining fuel models for estimating fire behaviour. USDA Forest Service General Technical Report INT-122, Intermountain Research Station, Ogden, UT. 22 p.

Antrop, M. 2004. Landscape change and the urbanization process in Europe. Landscape and urban planning 67: 9–26.

Alavalapati, J.R.R., Carter, D.R. and Newman, D.H. 2005. Wildland-urban interface: Challenges and Opportunities. Forest policy and Economics 7: 705–708.

Byram, G.M. 1959. Combustion of forest fuels. In: Davis K.P. (ed). Forest Fire: Control and Use. McGraw-Hill, New York.

Blaikie, P., Cannon, T., Davis, I. and Wisner, B. 1994. At risk: natural hazards, people vulnerability and disaster. Routledge, London, New York. 280 p.

Blanchi, R., Jappiot, M. and Alexandrian, D. 2002. Forest fire risk assessment and cartography. A methodological approach. In: Viegas, D. (ed.). Proceedings of the IV International Conference on Forest Fire Research. Luso, Portugal.

Brunet, R., Ferras, R. and Théry, H. 1993 (3rd Ed.). Les mots de la géographie. Paris, Montpellier, La documentation française. 518 p.

Bürgi, M., Hersperger, A.M. and Schneeberger, N. 2004. Driving forces of landscape change – current and new directions. Landscape Ecology 19: 857–868.

Caballero, D., Giroud, F., Picard, C. and Xanthopoulos, G. 2004. EUFIRELAB/ Euro-Mediterranean Wildland Fire Laboratory, a "wall-less" laboratory for wildland fire Sciences and technologies in the Euro-Mediterranean Region - Deliverable D-10-01-Wildland-Urban Interface Management: A state of the art. 28 p.

Camia, A., Guglielmet, E., Bovio, G. Deshayes, M., Lampin, C., Salas, J., Martinez, J., Molina, D., Carrega, P., Fox, D., Berolo, W., Sabate, S., Vayreda, J., Martin, P., Martinez, J., Conese, C., Bonova, L., Karteris, M., Mallinis, G., Sergiopoulos, I. and Gitas, I. 2004. Eufirelab: Euro-Mediterranean Wildland Fire Laboratory, a "wall-less" laboratory for wildland fire Sciences and technologies in the Euro-Mediterranean Region Deliverable D 08-02: Wildland fire danger and hazards: a state of the art. 57 p.

Carroue, L., Claval, P., Di Meo, G., Miossec, A., Renard, J.P., Simon, L. and Veyret, Y. 2002. Limites et discontinuité en géographie. Dossiers des images économiques du monde, Edition SEDES. 159 p.

Chen, K., Blond, R. and Jacobson, C. 2003. Towards an integrated Approach to natural Hazards risk assessment using GIS: with reference to bushfires. Environmental Management 31 (4): 546–560.

Chou, Y.H. and Minnich, R.A. 1993. Mapping Probability of Fire Occurrence in San Jacinto Mountains, California, USA. Environmental Management 17(1): 129–140.

Coburn, A.W., Spence, R.J.S. and Pmomonis, A. 1994. Vulnerability and risk assessment. Disaster management training Program, UNDP/DHA, 70 p.

Colin, P.Y., Lampin, C., Delboube, E., Coste, N., Marcillat, J., Pereira, J.C., Binggeli, F., Gaulier, A. ,Botelho, H., Loureiro, C., Loddo, G., Ditana, E., Guijarro, M., Hernando, C., Diez, C., Martinez, E., Madrigal, J., Vega, J.A., Gorostiaga, P., Alexandrian, D. and Dimitrakopoulos, A. 2002. SALTUS - Spot fires : mechanisms analysis and modelling - Final report 1998, ENV98-CT98-0701.

Countryside Agency and Scottish Natural Heritage, 2002. Landscape Character Assessment: guidance for England and Scotland (Wetherby, Countryside Agency and Scottish Natural Heritage).

Davis, J. B. 1990. The wildland-urban interface: paradise or battleground? Journal of Forestry 88(1): 26–31.

D'Ercole, R. 1998. Approches de la vulnérabilité et perspectives pour une meilleure logique de réduction du risque. Pangea 29(39): 20-28.

D'Ercole, R. 1996. Représentation cartographiques des facteurs de vulnérabilité des populations exposées à une menace volcanique. Application à la région du volcan Cotopaxi (Equateur). Bulletin de l'IFEA 25(3): 479–507.

Galiana, L., Herrero, G. and Solana, J. 2007. Caracterización y clasificación de Interfaces Urbano-Forestales mediante análisis paisajístico. El ejemplo de Sierra Calderona (Comunidad Valenciana, España). Book of Abstracts of the IV International Wildland Fire Conference, Seville, Spain. Organismo Autónomo de Parques Nacionales, Ministerio de Medio Ambiente. 285 p.

Gallopin, G.C. 2006. Linkages between vulnerabilty, resilience and adaptative capacity. Global Environmental Change 16: 293–303.

Hardy, C.C. 2005. Wildland fire hazard and risk: Problems, definitions, and context. Forest Ecology and Management 211: 73–82.

Jappiot, M., Gonzalez-Olabarria, J.R., Lampin-Maillet, C. and Borgniet, L. 2009. Assessing Wildfire Risk in Time and Space. Partie de Living with Wildfires: What science can tell us. Yves Birot (ed.) EFI Discussion Paper 15. European Forest Institute. Joensuu. Pp. 41–47.

Johnson, M. P. 2001. Environmental impacts of urban sprawl: a survey of the literature and proposed research agenda. Environment and Planning A 33: 717–735.

Lampin-Maillet, C. 2009. Caractérisation de la relation entre organisation spatiale d'un territoire et risque d'incendie : le cas des interfaces habitat-forêt du sud de la France. Thèse de doctorat de l'Université de Provence, Aix-Marseille I. 321 p.

Lampin-Maillet, C., Jappiot, M., Long, M., Morge, D. and Ferrier, J.P. 2010. Mapping wildland-urban interfaces at large scales integrating housing density and vegetation aggregation for fire prevention in the South of France. Journal of Environmental Management 91 (2010):732–741.

Lampin-Maillet, C., Jappiot, M., Long, M., Morge, D. and Ferrier, J.P. 2009. Characterization and mapping of dwelling types for forest fire prevention. Computers, Environment and urban systems 33(2009): 224–232.

Lampin-Maillet, C. 2008. 2007, Summer Fires in the European Mediterranean – The Cases of Greece, Italy and Spain. Mediterranean yearbook. European Institute of the Mediterranean. Med. 2008, Economy and Territory- Sustainable Development. Pp 243–247.

Lampin, C., Jappiot, M., Long M., Morge, D., Bouillon, C., Galiana, L., Herrero, G., Solana, J., Mantzavilas, A., Loddo, G. and Delogu G. 2007a. Characterization and mapping of wildland-urban interfaces: a methodology applied in the study case in Sardinia. Book of Abstracts of the IV International Wildland Fire Conference, Seville, Spain. Organismo Autónomo de Parques Nacionales, Ministerio de Medio Ambiente. 289 p.

Lampin, C., Long, M., Jappiot, M., Morge, D., Bouillon, C., Mantzavellas, A., Apostolopoulou, I., Lazaridou, T., Partozis, T., Topaloudis, T., Galiana, L., Herrero, G., Solana, J., Loddo, G., Brigaglia, S., Dettori, G. and Delogu, G. 2007b. Method to characterize and to map wildland urban interfaces. Deliverable D5.2-1 of the Integrated Project "Fire Paradox", Project no. FP6-018505. European Commission. 104 p.

Lampin, C., Long, M., Jappiot, M., Morge, D., Bouillon, C., Mantzavelas, A., Apostolopoulou, I., Lazaridou, T., Partozis, T., Topaloudis, T., Galiana, L., Herrero, G. and Solana, J.L. 2007c. Guide for end-users to characterize and to map wildland-urban interfaces. Deliverable D5.2-2 of the Integrated Project “Fire Paradox”, Project no. FP6-018505, European Commission. 18 p.

Lampin, C., Jappiot, M., Long, M. and Borgniet, L. 2006. Cartographie des interfaces habitat-forêt. Une approche spatiale pour estimer le risque d’incendie de forêt, Revue internationale de Géomatique. European journal of GIS and Spatial analysis, Information géographique et gestion des risques l16(3–4): 320–340.

Lampin, C., Jappiot, M., Alibert, N., Manlay, R. and Guillande, R. 2002. Prototype of an Intensity Scale for the Natural Hazards: Forest Fire. In Viegas, D. (ed.). Proceedings of the IV International Conference on Forest Fire Research. Luso, Portugal.

Macie, E.A. and Hermansen, L.A (eds). 2002. Human influences on Forest Ecosystems: The Southern Wildland-Urban lnterface Assessment.

McGarigal, K. 2002. Landscape Pattern Metrics. Chapitre du livre Encyclopedia of Environmentrics, Volume 2. John Wiley & Sons, Sussex, England.

Lampin, C., Mantzavelas, A., Apostolopoulou, I., Lazaridou, T., Partozis, T. and Topaloudis, T. 2009. Adapted method to assess and map fire hazard in wildland urban interfaces. Internal Report IR5.1-4 of the Integrated Project “Fire Paradox”, Project no. FP6-018505. European Commission. 19 p.

Mantzavelas, A., Apostolopoulou, I., Lazaridou, T., Partozis, T., Lampin, C., Long, M. and Jappiot, M. 2008. Literature review and synopsis of the methodologies to estimate vulnerability. Deliverable D5.2-5 of the Integrated Project “Fire Paradox”, Project no. FP6-018505. European Commission. 13p.

Mantzavelas, A., Apostolopoulou, I., Lazaridou, T., Partozis, T., Topaloudis, T., Lampin, C., Borgniet, L., Bouillon, C., Brewer, S., Curt, T., Ganteaume, A., Jappiot, M., Defossé, G., Gómez Fernán, M. and Lencinas Daniel, J. 2009. Method to assess with good spatial accuracy the meteorological and fuel moisture components of the fire risk. Deliverable D5.1-1 of the Integrated Project “Fire Paradox”, Project no. FP6-018505. European Commission. 89 p.

Martinez, J., Vega-Garcia, C. and Chuvieco, E. 2009. Human-caused wildfire risk rating for prevention planning in Spain. Journal of Environmental Management 90(2): 1241–1252.

Marzano, R., Bovio, G., Guglielmet, E., Jappiot, M., Lampin, C., Dauriac, F., Deshayes, M., Salas, J., Aguado, I., Martinez, J., Molina, D., Martinez, E., Carrega, P., Fox, D., Berolo, W., Martin, P., Gomez, I., Conese, C., Bonora, L., Karteris, M., Gitas, I., Mallinis, G. and Giannakopoulos, V. 2004. Common methods for mapping the wildland fire danger, EUFIRELAB, Deliverable D-08-05.

McGee, T. K. 2005. Completion of recommended WUI fire mitigation measures within urban households in Edmonton, Canada. Environmental Hazards 6: 147–157.

Radeloff, V.C., Hammer R.B., Stewart, S.I., Fried, J.F., Holcomb, S.S. and McKeefry, J.F. 2005a. The wildland urban interface in the United States. Ecological applications 15(3): 799–805.

Radeloff, V.C., Hammer R.B. and Stewart, S.I. 2005b. Rural and suburban sprawl in the U.S. Midwest from 1940 to 2000 and its relations to forest fragmentation. Conserv. Biol. 19(3): 793–805.

Rainha, M. and Fernandes, P.M. 2002. Using the Canadian Fire Weather Index (FWI) in the Natural Park of Montesinho, NE Portugal: calibration and application to fire management. In Viegas, D. (ed.). Proceedings of the IV International Conference on Forest Fire Research. Luso, Portugal.

San Miguel-Ayanz, J., Carlson, J.D., Alexander, M., Tolhurst, K., Morgan, G., Sneeuwjagt, R. and Dudley, M. 2003. Current Methods to Assess Fire Hazard Potential. In: Chuvieco, E. (ed.). Wildland Fire Hazard Estimation and Mapping. The Role of Remote Sensing Data. World Scientific Publishing, Singapore. Pp. 21–61.

Stewart, S.I., Radeloff, V.C. and Hammer, R.B. 2003. Characteristics and location of the Wildland-Urban-Interface in the United States. p. 6. Proceedings of the 2nd International Wildland Fire Ecology and Fire Management Workshop, November 16–20, 2003, Orlando, Florida.
USDA-USDI. 2001. Urban wildland interface communities within vicinity of Federal lands that are at high risk from wildfire. U.S. Department of Agriculture and U.S. Department of Interior, Fed.Reg. 66: 751–777.
Van Wagner, C. E. 1987. Development and Structure of the Canadian Forest Fire Weather Index System. Can. For. Serv., Ottawa. For. Tech. Rep. 35. 37 p.
Vasilakos, C., Kalabokidis, K., Hatzopoulos, J., Kallos, G. and Matsinos, Y. 2007. Integrating new methods and tools in fire danger rating. International Journal of Wildland Fire 16: 306–316.
Viegas, D.X., Sol, B., Bovio, G., Nosenzo, A. and Ferreira, A. 1994. Comparative study of various methods of fire danger evaluation in Southern Europe. In: Viegas, D. (ed.). Proceedings of II International Conference on Forest fire Research. Coimbra, Portugal. Pp. 571–590.
Vince, S.W., Duryea, M.L., Macie, E.A. and Hermansen, L.A. (eds.) 2005. Forests at the wildland-urban interface: conservation and management. CRC Press, Boca Raton.
Wilson, K., Pressey, R.L., Newton, A., Burgman, M., Possingham, H. and Weston, C. 2005. Measuring and incorporating vulnerability into conservation planning. Environmental Management 35(5): 527–543.
Xu, D., Guofan, S., Dai, L., Hao, Z., Tang, L. and Wang, H. 2006. Mapping forest fires risk zones with spatial data and principal components analysis. Science in China: Series E Technological Sciences 49(I): 140–149.

3.4 The Importance of Economics in Fire Management Programmes Analysis

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3.4.1 Introduction

Wildfires are a societal problem that threatens many ecosystems, affects millions of people worldwide, and causes major ecosystem and economic impacts at local regional, national and global scales. In Europe, and especially in the Mediterranean countries (France, Greece, Italy, Portugal and Spain), wildfires continue to be a major environmental threat (Requardt et al. 2007) where, an average 500 000 ha of forests are burned annually (San-Miguel and Camia 2009). Wildfires affect the forests and other wooded land, and neighbouring systems such as urban areas, infrastructure networks (i.e. power-lines and transportation corridors), agriculture lands, and the civil society. These impacts can be reflected in many ways – for example, loss of human life or health, decreased well-being of the population (local and wider), and temporary or permanent loss of employment possibilities and economic activities. For a worldwide perspective on the effects of fire on the earth systems see Bowman et al. 2009.

The last decades have seen increased social awareness and growing concerns for wildfires' negative environmental and economic consequences, and, particularly, the loss of human lives (McCaffrey 2008). The growing importance of wildfire issues at EU level is also reflected in the increasing number of research projects funded to better understand and address this problem (e.g. Eufirelab, Fire Paradox).

In Europe, this change was galvanized by the large-scale wildfires and their consequences in the Mediterranean region during the 2000s. For example, during 2003 in Portugal about 400 000 ha of forests lands were burned; during 2005 in Spain some 190 000 ha of forests lands were damaged; and during 2007 in Greece around 270 000 ha of forests and other wooded lands were destroyed (JRC 2007). Events in other parts of the world also helped to increase the concern on this topic in Europe. These included, Indonesia 1997/1998, where 8 million ha burned; Australia 2007, more than 1 million ha; and California, USA 2007, 120 000 ha affected. These major wildfire events clearly showed that they are not only an environmental problem, but have also a significant social dimension, affecting millions of people, having major economic impacts, and causing significant human casualties (González-Cabán 2007). For example, the wildfires affecting vast forest areas of Portugal in 2005 caused economic damage worth almost €800 million and caused 13 fatalities. Even worse, the large fires affecting Greece during the summer of 2007 caused 64 casualties, and according to the Greek authorities the economic damage was estimated at €2–5 billion (Papachristou 2007; Petsini Arlapanou and Petsini Arlapanou 2007).

These events increase the public interest and concern about the wildfires and prompted the development and implementation of improved policies and management measures at different levels. The main objective of these improved policies and management measures is to minimize the negative environmental, economic and social impacts of wildfires (EU 2005). However, the implementation of such measures requires substantial investment of financial, human and organizational resources, which must be justifiable and efficient.

Decision support systems based on economic models can help to decide what would be the optimal use of the resources. For example, economic models can help to estimate whether investments in wildfire related measures (e.g. prevention, suppression, fuel management) are financially justified, or to choose the most efficient amongst several alternatives (i.e. the combination of investments in fire prevention, fire fighting and amount of wildfire acceptable). For the implementation of these decision support systems reliable knowledge and data are needed on the physical and economic impacts (negative and positive) of wildfires and the economic efficiency of fire management measures. The understanding and assessment of socio-economic impacts of wildfires should be considered an essential part of the fire risk assessment, development of wildfire related policies, as well as planning and implementation of management practices (Morton et al. 2003).

This chapter will first introduce the basic model used for the estimation of the economic efficiency of fire management programmes and revise some of the problems related with its application. In the subsequent section we discuss why the social preferences should be considered when planning fire management programmes and present a study dealing with this topic that was conducted in Spain. In section three of this chapter, we look in detail at the problems and a possible solution for the adequate estimation of costs related to wildfires. The last part of the chapter presents the main conclusions.

3.4.2 Estimating the economic efficiency of and social preferences for fire management programmes

3.4.2.1 Economic efficiency of fire management programmes

To combat the wildfires problem forest managers can apply different management measures. These include prevention (e.g. education, publicity campaigns), fuel treatment (e.g. prescribed burning, thinning, mechanical fuel removal), pre-suppression and suppression, and restoration measures. One of the thorniest questions in fire management is to determine how the limited financial, equipment, and human resources should be most efficiently spent and distributed among alternative fire management options.

To answer this question, the economic analysis of the efficiency of fire management is generally evaluated by the cost plus net value change concept (C+NVC) (Althaus and Mills 1982; Donovan and Rideout 2003; González-Cabán

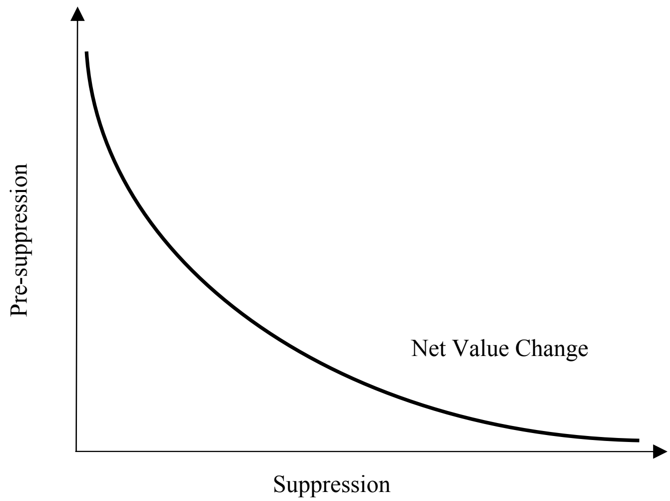

Figure 1. NVC level curve.

2007). This approach estimates all costs and benefits related to fire management measures. The model is derived by adding pre-suppression costs to the costs of fire suppression and the net value of the change in resources outputs that result from the fires (difference between benefits and damage to the resource). The pre-suppression costs represent the expenditure on fire management prior to the wildfire season (e.g. purchase of fire fighting resources such as fire engines, equipment for fire fighting crews). Suppression costs are fire fighting expenditures during a fire season (e.g. wages for fire fighting crews, fuel for aerial resources).

In the C+NVC model pre-suppression and suppression expenditures are considered as independent inputs, related through the Net Value Change (NVC) function (Donovan and Rideout 2003). The independence of pre-suppression and suppression expenditures means that one input does not determine the level of the other. For example, the purchase of some fire fighting equipment before the fire season, does not determine how frequently this equipment will be used during the fire season. Nevertheless, the pre-suppression may affect the optimal level of suppression through the NVC function (Figure 1). In Figure 1 the slope of the level curve is equal to the negative of the ratio of the marginal contributions of suppression and pre-suppression in reducing damage. It should be noted, that pre-suppression can be substituted by suppression, but only in the case that NVC is held constant (Donovan and Rideout 2003). Thus, both inputs are allowed to vary independently, but remain related through the NVC function (Donovan and Rideout 2003).

As mentioned at the beginning of this chapter, the objective of the C+NVC model is to find the most efficient management levels (González-Cabán et al. 1986; Lankoande 2005). Selecting the most efficient management level is an optimization problem, where we intend either to minimize the costs and the net value change, or to maximize the social benefits (Donovan and Rideout 2003; Mercer et al. 2007).

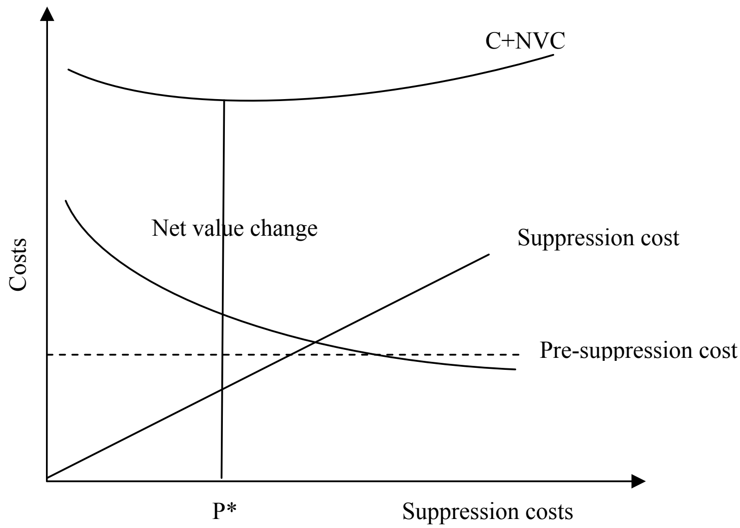

Figure 2. Illustration of the C+NVC model (Donovan and Rideout 2003).

For example, given that the pre-suppression expenses are at an optimal level (Figure 2), the most efficient level of fire programme is the point where the summation of costs and the net value change is minimized (i.e. P* in Figure 2). In the model, the cost part (C) is obtained by the estimation of the programme costs (pre-suppression and suppression activities); while the net value change (NVC) sums all the changes in the quantity/quality of resources outputs (goods and services) that result from the fire multiplied by the unit value of the output.

The objective of the evaluation of economic efficiency of fire management measures is not only to help identify the most efficient programme level, but also to decide how to distribute the resources (spatial component). Namely, once agencies have decided how many resources to use (e.g. fire detection facilities, suppression resources, fuel treatments), their most efficient and cost-effective allocation must be determined (Wei et al. 2008).

To be able to apply the C+NVC model and to include it into a decision support system (DSS) for planning and evaluation of the economic efficiency of management programmes it requires adequate information. For example, for each evaluated fire management program alternative it would at least need information on: monetary estimates of economic efficiency, quantitative estimates of effects on resource outputs, and assessments of the risk associated with these values. However, there are still considerable shortcomings in the knowledge and data availability.

One of the difficulties related to the application of the C+NVC model is the estimation of the NVC component. It requires information about the direct and indirect effects of fire on spatial and temporal provision of goods and services, and information about how fire-induced marginal changes in the quality and quantity of goods and services will affect social welfare. It is apparent that information is lacking in one or both of these areas for many of the types of goods and services that can be affected by wildfire (Venn and Calkin 2007). More on this issue will be presented in section 3.4.3 of this chapter.

The estimation of the costs and the NVC is further complicated by the possible temporal interrelation of fire events or management measures; meaning that present actions can influence decisions on applications of fire management measures in future fire seasons. For example, Mercer et al. (2007) showed that fuel management treatments applied in the current season can produce benefits (e.g. reduced fire risk) also in subsequent seasons. These, 'extended', benefits should also be taken into account when estimating the costs and benefits of fire management measures. Lagged benefits are not only a characteristic of management measures, but also of wildfires. Namely, wildfires significantly reduce the amount of fuels (similar to the effect of fuel management); thus, they notably affect the fire risk and intensity in the following seasons. According to Mercer et al. (2007) this reduced risk of wildfires can last up to 11 years.

Another important issue to consider when estimating costs and benefits of fire management is that multiple objectives can be accomplished by these measures. For example, prescribed burning can reduce fuels, dispose of logging debris, prepare sites for seeding and planting, improve wildlife habitat, manage invasive species, control insects and diseases, improve accessibility, enhance aesthetics and recreation activities, improve forage and grazing, and manage endangered species (Wade and Lunsford 1988).

At the European level, another important problem, and maybe the most fundamental, is the general lack of reliable data not only on the effects of fires on the quantity/quality of goods and services produced by the natural resources (in our case, forest lands), but the social value of different goods and services, as well as the costs and expenses of fire management and suppression activities. In many cases, there is no common methodology to collect and report such data, and therefore the available data is most often incomplete, unreliable, and available only for some countries or regions within countries. (Mavsar et al. 2007).

3.4.2.2 Social preferences for fire management programmes

Economic efficiency is an important criterion in deciding which fire management programme would be the most efficient. However, it should not be the only attribute considered when deciding about fire policies or management measures. In addition, it is important to consider other factors, for example social values and preferences for a certain programme or management measure (Daniel et al. 2007; Martin et al. 2008). Knowing the social preferences for different management actions and identifying when they might differ from the manager's viewpoint can help agencies to understand and predict how different audiences may react to these decisions. For instance, this knowledge may (i) help the administration recognize when policies or actions may be supported or opposed by the public[1], and (ii) help to develop

1 For an interesting discussion on how public perceptions affect the implmentation of fire management programmes see Laband et al. (2006) and Laband et al. (2008).

information or education campaigns, which might help to get public support for a certain policy or action. Thus, learning about the social preferences could be useful in different ways. It can serve as a support tool in the design of policies and/or specific fire management programmes; or, if faced with a fixed budget for wildfire mitigation, land managers may want to design a fire prevention measure that mirrors society's preferences – for example, for fire behaviour with a lower impact on forest resources. Therefore, social preferences may allow policy makers to better identify priority-attention areas in fire management. This is seldom the case in Europe and there are only a couple of case studies where social preferences for fire management measures have been elicited (see Box 1).

3.4.3 Estimating the costs of wildfires

A precondition for the estimation of the socio-economic damages caused by wildfires is to understand what the important factors are and how they influence the quantity and quality of goods and services provided by a natural resource (e.g. forest). This knowledge is vital for the identification of goods and services that can be or are damaged by a fire. Only a complete picture of the damages enables a reliable estimation of the socio-economic impacts of wildfires. Further, it should be acknowledged that wildfires can have positive effects (González-Cabán 2007). For example, improving the wildlife habitat, improving understory forage and grazing, managing endangered species and fire dependent species (Wade and Lunsford 1988). These positive effects (benefits), when existing, must also be included into the estimation methodology.

A wide range of costs can be related to a wildfire, and there are different ways to categorize them (Ashe et al. 2008; Dale 2009; Zybach et al. 2009). In general, we can divide costs into direct and indirect. Direct costs are those which are directly related to a wildfire event, and incurred as a result of the fire and/or exposure to the fire, such as losses or damages of environmental (forest) goods and services, property, and direct suppression costs. In contrast, indirect costs are related to the risk of wildfire occurrence or as a response to the occurrence of a wildfire, like prevention, monitoring and pre-suppression costs, restoration costs, and other costs associated to the individuals who suffer a loss of benefits as a consequence of a wildfire.

An important concern in evaluation of fire management efficiency and estimation of wildfire costs is the proper consideration of environmental (forest) goods and services that might have been damaged (or enhanced) as a consequence of a wildfire. In estimating the economic impacts of wildfires, only a few of them have traditionally been considered, mainly the decreased quantity/quality of timber. However, in the last decades it has become obvious that forests are also important as providers of environmental and social goods and services (Farrell et al. 2000). Thus, nowadays estimating the costs of wildfires must also include these goods and services (Butry et al. 2001; Dunn et al. 2003). However, it is important to understand that in contrast to forest goods and services that have a market price (e.g. timber, fruits, and mushrooms) that reflects their value, there are goods and services (e.g. biodiversity, recreation activities, erosion prevention, water purification) that are not

Box 1: Case study on social preferences regarding fire management measures[2]

Burned forest area or dead trees? A choice for Catalan citizens

The objective of the study, conducted in Catalonia (NE Spain), was to elicit the social preferences regarding fire prevention measures in terms of their impact on fire behaviour – fire propagation and intensity – and to estimate the value of these measures for the society. We applied the choice experiment methodology. The label 'choice experiment' refers to a survey-based valuation method that simulates actual market behaviour (Hanemann and Kanninen 1999; Bennett and Blamey 2001). This technique is based on the idea that any alternative, or good, can be described in terms of its attributes, or characteristics. In a choice experiment, respondents are presented with a series of choice sets comprising at least two alternatives and are asked to choose which alternative they prefer (Hanley et al. 2001; Bateman 2002).

In our empirical application, 207 interviews were conducted in three Catalan provinces – Barcelona, Gerona and Lérida – in June 2007. The first part of the interview presented the attributes to be valued, as well as the payment mechanism and the consequences of each choice. The second part contained the choice experiment exercise and a number of debriefing questions. The final part was designed to collect some socio-economic data about the respondents.

The study results suggest that additional fire prevention measures increase the welfare of the Catalan population (similar results were reported in Riera and Mogas (2004). Further, results show that the attribute of highest concern is fire propagation (area burned). A plausible explanation for this may be the publics' familiarity with information on the quantity of area burned, as this is often used by the media in Spain to quantify the consequences and the severity of a wildfire. The result implies that from a social perspective reducing the forest area burned is one of the most relevant elements when designing fire prevention and protection programmes. However, the design of fire prevention and protection programmes also depends on other factors such as vegetation type and characteristics, complexity of the fire problem, available funds, available experience and expertise. Thus, social preferences should be considered in the decision making process, but are not the only factor influencing the design of fire management programmes.

traded in traditional markets (hereafter non-market goods and services) and thus, we have no information about their value (González-Cabán 1998; Mavsar et al. 2008).

Non-market valuation methods can be applied to value these goods and services. Even though these methods have improved considerably in the last decades, they still have limitations, which should be considered when used. One of the most important limitations is that the estimated values cannot be easily extrapolated. For example, recreation values in different forests are probably different and this difference is not necessarily only the result of different site characteristics, but might also be influenced by other factors (e.g. population size, income in the region, accessibility). This limitation is especially important when developing a system for the assessment

2 For detailed information see Mavsar and Farreras (2008).

of socio-economic impacts of wildfires, because the fire may spread over areas where no values for non-market goods and services have been estimated. In this case, simply applying values from another site may generate significant estimation errors. Nevertheless, with the use of the right data, adequate techniques (e.g. benefit transfer method) or employing proxies (e.g. restoration costs) this problem could potentially be overcome (for example see Rideout et al. 2008).

Nevertheless, as mentioned earlier, in most cases only fire suppression costs and loss of timber production are considered, while damage to forest non-market goods and services are often omitted or very limited (Pettenella et al. 2009). The absence of non-market values is somehow expected, given the complexity and high cost in measuring them; in addition, the obtained values are site specific and transferable to other sites only under some specific conditions (e.g. similar forest site and population characteristics).

3.4.4 Conclusions

The extreme wildfire events of the past decade have shown that fires are not only an ecological, but even more a socio-economic problem. Economics has an important role in helping to quantify the magnitude of the problem (i.e. assessing the costs of wildfires) and to find adequate solutions (i.e. evaluate efficiency of fire management measures and provide information on public preferences). This also implies that the role of economics in the fire management process should change. Therefore, it is important for decision makers to start considering economic analysis as an integral part of a proactive fire management; a tool that provides information that can help managers make better informed decisions that can lead to selection of the most efficient alternatives in a given situation.

Although there has been considerable development of economic methods (e.g. non-market valuation methods) and models (e.g. C+NVC model), important problems still remain to be solved in the future. In this respect, the main issues are the inadequate understanding of:

- the impacts of wildfires on the spatial and temporal provision of goods and services (e.g. how the quality and quantity of a good or service is affected and for how long);
- the potential effect of the changes caused by wildfires on society's wellbeing (e.g. what is the value of the losses);
- the impact of fire management measures on risk, extent and severity of wildfires (e.g. quantify the effects of different management measures).

Thus, development of a decision support system (DSS) requires, first, answers to these three concerns. Once this is accomplished, the next step is to develop models that would adequately simulate the behaviour and impact of wildfires, the effects of fire management measures, and the potential economic impacts (positive and negative). Furthermore, development and implementation of a DSS necessitates that a significant amount of information be collected and processed (e.g. fuel models, historical fire data, weather parameters, geographic data, availability of fire management practices and resources, values of market and non-market goods and services). In addition, standardized procedures must be established on how to collect and process the needed data.

Finally, it is important to recognize that no decision support system or computer simulation model is a substitute for a decision maker. A decision maker must still weigh and assimilate a large number of relevant factors, many of which cannot be measured in common units or even be measured quantitatively at all, and must place fire programs within the context of other management programs and institutional constraints (Mills and Bratten 1982). A DSS simply quantifies some of the factors, which are relevant to fire management program planning and helps trace the interaction of relationships that are too complex and numerous for a person to easily follow. In the case of a fire economic efficiency DSS, this would provide the decision maker only with information on how to possibly design the most economically efficient fire management programme. However, the results depend on the model assumptions and restrictions (e.g. fire management policies). A DSS could show some of the costs of imposing institutional constraints on the programme; and while many of those constraints are valid, their costs must always be considered (Mills and Bratten 1982). After careful consideration of all the information provided by the DSS, and other sources, the final decision on what kind, and to what extent the fire programme will be implemented rest squarely on the decision maker's shoulders.

There are still many obstacles to overcome on the path to the development and application of a model for the evaluation of economic efficiency of fire management and protection programs at the European level. One of the main problems is the lack of reliable and comparable data on fire effects, the social value of affected goods and services, and the costs of fire management activities. Considering these limitations, there is a need not only to develop a relevant DSS, with the potential to deal with territorial differences, but furthermore to ensure that adequate data is collected in a standardized form. Hopefully, this will change for the best in the near future.

References

Althaus, I.A. and Mills, T.J. 1982. Resource values in analyzing fire management programs for economic efficiency. USDA Forest Service. 9 p.

Ashe, B.S.W., McAneney, K.J. and Pitman, A.J. 2008. Total Cost of Fire in Australia. Proceedings of the III International Symposium on Fire Economics, Planning and Policy: Common Problems and Approaches. Carolina, PR. Pp. 20.

Bateman, I. 2002. Economic valuation with stated preference techniques : a manual. Edward Elgar, Cheltenham.

Bennett, J. and Blamey, R. 2001. The choice modelling approach to environmental evaluation. E. Elgar Pub, Cheltenham, UK.

Bowman, D.M.J.S., Balch, J.K., Artaxo, P., Bond, W.J., Carlson, J.M., Cochrane, M.A., D'Antonio, C.M., DeFries, R.S., Doyle, J.C., Harrison, S.P. and others 2009. Fire in the Earth System. Science 324: 481–484.

Butry, D.T., Mercer, D.E., Prestemon, J.P., Pye, J.M. and Holmes, T.P. 2001. What is the price of catastrophic wildfire? Journal of Forestry 99: 9–17.

Dale, L. 2009. The True Cost of Wildfire in the Western U.S. Western Forestry Leadership Coalition, Lakewood, CO. 16 p.

Daniel, T.C., Carroll, M.S., Moseley, C. and Raish, C. 2007. People, fire and forests : a synthesis of wildfire social science. Oregon State University Press, Corvallis.
Donovan, G.H. and Rideout, D.B. 2003. An Integer Programming Model to Optimize Resource Allocation for Wildfire Containment. Forest Science 49: 331–335.
Dunn, A.E., González Cabán, A. and Solari, K. 2003. The Old, Grand Prix, and Padua Wildfires: How much did these fires really cost? USDA Forest Service, Pacific Southwest Research Station. 18 p.
EU 2005. Council Regulation (EC) No 1698/2005 of 20 September 2005 on support for rural development by the European Agricultural Fund for Rural Development (EAFRD). Offical Journal L: 1–40.
Farrell, E.P., Fuhrer, E., Ryan, D., Andersson, F., Huttl, R. and P., P. 2000. European forest ecosystems: building the future on the legacy of the past. Forest Ecology and Management 132: 5–20.
González-Cabán, A. 1998. Aspectos Económicos de la Evaluación del Danõ de Incendios. USDA Forest Service, Pacific Southwest Research Station.
González-Cabán, A. 2007. Wildland Fire Management Policy and Fire Management Economic Efficiency in the USDA Forest Service. Proceedings of the Wildfire 2007-4th International Wildland Fire Conference. Seville, Spain.
González-Cabán, A., Shinkle, P.B. and Mills, T.J. 1986. Developing fire management mixes for fire program planning. U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Exp. Stn. 8 p.
Hanemann, W.M. and Kanninen, B.J. 1999. The statistical analysis of discrete-response CV data. In: Bateman, I. and Willis, K.G. (eds.). Valuing environmental preferences: theory and practice of the contingent valuation method in the US, EU, and developing countries. Oxford University Press, Oxford [England]; New York. Pp. 302–442.
Hanley, N., Mourato, S. and Wright, R., E. 2001. Choice Modelling Approaches: A Superior Alternative for Environmental Valuatioin? Journal of Economic Surveys 15: 435–462.
JRC. 2007. Forest Fires in Europe 2006. EC Joint Research Centre, Institute for Environment and Sustainability.
Laband, D.N., González-Cabán, A. and Hussain, A. 2006. Factors that Influence Administrative Appeals of Proposed USDA Forest Service Fuels Reduction Actions. Forest Science 52: 477–488.
Laband, D.N., Hussain, A. and González-Cabán, A. 2008. The impact of Forest Service litigation success on administrative appeals of proposed fuels reduction actions. Forest Policy and Economics 10: 444–449.
Lankoande, M.D. 2005. Three essays on wildfire economics and policy [Thesis (Ph D)]. Washington State University, August 2005.
Martin, W.E., Raish, C. and Kent, B.M. 2008. Wildfire risk: human perceptions and management implications. Resources for the Future, Washington, DC.
Mavsar, R. and Farreras, V. 2008. Database on perception indicators. Deliverable D4.4-3 of the Integrated Project "Fire Paradox", Project no. FP6-018505. European Commission. 48 p.
Mavsar, R., Farreras, V., Kovac, M., Japelj, A., Kraus, D. and Piwnicki, J. 2007. Database of market values and on non-market values. Deliverable D4.4-1-2 of the Integrated Project “Fire Paradox”, Project no. FP6-018505. European Commission. 56 p.
Mavsar, R., Weiss, G., Ramčilović, S., Palahí, M., Rametsteiner, E., Tykkä, S., van Apeldoorn, R., Vreke, J., van Wijk, M., Prokofieva, I. and others. 2008. Study on the Development and Marketing of Non-Market Forest Products and Services, Study Contract No: 30-CE-0162979/00-21. EC DG AGRI. 137 p.
McCaffrey, S. 2008. Understanding Public Perspectives of Wildfire Risk. In: Martin, W.E., Raish, C. and Kent, B.M. (eds.). Wildfire Risk: human perceptions and management implications Resources for the Future, Washington, DC. Pp. 11-22.

Mercer, D.E., Jeffrey, P.P., David, T.B. and John, M.P. 2007. Evaluating Alternative Prescribed Burning Policies to Reduce Net Economic Damages from Wildfire. American Journal of Agricultural Economics 89: 63–77.

Mills, T.J. and Bratten, F.W. 1982. FEES: designg of a Fire Economics Evaluation System. Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture. 26 p.

Morton, D.C., Ressing, M.E., Camp, A.E. and Tyrrel, M.L. 2003. Assessing the Environmental, Social, and Economic Impacts of Wildfire. Research Paper. Yale University, School of Forestry & Environmental Studies - Global Institute of Sustainable Forestry.

Papachristou, H. 2007. Greek August Wildfire Damage Seen at €2 Billion, Minister Says. Bloomberg. http: //www.bloomberg.com/apps/news?pid=20601085&sid=ax1IYpsKfGmQ &refer=europe

Petsini Arlapanou, A. and Petsini Arlapanou, L. 2007. 5 billion Euro damages. http: //www. stockwatch.com.cy/nqcontent.cfm?a_name=news_view&ann_id=74961

Pettenella, D., Florian, D., Mavsar, R., Goio, I. and González-Cabán, A. 2009. Review of the methodologies for the assessment of economic impacts of forest fires and economic efficiency of fire management. EFIMED, Barcelona. 108 p.

Requardt, A., Köhl, M., Schuck, A., Poker, J., Janse, G., Mavsar, R. and Päivinen, R. 2007. Feasibility Study on means of combating forest dieback in the European Union. EC DG Environment. 79 p.

Rideout, D.B., Ziesler, P.S., Kling, R., Loomis, J.B. and Botti, S.J. 2008. Estimating rates of substitution for protecting values at risk for initial attack planning and budgeting. Forest Policy and Economics 10: 205–219.

Riera, P. and Mogas, J. 2004. Evaluation of a risk reduction in forest fires in a Mediterranean region. Forest Policy and Economics 6: 521–528.

San-Miguel, J. and Camia, A. 2009. Forest Fires at a Glance: Facts, Figures and Trends in the EU. In: Birot, Y. (ed.). Living with Wildfires: What Science Can Tell Us? EFI Discussion Paper 15. European Forest Institute. Pp. 11–20.

Venn, T.J. and Calkin, D.E. 2007. Challenges of accommodating non-market values in evaluation of wildfire suppression in the United States. Proceedings of the American Agricultural Economics Association Annual Meeting. Portland, OR.

Wade, D.D. and Lunsford, J.D. 1988. A Guide for Prescribed Fire in Southern Forests. USDA Forest Service, Southern Region. 56 p.

Wei, Y., Rideout, D. and Kirsch, A. 2008. An optimization model for locating fuel treatments across a landscape to reduce expected fire losses. Canadia Journal of Forest Research 38: 868–877.

Zybach, B., Dubrasich, M., Brenner, G. and Marker, J. 2009. U.S. Wildfire Cost-Plus-Loss Economics Project: The "One-Pager" Checklist. John Wildland Fire Lessons Learned Center. 20 p.

3.5 Improving Fire Management Success through Fire Behaviour Specialists

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3.5.1 Introduction

In numerous areas of Europe, and principally in the Mediterranean countries, the last decades have been characterized by drastic changes in land use, especially grazing pattern and land abandonment, combined with forest extension. These changes have caused a more dramatic wildfire spread than in previous decades. Therefore, the task of managing a wildfire is more complex than before and requires well trained managers who have a good understanding of fire propagation.

Specifically, in Europe dramatic fire events are characterized by being often beyond the capacity of suppression in large areas, including the wildland urban interface (WUI), with fast changes in fire behaviour, offering very few and localized opportunities of extinction. In these large fires, two critical tools are required to improve the efficiency in the complex task of managing a wildfire.

1. Fire analysis to plan fire fighting tactics in advance (pro-active way) instead of simply reacting to fire (re-acting way), thus taking advantage of the existing opportunities.
2. The wise use of fire as a tool to fight high intensity fires. Understanding and anticipating fire behaviour is also a critical part in managing fire as a tool.

Here, there is the need of three new Fire Specialists, requiring a higher level of knowledge in wildfire propagation:

1. Wildland Fire Analyst (WFA), or in more detail, a Wildland Fire Propagation Expert;
2. Firing Operations Leader (FOL);
3. Firing Specialist (FS).

Three aspects of the WFA position should be addressed.

1. How relevant is this job task in each region for this job?
2. What should be the required training (and education)?
3. Which kind of experiences can be transferred from some countries (or regions) to others?

In relation to the second aspect above, significant new training materials (i.e. Grillo et al. 2008; Molina et al. 2009), specifically aimed for such training, were recently produced in Europe, and sharing of existing ones has been promoted. These training documents are an innovative contribution to introducing changes into regional and national forest and fire management services across Europe. It should be noted that the approach toward the WFA position is different in Europe than in the USA. A major reason is that large wildfires in the USA last longer than in Europe and maybe far from towns. In Europe, most often the main fire runs occur in a matter of a few hours to a few days and often affect housing areas. Therefore, in Europe, suppression agencies not only need to forecast wildfire behaviour changes, but also to identify opportunities in the anticipated fire spread, and to employ tactics that take advantage of these opportunities.

This forecast has to be supported by tools like the Campbell Prediction System Language (CPSL; Campbell 1995) and the large wildfires propagation patterns (Castellnou et al. 2009). CPSL provides for a qualitative analysis that includes a language to communicate estimated fire behaviour changes. CPSL has been developed in southern California, where there are fast spreading large wildfires that affect housing developments in a very short time; it could also be appropriately applied for the densely populated Mediterranean Coast in Europe. On the other hand, the propagation patterns of large wildfires, developed after detailed study of past wildfires, helps to identity best management action in pre-attack or fuel management. These large wildfire propagation patterns have worked well in Catalonia (Spain) and have been used later with success in other regions of Spain (i.e. Canary Islands, Castilla-La-Mancha, Aragon) and beyond (i.e. Portugal, Italy).

This chapter is about the need for a comprehensive knowledge on fire propagation in support of fire management actions and the possibility to introduce some new job positions of fire behaviour specialists.

3.5.2 The Fire Specialist Group

3.5.2.1 Tasks

As experts on fire propagation, the tasks of the Fire Specialist group (WFA, FOL, FS) include:

1. To help plan the suppression action to be carried out. This is implemented by means of identifying which fire perimeter sectors are above the fire suppression capabilities (by which tool, at any given position in time and space). Therefore, they spot safe and efficient opportunities in time and space. Additionally, they set up a hierarchical classification of opportunities to contain the fire perimeter. Then, they assign priorities on which sectors of the fire perimeter should be contained first and which should be addressed later to diminish the potential fire damage.
2. To forecast fire behaviour changes in both time and space and to determine critical points or lines where a greater alignment of factors (i.e. slope, wind, fuel model, aspect) might put the fire behaviour out of suppression capabilities.

3. To train workers in safety and efficient work. Safety of personnel must be always a priority. Second in line, fire control efficiency has to be re-assessed often. Therefore, the fire behaviour specialists must train workers in basic fire analysis and in job hazard abatement actions all year round. In this training, an important role has to be played by a careful study of past fire propagation patterns and suppression actions (Molina et al. 2009) to allow for a secure and efficient fire control.
4. To use fire as a tool. To assess or be in charge of prescribed burning actions. To plan and perform backfires and burn out operations.
5. To lead operations combining different tools (i.e. aerial means, technical fire, hand tools, hoses).

Each of the Fire Specialist group tasks is performed by different specialists at different scales (i.e. time, fire sectors).

The FS is the one who decides how a fire operation should be performed in order to fulfill objectives, in prescribed burning in rangelands or understory burning, and in wildfires. Also, this firing specialist should forecast fire behaviour changes in time and space and determine critical points or lines where a greater alignment of factors (i.e. slope, wind, fuel model, aspect) might put a given fire front out of suppression capabilities. Later, the FS has to identify and select opportunities to contain the fire perimeter and propose tactics to implement the control. Personnel safety must always be a priority. Finally, the FS participates and often leads operations merging diverse suppression tools (i.e. hand tools and fire engines). A firing specialist may train other fire fighters in basic safety procedures, basic fire analysis and merging fire suppression tools for optimal results.

The FOL can be in charge of any operation involving the wise use of fire. Also, the FOL helps in selecting opportunities associated to changes of fire behaviour, recommending tactics and strategies. The FOL may also lead operations merging different suppression tools working in a given fire sector. A FOL may also train other fire fighters in advanced fire analysis and control and supervision of operations to ensure that both safety and efficiency would be accomplished.

The WFA is a key specialist who facilitates the wise use of fire as a tool (both in fuel management when there is no wildfire and in actual fire suppression actions).

3.5.2.2 What to expect from a Wildland Fire Analyst?

A WFA is an expert in both fire spread patterns and fire behaviour forecast that is employed (ideally all year round) by the agency in charge of wildfire control (i.e. Forest Service, Emergency & Fire Fighting Service). Among the duties assigned are:

1. To elaborate an advanced forecast of fire behaviour potential in active fires, and therefore to make an assessment on the best strategy that will take advantage of every opportunity to weaken the fire head, and to confine or extinguish the fire.
2. To elaborate full reviews of major past and present fires, to incorporate lessons learned specially in fire behaviour, but also in tactics and in strategy, to the training and response of the whole organization.

3. To characterize the different wildfire propagation patterns from past fires in the region, and therefore, to allow that new fires could be managed as incidents with known patterns of spread (and not as random in their behaviour), both in suppression and pre-suppression operations.
4. To assist the Incident Commander to set up the best fire control strategy for a given fire (based on specific wildfire propagation patterns or fire typologies (Castellnou et al. 2009). Based on this assumption, suppression action has a 'winning label' from the very beginning. In this way, both resources and efforts are aimed to victory and there is not room for an 'unpredictable fire blow-up'. However, there is a need to plan for any eventual misinterpretation or failed forecast (or failure of adequate accomplishment of the tactic by fire workers). For this, we have the LACES protocol (Lookout, Anchor lines, Communications, Escape routes, and Safety zones). Elsewhere are specific details on LACES safety protocol (Molina et al. 2009) or LCES protocol (USDA Forest Service 2004).
5. Identify areas where forecast fire behaviour allows opportunities and track opportunities with a light vehicle. When a potential opportunity is found, it is assessed, and if selected, an appropriated tactic is proposed.

The WFA position fills a gap that it is too often present when setting up a Local Emergency Command Group. It is very common to see a stressed out Incident Commander (fire boss) not receiving the best help possible to address how to match resources and effort with actual and future wildfire behaviour.

Specific duties of the WFA when not involved in active fire fighting operations are:

- To document current and past wildfires and to report them in detail.
- To work on developing, applying, reviewing and improving a high-quality standard fire safety education and training program. In this training, an important role has to be played by detailed case studies of past fire propagation patterns and suppression actions (Molina et al. 2009) to make future fire control actions more secure and efficient.
- To set up the fuel management plan, the prescribed burning plan and the infrastructure enhancement plan.
- To assess or be in charge of the implementation of any given fuel management action or any given infrastructure enhancement action.
- It should be highlighted that the WFA is the expert that assesses actual and forecast fire behaviour to report to the Regional Fire Resources Boss about:
- The distribution of resources covering risk and about the potential outcome of different on-going fires to ensure that proportional action is taken and that not all available resources go to the first fire to break out.
- Where and how to implement slow down operations, and also how to arrange a hierarchical classification of opportunities to contain the fire perimeter.

At the same time, the WFA participates with the 'fire management specialist' in the tracking, the assessment and supervision of any proposed suppression action (in terms of efficiency and personnel safety). This is especially true for backfiring or burn out operations and operations combining multiple tools (Figure 1). In this respect the contribution of the WFA is like an additional check on those actions,

Figure 1. Backfiring operations supervision in Gran Canaria 2007 (Canary Islands, Spain). (Photo by Daniel García-Marco).

taken from standard protocols. Therefore, it can be concluded that the role of a WFA in Europe should go beyond just planning and should include proposing suppression actions. This is different from what is the standard role of the equivalent specialist in the USA.

3.5.3 Wildfire Behaviour Forecast

The main task of the WFA and FOL is to have an educated, detailed look at the wildfire to assess potential changes in spatial and temporal fire behaviour. The WFA forecasts behaviour of one or several fires and, as a result of this, develops a fire control plan for the fire boss (Incident Commander) to approve. The FOL does the same within a fire sector, and the FS does this within a fire line. This plan would have an objective (and thus a strategy), a proposed methodology (and thus a tactic and explicit limitations), and an execution window as a result of the objective and methodology. In short, this plan would have a strategy, a tactic and an execution window. The tactic and execution window would be addressed most likely by a FOL and a FS, and maybe not by a WFA. The WFA does this not only during fire events to support suppression, but also in advance to support both planning and training.

3.5.4 Suppression planning (objective and strategy)

This is the process of establishing the best plan to accomplish secure and efficient fire control when suppression forces arrive to the fire scene. To do so, it is necessary to forecast fire behaviour changes in time and space and determine critical point or lines where a greater alignment of factors (Campbell 1995) might put the fire out of our suppression capabilities. The suppression plan is a set of sequential actions to be taken within a time frame. It may be a written document or an oral communication (most agencies record all radio telecommunications today). It is not required that this plan is something too intricate. On the contrary, it has to be simple; easy to understand by those in charge of executing it (i.e. this requires simple language and clear maps). The WFA helps the Incident Commander to set up this plan in one or several wildfires. The FOL may help the Division Supervisor, and the FS may help the Crew Boss.

This suppression plan has to be communicated and we must check that it has been properly understood (mandatory checking action). Security issues must always be a major part of the plan. Additionally, a drawing in a map may be provided to allow a better understanding of tasks and duties, as well as the current fire scenario and its potential runs (dead man zone concept, see below).

In case of failure to control the fire through this suppression plan, maps and drawings might help to set up an alternative plan. Failure could be due to any miscommunication among fire workers.

3.5.4.1 Strategy to control fire propagation

The strategy for fire propagation control is about how to establish the fire control objectives. The WFA helps the Incident Commander to plan for a secure and efficient fire control with the best strategy possible. It is up to the Incident Commander to decide the strategy after listening to the WFA and the leaders of the different agencies involved in the Incident Command System Group.

The objectives have to be communicated to all personnel involved in this emergency. Objectives have to be easy to communicate, easy to recognize, and with clear magnitudes. A bad objective could be "We want to control the fire as soon as possible". A better objective could be "we want to control the fire, slowing down the head in these fields in the bottom of the valley. The left flank should be stopped before this creek while the right flank should be anchored before this other creek on next morning. So in this moment, the priorities are the head and then the left flank with larger potential over the right one". But the priorities should be re-assessed according to changes in fire behaviour. The second objective has clear magnitudes (referenced to a map) and could be tested later to see if it was accomplished or not. This is not the case with the first objective.

It is the duty of the WFA to re-asses (or validate) that the proposed fire control lines are both secure and efficient to establish.

Lastly, sometimes the chosen strategy may be not to address the head fire because it is out of suppression capability even with indirect attack. It is important to recognize when there is not any possible safe and efficient tactic to use. In that case the head fire should be addressed later in time and space (see text box).

Box 1. Torre de Fontaubella 2007 (Catalonia, Spain)

Initial strategy: Set up by Incident Commander (the commandment of the first arriving crews) helped by the FOL. The objective is to contain fire in area 1. Tactic, set by this same Incident Commander, is anchoring the back and flanking towards the head. Therefore,

1. avoiding backing fire spreading to area 2;
2. avoiding right flank spreading to area 4;
3. containing downhill fire approaching area 3.

The fire goes from area 1 to area 4 by spotting driven by strong northwest wind (not surface topographic wind). The key factor is the lack of pre-attack infrastructure to help suppression efforts.

Area 2 is a key sector in the spread of the fire, is contained out of the sector with few hoses and fighting multiple spotting.

The fire goes slowly through area 3 and the execution window is very wide.

Extended attack strategy: Set up by Incident Commander helped by the Operation Section Chief and the WFA, present in the field one hour after the fire began.

The fire is in areas 1 and 4. The objective is to hold the flank where fire runs will begin driven by wind in the night when the northeast wind goes down to surface. Therefore,

1. hold the back of the fire out of area 2;
2. slow the head spread to reduce the fire front that arrives at area 6 and, with it, reduce the amount of suppression resources in a front with no potential of spread but with populated areas;
3. reduce the wide of right flank that goes to area 7, where the northeast expected winds can spread the fire to area 8 and then to area 5;
4. stop the fire that goes downslope in area 6 and the left flank.

The head and the back of the fire are under control (the fire does not spread to area 2, and nor to area 6). Part of left flank is under control. For safety reasons the hose lines on the right flank cannot hold all the line but is narrow. The front that jumps to area 7 is narrow and this slows the rate of spread.

Night extended attack strategy: Set up by Incident Commander helped by the Operation Section Chief and the WFA.

Fire on area 7. The objective is to avoid the fire reaching area 8. Therefore,

- avoiding that fire spreading to area 2 and to the populated areas of the village Torre de la Fontaubella, where the fire is making head runs;
- avoiding fire runs following the crests in area 7 and spreading to area 8 where there are no anchor points to begin the fire fighting work;
- stopping the left descending flank.

3.5.4.2 Tactics

The term tactics refers to the planning and execution of actions for accomplishing the strategy. Different tactics are available. The best tactics (to allow for a secure and efficient fire control) should be taken considering the resources available, the training, and the forecasted fire behaviour changes in time and space and trying to determine critical points or lines where a greater alignment of factors might put the fire out of suppression capabilities. Safety of personnel must always be a priority.

For a given strategy, several tactics could be possible in order to implement the control goals. Choosing one tactic among others is based on specific training, resources available, suppression protocols, and forest regulations. It is the way to pursue the goals set by the strategy, always looking for opportunities that (for the given resources) will maximize fire fighting effectiveness without compromising safety. Strategy is up to the Incident Commander, while tactics are up to the Division Supervisors and Crew Bosses. The Incident Commander has the leadership, the planning responsibility, and the management and co-ordination of resources. As large fires may change so quickly, decisions about tactics in a particular fire sector can be taken by the Division Supervisor and in any fire perimeter site by the crew boss. Let us look at an example: the chosen strategy in a fire sector is to control that fire line at the road. Then, the Division Supervisor may choose:

- to control it with engines and hoses;
- to rely on both engines and air tankers;
- to backfire from the road.

All of them are different possible tactics. In Figure 1, fire fighters are igniting fire to consume fuels in advance of the spreading wildfire; this approach can be very effective in limiting the spread of the main fire.

3.5.4.3 Execution window for the tactic

It is the third part of the wildfire control plan. It refers to the limits in time and space of the tactic that was decided upon. As we mentioned above, any possible tactic has to be validated by checking whether there is an appropriate “time execution window” and “space execution window”, but also the “weather window” and the “fire behaviour window”.

Sometimes, there is a starting restriction in the “execution window”; i.e. a backfiring operation may require steady wind suction in the fire line to conduct an efficient suppression fire. Therefore, we cannot light the fire line until suction (from the main fire) is noticeable. Another example could be when a wind change (i.e. timed with day/night topographic changes, or land/sea breeze) is required to allow a safe and efficient tactic to be performed.

The execution window is not only useful to ensure efficiency, but it is also part of the LACES safety protocol (Molina et al. 2009) or LCES protocol (USDA Forest Service 2004). Setting an appropriate execution window helps the look-outs understand what they should be looking for, and what they should be communicating.

Somehow adding new dimensions the execution window in a given fire sector can be described like this: “our execution tactic would be effective (and therefore,

Box 2. Tactics in an extended attack at Torre de Fontaubella 2007 (Catalonia, Spain)

- Backfire at head of the fire front. Set up by the WFA and the Incident Commander. Executed by the WFA.
- Hose line in the back of the fire. Upslope hose lines in the flanks set up by the Division Supervisor.
- Downslope hose line in both flanks helped by aircrafts as lookout, burned area as safety zone. Burn out to make wider the safety zone, made successfully in the left flank and stopped for safety reasons in right flank. Set up by WFA and Incident Commander, applied by Division Supervisor and FOL, and executed by Strike Team Leader (the boss of a three fire engine team).
- Aircrafts help the backfire operation and later on right flank. The suppression fire is set up by the WFA under the Incident Commander supervision.

Execution window for backfire on the head fire

- Meteorology. Starting the backfire when the suction of the fire holds the ignition inside the fire line.
- Fire Behaviour. Starting the ignition before the fire begins spotting.
- Safety. Starting the ignition after successful evacuation of the people remaining on the road.
- Safety. Firing from left flank to right flank for a better way out for firing specialists.

it would be still in shape) before the fire reaches the counter-wind area, before the daily topographic wind arrives, before wind changes direction due to storms, and while the fire perimeter sends firebrands less than 20 m away".

3.5.5 Wildfire Analysis: a needed tool

Fire spread analysis is the needed tool to accomplish a safe and efficient wildfire propagation control. This is especially true in fast large wildfires involving wildland urban interface areas. There are three keys to success:

- To have a fast forceful response: increasing distributed vigilance and suppression resources, directing prevention efforts to increase suppression efficiency and widening and combining the techniques used to contain fire spread.
- To have a suppression agency flexible enough to respond to rapid changes of fire behaviour: It will be necessary to plan in advance through fire behaviour anticipation (pro-active approach) and not to react to fire (re-acting approach). It will require lowering the decision levels to ensure a faster response to changes. Lastly, it will require a common technical language to describe fire behaviour changes,

- To be able to use fire as a tool to contain high intensity fire spread situations. It will require slowing down the fire head (high intensity fire behaviour), while allowing the standard fire-line construction to contain the fire perimeter.

As we have seen, for all these key aspects, applying fire analysis in every job position of a fire fighting organization is of paramount importance. The existence of Fire Specialists fosters these three key aspects, promoting the use of fire analysis in the three spatial scales of the fire (fronts, sectors, wildfires), and so improving knowledge and understanding all through the different levels in the chain of command.

In the words of some Incident Commanders we have interviewed, "to have a fire analyst as an assistant to the chief of the suppression forces (Incident Commander) is like having the peaceful feeling that our efforts will end up in success or that we are not just playing around the fire spread to justify our salary". In summary, safe and efficient wildfire suppression is harder to be accomplished without a proper WFA on duty.

Going into the details, the vision of an expert in fire analysis (i.e. WFA, FOL, FS) does differ from the perspective of an Incident Commander who is a manager of resources. Specifically, the WFA has specialized knowledge on fire behaviour, fire effects, and fire safety, and has the time and focus to apply this knowledge to fire analysis. Therefore, the WFA can properly identify fire suppression opportunities but can also assess in time when some efforts are either meaningless (inefficient to control the fire perimeter) or unsafe for the workers.

3.5.5.1 Agencies with Fire Specialist positions on duty in 2009

The current situation is rapidly improving over recent years in many regions in Europe. Clearly this progress needs to continue and to multiply. In Table 1, some specific data is provided regarding Fire Specialists and their training. It is perceived that the investment in training and positions results in improved fire management effectiveness. These first steps in Europe are promising, but the efforts need to expand and accelerate – positions need to be recognized and become a part of the regular fire operations during fires and year-round to support planning and training.

3.5.5.2 Required competences training and experience

The required level of education of a WFA should include a university degree in Forestry (or related degree), and an additional specific postgraduate or master degree in Forest Fire Management. Several years in fire fighting operations are certainly important to qualify as a WFA. However, it should be highlighted that it should be possible to transfer experience through high quality case studies. Lifelong learning (not necessary at universities) might permit the acquisition of formal qualifications and competencies. Therefore, some people may qualify for these positions with no formal academic degrees. However, the usual way to reach the qualifications is through attendance at a course run by a university.

This is a needed job position and requires a specific education and training. This specific degree in Forest Fire Management must include credits in prescribed

Table 1. Regions (and countries) and their Fire Specialist positions on duty in 2009.

Region	Wildland Fire Analyst	FS / FOL	Fire Analysis training
Catalonia (northeast Spain) GRAF. Since 1999	8 full time, 4 additional assistants.	Several FS, and FOL	Fire analysis for all levels[1]. Continuous training: Past wildfire analysis and actual wildfire reports. GRAF units training includes 200 h of training (FS), 150 h for FOL, including prescribed burning and analysis exercises for GRAF.
Portugal (all country). GAUF[2]. Since 2006.	4 – There is not yet an official function	Several FS, and FOL	GAUF units training includes 5 days training sessions of fire analysis and prescribed burnings.
L´Aude (France), GRAFF	-	FS	Training fire Incident Commanders in fire analysis.
Gran Canaria (Spain). Since 2002.	2 full time, 1 additional assistant in summer	Several FS, and FOL	Fire analysis for most levels. Continuous training: Past wildfire analysis and wildfire reports (in progress).
Castilla-La Mancha (Spain). UNAP since 2009.	Since 2009, 14 full time (some in training phase).	In progress	Fire analysis for most levels (in progress). Continuous training: Past wildfire analysis and wildfire reports (in progress).
Aragón (Spain)	5 forest fire managers in training	No	
Andalucía (Spain).	Expected 2010. Methods and protocols are tested in 2009[3]		Fire commanders are being trained in fire analysis.
Tenerife (Spain)	There are moves towards employment of WFA.[4]	4 FOL (in training)	4 forest managers analyze past fires, follow active fires
Sardinia (Italy). Mastros de Fogu. 2008	No	FS in training	Basic training in wildfire analysis Continuous training through past wildfire analysis.
Northumberland (UK)	-	No	Training high and intermediate fire commanders in Front and Sector fire analysis. Understory prescribed burning.

1 Fire suppression support, Basic Fire suppression, Fire Brigade unit commander for Fire suppression operations, Division commander for fire suppression operations in Mediterranean Ecosystems, Incident Commandment, Look-out, Control operators, Aerial means operators.
2 All GAUF members are forestry engineers as well as certified as prescribed fire specialist. Every year since 2006 they organize a 5 days training sessions concerning the wildfire analysis. In the civil protection system, in Portugal, there is not yet an official function of fire analyst, but GAUF personnel are often requested to help in this task.
3 An analysis unit, formed by full time WFA as well as part time Wildland Fire Operative Technicians, is expected to be operative by summer 2010.
4 There is a move towards this new job position but there is a complex protocol (in large wildfires) that accommodates several different tasks for up to four forest fire managers on duty. This could eventually allow for a more specific WFA position.

burning techniques, fire behaviour, fire effects, fire analysis, strategies and tactics, and the use of prescribed fire in ecosystem management. Fire analysts may enhance their performance by becoming knowledgeable about the body of works by Campbell (1995), Castellnou et al. (2009), and Cheney et al. (2001).

By addressing European-wide training needs, the new training systems and practices will strengthen European co-operation, will develop common principles for informal learning, and will amplify support at the local service level for the development of qualifications and competencies as WFA. These training materials will include fire science, fire ecology, fire weather, the social and cultural role of fire in Europe, fire prevention and suppression methods and technologies and the use of prescribed fire in ecosystem management. Additionally, they will cover the state-of-the-art of scientific knowledge in fire ecology in the European biota, the impacts of fire on atmospheric chemistry, climate, human health and security. Country 'Annexes' providing specific information on particularities of wildland fuels, management options and country specific legislature and protocols may be included.

In terms of suitable education, training, experience and certification of a WFA, these should be similar to what it is required for an Incident Commander. Additionally, the WFA should be:

- Familiar with Wildfire Typologies in the region (Castellnou et al. 2009) and capable to forecast and assess fire behaviour changes under changing topography and weather (Campbell, 1995; Castellnou et al. 2009). The WFA should also be able to use fire simulators (Finney 1998, Finney et al. 1997, Molina et al. 2006).
- Familiar with prescribed burning techniques. This helps to understand minor changes in fire behaviour and how to address them. Expertise (both education and extensive training) in the wise use of fire (prescribed burning as well as backfiring operations in suppression actions).
- Knowledgeable in fire ecology and fire effects (this may be obtained partially in prescribed burning actions).
- Familiar with job hazards abatement actions and aptitudes (Beaver 2001, Braun 1995, and Geller 1996), and with conditions leading to accident identification (Putnam 1995, Hart 1995, USDA Forest Service 2001, Mangun 1995, Mangun 1999) in order to carry-out fire analyses that help achieve efficient and safe fire suppression.

The required extensive training may include:

- A manager level position in Forest Fire Management during at least two fire seasons.
- A close-up participation in recreation and analysis of fire spread in numerous past fires as shown by Molina et al. (2006) and Grillo et al. (2008). In those works, several case studies are shown, in which the fire control actions either did match or did not match the fire spread pattern, as a result of this pattern either being properly perceived or not being properly perceived.
- A deep knowledge of fire ecology, in regard to how fire effects are linked to fire behaviour. This is something not required for the Incident Commander but it is a must for a WFA.

In summary, it is obvious that the WFA position is very important and deserves recognition. It is also clear that a proper certification system is needed to ensure that the most qualified candidates are hired for the job. There are already different attempts towards this accreditation throughout Europe (see Miralles et al. in the present volume).

As to the required competences needed for the Firing Specialist and the Firing Operations Leader positions, see Miralles et al. in the present volume.

3.5.6 Discussion

Molina et al. (2009) have shown several case studies in which the fire control actions did not match the fire spread pattern because this last one was not perceived properly. It should be highlighted that having an expert wildfire analyst on duty in those cases could have made a significant difference in the final fire perimeter and in human safety (including job hazard abatement actions).

The certified WFA may perform several tasks in both prevention and suppression. WFAs are able to write down fuel management plans or integrated fire management plans. Additionally, prescribed burning plans are their duty.

They can also carry out a host of other tasks, as listed above, in relation to fire suppression. These assignments may be carried out by any fire manager, but they can be accomplished much better by a certified WFA.

It is rewarding that there are new positions as WFA in different agencies; it has also contributed in enhancing the credit of those already doing this highly needed job. Having paved the way, it is certain that there will be even more WFAs in more agencies in the coming years. For example, some recent developments (i.e. Castilla-La-Mancha, Spain) have set up excellent working documents to ensure a smooth transition to a system that relies heavily on the WFA tasks.

This chapter has clearly been based on Fire Paradox activities including monitoring of active wildfires, demonstration sites and training actions in prescribed burning and detailed documentation of fire analysis of recent medium and large wildfires. Therefore, it integrates diverse aspects of wildfire propagation using the knowledge obtained. These diverse aspects (that indeed provide background knowledge to Fire Specialists) merge wildfire propagation with the wise use of fire. In fact, learning and training in prescribed burning provides an outstanding understanding of wildfire propagation because they allow for many hours to observe changes in fire behaviour and spread. If these hours are spent under adequate supervision, the trainees should be encouraged to anticipate fire behaviour changes (a pro-active look at fire spread).

3.5.7 Conclusions and recommendations

Field experience, large wildfire analysis, and arguments stated in this chapter strongly suggest that it is clearly beneficial to have a WFA on duty.

Fire specialists (i.e. WFA, FOL, and FS) would efficiently identify critical points (or lines) where fire intensity and spread could increase seriously (i.e. critical points) and opportunity sites (i.e. inflection points) where fire suppression actions would have an increased probability of success.

Fire specialists would have the knowledge to propose adequate strategies and organize tactical operations. However, knowledge on fire propagation should be common to all people involved in fighting fires. Therefore, as the top experts, the Fire Specialists should train teams in job hazard abatement actions and in fire fighting exercises all year round.

Additionally, it is necessary to address how to certify the required qualifications to ensure that those job positions will be filled with the best workers available. It is envisioned that the Fire Specialists should be standard job positions in those wildland suppression actions that exceed the limits of initial dispatch.

It is strongly recommended that Fire Specialists should be viewed as being equally indispensable as helicopters, airplanes, fire engines or logistic experts. Therefore the message to policy makers is to encourage agencies to have WFAs on duty for mid- and large-size wildfires.

In short, fire behaviour specialists would help to solve the fire paradox by means of merging a comprehensive knowledge on fire propagation with mastery of the wise use of fire.

References

Beaver, A.K. 2001. Evaluating risk and reward relationships in wildland fire-fighter safety. Proceedings of the 5th International Fire Safety Summit. International Association of Wildland Fire. Missoula, MT.

Braun, C.C. 1995. Addressing the common behavioural element in accidents and incidents. In: Putnam, T. (ed.). Proceedings of the findings from the wildland fire-fighters human factors workshop. U.S. Department of Agriculture, Forest Service. 9951-2855-MTDC. Missoula, MT. Pp. 28–30.

Castellnou, M., Miralles, M., Molina, D.M. and Martinez, E.R. 2009. Patrones de Propagación de Incendios Forestales: In: Vélez, R. (ed.). Incendios Forestales: Fundamentos y Aplicaciones. McGraw-Hill. Pp. 274–282.

Campbell, D. 1995. The Campbell Prediction System: A Wild Land Fire Prediction System & Language. D. Campbell ed. 129 p.

Cheney, N.P., Gould, J.S. and McCaw, L. 2001. Dead Man Zone – a neglected area of fire-fighters safety, Australian Forestry 64(1): 45–50.

Finney, M.A. 1998. FARSITE: Fire Area Simulator-model development and evaluation. USDA Forest Service, Research Paper RMRS-RP-4, Rocky Mountain Research Station, Ft. Collins, CO. 47 p.

Finney, M.A., Sapsis, D.B. and Bahro, B. 1997. Use of FARSITE for Simulating Fire Suppression and Analyzing Fuel Treatment Economics. Symposium on Fire in California Ecosystems: Integrating Ecology, Prevention, and Management. San Diego, CA.

Geller, E.S. 1996. The psychology of safety. Chilton Book Company, Radnor, PA.

Hart, D.O. 1995. Cultural attitudes and change in high-stress, high-speed teams. In: Proceedings of the findings from the wildland fire-fighters human factors workshop. Putnam, T. (ed.). U.S. Department of Agriculture, Forest Service. 9951-2855-MTDC. Missoula, MT. Pp. 34–39.

Grillo, F.F., Castellnou, M., Molina, D.M, Martínez, E.R., and Fababú, D.D. 2008. Análisis del Incendio Forestal: planificación de la extinción, Editorial AIFEMA, Granada, Spain. 144 p.
Mangun, R.J. 1995. Investigating wildland fire entrapments. U.S. Department of Agriculture, Forest Service. 9551-2845-MTDC. Missoula, MT.
Mangun, R.J. 1999. Wildland fire fatalities in the United States 1990 to 1998. U.S. Department of Agriculture, Forest Service. 9951-2808-MTDC. Missoula, MT.
Molina, D.M. 2009. Planes de quemas. Prescripciones. In: Vélez, R. (ed.). Incendios Forestales: Fundamentos y Aplicaciones. McGraw-Hill. Pp. 274–282.
Molina, D.M., Blanco, J., Galan, M., Pous, E., García, J.B. and García, D. 2009. Incendios Forestales: Fundamentos, Lecciones Aprendidas y Retos de Futuro. Editorial AIFEMA, Granada, Spain. 256 p.
Molina, D.M., Grillo-Delgado, F. and García-Marco, D. 2006. Uso del fuego prescrito para la creación de rodales cortafuegos: estudio del caso “Las Mesas de Ana López”, Vega de San Mateo, Gran Canaria, España. Invest Agrar: Sist Recur For 15(3): 271–276.
Putnam, T. 1995. (ed.). Findings from the wildland fire-fighters human factors workshop. U.S. Department of Agriculture, Forest Service. 9951-2855-MTDC. Missoula, MT.
USDA Forest Service 2001. Thirtymile fire investigation: Accident investigation factual report and management evaluation report. USDA Forest Service, Winthrop. 106 p.
USDA Forest Service 2004. Safety Protocol Review. Southern California Geographic Area. Fire Siege of 2003. USDA Forest Service, Pacific Southwest Region. 34 p.

3.6 Wildfire Scenarios: Learning from Experience

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3.6.1 Introduction

The occurrence of episodes with large wildfires has affected different regions of Europe; Portugal in 2003 and 2005, southeast France in 2003 and 2009, northwest Spain in 2003 and 2009, and Greece in 2000, 2007 and 2009. This demonstrated that strong suppression resources capabilities are still inadequate when faced by extreme fire behaviour. During all these large fires suppression crews faced extreme fireline intensities and fast fire spread which made it impossible to quickly suppress them by the known attack techniques (direct attack).

The applied strategy for most wildfire suppression cases was based on a fast and aggressive attack of all ignition points in the landscape, at every place and under all meteorological conditions. The efficiency of this strategy is outstanding and it succeeds in limiting most wildfires to very small burned areas. But under certain meteorological, fuel and topographical conditions, fire behaviour becomes extreme. When fire behaviour is clearly superior to the power of the suppression resources, the system becomes overwhelmed and turns out not to be efficient for various reasons.

- The distribution of the resources along the perimeter is slower than the growth of the wildfire perimeter. In other words, fire spread is faster than the fire suppression rate. For example, massive spotting at 200 m is very usual in large fires, so in an instant fire can advance by 200 m.
- With such extreme fire intensities, the suppression system cannot carry its operations efficiently as in the case under normal conditions. Extreme fire intensity thus overruns suppression limits. For example, crown fires with large walls of flame greater than 25 m length are not unusual in large fires, and no aerial or terrestrial resource can stop it.
- Fire perimeter growth, which is faster than the suppression capacity, increases the probability of damage to houses and people and the necessity of actions and resources to protect them. In the wildland urban interface situation, a negative feedback process has developed, where the relative amount of resources used to fight the wildfire is lower in comparison than the resources which are used to protect the houses and people. Every house can be regarded as an emergency (Rifà and Castellnou 2007).

Suppression of small fires can be effective under virtually all conditions however it is reasonable to say that once a fire develops under certain extreme weather conditions it is impossible to limit fire spread until the weather moderates. But this strategy that only focuses on total suppression has shown not to be successful under large wildfires. So, to mitigate wildfire effects it is necessary to focus on changing the landscape, towards a more tolerant and resistant land use. However, during the next 30 years, we will not have the desired landscape yet, and we will have large fires that no suppression effort can stop. So we need to gain suppression effectiveness to address these fires. Fire fighters cannot stop them. A change in strategy is needed, from strategies based on direct attack to strategies based on slowing and reducing fire behaviour and defending urban assets. This clearly requires an important investment in knowing and anticipating fire behaviour.

Anticipating wildfire spread pattern provides the opportunity to increase the success-rate of the suppression attacks by allowing fire fighters to pre-plan decisions and timely application of suppression methods. The anticipation of the attack opportunities is far from being a standard in suppression systems. A great opportunity to begin this task is before the fire occurs, included in prevention programs: locating the places where adequate and proactive forest management could reduce fire intensity, creating opportunities for the likelihood of successful suppression.

Different research initiatives have attempted to make progress in this direction:

- Wildfire spread patterns. The dominant spreading factor can be determined, and in this way it is possible to pre-determine which type of changes can be expected and will generate opportunities (developed in the first half of the 20th century).
- Surface-fire prediction by static simulations (Behave) (Andrews 1986) or spatial simulators of fire spread (Finney 1998) can be used with advantage to anticipate sites where lower fire intensities can be expected.
- Simulations based on minimum travel time which permit identification of fire opportunities (Finney et al. 2002; Finney 2007), based on main paths and predicted fire spread schedules.
- CPSL (Campbell Prediction System Language) analysis, helps to predict where the fire behaviour will change (Campbell 1995) based on factor alignments (slope, aspect – fuel temperature, wind,).
- Fire scenarios: large wildfire spread patterns that occur in a given forest massif, and ‘provinces of fire’ (with homogeneous fire behaviour) (Castellnou 1996). In the same way, Bahro et al. (2007) proposed a methodology for planning based on a “problem-fire”, in a “fire shed” and homogeneous fire behaviour.

There are several forecasting tools for fire behaviour (i.e. Anderson 1983; Andrews 1986; Rothermel 1991; Finney 1998), and the investments in models and simulations are impressive. However wildfires are very complex events, especially those with extreme fireline intensities. Processes like the interaction between different fire fronts or the changes in oxygen supply following changes in the convection column (by means of instability of the atmosphere) are very difficult to simulate but are essential for predicting fire behaviour (Dupuy 2009; Mazzoleni et al. 2008). Furthermore, the available data is scarce, mainly because of the complexity of the wind-relief interactions.

For these reasons, it is important not only to create and to improve simulation models (Vega et al. 2009; Dupuy 2009; Mazzoleni et al. 2008), but to put emphasis on the investigation of historical large wildfires. Based on this, we recommend a methodology to anticipate the local spread paths followed by large fires moving in a given fire scenario (Castellnou 2000; Bahro et al. 2007), to anticipate as much as possible the suppression opportunities, and to anticipate extreme weather conditions associated with extreme fire behaviour in each scenario.

By understanding the schedules of fire spread we can now determine which areas are inaccessible for suppression and which ‘zones’ present opportunities for successful fire fighting. These strategic zones are:

- Critical areas to be managed: where the suppression resources can have an opportunity to reduce fire intensity during the day of a large wildfire. These areas are in the main axe of the local spread path, areas associated with large fire potential. To be safe and useful for suppression attack it should be prepared before, and fire prevention should locate the needed infrastructures (Rigolot et al. 2009).
- Areas to reduce fuel combustibility: not directly related to the main local spread path, but forest management should be directed to reduce the potential fireline intensity. This cannot be seen as a genuine opportunity.

The methodology to determine strategic zones is based on the development of the following:

- Research and study of historical large wildfires in an area. The fire reports should describe fire behaviour, based on the analyses of past fire spread (propagation) and CPSL (Campbell Prediction System Language, Campbell 1995) to determine the main paths followed by the fire and its trigger points[1]. Those are classified for given fire types, which are based on repeated, observations of paths of spread following the topography (Castellnou et al. 2009). The objective of these reports should include capturing the lessons learned from these fires.
- Determine the fire scenarios in zones with homogeneous fire regime:
  - Identify the schedules of fire spread which are repeated in every zone with a homogeneous fire regime.
  - Study the probability that the determined scenario of opportunities would be useful.

3.6.2 Research of former wildfires and related synoptic situations

Predicting fire behaviour and fire spread patterns requires going back to the records of wildfires that have occurred in the past. This process requires a structured standard (fire types) which allows the relevant information to be identified and highlighted, and which characterizes the wildfires; this information usually becomes part of the fire fighters’ knowledge. Every wildfire can be related to a certain meteorological condition and a synoptic situation of the parameters which define the fire (wind intensity, type of wind, and relative humidity during day and night); these determine fire spread pattern and fire behaviour. Vegetation structure and drought

1 Trigger point: site in which fire spread and fireline intensity will be beyond the holding capacity of the suppression forces in direct attack. The implication is that the fire spread potential increases notably by not identifying such sites.

affect the quantity and distribution of fuel, and therefore also fire behaviour. It is important to link the former wildfires to the drought level at that time, to make it feasible to determine possible return-period/recurrence-interval.

For every fire scenario, the most relevant historical fires are analyzed, focusing on the following aspects:

- Main conclusions. The transfer of useful information and the lessons which are learned from the fire are the main objectives of these reports. Lessons with respect to the organization of the suppression operations applied, the implementation of selected tactics, or lessons related to safety are some likely products.
- General information about the fire: Date, hour, size, general behaviour and existing resources. This includes patterns of spread and fire type. (Castellnou et al. 2009).
- Meteorological conditions at a synoptic scale (Castellnou 1996; Millan et al. 1998; Montserrat 1998) and, if available, at local scale.
- Location of the fire with respect to the topography. For analyzing the local winds, the interaction between wind and topography, and the influence of topography by itself on fire behaviour.
- Used strategy and discussion of the performed tactics and operations.

3.6.3 Fire scenarios

In Europe, the problem of huge wildfires is changing. The developments of different land use, in combination with the socio-economic changes during the last century, have influenced the landscape and the load and distribution of fuels. The development of the territorial scenario has caused changes in the scientific world, in operational actions and in politics. Hence, we do not only transfer data from fire perimeter simulators like Farsite (Finney 1998) to trajectory simulators which draw spread path schedules and identify points where fire fronts multiply (Finney et al. 2002). Nowadays there is also a change at the operational site, from temporary workers during the 1960s to highly specialized suppression crews like GRAF (Catalonia) or GAUF (Portugal). These crews have a solid training background (not only in using suppression tools, but also in anticipating fire management opportunities), operate in extended attack and most of the personal is involved full time. In addition, more and more regions and countries integrate new tools of fire prevention in their systems, like prescribed burning and new regulations with respect to wildfires (Herrero et al. 2009).

The contrast between wildfires with large perimeters (large areas) and very complex wildfires with crown fires, wildland urban interface problem areas and simultaneous fires, requires a shift from few resources exploiting the existing opportunities, into numerous suppression troops which, unfortunately, also only have a small number of real opportunities. This has caused a change:

- from prevention based on infrastructures and water points to facilitate the creation of anchoring points, and roads and observation posts for fast suppression;

Box 1. Examples of large wildfire reports and their use in simulation.

When working with reports of large wildfires, it is necessary to identify those in which the most important lessons were learned, and those which faced major problems in fire suppression

An example of the extracted information from former wildfire reports can be seen here:

- In Casarabonela, 2009 (Andalucía, Spain) the main fire potential was limited by the presence of agricultural areas, which act as a fuel break making suppression actions easier (Ruíz and Senra 2009).

Another way to explain the lessons learned from past fires is by the use of video and documentaries. These are very educational for civilian people to help them understanding how a wildfire behaves (e.g. Binggeli 2009). The videos can also be used as for a professional public as an education tool about the use of fire.

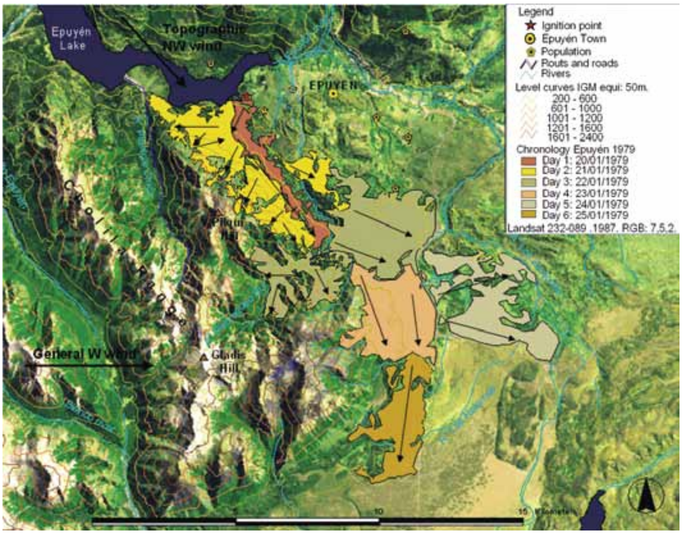


Figure 1. Picture from the Epuyén-report (Argentina, 1979). When the fire crossed the area of the main river, the direction and speed of fire spread changed drastically due to the slope, and the wind increase on the 3rd day (Sagarzazu Ansaldo and Defossé 2009).

Figure 2. Fire behaviour in Sant Llorenç Savall 2003 (Catalonia, Spain). This was the first significant wildfire in terms of size, duration and social importance since the formation of the specialized crews for wildfires in Catalonia (GRAF). These crews have a large capacity to analyze fire behaviour and to identify local operations and possibilities. Furthermore they assisted in coordinating the various different volunteers following the strategy of the fire fighters (GRAF 2009).

- to prevention based on the strategic opportunities of large wildfires; adapting the land use and forest management to wildfires by reducing the vulnerability of forest stands.

There is a significant change: from the objective of eliminating fire from ecosystems, an adaptation to fire, using the opportunities provided by fire. With this purpose it is necessary to understand very well how fire behaves, and especially how large wildfires develop. Large wildfires are not very selective concerning fuels, and propagate in almost every type of fuel, including agricultural areas or decorative vegetation (Bajocco and Ricotta 2007; Rigolot et al. 2009). We have also seen examples of this type of destructive behaviour in Spain, Portugal, the south of France and Greece in 1994, 2003, 2007 and 2009. These fires do not respond to small details, but to larger landscape-scale features. The macro-topography (with synoptic situations associated to large wildfires) is the main factor which controls fire propagation in complex terrains (Taylor and Skinner 2003; Expósito and Cordero 2004; Iniguez et al. 2008). This is based on the repetitive observations of fire spread under similar topography and meteorological conditions, where subsequently the underlying pattern can be seen (Castellnou 1996; Expósito and Cordero 2004), only differing in intensity and therefore the distance which the fire reaches, depending on the available fuel.

The existence of repeated fire spread patterns linked to a specific territory provides an opportunity to identify a 'problem fire' and to set up the proper planning (Castellnou 2000; Bahro et al. 2007). From the former wildfires, a series of fire scenarios in different synoptic and topographical situations are determined. The history of wildfires is essential, connecting the world of suppression to the world of prevention.

Wildfire type characterisation for homogeneous areas of risk

From the three basic patterns of fire spread (topographical fires, wind-driven or plume-dominated fires) several specific and repeated aspects are determined for every pattern. Common 'fire types' are proposed by Castellnou et al. (2009), based on the study of the wildfire history of Catalonia, from the characterization of coincidences of synoptic and topographic conditions with repeated fire path schedules. This fire types are a useful way to extract information from the main observers of fire behaviour, the fire fighters.

For a given scenario the first step is to identify areas with a common fire type. Nevertheless on the same site, there may be more than one type of wildfire.

Identifying fire-design and strategic zones

Identifying where the fire behaviour will change, to the advantage or disadvantage for the suppression crews (Campbell 1995) and predicting how fire front will subdivide into several directions (Finney et al. 2002) will assist in understanding fire spread of the large wildfires (Castellnou et al. 2009). Based on these fire spread patterns and the associated fire potential, the pre-suppression actions and prevention needs are able to be effectively planned.

The planning of the use of terrain features is not done based on some general and abstract fire types, but each fire type and its associated opportunities should be applied to a specific territory. Therefore well documented and relevant wildfire history for the region should be studied. Fire behaviour and spread pattern of these fires are analyzed, as well as the operations conducted. In these past fires, different theoretical opportunities considering relevant fire types for the zone are studied, as well as real opportunities for suppression. We can then consider if these opportunities could be used or not in this terrain. This will lead to a development of common schedules, similar scenarios and repeated windows of opportunity for each wildfire type. With this information, particular properties of the fire spread are defined for the specific study area, related to the topography, typical development of the synoptic episodes, and properties of vegetation types.

By specifying the fire types adjusted to the specific properties of the site, we end-up with a concept of 'wildfire-design'. The fire-design represents a 'best-reference fire' or a fire with the ability to become a large wildfire in a specific environment (Castellnou et al. 2009). The fire-design is a tool to understand how large wildfires perform in a certain territory, and to predict how it spreads, also taking notes on its weak points. It is a way to provide information and provides criteria to locate the infrastructures which will support fire suppression actions, and will result in safer and more efficient suppression actions. The use of simulations permits confirmation and adjustment of several parameters which are used for the planning of strategic zones:

- map inaccessible areas for the suppression crews;
- confirm the location of the opportunities, associate to rates of spread and intensities safe and efficient to work;
- determine sites with different vegetation treatments, to establish safety zones from where suppression operations can be applied;
- select the best sites where fuel reduction methods should be applied to reduce fire spread potential;
- recognize when resource allocation will not result in a positive outcome.

Taking the information collected of the fire-design as a reference point, and gathering the experiences of the validated opportunities of historical wildfires, allows the identification of strategic sites for each environment. Each of these strategic sites is associated with a fire potential area, which will be one of the criteria to select the best sites where to invest resources.

3.6.4 Conclusions and recommendations

The most useful tool to stop wildfires – which escape from the conventional suppression methods (mainly because of high flame lengths and fast rate of spread), is the anticipation of fire trajectories (fire spread schedule in time and space) in the near future, i.e. by identifying the type of each particular wildfire.

This anticipation is not only based on insight gained by people or on mathematical models adjusted to real interaction between fire and a landscape, but on information extracted from past fires. This type of understanding (based on the underlying mechanisms) is obtained from detailed analyses of former wildfires. By gathering this information, we create databases of wildfires which will describe the shape of fire spread patterns in a particular synoptic (fire weather) and elevation (topography) framework. This will then serve to make sound decisions in fire fighting, and

Box 2. Instructions to integrate fire in forest management.

This box describes the fire types and related opportunities; with similar fire paths schedules with analogue synoptic situations and macro topographical conditions (Castellnou et al. 2009).

The properties of each fire type in a given scenario due to local topography, to the development of the synoptic situations in the area or to vegetation characteristics, are all captured in the fire-design.

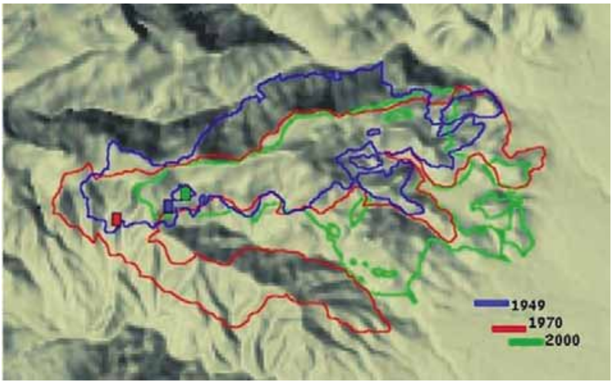


Figure 3. Perimeters of fires in 1949, 1970, and 2000. The three fires show similar spread patterns with a synoptic situation of northern wind. Location: Albiol, Catalonia, northeast Iberian Peninsula. Fire spreads following ridges until the end, and open to new ridges if available (for example, as the ignition in 1979 was more to the east than the other two, a second ridge was available and burned).

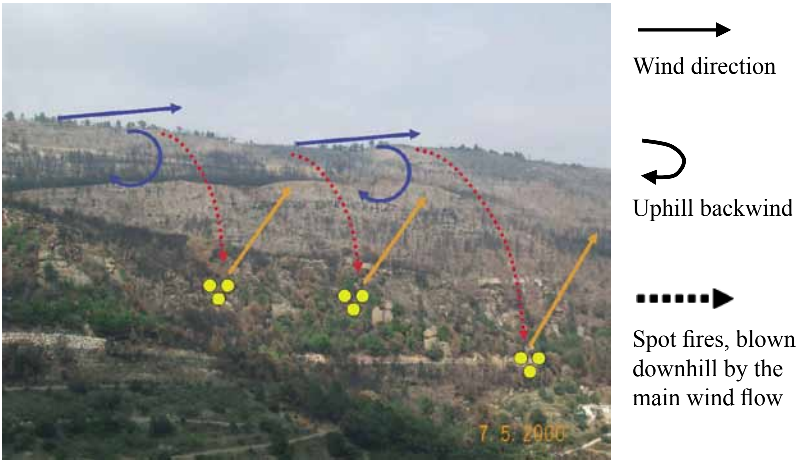


Figure 4. Propagation by lee winds. The counter directive winds reach the higher part of the ridge where the main wind occurs, spotting fire downhill. In this way, new fire-runs develop uphill following the lee winds.

Acknowledging and understanding the fire paths in a lee wind area, provides possibilities to identify the suppression potential at the end of a ridge or where the ridge drastically changes direction.

Box 2. Continued.

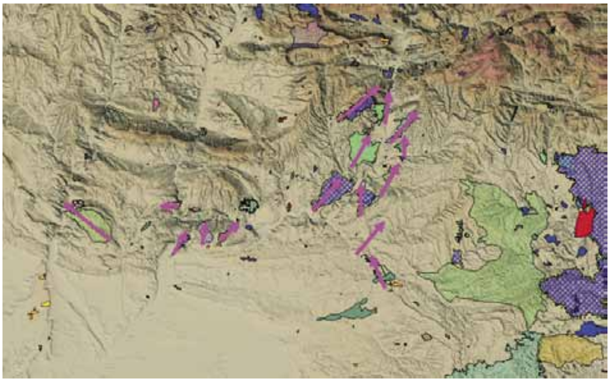


Figure 5. Perimeters of the fire in the main valley of the River Segre, Catalonia.

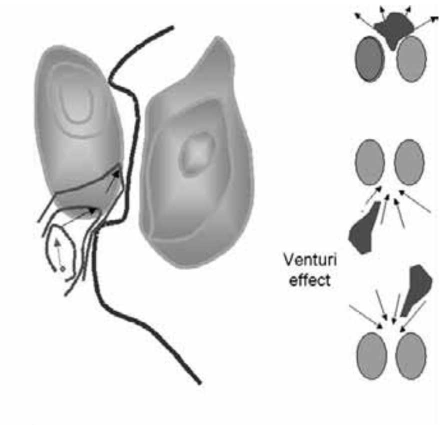


Figure 6. Topographical fire spread pattern near a canyon.

will provide possibilities to plan the pre-attack needs and extinction resources accordingly. In this way we can search for minor actions (CSM – Critical Sites to be Managed) which will reduce large wildfire spreads.

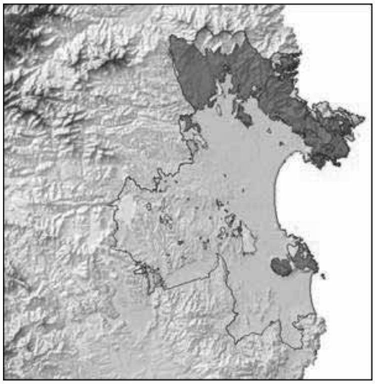
Therefore, studying the repeated local spread path of past wildfires allows managing a fire scenario, creating discontinuities of vegetation disrupting these paths and managing vegetation to manage the whole scenario.

One single methodology of gathering general data for the whole European Union should cover the complete range of different fire types, and increase the number and accuracy of fire-designs. A platform of exchanges of information for the whole Europe is needed. Using one common language in the characterization of wildfires will simplify the know-how transfer of specialists/analysts between the regions' fire fighting projects and between the states of the European Union. With respect to wildfire prevention, this exchange of knowledge allows the creation of a

Box 3. Wildfire Scenarios – l'Empordà, Catalonia, Spain.

The study of large wildfires (those in the country but also nearby) resulted in the identification and confirmation of the fire scenarios which affected each area. From a database of 46 perimeters representing 67 471 ha, we can conclude that the Cap de Creus (the little peninsula in the northwest part of the picture) burns every 26 years mostly by wind-driven fires (also with topographical constraints).

The validation of former wildfire control opportunities permits us to extrapolate the lessons learned to each new wildfire scenario. Then, the CSM (Critical Sites to be Managed) can be determined. Every CSM is linked to a potential, planned burning surface that can be protected.



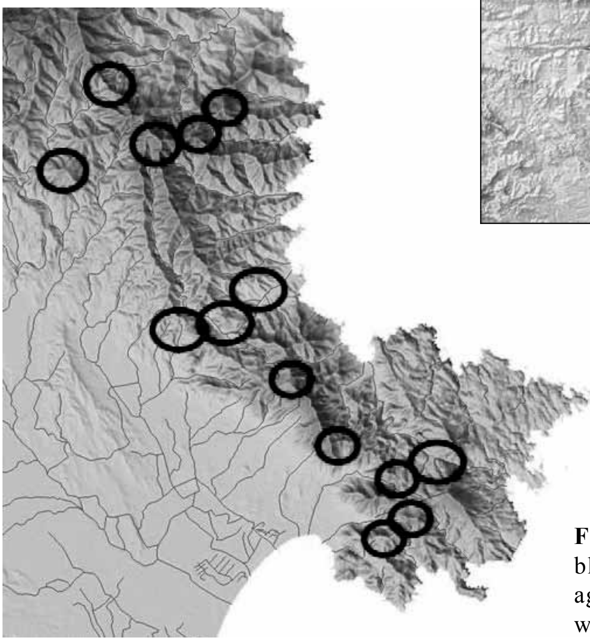


Figure 7. Main CSM as black ellipses, to protect against eventual 5000 ha wildfires.

common working guide. This could help to implement suppression models and their requirements, while establishing an assortment of general opportunities for every fire type in all the regions.

With this methodology it is also possible to highlight the different problems which the suppression crews (in different regions) may face. It is possible to search for common/shared solutions within the mix of measures that every suppression system can provide. Thus we can clearly map the problems, and investigate different solutions.

In this manner it is possible to work on preventing the worst possible wildfires in these zones. Besides, we will know beforehand what the critical situations will be, which can occur simultaneously (or within a short period of time) in different parts of Europe. This was the case within the synoptic pattern at the end of July 2009 when there were large wildfires occurring at the same time in different parts of Spain (Castilla La Mancha, Aragón and Catalonia) and one day later in Sardinia (Italy).

The study of present and past large wildfires is essential for integrating forest management and suppression actions where both have the same objective: the persistence of structures and species as far as possible. We should focus on the larger wildfires, because for the smaller fires the present suppression methods are adequate.

This will allow to plan several actions like pre-attack (locate the places where the fire fighters could have suppression opportunities) and prevention (locate the places where adequate forest management could reduce fire intensity, and by this creating opportunities for the likelihood of successful suppression). This will also assist in deciding where to make use of agricultural breaks, and to determine where houses are most vulnerable. It helps also to reinforce or favor vegetation structures which are more resistant in areas of full alignment (i.e. worst fire behaviour). In the same way as it is possible to place structures which are less vulnerable to crown fires in trigger points, so, the study of wildfire scenarios is also an integral tool for forest management.

Nevertheless, it is important to remember that determining where to act and increasing the planned activities is necessary but not sufficient to limit the destructive effects of the large wildfires. The integrated actions will then be completed by an increase in the most effective forest management options in which the risk of wildfires is explicitly incorporated, with expanding forest tracks which facilitate establishment and maintainance of forest structures which are more tolerant to the fire spread and related damage. This will also reduce the capacity for sustaining crown fires because of the more discontinuous nature of the vegetation, which will assist fire suppression in general.

References

Anderson, H.E. 1983. Predicting wind-driven wild land fire size and shape. Intermountain Forest and Range Experiment Station, Ogden, UT, USA. 26 p.

Andrews, P.L. 1986. Behave: fire behavior prediction and fuel modeling system - BURN subsystem Part 1. USDA Forest Service, Intermountain Research Station, Ogden, UT, USA. 130 p.

Bahro, B., Barber, K.H., Sherlock, J.W., and Yasuda, D.A. 2007. Stewardship and fireshed assessment: a process for designing a landscape fuel treatment strategy. Restoring fire-adapted ecosystems. Proceedings of the 2005 national silviculture workshop, Gen. Tech. Rep PSW-GTR-203. Pp. 41–54.

Bajocco, S. and Ricotta, C. 2007. Evidence of selective burning in Sardinia (Italy): which land-cover classes do wildfires prefer? Landscape Ecology 23: 241–248.

Binggeli, F. 2009. Linking bulletin and video reports for the website. Internal Report IR8.5-1 of the Integrated Project “Fire Paradox”, Project no. FP6-018505. European Commission. 6 p.

Campbell, D. (ed.) 1995. The Campbell Prediction System: A Wild Land Fire Prediction System & Language. 129 p.

Castellnou, M. 1996. Reconstrucción de la progresión de los incendios históricos y su efecto modelador en la vegetación: Ribera de Ebro. In: Gonzalez, J.M. (ed.). Seminario sobre incendios forestales. Centre Tecnològic Forestal de Catalunya. Solsona, Spain. Pp. 207–223.

Castellnou, M. 2000. Nuevas Metodologías de Prevención de Grandes Incendios. Congreso Forestal Ibérico. Castelo Branco, Portugal.

Castellnou, M., Miralles, M., Pages, J. and Pique, M. 2009 Tipificación de los incendios forestales de Cataluña. Elaboración del mapa de incendios de diseño como herramienta para la gestión forestal. Proceedings of the 5th Congreso Forestal Español. Ávila, Spain.

Dupuy, J.L. 2009. Fire start and spread. In: Birot, Y. (ed.) Living with wildfires, what science can tell us. EFI Discussion Paper 15. European Forest Institute. Pp. 27–31.

Expósito, R. and Cordero, T. 2004. Albiol fire. Did we learn at the third time? In: Viegas, D.X. (ed.). Proceedings of the IV International Conference on Forest Fire Research. Coimbra, Portugal.

Finney, M.A. 1998. FARSITE: Fire Area Simulator - Model development and evaluation. RMRS-RP-4. USDA Forest Service Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO, USA. 47 p.

Finney, M.A., Sapsis, D.B. and Bahro, B. 2002. Use of FARSITE for simulating fire suppression and analyzing fuel treatment economics. Sugihara, N.G., Morales, M.E., Morales, T.J. (eds.). Proceedings of the symposium: Fire in California ecosystems: integrating ecology, prevention and management. San Diego, CA, USA. Pp. 121–136.

Finney, M.A. 2007. A computational method for optimizing fuel treatment locations. International Journal of Wildland Fire. 16: 702–711.

GRAF 2009. The Sant Llorenç Savall Forest Fire – Operational Report. Generalitat de Catalunya. 23 p.

Herrero, G., Montiel, C., Agudo, J. and Aguilar S. 2009 Assessment document on the main strengths and weaknesses of the legislation and policy instruments concerning integrated wildland fire management in EU, in European Member States and in North African countries. Deliverable D7.1-1-2 of the Integrated Project “Fire Paradox”, Project no. FP6-018505. European Commission.117 p.

Iniguez, J.M., Swetnam, T.W. and Stephen, R.Y. 2008. Topography affected landscape fire history patterns in southern Arizona, USA. Forest Ecology and Management 256: 295–303.

Mazzoleni, S., Giannino, F., Beccarisi, L. and Ricotta C. 2008. Comparison of contamination models. Deliverable D6.2-3 of the Integrated Project “Fire Paradox”, Project no. FP6-018505. European Commission. 43 p.

Millan, M., Estrela, M.J. and Badenas, C. 1998. Meteorological processes relevant to forest FIRE dynamics on the Spanish Mediterranean COAST. Journal of Applied Meteorology. 37: 83–100.

Montserrat, D. 1998. La predicció dels Grans Incendis Forestals. Catalunya Rural i Agrària. 54: 5–13.

Rifà, A. and Castellnou, M. 2007. El modelo de extinción de incendios forestales catalan. Proceedings of the IV International Wildfire Conference. Seville. Spain.

Rigolot, E., Fernandes, P. and Rego, F. 2009. Managing Wildfire Risk, Prevention, Suppression. In: Birot, Y. (ed.) Living with wildfires, what science can tell us. EFI Discussion Paper 15. European Forest Institute. Pp. 49–52.

Rothermel, R.C. 1991. Predicting behaviour and size of crown fires in the Northern Rocky Mountains. Res. Pap. INT-438. USDA Forest Service, Intermountain Research Station, Ogden, UT, USA. 46 p.

Ruíz C. and Senra F. 2009. The Casarabonela 2009/07/14 Fire - Operational Report. Junta de Anadalucia. 15 p.
Sagarzazu Ansaldo, M.S. and Defossé, G.E. 2009. Study of a 2nd set of largest past fires. Deliverable D8.3-1 of the Integrated Project "Fire Paradox", Project no. FP6-018505. European Commission. 82 p.
Taylor, A.H. and Skinner, C.N. 2003. Spatial patterns and controls on historical fire regimes and forest structure in the Klamath Mountains. Ecological Applications. 13: 704–709.
Vega, J.A., Jiménez, E. and Pérez, J.R. 2009. Effectiveness of suppression fires: methods and first results. Internal Report IR2.3-2 of the Integrated Project "Fire Paradox", Project no. FP6-018505. European Commission. 27 p.

4. Prescribed Burning: Preventing Wildfires and More

4.1 Overview of Prescribed Burning Policies and Practices in Europe and Other Countries

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4.1.1 Introduction

Prescribed burning is a technique that represents the controlled application of fire to vegetation under specific environmental conditions to attain planned resource management objectives (FAO 1986). Twenty years after the first experimental initiatives of prescribed burning in Europe, launched in southern countries in the 1980s (Botelho and Fernandes 1997), the use of fire for different management purposes remains rather limited. The main constraints for prescribed burning introduction and implementation in the continent are fire bans, complex land structure, lack of professional experience and negative public perception (Xanthopoulos et al. 2006). However, important changes have taken place for prescribed burning in the last years, especially in those countries which were pioneers in its introduction, and mainly for wildfire hazard reduction objectives.

Portugal and France were the first European countries to initiate policy processes aiming to develop prescribed burning practices, based on specific legal frameworks and national systems for the professional accreditation in the use of this technique. Spain has also progressed in this direction, but mainly at the regional level. In fact, Catalonia and the Canary Islands have created professional teams in the use of fire for management purposes. Moreover, objectives for the use of this technique have broadened towards more environmental oriented purposes as more experience has been accumulated both in prescribed burning research and management fields. Thus, prescribed burning has been progressively included in nature conservation policy documents (Rigolot 2005).

In Northern European countries (e.g. Sweden and Finland) the use of prescribed burning is at present included as a management practice required by forest certification schemes and also for nature conservation of protected areas. Moreover, although still maintained at the experimental level, changing paradigms in nature and landscape policies in Atlantic and Central European countries have propitiated the development of prescribed burning initiatives in the frame of research projects (Goldammer et al. 2007).

Thus, the introduction and implementation of prescribed burning practices with different management objectives is a progressive trend in fire and land management policies, affecting even the more reluctant countries. The support of Fire Paradox project and the influence of the exchanges between fire professionals of Europe and other continents have allowed the barrier against the use of prescribed burning to be overcome in countries which traditionally had maintained a negative attitude towards the use of prescribed burning. The most prominent example in this sense is the development of a professional fire use team in Sardinia (2008) and the development of the first prescribed burning initiatives for fire prevention in the Cilento National Park, southern Italy (2009).

The research on prescribed burning practices and policies carried out within the frame of Fire Paradox has enabled a general overview of prescribed burning spatial patterns at the EU level to be obtained, identification of the different existing policy scenarios in European countries towards prescribed burning practices, and identification of the main factors that are key to promote these practices as well as to provide recommendations to overcome the principal constraints for the future. Besides, the research has considered neighboring countries in the southern Mediterranean basin by acquiring a general sense of their fire uses, and where the possibility to use prescribed burning for fire hazard reduction has similarly aroused technical and political interest.

4.1.2 Inventory and classification of fire use practices

The available information about the development and distribution of fire use practices in Europe is scattered and rather scarce, with a few exceptions focusing on some European regions (Pyne 1997; Botelho and Fernandes 1997; Goldammer et al. 2007). Thus, the first aim of fire use practices assessment within Fire Paradox project was to obtain a complete summary of spatial distribution of traditional and prescribed burning in Europe and North African countries. At this point, we find it relevant to include also traditional fire use practices since it is considered as an important factor for the development of prescribed burning policies in the future, that is either regulating traditional fire use and profiting from this experience to develop prescribed burning policies, or by (re)introducing prescribed burning as a modern technique for management purposes within a professional structure (see Box 1). However when considering both types of practices, it is important to clearly differentiate between traditional burning practices and prescribed burning practices. In this regard the main characteristic that clearly distinguishes prescribed burning from traditional fire use is an adequate planning (Pyne et al. 1996) as well as the latter evaluation which determines whether the pre-determined management objectives have been reached and allow for future improvements (Fernandes 2002).

For this purpose, information was collected, classified and referenced at the regional level for the EU-27 member states and the North African countries (Morocco and Tunisia), based on a questionnaire distributed to national experts with responsibilities in forest and fire management[1].

1 For more information on sources and methods see Lázaro et al. (2008).

4.1.3 Antecedents for prescribed burning practices: traditional fire use

As in other continents around the world, anthropogenic fire has been recognized as one of the most significant alterations to fire regimes in Europe (Conedera et al. 2008; Scott et al. 2000). This has been the case especially since Neolithic times where fire became an essential tool to expand agricultural lands. In the Mediterranean region, the pastoral use of fire has continued throughout history until present (Di Pasquale et al. 2004) and together with grazing and other traditional cultivation systems have become part of integral components which have shaped Mediterranean landscapes (Naveh 1975). In countries from temperate and boreal Europe, fire became an essential tool for the expansion and occupation of new lands). The most representative techniques were the use of fire in swidden agriculture and shifting cultivation systems (Pyne 1997; Goldammer 1998; Bradshaw and Hannon 2006). Also on lands that were too poor for agriculture the burning of grasslands for pasture was common. In particular the heather and moor landscapes characteristic in Atlantic countries such as Belgium, Germany, France, Norway and United Kingdom are product of more than 5000 years of burning by rural communities (Haaland 2003; Dodgshon and Olsson 2006).

The current situation in the maintenance of the traditional practices of burning in Europe consists on a general abandonment in northern countries and central Europe while it is still a widespread practice in Mediterranean countries where there can be a wide range of management objectives (e.g. grazing improvement, burning of agro-forestry remains, hunting, etc.) (see Figure 1).

In southern and eastern European countries, traditional burning practices have been maintained and in some rural areas the use of this technique still constitutes the most effective and economic tool for stubble burning and grazing improvement (Metailié 2006; Velez 2005; Merou and Papanastasis 2002), However changing spatial and socio-economic conditions in these areas (e.g. vegetation encroachment, aging of rural population, etc.) have increased the risk of traditional fire use practices which have evolved to be at present the main cause for wildfire in Mediterranean countries (FAO 2007; JRC-IES 2008). In countries from the southern Mediterranean basin like Morocco, traditional burning practices are maintained although fire has not being used in their grazing management but for other purposes (e.g. wars between tribes, wildlife management, forest harvesting).

In addition, it is important to highlight the maintenance of traditional burning outside the Mediterranean, as in the case of the British heathlands (Davies et al. 2008). Heathlands dominated by *Calluna vulgaris* species are frequently burned by shepherds to develop a mosaic habitat favorable for the red grouse (*Lagopus lagopus*), sheep, deer and improvement of grasses (SEERAD 2001, DEFRA 2007). Similarly, traditional burning methods have been recently re-established in Atlantic heathlands in Norway (Haaland 2003) and in the Black Forest in Germany (Goldammer et al. 2007) (see Box 1).

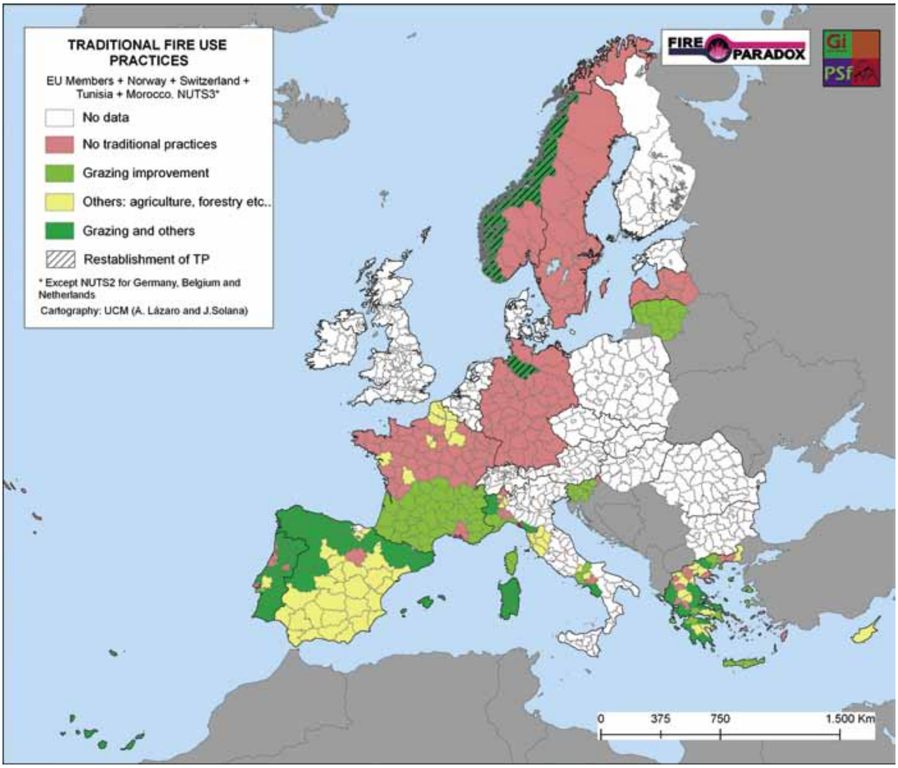

Figure 1. Distribution of traditional burning practices in Europe and North African countries.

4.1.4 Development of Prescribed Burning practices in Europe

With regard to prescribed burning practices, a general pattern can be differentiated with regard to its management objectives (see Figure 2). Since its first introduction in the 1980s fire hazard reduction has been the predominant goal of prescribed burning in southern European countries. However, as more experience has been accumulated, the objectives of its application have broadened towards other management targets (e.g. nature conservation, forest or game management). This is the case of France, Portugal and some Spanish regions like Catalonia, Galicia or the Canary Islands which during the last decade have developed professional prescribed burning teams, specific training for prescribed burning specialists, expert networks, and first legal instruments to regulate this practice. In the last years Italy has progressed in the development of prescribed burning promoted through exchanges between professionals from Portugal. Results from this progress have been the initiation of the first prescribed burning initiatives in the Cilento National Park (Campania region) included in the Forest Fire Defense Plan (2008) with the objective to manage fuel accumulation under pinewoods (*Pinus halepensis* and *Pinus pinaster*), as well as with the creation of professional teams in the use of fire in Sardinia in 2008 (Mastros do Fogu).

Box 1. The re-establishment of traditional burning practices: new perspectives

The recognition of the role that traditional management techniques have had for the maintenance of many European landscapes and ecosystems (Pyne 1997; Goldammer 1998; Goldammer et al. 2007) as well as its contribution as a management scheme for the reduction of forest fuel accumulation have contributed in recent years to the development of programs aimed at the support of traditional burning practices.

In those areas where these type of practices had been lost, mostly in Northern countries as well as in Central European and Atlantic countries, the re-establishment of traditional burning systems are valuable not only to the cultural heritage values but also the role that these management practices had in the conservation and maintenance of valuable ecosystems related to them. Some examples of this type of initiative are found in the Black Forest (Germany) and in the Koli National Park (Finland) (Loven and Äänismaa 2004). Also in Norway, in the Heathland Centre (Lygra, Bergen) the traditional management has been continued in cooperation with local farmers in order to preserve the open heathlands and the culture connected to them (Haaland 2003).

On the other hand, in those places where traditional burning practices have been maintained, pasture burnings have been subject to support schemes and in some cases have converged in a modern management technique used for fire hazard reduction or the management of natural areas, that of prescribed burning. In those cases the traditional practice is re-established through institutional supports based on historical precedents (Ribet 2009). However, in practice, the development of PB programs can be carried out with greater or lesser integration of traditional know-how – from a complete implementation by professionals, to implementation by professionals with the support of shepherds, to training of and then implementation by shepherds.

Figure 3. Dialogue between professionals and shepherds in Salamanca, Spain.Photo by I. Juárez, 2006.

Figure 4. Pasture burning in Sardinia, Italy. Photo by N. Ribet, 2006.

In Central European and Atlantic countries the use of prescribed burning is focused on the management of endangered habitats and the maintenance of open landscapes. Although the first experiments where initiated in the early 1970s (Goldammer 1978) the map demonstrates how prescribed burning within this region is still used at the experimental level, within the framework of demonstration

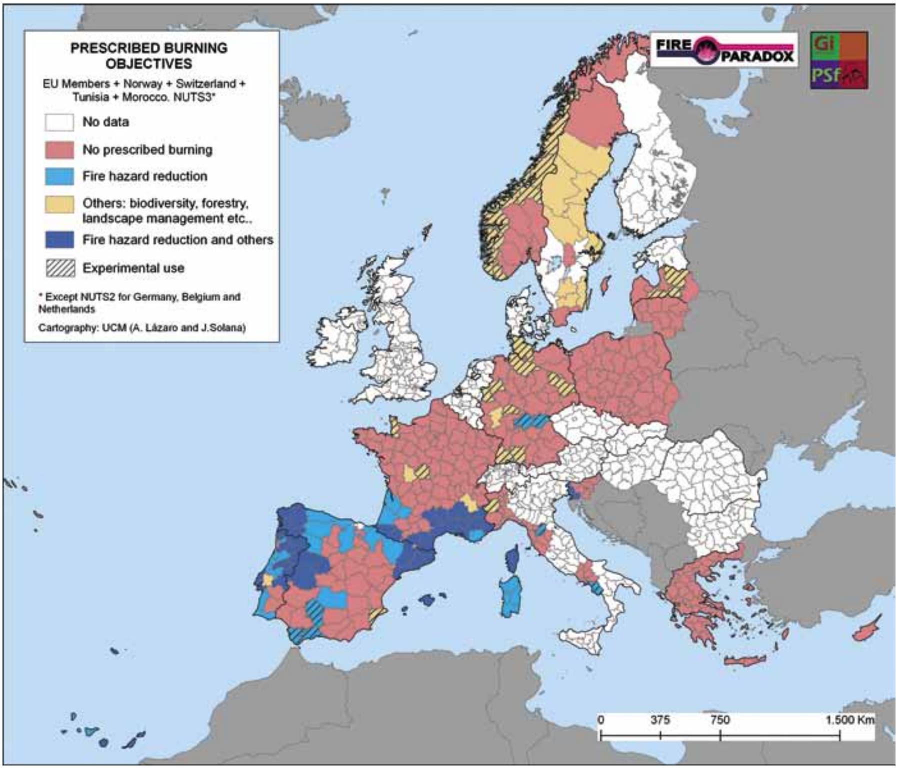

Figure 2. Distribution of prescribed burning practices with regard to its management objectives in Europe and North African countries.

projects in nature conservation (e.g. LIFE) in Germany (Goldammer et al 1998), Netherlands (van der Zee 2004), Denmark (Jensen 2004), United Kingdom (Bruce 2002) etc. Some of the most commonly managed landscapes are the *Calluna* heathlands and other open landscapes such as grasslands and fen mires. Other examples include the management endangered species habitats such as for the black grouse (*Tetrao tetrix*) and the woodland grouse (*Tetrao urogallis*). Exceptions to these experimental fire uses are in Northern European countries, Sweden and Finland, where the use of prescribed burning is promoted as a sustainable practice for forest certification (FSC Suecia 2006; FSC Finlandia, 2005) and for biodiversity management in protected areas with promising examples such as the nature reserves of Jämtgaveln and Stormyran-Lommyran in Sweden and the Koli National Park in eastern Finland (Goldammer et al. 2007).

New scenarios for the development of prescribed burning practices are being initiated in other regions. For instance in eastern European countries experimental trials are taking place for both nature conservation in open landscapes (e.g. Poland) as well as for its potential application in fire risk reduction use within the frame of the EU sponsored SEERANET (southeast-European Research Area), in which Germany, Hungary and the Former Yugoslav Republic of Macedonia are participating. In North Africa, Morocco began in 2008 to apply prescribed burning on shrubs located along the freeways for clearing the external and central bands as an alternative method to the mechanical clearing.

4.1.5 National and regional legal frameworks related to prescribed burning in Europe

The assessment of national legal and policy frameworks with respect to prescribed burning practices in Europe and North African[2] countries has identified that there are few legal initiatives that exist with regard to prescribed burning, with most examples restricted to a few Mediterranean examples.

Portugal and France were the first European countries to develop legal instruments regulating the use of prescribed burning. France, for the first time, introduced in the Forest Management Law (2001), modifying the Forest Code (1987), the possibility to use fire for prevention purposes by the responsible authorities outside of the risk period (art. L321-12)[3]. At the regional level, the "Départements" have regulated the use of prescribed burning through local regulations (arrêtés préfectorales) and by the development of the corresponding prescribed burning plan (cahier des charges). A few years later Portugal enacted a specific regulation on prescribed burning (fogo controlado) (Portaria 1061/2004), and in 2009 major policy changes have used the term fogo técnico, including both components: prescribed burning and suppression fire (fogo de supressão) (Decree-Law No. 17/2009 and Despacho nº143031/2009).

Spain and Italy as decentralized countries have progressed in this field only at the regional level. In Spain, the region of Catalonia which has developed a specific regulation on this subject, the Decree 312/2006 on Tactical Fire which regulates the use of fire both in wildfire prevention and suppression duties by the forest and civil protection services. Other regions like Galicia and Balearic Islands have introduced this possibility within their basic forest fire regulations. In Italy some regions have considered the possibility to use this technique in their regional laws and programs (e.g. Piemonte, Basilicata, and Liguria) but except for Sardinia, little has been translated into practice.

However the majority of European countries do not have a legal framework for prescribed burning and this factor constitutes one of the main impediments to the development of this practice. This is due to the general prohibition of the use of fire in forest lands and other open landscapes (e.g. grasslands, wetlands, mires) which on occasions come from different legal acts (e.g. Nature Conservation and Forest Acts) and explains the need to obtain special permits to be able to implement this technique.

2 For more information on sources and methods see Montiel et al. (2009).

3 This article applies only to the regions of Provence-Alpes-Côte d'Azur, Languedoc-Rousillon, Corse, Midi-Pyrénées, Aquitaine, Poitou-Charentes and the departments of L'Alderche and Drôme.

In Central European and Atlantic countries fire bans have arisen very often from new air quality standards and the widespread opinion from the authorities of the detrimental effect that fire had on the stability and biodiversity of the ecosystems (Goldammer et al., 1998). For instance, in the late 1970s Germany imposed a total fire ban in open spaces through the Federal Law of Nature Conservation. It provided the legal framework legislation to ban the application of these practices by the Landers which enacted respective laws in the subsequent years (Goldammer et al. 2007). In Belgium there is a general fire use prohibition. It is prohibited in forest areas, within a distance of 100 m from forest edges (art. 167. Forest Code 1854-2003) as well as in nature reserves (art. 11, Nature Protection Act 1973).

For eastern European countries prohibitions might have been either derived from the examples of their neighboring countries, either because of the increasing perception of fire risk derived from the spatial and socio-economic changes that have taken place in the region during the last decades (FAO 2007; JRC-IES 2008). For example, in Poland different legal acts have meant that there has been a total ban in force during the last three decades: the Forestry Law (1991), prohibited the use of fire outside the designated areas in “forests and in areas of grass, peat bogs and heather moor, as well as in a perimeter of 100 m of the forest zone”; and the Law on Protection of Nature (2004) prohibited the use of fire in “meadow vegetation, pasture grounds, waste land, ditches, along roads, train trails, or in the zones of bulrush and reed”. In Hungary, the Law of Nature Protection (1996) prohibited the use of fire in open spaces. The Forest Act (1996) specifies that it is forbidden to light any kind of fire in forest areas as well as within a distance of 200 m from the edge of a forest area, except for the forest managers or any person who has a written permission (art. 53).

Other countries just do not include provisions for fire use in their main legislation texts. In Denmark, neither the Forest Act (2004) nor the Nature Protection Act (1992) includes provisions for the use of fire. This is the same situation for national legislation in Switzerland in both the Forest Law (1991) and Nature Protection and Landscape Act (1966). In Scandinavian countries (Sweden, Norway and Finland) the use of fire is not referenced within the main legislative instruments at national level.

However there are also exceptions to this restrictive general framework. The most prominent case is the regulation of the practice of burning heather and grasses in the United Kingdom which is subject to regulations and codes of practice in Scotland (SEERAD 2001), England (DEFRA 2007) and Wales (by the Welsh Assembly Government in 2008). With regard to legislation, the Hill Farming Act (1946) includes provisions to regulate of the practice for the three regions. Additionally, England (2007) and Wales (2008) have developed Heather and Grass Regulations. Other exceptions are those acquired at the regional level in administrative decentralized or decentralized countries. For instance in Germany, although most states followed the general fire ban of the Federal Government two exceptions have regulated the use of fire: Hessen State and Baden-Württemberg State. In the case of Switzerland, exceptions for the use of fire in forest areas and its perimeter (e.g. 10 m) are also contemplated at the regional level in western Switzerland (French cantons) and the Ticino region (Italian canton).

4.1.6 Strengths and weaknesses of prescribed burning practices in Europe

The assessment of national and regional legal frameworks and policy instruments shows the main strengths and weaknesses for the introduction and development of prescribed burning practices in the short to medium term for the main European regions (See Table 1). It is noteworthy that the use of prescribed burning is supported on present demands and needs to solve different fire problems. Furthermore, at present prescribed burning constitutes an opportunity to deal with new problems that have emerged due to recently changing socio-economic conditions (e.g. new fire scenarios at the wildland urban interface, loss of traditional landscapes).

Also experience gained in the experimental and management field, as well as the creation of network structures joining principal stakeholders involved in the implementation of prescribed burning practices and policies, both constitute strengths in those countries with longer experience. On the other hand, these countries have a valuable potential to export and adapt key factors for success to other countries where this technique is facing greater limitations. Nonetheless, even in those countries where prescribed burning practices are well-established, continued training of personnel and an increased number of qualified technicians is needed to consolidate the use of prescribed burning for the future.

On its side, the maintenance or loss of traditional fire use know-how (fire culture) might constitute a strength or weakness in either way. For instance in those countries where the fire culture has been maintained, this might constitute a strength since part of the general public, mainly rural are still familiar with the use of fire. This culture also constitutes a starting point for forest and civil protection services for the (re)-introduction of fire as a management tool. However where fire culture is maintained but not aligned with policy, conflicts may arise between the rural communities and the responsible administrations. The challenge in these areas is to achieve the same level of recognition for competences in traditional burning practices than in prescribed burning as well as to assure a real integration of both traditional and prescribed burning practices in the development of future fire use policies (Ribet 2009).

Finally, other important limitations for prescribed burning practices are the over-restrictive character of some legal frameworks for fire use in some countries, or the still non-adapted traditional fire use regulations in other countries.

4.1.7 Conclusions and recommendations

The recent evolution of prescribed burning policies and practices in Europe and North African countries demonstrates that new opportunities are opening for the use of fire as a management tool for wildfire hazard reduction as well as for nature conservation and other objectives. However, the context for fire use differs greatly between countries, regions and even within the local level. Furthermore, the fire problem is different in each European region and is evolving within the context of global change.

Table 1. Main strengths and weaknesses of prescribed burning (PB) practices in Europe.

	Strengths and opportunities	Weaknesses and challenges
Northern countries	Recognition of the natural role of fire in boreal and sub-boreal ecosystems: promotion of PB in the field of FSC and in protected areas	Predominance of the environmental and timber production functions in forest areas
	Absence of a restrictive legal framework and negative public perception.	Lack of awareness for forest fire risk in the region
	Experience for PB planning and operational implementation in Sweden.	Loss of fire culture
	Existence of the European Eurasian Fire in Nature Conservation Network (EFNCN) for technology transfer and enhancing dialogue between countries	
Central European and Atlantic countries	Re-evaluation of the role of fire in nature conservation and landscape policies	Restrictive legal framework for the use of fire in open landscapes and loss of fire culture (except for UK)
	Experience accumulated in PB research in the frame of nature conservation and landscape maintenance.	Current debates and conflicts related to the use of this technique and its impact (e.g. carbon budget, water quality)
	Existence of the European Eurasian Fire in Nature Conservation Network (EFNCN) for technology transfer and enhancing dialogue between countries	

Table 1. Continued.

	Strengths and opportunities	Weaknesses and challenges
Eastern countries	Opportunities for the development of PB derived from changing socio-economic conditions (e.g. increased fire hazard and loss of open landscapes and biodiversity)	Restrictive legal framework for the use of fire in open landscapes
	Maintenance of traditional fire culture	Fire associated with other environmental issues (radioactivity, land mines, etc.)
	Existence of the European Eurasian Fire in Nature Conservation Network (EFNCN) for technology transfer and enhancing dialogue between countries	Structural problems associated to the transformation towards market economy
		Poor knowledge of the ecological role of fire
Southern European countries	PB constitutes an efficient, economic and adapted tool to solve present demands (e.g. fuel build-up and new environmental concerns)	Effects of long term fire exclusion policy in public perception and responsible administration
	Development of PB professional structures and first regulatory frameworks exportable between countries within the region	Clandestine and negligent fire use practices which constitute a high percentage of the causes of forest fires
	Maintenance of traditional fire culture	The challenge to make the process of development of PB perdurable (i.e. not depending on the motivation of reduced group of persons)

It is evident that the increasingly frequent episodes of large fires and the development of new fire scenarios create a challenging reality which requires different political approaches and new management tools. Nevertheless, the political, ecological and socio-economic diversity of the continent requires adaptable and flexible proposals able to respond to different problems and to adapt to different contexts.

The Fire Paradox project is potentially capable to induce changes in the EU and national fire management policies. In this context a proposal of a Fire Framework Directive (FFD)[4] has been launched to start a shift in fire policies in Europe towards integrated fire management (IFM) and fire use regulation. The proposed Framework Directive would be a basic approach or minimum legal harmonization of Member State legislation to deal more efficiently with the fire problem in Europe. In particular with regards to fire use practices a series of recommendations are proposed to be included in the FFD in line with the philosophy of the project:

- There is a need to assume that there are European rural communities with a fire culture which depend on the use of fire for its welfare. This is not only beneficial for them but also constitutes a fuel management scheme which reduces fire risk in the community.
- Fire-relying communities need legislative frameworks which contemplate and regulate their fire use activities as well as reduce un-wanted ignitions through the development of social prevention programs.
- A best practice approach for the regulation of traditional use of fire should be promoted instead of the conventional restrictive regulatory approach that has been adopted by most Mediterranean countries.
- A general legal framework for the use of prescribed burning in those countries where an over-restrictive framework impedes the development of this technique and keeps it at the experimental level. Existing prescribed burning regulations (e.g. France, Portugal and Spain) can serve as reference for its definition since they include common elements to all of them. However member states should adapt their national legal frameworks to their own particular demands and needs.
- There is a need to promote the recognition of competences for both traditional fire use and prescribed burning. Traditional practices share the same skills than professional use of fire and this should be recognized and supported by organizational assistance, equipment supply and training sessions for local populations (Community Based Fire Management). With regard to the professional technique there is a need for the formalization of required competences through the development of adequate training systems and certifications.

4 For more details, see Agudo and Montiel (2009).

References

Agudo, J. and Montiel, C. 2009. Basis to start the process for a proposal of a new legislation at EU level. Deliverable D.7.1-1.3 of the Integrated project "Fire Paradox". European Commission. 45 p.

Botelho, H and Fernandes, P.M. 1997. Controlled burning in the Mediterranean countries of Europe. European Commission; Environment & Climate Programme; Advanced Study Courses; Marathon; 6–14 October 1997. Pp. 163–170.

Bradshaw, R.H.W. and Hannon, G.E. 2006. Long-term vegetation dynamics in southern Scandinavia and their use in managing landscapes for biodiversity. In: Anoletti, M. (ed.). The conservation of Cultural Landscapes, CAB International. Pp. 94–107.

Bruce, M. 2002. Country report for the United Kingdom. International Forest Fire News 27: 68–76.

Conedera, M., Tinner, W., Neff,C., Meurer, M., Dickens, A.F. and Krebs, P. 2008. Reconstructing past fire regimes: methods, applications, and relevance to fire management and conservation. Quaternary Science Review 28: 555–576.

Davies, G.M., Gray, A, Hamilton, A. and Legg, C.J. 2008. The future of fire management in the British uplands, Int. J. Biodivers. Sci. Manag. 4(3): 127–147.

DEFRA 2007. The heather and grass burning code 2007 version. 28 p.

Di Pasquale, G., Di Martino, P. and Mazzoleni, S. 2004. Forest history in the Mediterranean region. In: Mazzoleni et al. (eds.). Recent Dynamics of the Mediterranean Vegetation and Landscape. John Wiley and Sons Inc. Chichester, UK. Pp. 13–20.

Dodgshon, R.A. and Olsson, G.A. 2006. Heather moorland in the Scottish Highlands: the history of a cultural landscape, 1600–1880. Journal of Historical Geography 32: 21-37.

FAO 1986. Wildland Fire Management Terminology. Food and Agriculture Organization of the United Nations, FAO Forestry Paper 70. Rome. 257 p.

FAO 2007. Fire management – global assessment 2006. FAO Forestry Paper 151. Rome. 156 p.

Fernandes, P. 2002. Prescribed fire: strategies and management. In: Pardini, G., and Pintó, J. (eds.). Fire, Landscape and Biodiversity: an Appraisal of the Effects and Effectiveness. Diversitas 29. Universitat de Girona, Institut de Medi Ambient, Girona. Pp. 187–200.

Goldammer, J.G. 1978. Feuerökologie und Feuer-Management. Freiburger Waldschutz Abh. 1 (2). 150 p.

Goldammer, J. G. 1998. History of fire in land-use systems of the Baltic Region: Implications on the use of prescribed fire in forestry, nature conservation and landscape management. First Baltic Conference on Forest Fires, Radom-Katowice, Poland.

Goldammer, J. G., Hoffmann G., Bruce, M, Konsrashov L., Verkhovets S., Kisilyakhov Y. K., Rydkvist T., Page H., Brunn E., Lovén L., Eerikäinen, K, Nikolov, N. and Chuluunbaatar, T-O 2007. The Eurasian Fire in Nature Conservation Network (EFNCN): Advances in the use of prescribed fire in nature conservation, landscape management in temperate-boreal Europe and adjoining countries in Southeast Europe, Caucasus, Central Asia and Northeast Asia. 4th International Wildland Fire Conference, Seville, Spain. Pp. 13–17.

Haaland, P. 2003. Five thousand years of burning: The European heathlands, 165 p.

Jensen, H.S. 2004. Denmark: Restoration of Dune Habitats along the Danish West Coast. International Forest Fire News 30: 14–15.

JRC-IES 2008. Forest Fires in Europe. Report nº 9/2009. JRC Scientific and Technic Reports. 88 p.

Lázaro, A., Solana, J., Montiel, C., Goldammer, J.G., Kraus, D. and Rigolot, E. 2008. Collection, classification and mapping of the current prescribed fire and suppression fire practices in Europe. Deliverable D7.1-3-1 of the Integrated Project "Fire Paradox", Project no. FP6-018505. European Commission. 47 p.

Lovén, L. and Äänismaa, P. 2004. Planning of the sustainable slash-and-burn cultivation programme in Koli National Park, Finland. International Forest Fire News 30: 16–22.
Merou, T.H. and Papanastasis, V. 2002. Legume and grass density under various treatments in a Mediterranean grassland in Macedonia. In Lowland and grasslands of Europe: Utilization and development. FAO, Rome. Pp.112–117.
Métailié, J.P. 2006. Mountain landscape, pastoral management and traditional practices in the Northern Pyrenées (France). In Anoletti, M. (ed.). The conservation of Cultural Landscapes. CAB International. Pp. 108–124 p.
Montiel, C., Herrero, G., Lázaro, A., Agudo, J. and Aguilar, S. 2009. List and classification of the existing EU and national forest legislation and national policy instruments with reference to wildland, suppression and prescribed fires. Deliverable D7.1-1-1 of the Integrated Project "Fire Paradox", Project no. FP6-018505. European Commission. 110 p.
Naveh, Z. 1975. The Evolutionary significance of fire in the Mediterranean Region. Vegetation 29(3): 199–208.
Pyne, S. J., Andrews, P.L. and Laven, R.D. 1996. Introduction to Wildland Fire, 2nd edition John Wiley and Sons, New York.
Pyne, S. J. 1997. Vestal Fire. An environmental history told through fire, of Europe and Europe's encounter with the world. University of Washington Press.
Ribet, N. 2009. Thèse de 3ème cycle –- Les parcours du feu. Techniques de brûlage à feu courant et socialisation de la nature dans les Monts d'Auvergne et les Pyrénées centrales.
Rigolot, E. 2005. Bûlage dirigé: Quinze ans d'expérimentation. Espaces Naturales 12: 16–17.
Scott, A.C., Moore, J. and Brayshay, B. 2000. Introduction to fire and the palaeoenvironment. Palaeogeography, Palaeoclimatology, Palaeoecology 164: 7–11.
SEERAD 2001. The Muirburn Code. Scottish Executive, 21 p.
Van der Zee, F. 2004. Burning of Heathland in Military Areas in the Netherlands International Forest Fire News 30: 75–76.
Vélez, R. 2005. La población rural en la prevención de incendios forestales, Documento de Trabajo sobre Protección forestal. FAO, Rome.
Xanthopoulos, G., Caballero, D., Galante M., Alexandrian D., Rigolot, E. and Marzano, R. 2006. Forest Fuels Management in Europe. In: Andrews, P. L. and Butler, B. W. (eds.). Fuels Management-How to Measure Success: Conference Proceedings. USDA Forest Service, Portland, OR. 807 p.

4.2 Scientific Knowledge and Operational Tools to Support Prescribed Burning: Recent Developments

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4.2.1 Introduction

Fuel hazard reduction, ecological management or applications in silviculture are the most common objectives for prescribed burning operations. Prescribed burning seeks to apply fire to wildland vegetation as exactly as possible, meaning that specific treatment objectives are formulated (preferably quantitatively) and burning is then carried out under well-defined specific conditions (the prescription) that are expected to meet those objectives. Other attributes – pre-burn procedures, ignition patterns, post-burn assessment and monitoring – concur to rationalize and optimize prescribed burning, as well as to individualize it from traditional burning practices (Pyne et al. 1996). However, the burn prescription is vitally important because it translates environmental and fuel conditions into fire behaviour characteristics and these into fire effects. The ability to prepare and comply with adequate burn prescriptions is thus central to attain the treatment objectives.

Wildfire science should underpin the decision whenever the use of fire is considered as a tool to manage vegetation. The fundamental and applied fire research can directly or indirectly contribute to the development of prescribed burning technology. Research on fire behaviour and fire ecology issues has provided the much needed support to implement and maintain successful prescribed burning programs (e.g. McCaw et al. 2003). As a consistent body of knowledge takes shape and builds up, increasingly robust and refined burning guidelines leading to more exact (and desirable) fire effects will hopefully develop.

The initiation and adoption of prescribed burning by managers and management organizations is relatively new in Europe and dates back to the early 1980s. Prescribed burning use is geographically restricted and its potential to manage wildlands is still largely unfulfilled, especially in forested areas. While the political and socio-economic environment is decisive, there is a need for more basic knowledge and operational guidelines to assist in implementing prescribed burning programs. The narrow gap that often separates prescribed burning from traditional burning in Europe testifies to the incipient technical development of the former. This chapter will provide an overview of the Fire Paradox contribution to advance the scientific and technological support to prescribed burning management.

4.2.2 Supporting prescribed burning through increased wildland fuel knowledge

Dead fuel moisture content usually is the single most relevant variable to plan and execute a burn operation, as it is directly related with the possibility of fire spread and is a central element in a prescription. Hence, the ability to produce fuel moisture content estimates whose accuracy is commensurate with the achievement of specific burn objectives is perhaps the most significant asset to prescribed burning planning. Several empirical dead fuel moisture content models based on atmospheric variables were analysed for needles of pines (*Pinus halepensis*, *P. sylvestris*, *P. pinea*, *P. pinaster* and *P. radiata*), leaves of South American tree species (*Nothofagus antarctica* and *Astrocedrus chilensis*) and for *Eucalyptus globulus* litter (Vega et al. 2009). While adequately reflecting the pattern of variation in litter and duff moisture, the examined models fell short in terms of predictive ability. Simple vapour exchange models (Ruiz et al. 2009) seem suitable for dead fuel moisture content predictions during periods free from the influence of rainfall. Laboratory and field experiments were carried out to quantify the role of fuel moisture on ignition likelihood for typical Mediterranean fuel types (*Pinus halepensis* needles, grass, *Quercus coccifera* leaves), highlighting the effect of fuel type and ignition source on moisture of extinction (Dimitrakopoulos et al. in press).

Being the treatment target, the appraisal and physical description of wildland fuel is implicit in prescribed burning planning. In particular, the ability to estimate fuel load and to describe how fuel complexes change with time is of paramount importance, because those attributes are a major factor in designing a prescribed burning regime for hazard reduction. A thorough system, outlined in Mårell et al. (2008), has been devised to collect, organize and exploit fuel data from the point of view of fire behaviour modelling. Fuel characteristics assessed at different levels – the fuel particle, the plant, the stand characteristics – from a combination of destructive and non-destructive sampling methods are stored in a data and knowledge base (EuroForestFuels) for modelling purposes, including modelling of fuel dynamics (Krivtsov et al. 2009). The fuel data base interacts with the Fire Paradox Fuel Manager software (Lecomte et al. 2009), which processes the vegetation scenarios into 3-D fuel complexes that feed physically-based models of fire behaviour. The complete process has been applied to Mediterranean France and resulted in a classification based on fire behaviour and vegetation physiognomy and structure that consists of 10 fuel types (Cassagne et al. 2009a).

4.2.3 Fire-induced pine mortality: setting the limits to prescribed burning

One important concern when underburning forest stands by prescription is the amount of damage inflicted to the tree canopy. The height of crown scorch is the basis to assess fire severity and post-burn conifer survival. However, heat transfer mechanisms linking fire behaviour and tissue necrosis are incompletely understood. Dupuy and Konovalov (2007) have shown that scorch heights computed from

Figure 1. Tree survival experiments on a young *Pinus nigra* stand, northern Portugal: during the fire (left) and one year after (right).

temperature fields generated by the physically-based Firestar 2D model agree well with plume theory estimates, the current basis to prescribed burning applications.

High flammability and survival to fire intensities in the low to moderate range justify prescribed burning in pine stands. The fire resistance of European pine species was ranked on the basis of a combination of morphological and experimental data with a semi-physical mortality model (Fernandes et al. 2008). All European pines are amenable by treatment with fire. *Pinus canariensis*, *P. pinaster* and *P. pinea* possess traits associated to the highest fire survival likelihood, but species often classified as fire-sensitive (*P. halepensis* and *P. radiata*) do tolerate low-intensity fire. In South Africa, *P. elliottii* is the most fire-resistant species of all commercially grown pines (including *P. pinaster*), especially when established on former grassland (De Ronde 2008).

The source of all experimental results that follow is Vega et al. (2008). A study conducted in a young *P. nigra* stand (Figure 1) highlighted the role of cambium kill when crown injury is irrelevant: the survival of individuals with a stem diameter at 1.3-m height (dbh) < 10 cm, corresponding to bark thickness < 0.7 cm, was assured only when less than half of the bole perimeter at the dbh-level was charred. The probability of *P. pinaster* mortality after surface fire was modelled as a function of crown injury, dbh and season of burn, in the form of three alternative (and similarly efficient) models where crown damage was expressed as (i) relative scorch height (RSH), i.e. the crown scorch height as a proportion of tree height, (ii) estimated crown scorch volume, or (iii) length of the green tip. Nearly all trees with dbh < 7 cm and RSH $\geq$ 0.90 died, while growing season burns resulted in high (70%) mortality rates for trees with dbh < 13 cm.

Most results of research on post-burn pine mortality reflect the short-term outcomes of dormant season, low-intensity fire experiments. The development of robust, more general models to predict tree mortality implies the need to broaden the scope of experimental studies in terms of time since fire, burn season and fire intensity. Data collected in northwest and central Spain revealed that *P. pinaster* survival 15 months after wildfire was best explained by either crown scorch as a fraction of crown length or crown scorch volume, and by either the proportion of bark depth consumed by fire or an exponential function of bark depth. Within patches or stands of *P. pinaster* in northern Portugal that experienced single or multiple fire events, trees with a 12-cm dbh had a 50% probability of surviving wildfire, the average live tree retaining 64% of its live crown length.

4.2.4 Analysis of prescribed burning treatments: assessing effectiveness and planning in time and space

Fuel types mapping is the cornerstone of landscape-level analysis of fire hazard, and hence is vital to the process of selecting areas to treat with prescribed burning, preferably following an integrated and top-down approach, i.e. from the broad regional scale to the local level (De Ronde 2009a). The traditional methods used to recognize and map fuel types are time-consuming and lack accuracy. Several technologies and software to process high-resolution imagery from remote sensing have been developed or tested, based on spectral, textural, object-oriented and 3-D methods applied to study areas in France, Morocco and Greece (Borgniet et al. 2009a). A processing framework and software have been developed to tackle the various end-user needs and data constraints in order to choose the best mix of fuel mapping methods; the user can take into account the different constraints and specificities of geodata (Borgniet et al. 2009b).

The spatial patterns of prescribed burning are critical to its hazard reduction effectiveness when extensive landscape treatment is precluded by the available resources (as well as by other constraints), which very often is the case. After defining the annual fraction of the landscape that can be treated, optimization is essentially a matter of defining the spatial arrangement and location of treatment units. Large, longilinear and irregularly shaped burn units overlapping in the direction of fire spread will maximize fire growth disruption and fire severity fragmentation (Loureiro et al. 2006).

Fire simulation is a powerful and flexible tool to assess the effectiveness of alternative fuel management scenarios and to assist in the temporal and spatial planning of fuel treatments. Fuel complexes typical of limestone region in southern France were generated from known post-burn fuel dynamics as an input to the physically-based Firetec model (Linn et al. 2002). The corresponding fire behaviour simulations indicate that prescribed burning will mitigate fire hazard effectively if applied at 2- to 3-year intervals, but this threshold can be seen as a worst-case scenario, because the spatial resolution used in fuel description underestimates gaps in the fuel complex (Cassagne et al. 2009b); the annual prescribed burning efforts required to eradicate high fuel hazard sections were then estimated for two fuel-breaks. The Farsite fire growth software (Finney 1998) was used in the Marão Mountains, Portugal (Loureiro et al. 2006) and in the Kassandra Peninsula, Greece (Cassagne et al. 2009b) to quantify the landscape-level impact of prescribed burning on the behaviour and size of wildfires conforming to historical patterns. While the first case study was applied to an actual treatment in shrubland and the second one was

Box 1. A tool to plan and evaluate prescribed burning operations in pine stands

PiroPinus (Prescribed Burning Guide for Maritime Pine Stands) is an all-in-one tool based on empirical models to predict fire behaviour and effects for site-specific stand and fuel conditions. PiroPinus was conceived for operational use when planning and evaluating hazard reduction burns and has constantly evolved since its first version (Fernandes 2003). It is composed of several inter-related or stand-alone worksheets and includes the following main functionalities:

- Estimation of fuel loads in each fuel layer, and of moisture contents of surface fine dead fuels and decomposing litter;
- development of prescriptions by combining restrictions for fire severity on the tree canopy and on the forest floor, expressed respectively by crown scorch ratio and duff consumption %;
- assessment of the likelihood of sustained fire spread and of marginal burning conditions and fire characteristics quantification (rate of spread, flame length, Byram's fire intensity);
- ignition planning to optimize treatment rate;
- assessment of canopy injury and tree mortality;
- estimation of fuel consumption and post-burn fuel accumulation;
- post-burn evaluation of fire impacts.

PiroPinus was not tested in species other than maritime pine (*Pinus pinaster*). Nevertheless, it can be easily adapted by replacing equations or adding options for other pines.

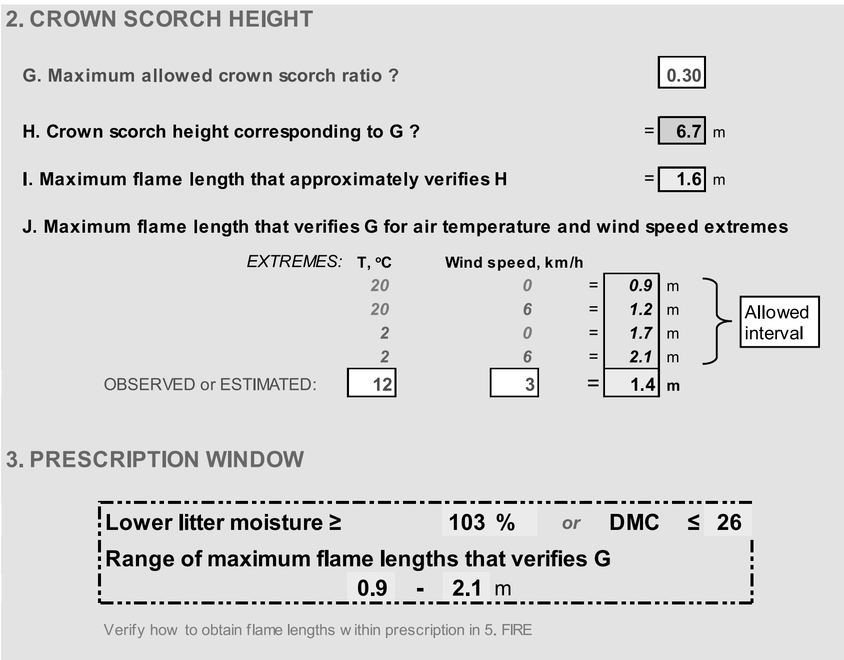

Figure 2. PiroPinus screenshot illustrating the development of a prescription.

applied to an hypothetical treatment in conifer forest, both highlighted the potential of prescribed burning to decrease the likelihood of large-scale wildfire, as well as the crucial role played by the spatial patterns (strategic versus random) of treatments.

Prescribed burning was discussed and proposed as a tool to mitigate CO_2 emissions to the atmosphere in countries with an acute wildfire problem (Narayan et al. 2007). This would encourage its expansion provided that the current carbon accounting practices change (Hurteau et al. 2008). However, the potential of prescribed burning to reduce emissions depends on how the fire regime is changed, especially in terms of the overall area burned and fire intensity (Bradstock and Williams 2009). This would increase even more the relevance of prescribed burning optimization in space and time, as well as giving more weight to fuel consumption and smoke production issues when planning burning operations.

4.2.5 Planning prescribed burning operations

Decision-support systems for prescribed burning operations at the treatment unit level may take several forms, from general guidelines and burning windows to complex software tools. The feasibility and relevance of prescribed burning in pine stands, as well as general technical guidelines that consider fuel classification and stand structure, relative fire resistance, silvicultural regimes and firing techniques, have been compiled by De Ronde (2009b). While derived for the South African environment most of those guidelines are broad enough to apply elsewhere, including in the Mediterranean Basin. However, as previously mentioned, tying the burn objectives to the fire environment is an essential feature of decision support in prescribed burning operations.

Fernandes (2010) has compiled the current burn prescriptions and technological solutions used to develop prescriptions in Europe, noting that burning guidelines are not always consistent (or up to date) with the available scientific knowledge. General burning windows consisting of ranges in weather conditions or in fire danger rating indexes (like in Sweden and Portugal) are commonplace. In Catalonia, Spain, 12 standard prescriptions are individualized on the basis of fuel availability and wind speed. USDA Forest Service fire simulation tools (e.g. Scott and Reinhardt 2001) are used in Spain to prepare site-specific prescriptions, which include sets of values (minimum, preferred, maximum) for weather conditions, fuel moisture contents, fire behaviour characteristics and selected fire effects. In Portugal, the PiroPinus tool (Fernandes, 2003) was developed to assist in planning and evaluating the results of prescribed underburning in maritime pine (*Pinus pinaster*) stands.

4.2.6 Conclusion

This chapter has described the contribution of Fire Paradox to expand the scientific knowledge and technical application for prescribed burning. Past and current research efforts on topics that explicitly or implicitly are relevant to prescribed burning have contributed to answer why, when and how to burn selected European vegetation types. Our understanding of the fire regimes required to perpetuate species and communities has advanced. Wildland vegetation has been characterized into fuel parameters, allowing fire hazard classification and mapping, for inputs into operational and theoretical models of fire behaviour characteristics. Links between the fire environment and indicators of fire severity have been identified and described. Decision-support tools for a more efficient and safe use of prescribed burning are available.

Despite the advances made, the knowledge accumulated up to now is still too fragmented and incomplete, mirroring the present under-development of prescribed burning in Europe. In particular, the relationships between fire behaviour and specific fire effects are poorly understood for many vegetation types. While this may not be an obstacle for sound land management using fire as a tool, it will certainly affect the quality of the achievements of an activity that will likely undergo increased complexity, public scrutiny and debate. Research and development on prescribed burning will continue to be required, but scientific monitoring of the results of both traditional and prescribed burning practices may well be an additional key source of data and information.

References

Borgniet, L., Long, M., Capel, A-C., Bouillon, C., Morge, D., Ganteaume, A., Lampin, C., Jappiot, M., Curt, T., Machrouh, A., Sesbou, A., Mantzavelas, A., Apostolopoulou, I., Partozis, T. and Gitas, I. 2009a. Method to produce vegetation and fuel maps using satellite imagery: Deliverable D5.1-2 of the Integrated Project "Fire Paradox", FP6-018505. European Commission. 51 p.

Borgniet, L., Long, M., Capel, A-C., Bouillon, C., Morge, D., Ganteaume, A., Lampin, C., Jappiot, M., Curt, T., Machrouh, A., Sesbou, A., Mantzavelas, A., Apostolopoulou, I., Partozis, T., Gitas, I., Marell, A., Cassagne, N., Pimont, F., Rigolot, E., Morsdorf, F., Koetz, B. and Allgöwer, B. 2009b. Development of an easy to use tool to recognize and map fuel models: Deliverable D5.1-6 of the Integrated Project "Fire Paradox", FP6-018505. European Commission. 107 p.

Bradstock, R.A. and Williams, R.J. 2009. Can Australian fire regimes be managed for carbon benefits? New Phytologist 183: 931–934.

Cassagne N., Curt, T., Pimont, F., Schaffhauser, A., Rigolot, E., Borniet, L., Dupuy, J.L., Estève, R., Ganteaume, A., Jappiot, M., Martin, W., N'Diaye, A., Petit, P., Portier, D. and Valette, J.C. 2009a. Fuel description and modelling. Internal Report IR3.4-4 of the Integrated Project "Fire Paradox", FP6-018505. European Commission. 41 p.

Cassagne, N., Mantzavelas, A., Dupuy, J.L., Lazaridou, T., Pimont, F., Partozis, T., Fernandes, P., Loureiro, C. and Rigolot, E. 2009b. Report on the effects of broad scale and long-term application of prescribed burning on fire risk components. Deliverable D5.3-1 of the Integrated Project "Fire Paradox", FP6-018505. European Commission. 88 p.

De Ronde, C. 2008. Knowledge base in damage assessment to forests and plantations. Deliverable D3.2-7 of the Integrated Project "Fire Paradox", FP6-018505. European Commission. 21 p.

De Ronde, C. 2009a. Recommendations for prescribed burning mapping in Mediterranean-type natural vegetation and forests. Deliverable D5.4-2 of the Integrated Project "Fire Paradox", FP6-018505. European Commission. 17 p.

De Ronde, C. 2009b. Guidelines for prescribed burning for the specific vegetation types assessed within the FIRE PARADOX community. Deliverable D9.1-4 of the Integrated Project “Fire Paradox”, FP6-018505. European Commission. 63 p.
Dimitrakopoulos, A., Mitsopoulos, I. and Gatoulas, K. 2010. Assessing ignition probability and moisture of extinction in a mediterranean grass fuel type. International Journal of Wildland Fire. In press.
Dupuy, J.L. and Konovalov, V. 2007. Simulations of fire impact on tree foliage: 2D results. Deliverable D2.4-2 of the Integrated Project “Fire Paradox”, FP6-018505. European Commission. 26 p.
Fernandes, P.M. 2003. Sistema de apoio ao planeamento, execução e avaliação do fogo controlado em pinhal bravo. In: O Estado da Arte em Modelação da Floresta – o Caso Português, Actas da I Jornada Técnica de Modelação Florestal. ISG, CIGest, Lisboa. Pp. 33–34.
Fernandes, P.M. 2010. Handbook to plan and use prescribed burning in Europe. Product P13.1-3 of the Integrated project “Fire Paradox”, FP6-018505. European Commission.
Fernandes, P.M., Vega, J.A., Jiménez, E. and Rigolot, E. 2008. Fire resistance of European pines. Forest Ecology and Management 256: 246–255.
Finney, M. 1998. FARSITE: Fire Area Simulator-model development and evaluation. USDA Forest Service, Rocky Mountain Research Station, Res. Pap. RMRS-RP-4. Ogden, UT. 35 p.
Hurteau, M.D., Koch, G.W. and Hungate, B.A. 2008. Carbon protection and fire risk reduction: towards a full accounting of forest carbon offsets. Frontiers in Ecology and Environment 6: 493–498.
Krivtsov, V., Fernandes, P., Higham, B., Pezzatti, G.B. and Legg, C. 2009. Release of prototype software for allometric modelling of fuel structure with provisional case studies. Deliverable D3.3-5 of the Integrated Project “Fire Paradox”, FP6-018505. European Commission. 33 p.
Lecomte, I., de Coligny, F., Griffon, S., Pimont, F., Rigaud, E., Rigolot, E. and Vigy, O. 2009. Fire Paradox fuel manager: software and user’s manual. Product P6.1-6 of the Integrated Project “Fire Paradox”, FP6-018505. European Commission. 85 p.
Linn, R., Reisner, J., Colman, J. and Winterkamp, J. 2002. Studying wildfire behavior using FIRETEC. International Journal of Wildland Fire 11: 233–246.
Loureiro, C., Fernandes, P., Botelho, H. and Mateus, P. 2006. A simulation-based test of a landscape fuel management project in the Marão range of northern Portugal. In: Viegas, D.X. (ed.). Proceedings of the 5th international conference on forest fire research. Elsevier B.V., Amsterdam. CD-ROM.
Mårell, A., Abdelmoula, K., Allgöwer, B., Borgnier, L:, Cassagne, N., Curt, T., Ganteaume, A., Ghosn, D., Gitas, I., Jappiot, M., Jimenez, E., Kazakis, G., Koetz, B., Lampin, C., Machrouh, A., Morsdorf, F., Pimont, F., Rigolot, E., Sesbou, A., Vega, J.-A. and Wellani, W. 2008. Fuel description: first results. Deliverable D3.4-3 of the Integrated Project “Fire Paradox”, FP6-018505. European Commission. 80 p.
McCaw, L., Cheney, P. and Sneeuwjagt, R. 2003. Development of a scientific understanding of fire behaviour and use in south-west Western Australia. In: Abbott, I. and Burrows, N. (eds.). Fire in Ecosystems of South-west Western Australia: Impacts and Management. Backhuys Publishers, Leiden, The Netherlands. Pp. 171–187.
Narayan, C., Fernandes, P.M., van Brusselen, J. and Schuck, A. 2007. Potential for CO2 emissions mitigation in Europe through prescribed burning in the context of the Kyoto protocol. Forest Ecology and Management 251:164–173.
Pyne, S.J., Andrews, P.L. and Laven, R.D. 1996. Introduction to wildland fire. John Wiley & Sons, Inc., New York, USA. 769 p.
Ruiz, A.D., Vega, J.A. and Alvarez, J.G. 2009. Construction of empirical models for predicting Pinus sp. dead fine fuel moisture in NW Spain I: response to changes in temperature and relative humidity. International Journal of Wildland Fire 18: 71–83.

Scott, J.H., and Reinhardt, E.D. 2001. Assessing crown fire potential by linking models of surface and crown fire behavior. USDA Forest Service, Rocky Mountain Research Station, Res. Pap. RMRS-RP-29. Ogden, UT. 59 p.

Vega, J.A., Ruiz, A.D., Ubysz, B., Guijarro, M., Bianchi, L., Defossé, G. and Todone, J.F. 2009. Dead fuel moisture modelling and validation. Deliverable D3.1-8 of the Integrated Project “Fire Paradox”, FP6-018505. European Commission. 68 p.

Vega, J.A., Fernandes, P., Conedera, M., Botelho, H., Fernandes, M., Jiménez, E., Loureiro, C., Lucini, L., Pérez, J.R. and Pezzatti, B. 2008. Tree resistance to fire: first results. Deliverable D3.2-2 of the Integrated Project “Fire Paradox”, FP6-018505. European Commission. 24 p.

4.3 Learning and Training on the Use of Prescribed Burning Techniques

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4.3.1 Introduction

Prescribed burning is often described as a mix of art and science that departs from traditional burning practices by the existence of formal planning and monitoring procedures (Pyne et al. 1996). Due to the special nature of this technique, prescribed burning must be based both on science and experience, and simultaneously, those who perform it, must be skilful and competent.

A prescribed fire seeks well-defined effects that will fulfil one or more management goals, which are attained by burning in a specific fire environment (the prescription) and following specific operational procedures (the burn plan) (Pyne et al. 1996). Fire hazard reduction frequently is the main reason to use prescribed burning, but this technique is also used to manage habitats for pastures, game and conservation (Fernandes et al. 2002).

The traditional use of fire by many rural communities in Europe was, and continues to be, a very important tool in shaping the landscape, together with other techniques like grazing, and cutting, creating a landscape mosaic with high ecological and cultural diversity (Goldammer et al. 2007; Silva 1990; Trabaud 1992; Pyne 1984). However, even if in the history of land use in Europe, fire was an important element with a strong presence in agriculture, forest and grazing areas, after World War II, fire use in rural areas was almost excluded because of land-use changes with the arrival of more technologies and also by the increasing abandonment of rural areas particularly in the Mediterranean. At present, there is a general neglect of traditional fire uses in the northern countries and central Europe in contrast with the continued practice in Mediterranean countries but on a smaller scale than before (see the chapter by Montiel et al. in this book). These traditional practices can be one of the main causes of wildfires through fires escaping (FAO 2007; DG JRC-IES 2008). Because of this problem, the traditional use of fire often has strict regulations, while the knowledge acquired on the utilization of fire to prevent wildfire has started to vanish.

Although in some cases the traditional use of fire can be a cause of destructive wildfires, prescribed burning performed by experienced practitioners has been known for a long time to be beneficial to the reduction of forest wildfire hazard. In the 19th century, the use of fire was already recommended by some Portuguese forestry experts (Varnhagen 1836; Pimentel 1882) as a tool to "control the undesirable understory, especially in pine forests" to prevent wildfires. Similar examples were found in France, in the second half of the 19th century, and the long history of the different cycles on the use of prescribed burning in forestry, including the recent cooperation between Europe and the USA was described in the documentary "Fire in the Balance" (Manso et al. 2008) produced by Fire Paradox and shown at the 20th anniversary of the Yellowstone Fires.

In the most recent decades the use of prescribed burning for the reduction of wildfire hazard in Portugal, Spain and France has importantly increased, with some valuable efforts focused on operational training for prescribed burning.

The first attempts to promote training in prescribed burning for fire prevention in European forests date from the 1980s in Portugal (Rego et al. 1989: Silva 1990). In Spain, the first prescribed burning training course was conducted in 1995 at the University of Lleida, which included a detailed prescribed burning plan and its prescription window using Behave 'RxWindow' software (Andrews and Bradshaw 1990). These prescribed burnings (ca. 2 ha total) were accomplished in plots established in the Tortosa Mountains (Catalonia, northeast Spain). In 1998, the Spanish Ministry of the Environment developed and disseminated a training and demonstration video on prescribed burning with the scientific and didactic support of the University of Lleida. Since 2000, GRAF (the fire fighting organization of Catalonia) has trained on prescribed burning on a regular basis in Catalonia (Spain). At the beginning of the 1990s fire professionals in France created a Prescribed Burning Network and the first "Charter of prescribed burning", signed by 74 technicians in 1997. Materials with contents for the use of fire to support their training program have been permanently updated since then (CIFSC 2004; Binggeli and Bento 2009). Many of these early efforts followed similar programmes in the USA, Canada and Australia where the use of prescribed fire was more widely spread than in Europe and systematic approaches to provide training on the use of prescribed burning techniques were more developed.

In other parts of the world, prescribed burning courses followed similar patterns. For example, in Argentina courses started in 1996 promoted by INTA in Santiago del Estero (Kunst and Moscovich 1996). Before that, several isolated attempts to carry out prescribed burning based on scientific knowledge were made only by the National Park Administration and other organizations. In South Africa, prescribed burning courses have existed since 2001, mainly attended by foresters and nature conservationists.

In all cases, many of the technicians who applied the technique of prescribed burning were forest and range managers, but they could also be fire fighters, among many other professions. We will use the term fire professional for all of those trained in fire. In our point of view, agreeing with Kobziar et al. (2009), fire professionals should have not only specific training on prescribed burning (professional/continuous training) and practical experience in the field, but also a good fire education (university courses).

Following this premise, the objectives of this chapter are to:

- Describe and assess the current context on prescribed burning training in Europe (Spain, Portugal and France);
- Propose ways to continue the efforts to harmonise qualifications in Europe and to permanently exchange experiences on prescribed training;

- Describe and assess the current situation with regard to forest education, university level in Europe (Spain and Portugal) and compare it to the US forest education;
- Propose new ways for the example of an International Graduate Program in Fire Science and Management.

4.3.2 Training on prescribed burning in Europe

When addressing the term vocational training, the focus is on "providing the skills, knowledge and competences needed in the labour market" (Tissot 2004). In this section we will describe the vocational training on prescribed burning in Portugal, Spain and France since these are the countries in Europe with the most experience on this subject. Details on the training systems are provided in Molina et al. (2009).

In Portugal there are several institutions and professionals that work in a direct or indirect way with fires. To acquire competences on the use and management of fire (prescribed burning included), these professionals look for specific training that can be provided by universities, institutions like the National Forest Authority (at the base of Lousã) or by some Portuguese Forest Associations (in particular Forestis) in partnership with the universities.

In Portugal, by law, only an accredited technician can conduct a prescribed burn. Due to that obligation, the National Forest Authority (AFN) certifies the technicians and their training by law (Portaria nº 1061/2004 of 21st of August). Also, to perform a prescribed burn, the 'Burning plan' must be evaluated by the municipalities and forest services, with the technicians of those entities also receiving specific training to acquire the knowledge to evaluate the burning plans. Finally, there is a specific training provided by AFN for the forest workers and fire prevention brigades that support the use of prescribed fire.

The contents of the three types of training are common in addressing issues as guidelines for use of fire, fire behaviour and its impacts, and prescribed burning planning and operational implementation. These issues are addressed at different depths and the practical modules with field experience are not required for the group of the evaluators. The duration of the courses vary accordingly:

1. Prescribed burning training for technicians accreditation
   Theoretical modules (duration: 21 hours)
   Theoretical-practical modules (duration: 35 hours)
   Practical modules (duration: 49 hours)
2. Training for technicians able to evaluate the prescribed burning plan
   Theoretical modules (duration: 9 hours)
   Theoretical-practical modules (duration: 19 hours)
3. Forest workers and fire prevention brigades
   Theoretical modules (duration: 4 hours)
   Simulated practice modules (duration: 31 hours)

In Spain, although several vocational courses are offered to professionals by the Ministry of the Environment, or by fire fighter academies, none of them work specifically on prescribed burning except for the region of Catalonia. There, the Institute for Public Safety (ISPC) has been providing training in the use of fire since 2001. There are five training levels for different job positions (all end-users in the fire fighting institute) and two specific modules for: (i) specialists that will execute both prescribed burning and backfiring), and (ii) managers who plan and supervised them. Today a total of 120 fire fighters and managers have taken these courses. Since 2009, 55 of them have a certificate that ensures the required competence for a wise use of fire.

Recently (since 2008), the Department of the Environment of Gran Canaria (Canary Island local government) is developing a prescribed burning course in collaboration with the University of Lleida. They have accomplished three editions with more than 50 people. Trainees receive a diploma if they pass the course. Additionally, the Department of the Environment will latter certify their competence (for their workers) after successful work on 20 prescribed burning days (equivalent to 160 hours).

In France, fire is taught through a professional training system that is only available in some regions. Since the risk of wildfire is only important in part of the country, only 32 departments (mostly in the south) among the 95 departments are subject to the wildfire risk legislation. Only fire fighters and fuel managers of this part of France are to be trained in prescribed burning techniques. Therefore, there are two schools for fire professionals in France dealing with prescribed burning – an established one in the southeast, and a more recent one in the southwest). The schools are managed by the civil protection services but are open to foresters.

French trainees on prescribed burning get a training certification if they follow and complete a specific course and are endorsed by the trainers. The certificate is valid for five years and they can become prescribed burning bosses if asked by their employers. The assessment of practices in the field is only performed by the employers. Better assessment of the quality of the practices in the field could strengthen the development of this technique.

Training in prescribed burning is the same for fire fighters and for vegetation and fuel managers. They are learning in the same classrooms and practicing together in the field. A general certification for conventional fire fighting activities, with five levels, includes assessment of trainees. However, prescribed burning is a training option that French fire fighters or foresters are not required to take.

4.3.3 Cooperation, exchanges and the search for harmonization of European qualifications on prescribed burning

One of the objectives of Fire Paradox was the creation and sharing of knowledge between fire professionals of Europe and elsewhere and the promotion of their mobility between countries. However, with the diversity of educational qualifications in different European countries, the mobility of workers in Europe is very difficult. To solve this question, the European Commission created The European Qualifications Framework (EQF) that acts as a translation device to make national qualifications more readily understood and compared across Europe,

Table 1. EuroFire competency standard units and training modules for self learning.

Competency standard units	Training modules for self learning
EF1:Ensure that your actions in the vegetation fire workplace reduce the risks to yourself and others.	EF1: Ensure that your actions in the vegetation fire workplace reduce the risks to yourself and others
EF2: Apply techniques and tactics to control vegetation fire	EF2: Apply techniques and tactics to control vegetation fire
EF3: Communicate within a team and with supervisors at vegetation fires	EF4: Apply hand tools to control vegetation fire
EF4: Apply hand tools to control vegetation fires	EF6: Apply vegetation ignition techniques
EF5: Control vegetation fires using	
EF6: Apply vegetation ignition techniques pumped water	

promoting the mobility of workers and learners mobility between countries and facilitating their lifelong learning (EC 2008). The EQF does this by setting qualifications into a series of reference levels (1–8), from basic to advanced. The eight reference levels are described in terms of learning outcomes, split into knowledge, skills and competence.

In collaboration with Fire Paradox, the EuroFire project (www.euro-fire.eu/), has developed fire training materials to support the development of similar fire management skills across the European Union. These materials have been developed to support fire training and assessment for a Level 2 work environment (members of a tanker crew, hand crew, or prescribed burning crew) whose personnel are instructed to do tasks under direct supervision. Six EuroFire competency standard units (Table 1) for fire crews and personnel involved in the suppression of wildfires (forest fires and rangeland fires) and in prescribed burning have been developed. Four training modules to support fire fighters self-learning are also available on the EuroFire website.

The diversity of fire professional qualifications in different European countries is also related to the complexity and diversity of cooperation mechanisms between departments dealing with fire management at the European and National Level (Correia et al. 2008). In spite of this complexity there are good examples such as that of the cooperation in the field of sharing knowledge, information and practical experiences between Spain and Portugal. Because of the lack of a global European framework for continuous cooperation between fire professionals the opportunities provided by the General Assemblies of Fire Paradox were used to promote exchanges between these professionals:

- Cagliari, Sardinia, Italy (2007) Seminar on the use of prescribed burning in Italy for the prevention and fight against forest fires. The objective of this seminar was to initiate and stimulate the development of the theme of prescribed burning in Italy, through the exchange of ideas, knowledge and experiences between Italian professionals and professionals from other countries;

- Chania, Crete, Greece (2008) Enriching fire management in Greece with new tools: suppression fire and prescribed burning. This seminar had the purpose of initiating a plural debate on the use of fire in Greece, where it is still not allowed. Some professionals, forestry and fire fighters, and Greek researchers, gave their contribution, in order to show some initial experiences on prescribed burning, as well as, the need to legalise suppression fire, often used in fire fighting without consent. International experts explained the use of fire in their respective countries, as a way to influence a serious reflection on the introduction of the use of fire on prevention and fighting Greek wildfires.
- Puerto Madryn, Patagonia, Argentina (2009) 1st South American Symposium on Fire Ecology and Management. This symposium had the purpose of gathering South American professionals together to debate on fire ecology and management. Some professionals, forestry and fire fighters, and Argentine researchers, gave their contribution, describing the diversity of situations on the use of fire in South American countries (Argentina, Uruguay, Chile and Paraguay).

These types of meetings are also a very good opportunity to discuss and exchange views, experiences and actions and to address issues as job hazard abatement during the use of fire, allowing for the completion of an educational and training report on "Guidelines to mitigate personal risk in prescribed burning and suppression" (Pous et al. 2010).

The way forward for the continuation of the exchanges and cooperation between fire professionals can be based on the experience of these meetings and especially on the Euro-Mediterranean meeting for prescribed burning professionals held in Lousã, Portugal, 4–8 February 2009.

Similarly to the objectives of the annual meetings of the French National Prescribed Burning Network, this Euro-Mediterranean meeting had the main goal to expand exchanges to a much broader public, encouraging knowledge transfer and promoting interactions between European prescribed burning professionals. This was a very fruitful initiative, gathering almost one hundred Portuguese, Spanish, Italian, French, Moroccan and German prescribed burning professionals (Figure 1). For five days the participants had the opportunity to visit twelve sites where prescribed burning had been applied, as demonstration sites.

Future training initiatives at the European level should also make extensive use of the Network of Demonstration Sites for Prescribed Burning created by Fire Paradox (Molina et al., 2009b). Documentation of the most relevant sites can be found in the Fire Paradox information platform – Fire Intuition (fireintuition.efi.int/).

A permanent framework for these exchanges of experiences at the European level, taking advantage of the networks of sites, people and materials gathered in projects such as Fire Paradox, and building on the experiences of national and international meetings is fundamental for the future.

Figure 1. Visit to a prescribed burning demonstration site during the "Euro-Mediterranean meeting for prescribed burning professionals".

4.3.4 Fire education in Europe (Portugal and Spain)

The European Universities and Institutes must enter by 2010 the European Higher Education Area (EHEA) where the university systems will be harmonized under the Bologna agreements, consisting of three different levels of studies:

- 1st cycle, with 3–4 academic years of study (depending on each country the denominations can be Bachelor of Sciences BSc, engineer, deputy forestry engineer, technical engineer, among others);
- 2nd cycle with 1, 1.5 or 2 more academic years (denominations like Master of Science MSc, graduate, and forestry engineer are common);
- 3rd cycle, consisting of more 3–5 academic years (the denomination of this level is Doctorate, Philosophy Doctor, PhD).

In Europe, specific university level courses on fire management are mostly available in Portugal and Spain, and these were reviewed by Colaço (2005) and by Molina et al. (2009a). Although France is a country with a tradition of forest science, and experience in the use of the prescribed burning technique, at present, this formal education system does not include courses on prescribed burning, even if they are topics in the PhD programs of some French university schools (Molina et al. 2009a).

In Portugal, fire management education is inserted both in the educational formal context as a forest engineering graduation major (university level) and in continuous learning and training programmes, that can also be offered by polytechnic institutes,

Table 2. Forestry Science higher studies in Portugal and corresponding fire courses.

	Courses (with the corresponding European Credit Transfer System – ECTS*)	
	First cycle	Second cycle
ESAB, ESAV	Forest Fires (6 ECTS)	
ESAC	Forest Defense Against Wildfires (6 ECTS)	Planning of Forest Defense Against Wildfires (6 ECTS)
UTAD, ISA/UTL	Forest Protection (7-7.5 ECTS)	Fire Ecology and Management (5-6 ECTS)

* 1 ECTS = from 25 to 30 hours (EC 2007)

especially with technological specialization programmes (CET). The CET training programmes in Portugal allow for integration into the working world after the secondary school or the continuation of studies at university level. The training held in CET is credited within the university where the student is admitted. In Portugal there are two approved CET programmes on Forest Defence Against Wildfires. Both are promoted by Polytechnic Institutes, (Coimbra and Bragança) with 43 European Credit Transfer System (ECTS) credits each and two semester duration (including 420 to 600 hours of training in a work context). Both schools have the course of prescribed burning with 3 ECTS.

In Portugal, there are five schools that offer graduate studies in Forestry science: two Universities (the University of Trás-os-Montes and Alto Douro - UTAD - in Vila Real, and the Technical University of Lisbon with the Institute of Agronomy - ISA/UTL), and three polytechnic institutes (the Agrarian Schools of Bragança ESAB, Viseu ESAV and Coimbra ESAC). All the schools have courses related to fires (Table 2).

The PhD degree is given by ISA/UTL and UTAD. On this cycle there are no specific courses on fire, however students can do their research in this subject area.

In Spain, there are twelve universities/colleges offering higher education for fire professionals. On the 1st cycle, corresponding to six semesters, 11 schools have a mandatory course on 'Natural Resources Protection' including Wildland Fire Issues with around 120 hours of instruction. On the 2nd cycle, seven schools have a mandatory course on 'Natural Systems Management & Protection' including Wildland Fire Issues with around 240 hours of instruction (Table 3).

Spanish universities also provide graduate courses or fire management that are nearly always short (less than 9 ECTS credits), and frequently are partly on-line courses. These courses are addressed to professionals who want to improve the knowledge that they have in specific subjects, to know the advances and the new contributions and also to be in touch with other specialists. The University of Lleida, University of Cordoba, and Polytechnic University of Madrid offer different courses on the subject 'Wildland Fire Management'.

Taking the University of Lleida as an example, we see that in this school, students can enrol in any of these courses individually and get credit and a diploma for it. However, a 'Wildland Fire Management Master' degree can be achieved if a final thesis or project is completed and a total of 45 ECTS credits is obtained.

Table 3. Forestry science higher studies in Spain with fire contents.

Universities	First cycle	Second cycle
Universidad de Córdoba	No	Yes
Universidad de Castilla-La Mancha, Universidad de Extremadura, Universidad de Huelva, Universidad de León, Universidad de Oviedo	Yes	No
Universidad Católica Santa Teresa de Jesús de Ávila, Universidad de Lleida, Universidad Politécnica de Madrid, Universidad de Santiago de Compostela, Universidad de Valladolid, Universidad Politécnica de Valencia	Yes	Yes

At the European level, the existing cooperation in forestry associates six European universities (Joensuu, as coordinator, Lleida, Freiburg, Vienna, Wageningen, and the Swedish Agricultural University) for a Master of Science in European Forestry. The Master of Science in European Forestry Erasmus Mundus (MSc EF) is a 2-year double-degree program including various topics. The idea of the MSc-program is to respond to the increasing number of issues in forest and nature management that are formulated, implemented, and co-ordinate above the classical nation-states, providing a whole range of new challenges and demands for policy and management at the European level. In this context, the participation of the University of Lleida includes a course on 'Principles of Wildland Fire Science and Management' and a 'Prescribed Burning Laboratory' with the cooperation of GRAF in Catalonia.

Cooperation between universities of different European countries exist in many research projects dealing with fire management but no specific common degree programmes under this topic have been developed.

4.3.5 Current initiatives in cooperation on fire education outside Europe

International cooperation developed under the Fire Paradox project outside Europe. Four international prescribed burning courses were taught between 2007 and 2009 in Patagonia and Santiago del Estero. The courses were organized by the two Argentinean teams (INTA and CIEFAP) with the assistance of the University of Lleida. More than 180 fire fighters, forestry students and professionals (most of them from different Argentinean provinces, but also from Spain, Uruguay and Paraguay), were trained in the use of prescribed burning techniques. The end result was the decision taken by the University of Patagonia during the 1st South American Fire Ecology and Management Symposium, to support the creation of a Masters Degree Program, which will continue with the task of broadening the knowledge and giving a more academic and professional scope to the dissemination of fire science, and in particular to training and learning about the use of prescribed burning techniques initiated during the development of the project.

Table 4. Universities in the USA offering both undergraduate and graduate fire specific courses (adapted from Kobziar et al. 2009).

US Universities	Number of fire specific courses Undergraduate Level	Graduate Level
Humboldt State University	6	2
California Polytechnic & State University; University of Idaho	6	1
Colorado State University	4	2
Oklahoma State University; Oregon State University	3	2
Northern Arizona University	3	1
Texas Tech University; University of Florida	2	2
Clark University; Stephen F. Austin St University; University of California-Berkeley; University of Oregon; University of Montana; University of Washington	1	1

New initiatives to enhance international cooperation should be based in the knowledge of the status of fire education outside Europe. To compare the academic studies on fire outside Europe we decided to use the case of the USA since it is a country with strong experience in fire education and training, with a recent and excellent review on the challenges to educate their fire professionals (Kobziar et al. 2009).

As in Portugal and Spain, fire management and ecology education have been concentrated in forest and range management programs at universities and technical community colleges. According to a recent study, only 22 of the thousands of US universities (providing 2- or 4-year programs), "provide substantial educational opportunities in wildland fire management and ecology" (Kobziar et al. 2009).

From the 22 universities and colleges that provide at least one certificate or degree in fire science, 15 of them offer courses both for undergraduate and graduate studies (Table 4). Nine universities offer several fire specific courses at both levels. This allows for a certain specialization very useful for cooperation.

The need to target mid career professional, technicians or fire professional that are already employed, meant that both the US and Spanish universities prepared specific courses for them. This is the case of the University of Idaho which has an academic major and eight fire-specific continuing/distance/ short courses related to fire science.

4.3.6 New challenges and initiatives for the educational profile of a fire professional

To have a well educated fire professional, the professional needs to learn, and that is a "process where knowledge is presented to us, then shaped through understanding, discussion and reflection" (Freire 1998).

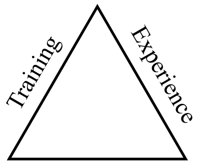

Figure 2. The fire professional development triangle (Kobziar et al. 2009)

In the last decades, there has been a substantial effort to understand, discuss and reflect about fire and new challenges have appeared for the educational background of a fire professional. According to Stephens and Ruth (2005), "fire management is in transition from an era dominated by fire suppression, to one where fire use and suppression are equally viable resource management options." Due to this changing paradigm, the education and training system must evolve to a more integrated way of looking into the use of fire in the ecosystem.

As referred to in Kobziar et al. (2009) the "new generation of fire professionals must continuously incorporate new knowledge on fire ecology, fire behaviour, and social sciences to tackle the multifaceted issues they will face". Kobziar et al. (2009) developed the 'Fire Professional Development Triangle', which depends on integrating training, education and experience (Figure 2). None of the sides of the triangle should be underestimated, but should be complementary.

In spite of these new needs, recognized internationally, there are still no internationally stable frameworks for cooperation between entities that would provide the new fire professionals with the knowledge, skills and competences for the future demands.

In addition, it is widely recognized that modern approaches to education in fire science should use the concepts of Integrated Fire Management. This implies that a complete fire professional could be trained to understand and/or use both prescribed burning and suppression fire. Simultaneously he/she should understand the social context including the traditional fire uses. This is a new perspective, solving the apparent paradox of having agents only prepared to use fire and others only prepared to extinguish it without an integrated perspective. At the moment there are no such international education programs.

Being aware of this gap at the international level, Fire Paradox launched the initiative to develop an International Graduate Program in Fire Science and Management for a Masters Degree (FireMaster). A partnership was established between the members of the Fire Paradox consortium with more experience in education in prescribed burning (University of Lleida and UTAD) and two of the more experienced US universities in this subject (Idaho and Florida) with the intent to extend the partnership in a second step to other universities (e.g. ISA and Patagonia). The objective of the partnership is to jointly develop a program to educate European and American graduate students in understanding, synthesizing and applying science to support Integrated Fire Management for forests and other natural resources.

Globally, the Graduate Program could involve three complementary parts, referring to science, applications and projects:

- Advanced Fire Science courses offered online and developed jointly for different topics (Fire Ecology, Fuels Inventory and Management, Fire Behaviour, Analysis of Real Case Studies, Fire and Landscape Dynamics, and an International Seminar), with a strong theoretical foundation and case studies from multiple ecosystems around the world.
- Field/laboratory/hands-on application courses (Prescribed Burning Laboratory, Restoration and Post-Fire Management, and Integrated Fire Management). These courses involve learning how the social, cultural and environmental context influence the fire challenges and their practical solutions.
- Professional project, including design, implementation and evaluation. These projects could benefit from the assistance of collaborators at partner institutions in the USA (e.g. US Forest Service Fire Science Labs), in Europe (e.g. Centre for Applied Ecology in Portugal), and agencies operating internationally, including the Global Fire Initiative of The Nature Conservancy, World Wildlife Fund for Nature, International Union for Conservation of Nature and the International Association of Wildland Fire.

This Fire Paradox initiative could be the international framework for the fire education of professionals of the future generation, taking advantage of all the materials and the network provided by the project. Such an initiative should use the global concept of Integrated Fire Management, and fully utilize the possibilities provided by the different nature of the partners, applying the positive spiral started in the triangle of Education, Training and Experience.

References

Andrews, P.L. and Bradshaw, L.S. 1990. RXWINDOW: defining windows of acceptable burning conditons based on desired fire behavior. USDA For. Serv. Gen. Tech. Rep. INT-273.

Binggeli, F. and Bento, L. 2009. Paradox – Living and working with fire – International News Magazine for Professional Fire Fighters. Edition 1, April 2009. "Fire Paradox" European Commission. 17 p.

CIFSC 2004. Mémento Permanent – Responsable de Chantier Brûlafe Dirigé. Centre Interregional de Formation de la Securite Civile. Château de Valabre, Gardanne, France.

Colaço, M.C. 2005. Prevenção de Incêndios Florestais: Um estudo sobre a formação dos técnicos florestais. Traballo de Investigación Tutelado, Programa Interuniversitario de Educación Ambiental, Universidade de Santiago de Compostela, Departamento de Teoría e Historia da Educación, España.

Correia, A., Colaço, C., Rego, F., Solana, J., Herrero, G., Montiel, C., Sesbou, A. and D. Kraus. 2008. A review of the existing cooperation mechanisms between departments dealing with fire management at the European and national level. Deliverable D7.1-4-1 of the Integrated Project "Fire Paradox", Project no. FP6-018505. European Commission. 58 p.

EC 2007. Características principais do ECTS. DG Education and training. http://ec.europa.eu/education/lifelong-learning-policy/doc/ects/key_pt.pdf

EC 2008. The European Qualifications Framework (EQF). EC Education and training. http://ec.europa.eu/education/lifelong-learning-policy/doc44_en.htm

FAO 2007. Fire management – global assessment 2006. FAO Forestry Paper 151.

Fernandes, P., Botelho, H. and Loureiro, C. 2002. Manual de formação para a Técnica do Fogo Controlado. Departamento Florestal, UTAD, Vila Real. 55 p.
Freire, P. 2008. Teachers as Cultural Workers – Letters to Those Who Dare Teach, Translated by Donoldo Macedo, Dale Koike, and Alexandre Oliveira, Westview Press, Boulder, CO.
Goldammer, J. G., Hoffmann G., Bruce, M, Konsrashov L., Verkhovets S., Kisilyakhov Y. K., Rydkvist T., Page H., Brunn E., Lovén L., Eerikäinen, K, Nikolov, N. and Chuluunbaatar, T.O. 2007. The Eurasian Fire in Nature Conservation Network (EFNCN): Advances in the use of prescribed fire in nature conservation, landscape management in temperate-boreal Europe and adjoining countries in Southeast Europe, Caucasus, Central Asia and Northeast Asia. 4th International Wildland Fire Conference, Seville, Spain. Pp. 13–17.
JRC-IES. 2008. Forest Fires in Europe. Report nº 9/2009. JRC Scientific and Technical Reports. 88 p.
Kobziar, L.N, Thode, A., Rocca, M., Dicus, C., Hoffman, C., Sugihara, N., Varner, J. M. and Morgan, P. Challenges to educating the next generation of wildland fire professionals in the US. Journal of Forestry 107(7): 339–345.
Kunst, C. and Moscovich, F. 1996. Fuego Prescripto. Introducción a la Ecología del Fuego y Manejo de Fuego Prescripto. INTA and Universidad Nacional de Santiago del Estero. Santiago del Estero. Argentina
Manso, F., Rego, F.C., and Binggeli, F. 2008. Fire in the balance (video documentary). Fire Paradox. Lisbon.
Molina, D., Cabré, M., Pous, E.; Valese, E., Colaço, C., Rego, F., Sesbou, A., Kunst, C., Defossé, G., Lazaro, A., Herrero G., Solana, J., Rigolot, E., Kraus, D. and Delogu, G. 2009a. Survey of the existing academic and professional training materials related to forest fire. Deliverable D10.1-1 of the Integrated Project "Fire Paradox", Project no. FP6-018505. European Commission. 52 p.
Molina, D., Cabré, M.M., Valese, E., De Ronde, C., Kunst, C., Defosse, G. and Loureiro. C. 2009b. Implemented set of demonstration sites for prescribed burning. Product P9.1-3 of the Integrated Project "Fire Paradox", Project no. FP6-018505. European Commission. 41 p.
Pimentel, C.S. 1882. Pinhaes, Soutos e Montados – Cultura, Tratamento e Exploração D'estas Matas. Lisboa.
Pous, E., Molina, D., Cabré, M. and Blanco, J. 2010. Guidelines to mitigate personal risk in prescribed burning and suppression. Deliverable D7.1-3-7 of the Integrated Project "Fire Paradox", Project no. FP6-018505. European Commission. 80 p.
Pyne, S.J., Andrews, P.L. and Laven, R.D. 1996. Introduction to Wildland Fire. 2nd ed. John Wiley & Sons, New York.
Pyne, S.J. 1984. Introduction to Wildland Fire, John Wiley & Sons, New York.
Rego, F.C., Botelho, H.S., and Silva, J.M. 1989. Workshop on prescribed fire research (Proceedings). UTAD/DGF/ESF (FERN) Commission of the European Communities. Vila Real, Portugal.
Silva, J.M. da. 1990. Alterações profundas sofridas pelos ecossistemas florestais portugueses e a sua relação com a incidência de incêndios - A Técnica do Fogo Controlado, UTAD, Vila Real, Portugal.
Stephens, S.L. and Ruth, L.W. 2005 Federal forest fire policy in the United States. Ecological Applications 15:532–542.
Tissot, P. 2004. Terminology of vocational training policy: A multilingual glossary for an enlarged Europe. European Centre for the Development of Vocational Training (Cedefop), Luxembourg: Office for Official Publications of the European Communities.
Trabaud, L. 1992. Les Feux de Forêts, Mécanismes, Comportement et Environnement – France-Selection, Aubervilliers.
Varnhagen, F.L.G. 1836. Manual de Instruções Práticas sobre a sementeira e corte dos pinheiros, e conservação da madeira dos mesmos: indicando-se os methodos para o clima de Portugal. Academia Real de Sciencias de Lisboa.

5. Suppression Fire: a Tool to Control Wildfires

5.1 Overview of Suppression Fire Policies and Practices in Europe

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5.1.1 Presence, diversity and complexity of suppression fire practices in Europe

Suppression fire is defined as the use of fire to fight wildfires. This is an 'intentional application of fire to speed up or strengthen fire suppression action on wildfires; types of suppression firing include burning out, backfiring, line firing, counter firing, and strip burning' (FAO 1986). This technique for wildfire suppression has a long tradition in Europe. Fire has been used by the local population as a wildfire fighting tool for protecting their own lives and assets long before fire fighting services were established in many European countries prone to fire hazards. In the recent past, fire fighting agencies have also looked more in detail towards the use of fire as a complementary tool to other fire fighting techniques because of the evolution of wildfire hazard conditions.

Indeed, the current situation of forest ecosystems (overgrowth of vegetation) in conjunction with unfavourable weather conditions (high temperatures, very low humidity and strong winds) means that, in the worst situations, the magnitude of wildfires overwhelms the extinction capacity of conventional means for fire fighting. The velocity at which flames propagate and and the high intensity make wildfires unstoppable. In this context, suppression fire is one of the methods of conducting indirect attack, by planning the control of the fire fronts by surrounding the fire with fuel-free strips, fire and control lines. Once the control stage is achieved, if fire intensity allows, direct attack is continued otherwise performing backfiring techniques is advisable (Martínez 1997). Suppression fire is therefore not the solution to extinguish a wildfire, but in the right circumstances suppression fire supports containment and helps control the fire. Hence it is one more contribution to extinction strategies.

Thus, suppression fire is a potentially powerful and very efficient technique, especially in the event of large wildfires. In the Mediterranean area, it is used for facing quick and intense fire fronts, and in Northern-Central Europe, suppression fire is mostly directed to anchor extensive flanks that are difficult to access or flanks which overcome the capacity of the extinction means. Nevertheless, this technique to stop wildfire propagation is not sufficiently used in Europe. Its development had an earlier start in Portugal and Spain (in the 1970s and 1980s), and more recently also in southern France and a number of other European countries. Currently, the use of suppression fire is mainly concentrated in southern Europe.

The assessment of suppression fire practices is a very complex issue. It is often difficult to distinguish between traditional use of suppression fire by the rural population and its implementation by forest and civil protection services; in many European countries suppression fire is used in a clandestine way. Suppression fire therefore raises a complex paradox in Europe: it is an ancient and very efficient technique in wildfire extinction, especially in the event of large fires, but its use is limited, and often clandestine. The origin of this paradox has sociopolitical roots and hence tackling and solving the paradox must involve social and political channels. It is necessary to have a previous knowledge of the problem, identifying where and under which conditions suppression fire is used, as well as the positive and negative factors which have an influence on its use. This has been the approach of Fire Paradox to obtain an overview of suppression fire practices in Europe at national and regional level, allowing identification of existing conflicts and opportunities for the use of suppression fire framed in an integrated fire management system.

The purpose of this chapter is to show the results obtained through the analysis of policies and practices of suppression fire in Europe. Firstly, the spatial pattern of suppression fire practices is displayed, as well as the diverse legal and political approaches existent at the national and regional scale regarding suppression fire. After that, the key elements and challenges for the use of suppression fire in Europe are identified, highlighting the importance of the local scale in planning, management and decision making. Finally, recommendations are formulated in order to promote the use of suppression fire according to the socio-spatial circumstances of the European territories.

5.1.2 Introduction of suppression fire techniques in legal and policy instruments

Large wildfires have been a major problem for Mediterranean countries since the 1990s. Simultaneous large wildfires occurring in “windows” of severe fire weather takes turns from one country to another throughout summer. The episodes of large wildfires recorded in Portugal, southeastern France and northeastern Spain (2003), Portugal (2004, 2005), Greece (2000, 2007 and 2009) show how the behaviour of large fires exceeds suppression capacity. Nowadays, large wildfires spread so fast and with such energy, that it is necessary to have an extinction system enough flexible to easily allow a change of priorities. Nevertheless, wildfire suppression tactics are still almost completely dependent on direct attack methods, based on water use and aerial support.

The system of fire prevention-extinction must adapt to the real necessities of the problem. It must change from a total-attack strategy reacting to wildfire, towards a confinement strategy based on the anticipation of fire behaviour, in order to maximize opportunities in those places where fire is vulnerable. In this context, the use of fire is coming back and claiming its role as a safe, efficient tactic, dependent on time and place. Fire used as a suppression tool has been very successful in fighting large fires, as it broadens the range of opportunities and speed in which successful tactics can be performed. Also it offers a wide range of tactical options, from backfires or burnout operations, to perimeter definition or linking suppression actions up to an anchor point or a strategically defensible area.

There are many possibilities for using fire to fight fire that are at present misused or neglected because of the loss of fire culture and knowledge in European countries, and also because of the fire suppression policies and regulations. Suppression fire practices are used extensively but insufficiently regulated in southern Europe. On the other hand, it is difficult to distinguish between the use of suppression fire by rural population as a fighting tool to defend their territory[1], and the professional use by fire fighting services as an extra tool for wildfire suppression. This is one of the reasons why it is so difficult to find information about the professional, regulated use of suppression fire in Europe (Lazaro et al. (2008) (see Figure 1). Furthermore, even though suppression fire is a well known practice in Europe, national fire polices have not taken this technique into account from the beginning and not all the countries have a legal or technical definition for it. That means that fire use in wildfire suppression is generally not regulated, except in Catalonia (Spain), Portugal, France and recently in Sardinia (Italy) (Herrero et al. (2009).

Obviously, each country has a different fire problem and needs different regulations on fire suppression, fire prevention, or the use of fire in suppression or in prescribed burning. In general, the existing regulations endorsing the use of technical fire as both a tool for management and wildfire extinction require the necessity of setting out a change as for large wildfire management. The concepts on which technical use of fire is based, and the qualifications required to perform duties involving these techniques need to be laid down. Additionally, these regulations also usually define the main applications for suppression fire. For instance, the Catalonian Decree[2] includes legal definitions for two types of suppression fire:

- Backfiring as ‘an extinction manoeuvre carried out with technical fire with the aim of eliminating and/or shifting oxygen, verticalizing the column and achieving that secondary spots fall within the burned area hence halting the advance of the main fire front’.
- Burning out as ‘an extinction action performed by means of technical fire, pursuing the aim of removing vegetation fuel in those areas in potential danger of being burnt by the uncontrolled advance of wildfires’.

5.1.3 Key elements and challenges for suppression fire practices

European countries and regions must have their own fire task forces ready to deploy all parts of their territories with a complete set of tactics in the case of wildfire, including indirect attack using suppression fire. There are however a number of constraints which hinder the use of fire as an extra-tool for wildfire suppression, amongst which we can find the following:

1 This practice is forbidden in European countries, meaning the igniter of a fire is identified as an arsonist who sets fire during the summer period. Lighting a fire, even when the intention is to extinguish another one, may be considered a crime.

2 Decree no. 312/2006. BOGC nº 4685 of 27 July 2006.

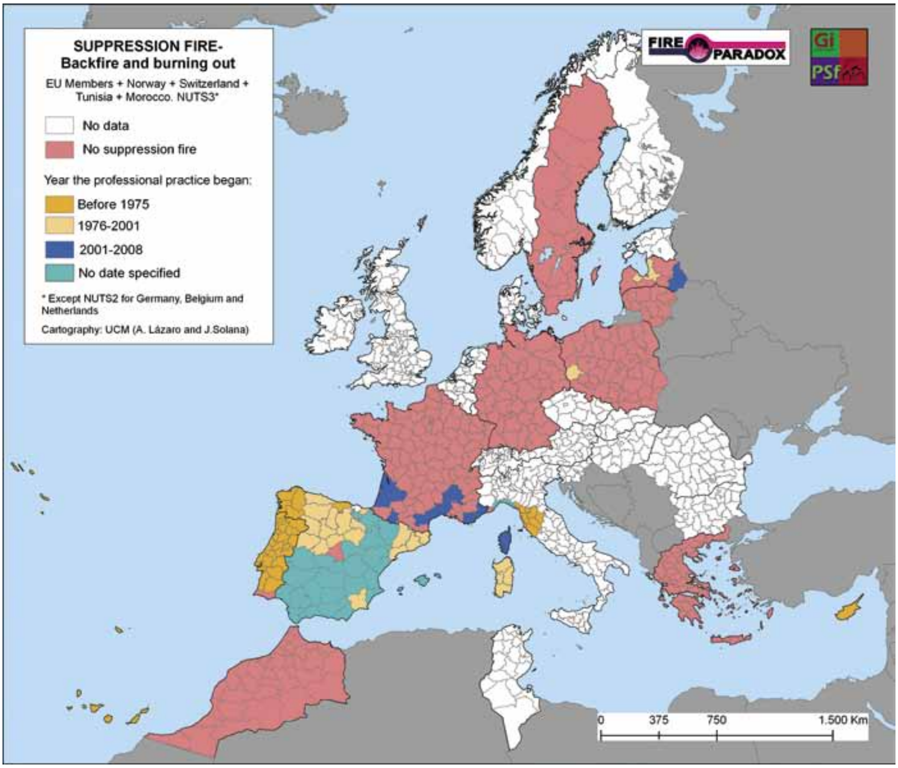

Figure 1. Suppression fire use in European regions and year when the professional practice began.

a) This technique requires support from local forces, which usually are neither reliable nor flexible enough to perform joint manoeuvres with personnel of higher administrative levels;
b) The loss of culture of fire or the lack of social consensus to carry out the use of fire can result in counterproductive social behaviour;
c) The conflicting position of land-owners regarding backfiring in emergency situations;
d) The civil responsibility of the Incident Commander leading wildfire suppression actions and taking the decision to use suppression fire techniques or not.

Therefore, the opportunity and capacity to perform indirect attack methods for wildfire suppression does not only depend on regulations and their implementation, but also on developing planning and management actions at the local level and beyond.

Figure 2. Cork oak slope with sweet chestnuts stands in Maures mountains (municipality of Collobrières, France). The application of suppression fire techniques require certain territory conditions in order to manage fire by using anchor points and areas with different combustibility: mosaic landscape structure (mountain topography and discontinuity in forest fuels), absence of isolated settlements and a well-maintained path network. (photo by C. Montiel).

Planning and management at the local level:
The effective and socially accepted use of suppression fire in Europe depends on a string of spatial and socioeconomic factors that influence the existence and nature of fire use practices in the different countries and regions. These include:

a) *Landscape conditions:* the traditional use of fire by rural population as a fire fighting tool was based on a mosaic landscape with a well-maintained path network and clustered houses, that is, the maintaining of the traditional Mediterranean agro-silvo-pastoral socio-spatial system (see Figure 2).
b) *Know-how:* suppression fire practices are to a large extent sustained in traditional fire use knowledge. Fire culture and collective experience were essential for the traditional use of fire. Nowadays we can speak about knowledge of fire behaviour and professional experience.
c) *Territory appraisal and awareness:* knowledge of the territorial characteristics-, such as topography, vegetation structure, distribution of habitats and infrastructure, path conditions, etc. (see Figure 3).

Figure 3. Second front of the backfire practiced in La Malière (municipality of Collobrière, France) during the wildfire of 1990: the asphalt road and the herbaceous area of the valley were the anchor points of the backfire which progressed up-hill, under the chestnut stand, towards the fire front (photo by C. Montiel).

Consequently, the introduction and implementation of professional and technical use of suppression fire requires a protocol of key actions which should be implemented at the local level. Suppression fire is a local practice, in fact one that people only used within the boundaries they were familiar with and which constituted their heritage. That is the reason why it is so difficult to frame suppression fire practices within general policies.

In those regions where fire culture survived, local experts have knowledge of the territory (relief, paths, local wind, vegetation, assets, etc.) and historical knowledge of fire behaviour in that territory, but their objectives are not the same as fire fighting services. Their focus is to defend local assets; they do not have the holistic strategic approach of suppressing wildfires, though the intention to reduce damage to the landscape is common to both. In such regions there are the most numerous and the most permanent experts in fire use with a kind of legitimacy in the local territory because of their property and land tenure rights. Therefore it is necessary to: (i) establish a dialogue between the stakeholders involved in suppression fire use; and (ii) normalize the use of fire at the local scale, defining the duties of each stakeholder and reaching a consensus to allow collaboration. The final aims are to regularize suppression fire practices and to define a successful way for wildfire suppression cooperation at the local level.

Governance mechanisms and civil responsibility exercise

Fire fighting strategies in Mediterranean countries have evolved through the second half of the 20th century from a defence system based on the organization of local populations and the use of their own resources to a professional system run by forest and civil protection services (Castellnou 2010). This enabled the adoption of a strategic approach and means of suppression to address the increasing significance of wildfires (Dujas and Traimond 1992). However, socio-spatial evolution and changes in fire scenarios mean that new ways of collaboration are needed which consider the organized participation of certain sectors of the population in prevention and suppression duties (Aguilar and Montiel 2009).

Suppression fire techniques are a very effective and powerful fire fighting tool, but its local and technical application require the availability of responsible, qualified people with technical skills and good relations with the local population, as well as to an extent the maintenance of traditional social-spatial structures. Therefore, fire policies should consider these aspects when regulating suppression fire use and also the establishment of the corresponding governance mechanisms.

In those municipalities with a forest culture, there is a need for empowerment of local groups (Aguilar 2003). Land owners are willing to collaborate with fire fighters and demand their right to take part in extinction duties, on the basis of their knowledge and legitimacy on the territory. Moreover, by demanding their right to get involved in fire fighting, locals also claim a certain control of fire, which somehow is a symbolic expression of territorial power.

Social participation in policy-making and application of policy is less frequent in Mediterranean countries than in other EU member states. Another important element associated with governance, which also applies to forest policy, are learning processes that operate through diffusion mechanisms or networks. Expertise in fire use is a crucial resource, but also the revival of old and wise, yet abandoned, fire practices that were in hands of rural communities (Aguilar and Montiel 2009). Furthermore, learning processes and cooperation should be carried out in a context of confidence, and with a will to cooperate; this will allow the legal and policy framework for a regulated and effective action to be formulated (see Figure 4).

On the other hand, suppression fire practices entail a responsibility which slows down its application in operations due to the risks associated with it (risk of fatalities, material losses, etc.). Current urban societies are not willing to forgive mistakes, and hence it is necessary to develop a legal framework as well as an appropriate suppression fire plan. The effectiveness of technical fire depends on determination and immediate action, which means that it is not susceptible of detailed prior planning. In fact, professionalization and normalization of suppression fire practices will likely reduce the effectiveness of traditional practices, although appear to increase safety. In any case, it is necessary to clearly regulate the civil responsibility of duties involving technical fire, and to do that defining the roles played by different stakeholders is essential.

Professional training:

Suppression fire is a very challenging practice which requires in-depth knowledge of fire, ecosystems and the relations between them. Fire users need a high level of knowledge about fire behaviour and also about fire fighting. Theoretical knowledge

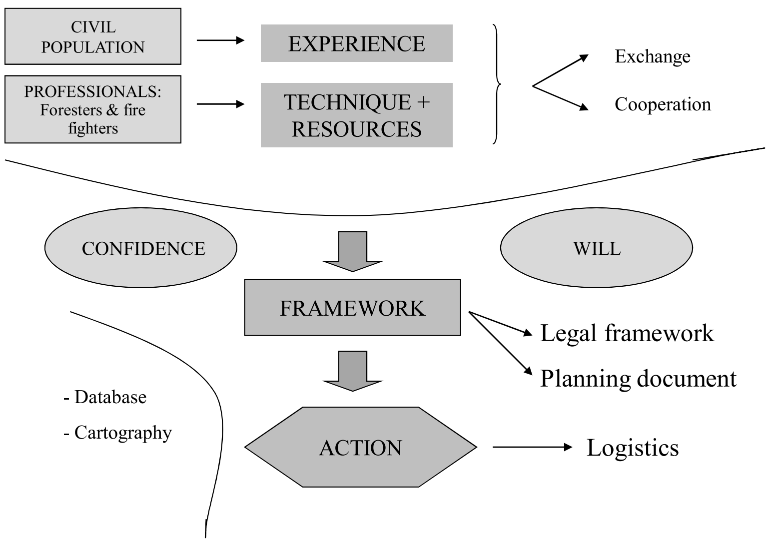

Figure 4. Scheme of an innovative and participative governance mechanism for the use of suppression fire.

must be complemented with practical experience which enables prediction of fire propagation behaviour, including the interaction between fire fronts.

Expertise and experience are needed for the responsible and effective use of suppression fire. Regarding that, professional training concerning the use of fire as a tool for fighting fire involves the formalization of required competences (theoretical and practical), adapted to each territorial context. For instance, the use of fire in North Atlantic areas should face medium-low intensity burnouts without convection processes while, in Mediterranean areas, training must focus on convection processes. So, training to perform fire suppression actions means different levels of capacity for different types of fire.

If Europe is to respond to the fire problem in a forceful way, it should take into account all the possibilities offered by different extinction systems. This includes training professionals to acquire appropriate qualifications in order to offer to the different countries qualified teams that are flexible and ready to give a measured, organized response where they are needed. That is, a strong training programme must be developed, with progressive skill levels, which enables a smooth harmonization of the different national and regional existing training programmes in Europe.

It would be therefore interesting to develop a European integrated qualification system, which could be further developed in each country to match with the different political, administrative or cultural systems, customs and values. This would enable certification of the acquired qualifications and would make professional exchange and cooperation easier between countries and regions. The Fire Paradox initiative 'recording system and identification for the professionals in the fire use' aims to promote a European qualification system for fire management, based on the formalization of training protocols that would facilitate international cooperation and would enhance the global interoperability of emergency managers.

Table 1. Proposal for a European fire fighting training framework.

Level	Available operations
1	Basic Level Competencies: • Backfires and burnout operations. • Definition of a special perimeter by means of burnout operations. • Safety improvement in fire management operations. • Combined operations with fire and other tools.
2	Additional Competencies: • Carry out ignitions to manage vegetation fires. That is a greater ability to manage each single drip torch, with a broader range of objectives and techniques to manage wildfires. Such as limit suppression actions to an anchored point or a design unit. • Greater ability in combined operations. • Track opportunities associated to anticipated changes of fire behaviour to propose tactics to prevent and fight wildfires in Mediterranean ecosystems.
3	Additional Competencies: • Control of operations with technical fire to manage wildfires in Mediterranean ecosystems. So, greater ability to manage groups of drip torches combined with other tools, with a broader range of objectives. • Direct or delay fires spread to reach specific resource management objectives. • Prioritize opportunities associated with anticipated changes of fire behaviour to propose strategies and tactics to prevent and fight wildfires in Mediterranean ecosystems.

5.1.4 Conclusions and recommendations

The use of suppression fire is a social, political and technical challenge. It enables responsible agencies in cooperation with actors at the local level to act upon areas in which the use of conventional means of fire fighting would involve certain danger, as well as a rapid intervention upon areas where there is difficult access and limited human resources. It constitutes a complementary strategy to other fire fighting techniques and an opportunity to fight large wildfires, although its implementation requires previous social acceptance as well as regulation of fire use.

The constraints on the use of suppression fire are social acceptance and legal regulation, and are very complex: on one hand, the conflictive position of land owners regarding backfiring in emergency situation; on the other hand, the civil responsibility of the Incident Commander, when taking the decision to use suppression fire techniques, based on the existing legal framework. Moreover, there is often confusion between the traditional use of suppression fire performed by rural population and its implementation by forest and civil protection services, which strengthens the clandestine character associated with this technique in many European countries.

Regarding the basic elements to be considered for the formulation of the legal framework for this practice, the following aspects are highlighted: (a) suppression fire should be carried out even if the land owner does not provide authorization, due to the emergency situation; (b) the Incident Commander is responsible for taking the decisions, and his liability should be covered by the responsible administration; (c) the execution of a technical fire should have some minimum and general regulation, as well as the establishment of common techniques, but it cannot be pre-conditioned to a fixed and detailed method; and (d) technical knowledge is required and it must entail both research and training efforts.

Cooperation between different stakeholders through learning processes and participatory mechanisms are also badly needed for the use of suppression fire. Learning and drawing lessons, know-how transfer and training schemes are required in order to solve the social conflicts that are constraining the use of fire as an extra tool to fight wildfires.

The use of fire requires the availability of responsible, qualified people with technical skills, and well established communication with the local population, as well as an insight into traditional socio-spatial structures. Therefore, fire policies should consider the need to regulate the use of suppression fire and also to develop professional training and to establish the corresponding governance mechanisms. Furthermore, the use of fire as a tool for wildfire prevention or suppression needs to be designed, applied and evaluated. All this makes widespread application of suppression fire techniques difficult. It is a matter for experts on fire behaviour and fire fighting systems, and consequently the use of fire must, by definition, be in few hands.

With regard to the authority of landowners and other people who hold rights over land affected by wildfires, it must also be determined whether any of the persons holding property rights may prevent or restrict the use of suppression fire. As for the intervention of the authorities, the examination of the regulations reveal that at least the reference to administrative reports is meaningless because the Incident Commander cannot wait for an answer to act. In those circumstances where recourse to suppression fire is necessary it does not seem feasible to depend on the issue of any official permission. Likewise, the need to notify the corresponding authority about the execution of suppression fire seems rather unfortunate, though understandable, because the participating agents are responsible for the intervention and act as representatives of that authority. This is the reason why, in the few cases in which this matter has been regulated, the execution of suppression fire techniques is considered a power that rests with the Incident Commander. In fact, because of the speed needed to act in these cases, the state of necessity that may lead to the performance of such a risky and dangerous operation and the unpredictable and changeable nature of fire behaviour, it should be the Incident Commander who makes the decision to use suppression fire, without prejudice to a legal provision, and with timely notification to the authorities.

Without doubt the issue is not only about legislation and application of laws. Regulations must be accepted by the whole society and, in order to achieve that, political efforts are required to understand the problem from the viewpoint of professional forums and along with other social agents. It is likewise necessary to set measures involving education, social awareness and above all, to establish a standardized training system for all the professionals of the sector (extinction task forces, personnel involved in prevention duties, etc.), which integrates each and every method offered by extinction techniques.

References

Aguilar, S. and Montiel, C. 2009. New governance strategies for wildland fire management in Mediterranean countries. In: Buttoud, G. (ed.). Pre Conference Proceedings of the International Symposium Change in Governance as Collective Learning Process: Management, Politics and Ethics in Forestry, Nancy, France. Pp. 9–18.

Aguilar, S. 2003. Environmental conflict resolution: litigating patics having to face environment decisions. Observatorio Medioambiental 6: 25–33.

Castellnou, C. 2010. EL Programa Catalan de gestión del Fuego: El GRAF en el Cuerpo de Bomberos de la generalitat de Catalunya. In: Montiel, C. and Kraus, D. (ed.). Best practices of fire use. Prescribed burning and suppression fire programmes in selected case studies regions in Europe. EFI Research Report 24. European Forest Institute. In press.

Dujas, J.M. and Traimond. 1992. Le maitre du feu. Les incendies dans les landes de Gascogne. Terrain 19: 49–64.

FAO 1986. Wildland Fire Management Terminology. Food and Agriculture Organization of the United Nations, FAO Forestry Paper 70. 257 p.

Herrero, G., Montiel, C., Agudo, J. and Aguilar, S. 2009. Assessment document on the main strengths and weaknesses of the legislation and policy instruments concerning integrated wildland fire management in the EU, in European Member States and in North African countries. Deliverable D7.1-1-2 of the Integrated Project "Fire Paradox", Project no. FP6-018505. European Commission. 117 p.

Lázaro, A., Solana, J., Montiel, C., Goldammer, J.G., Kraus, D. and Rigolot, E. 2008. Collection, classification and mapping of the current prescribed fire and suppression fire practices in Europe. Deliverable D7.1-3-1 of the Integrated Project "Fire Paradox", Project no. FP6-018505. European Commission. 47 p.

Martínez Ruíz, E. 1997. Manual del contrafuego. El manejo del fuego en la extinción de incendios forestales. TRAGSA, Madrid.

5.2 Suppression Fire Use in Learning Organizations

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5.2.1 Introduction

Fire is a natural part of European landscapes both because of natural lightning ignitions and by human activity for hunting, fighting or land management. However, fire has recently started to be regarded as an economic and social problem. The cost of fire suppression is higher than ever, and large fires are becoming larger, with faster spread rates and higher fire intensities. The landscape is changing to a continuous mosaic of fuels, as most small and medium-size fires are extinguished as soon as they develop. The consequences of this fast growth in fire fighting organizations only focused on fire suppression are increased fuel accumulation and increased fuel continuity at the landscape level. As a result wildfires can become non-containable and the proportion of area burned in such big wildfires will continue to grow. During the past century, this problem has developed in different ways throughout Europe. However, if we look at this problem from a global perspective, we can only come to the conclusion that fire is becoming a more important problem. There is a clear increase in the number and proportions of so called megafires in countries such as Portugal, France, Spain, Italy, and Greece, but even in England, Sweden and Norway large wildfires are occurring simultaneously. The trend observed in Europe is that wildfires larger than 50 ha affect more than 75% of total surface burned in Europe (San-Miguel and Camia 2009).

Europe is now faced with a new fire-related problem all over the continent, and trying to enforce a fire suppression policy is not going to solve the problem. In this sense, suppression fire techniques are not only an opportunity to improve efficiency to fight these large fires that are beyond the capacity of extinction, but they are also linked to skillful, experienced and trained groups of fire specialists that are able to introduce learning in organizations. The aim of this chapter is to explore the deep changes in fire management organizations that are associated to the introduction of suppression fire techniques, and this calls for new concepts not only in fire management but also in organizational learning.

5.2.2 Key concepts and a new strategy for wildfires

Since most EU states are still trying to enforce a fire suppression policy, it is evident that the situation all over Europe is simply not going to be solved by the use of more resources or a more aggressive direct fire suppression strategy. There is a need to change the strategy towards reinforcing fire as a suppression technique. It is necessary to focus not only on improving individual training, but especially on improving the way organizations are learning and applying lessons learned from experience. So, two new concepts arise as a part of a global solution all over the world: suppression fire and learning organizations are both key concepts in the future process of change.

Any fire used as a suppression technique during uncontrolled fires is considered suppression fire, where the main objectives and tactical options can be summarised as follows:

- Directing or delaying fire spread;
- Mitigate re-ignition risks;
- Improving the safety of the public and fire fighters;
- Always to be more efficient and safer in direct suppression fire;
- This type of fire application can provide a range of applications, from burning out or backfiring operations to limiting suppression actions to an anchor point.

Sometimes the most effective fire tool that will strengthen suppression of a large fire is to reduce the fire intensity of the fire front, so that an anchor point can be established (see Figure 1d). This can be the most successful tactic to mitigate re-ignition risks by avoiding an increase of fire intensity through a firing operation near a critical point.

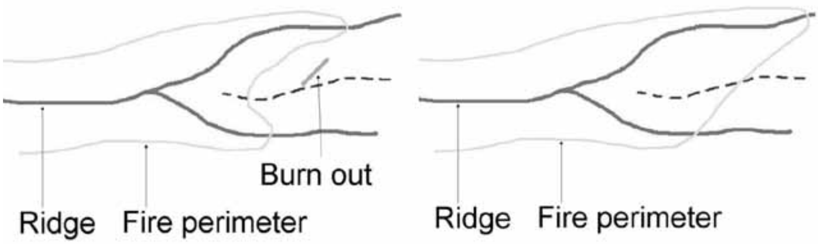
A learning organization is skilled in creating, acquiring, interpreting, transferring and retaining knowledge, and adapts to reflect new learning (Alexander and Thomas 2003). This means to become a learning organization; new knowledge, new opportunities and new diagnoses must be constantly included in the organization (Nasiatka 2008). This is an important prerequisite for the use of suppression fire where the scale of consequences of a high risk operation precludes learning through experimentation and the potential for failure is high.

5.2.3 A new strategy for wildfire

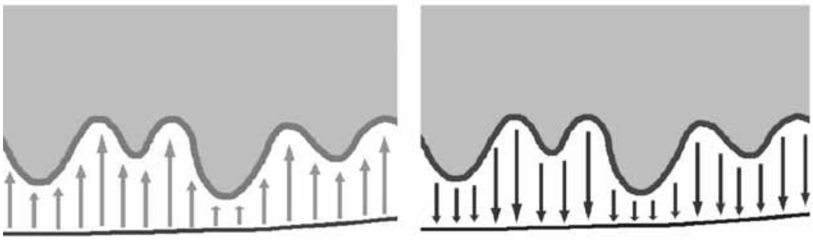
In order to cope with a worsening wildfire situation, there is a need to change the strategy towards the following:

- changing the landscape by managing fire regime itself to solve the problem, i.e. a change from suppressing all fires that lead to a regime of high intensity fires towards a new approach based on tolerating a fire regime with low intensity fires;
- adapting fire-fighting organizations to cope with low frequency, high impact large fire situations through building of knowledge and experience .

In this context, introducing fire use techniques in fire fighting organizations is the first step towards a change of the core values in fire services. Managing fire use techniques are basic to managing landscapes, and as high risk techniques these must be grounded in a modern learning organization.



1a + b. On the left, the fire has two main heads following the ridges. On the right, a burn out has called the lower head into the upper one. The result is a single head of the fire and a flank, where before there were two main heads.



1c. Ignition from anchor line where fire will be held.

1d. No ignition is done in a fire front close to the anchor line, but also it is not extinguished. The only action performed is controlling intensity; by doing that, the front is well-anchored, reducing the risk of re-ignitions or flare ups.

Figure 1. Multiple-use of suppression fire: it does not only stop the fire before it reaches critical points from where fire behaviour would be worsening, suppression fire can also reduce spotting distance through raising the smoke column of the advancing fire with its convection. In 1a and 1b, suppression fire reduces the perimeter of the head of the fire through drawing the one head into the other. It can also be used to ensure that no flare-ups develop, by means of anchoring the head fire front. This can be done by igniting a fireline from the anchor line (1c), or by means of reducing fire intensity before the fire reaches the anchor line, (1d).

5.2.4 Evolution of fire management

The historical evolution of fire management in Europe is key to understanding what policies and paradigms have been used by countries as the fire scenario evolved. In landscapes with a high proportion of large fires, the process of understanding fire and reaching a fire management situation is a step by step process.

Phase 1. Fire exclusion

Traditional use of fire has been substituted by prohibition, centralized from governments during the 20th century. Initially fire was used by shepherds, gamekeepers, rangeland managers or villagers for local interest (Lázaro et al. 2008).

Figure 2. The slow descending, low intensity fire (dotted arrow) allowed the survival of trees, but also provided the opportunity for fire extinction. Subsequently, another fire started at the bottom of the valley, and exposed every tree to significantly higher fire intensity (continuous line). The suppression of the low intensity fire front which the trees survived allowed the development of a high intensity fire which killed all the trees. Source: GRAF, Catalonia.

As the socio-economic context changed, the techniques used by rural villagers to deal with productivity, regeneration of pastures, or fire risk management changed. The perception that society had of fire changed. Fire became the enemy that threatened the landscape and the ecosystem. Consequently, the use of fire was prohibited (Seijo 2009),

However, policies based on extensive fire suppression began to fail in different parts of Europe, and were leading to an increase of relative importance of large fires. Several recent cases substantiate this paradox: Catalonia (1986 to 1993), Galicia (1994 to 2005) and Greece (2001 to 2006) were regarded as examples of success and in each case catastrophic fire seasons followed those periods (Rigolot et al. 2009). Slowly, fire´s role in managing the ecosystem and in creating the landscape began to be understood.

Phase 2. Prescribed burning is introduced

Prescribed burning is not only an important tool for nature conservation, but also a technique useful for wildfire prevention in different ways: as a basis to train and maintain the know-how of using suppression fire techniques, and to create a fuel mosaic in the landscape, which, when strategically placed, is able to provide opportunities to fight wildfires. This especially happens when the mosaic is formed by patches with less fuel to burn and with forest stand with less capacity to develop crown fires. (Finney et al. 2005; Rigolot et al. 2009; Cassagne et al. 2009). The number of countries performing prescribed burning is increasing, both for fire prevention purposes (Portugal, France, and north of Spain) or other land management objectives (Sweden, Scotland, Germany, and parts of Spain) (Lázaro et al. 2008).

Phase 3. Suppression fire is re-introduced

When large wildfires overcome extinction capacity (become uncontrollable), they can have a serious impact on the economy and may put populations at risk. Old ways of fighting fire are remembered, and fire application can become a "technique" to fight and control wildfires. In Portugal, Spain or Cyprus suppression fire was introduced during the mid 20th century as a tool to fight continuous and large fire perimeters. The large fires in the decade since 2000 have added some countries to this short list, but in those cases fire is used by highly trained fire specialists: Catalonia (2000), France (2005), Sardinia (2006) and Portugal (2004) (Lázaro et al. 2008; Rifà and Castellnou 2007).

Phase 4. Managing natural ignitions
In areas very prone to large fires, the introduction of medium fires in a significant proportion in the landscape reduces the proportion of large fires (Piñol et al. 2007). The extension of surface area to be burned is recognized as a necessity, but also as very difficult and expensive to achieve (State of Victoria 2003; Nasiatka 2003; Van Wilgen 2002; Cassagne et al. 2009). As the objective of fire extinction is not to reduce the surface area burned, but to reduce the negative impacts of wildfires, the opportunity to manage natural fires for that purpose seems a logic step. However, there are socio-political constraints. Wildland Fire Use policies appeared associated to natural ignitions in large natural landscapes, when the fire suppression cost is perceived as higher than the perceived risk associated with managing unplanned ignitions. Examples can be found in the USA in the 1960s and 1970s (Van Wagtendonk 2007) and in South Africa in 1992 (Van Wilgen 2002).

Phase 5. Managing all ignitions
In a densely populated Europe, where natural and cultural landscapes cannot be separated, Portugal is initiating a new path. Each part of a wildfire is managed according to its resource objectives, whatever caused the fire,. The purpose of fire fighting operations goes beyond "minimizing surface area burned", and considers also land use objectives or ecosystem sustainability. This shift from fire fighting to fire management has clear ecological and economic benefits in landscapes with a high proportion of large fires and with prescribed burning and suppression fire programmes in place. It will be a very slow process, due to perceived risk, social acceptance and the need of different services working together: emergency services, forest services, fire services and landscape planning services.

5.2.5 From resources to knowledge

This shift from focusing on fire exclusion towards fire management implies also a shift in investment, from "more resources" to "knowledge". Now, in the ‘large wildfire era’, resources are still needed, but knowledge of fire behaviour and of operations is fundamental (Sagarzazu Ansaldo and Defossé 2009). Identifying the main factor that is allowing fires to escape control in each region (see Box 1), and the lessons to be learned in each experience allows fire-fighting organizations to be efficient and to progress towards appropriate fire management policies, strategies and tactics.

Fire Reports and Case Studies
These are essential to learn from own experience and past history (Garvin 2000). Each fire provides an opportunity to explore and adjust new operations, new

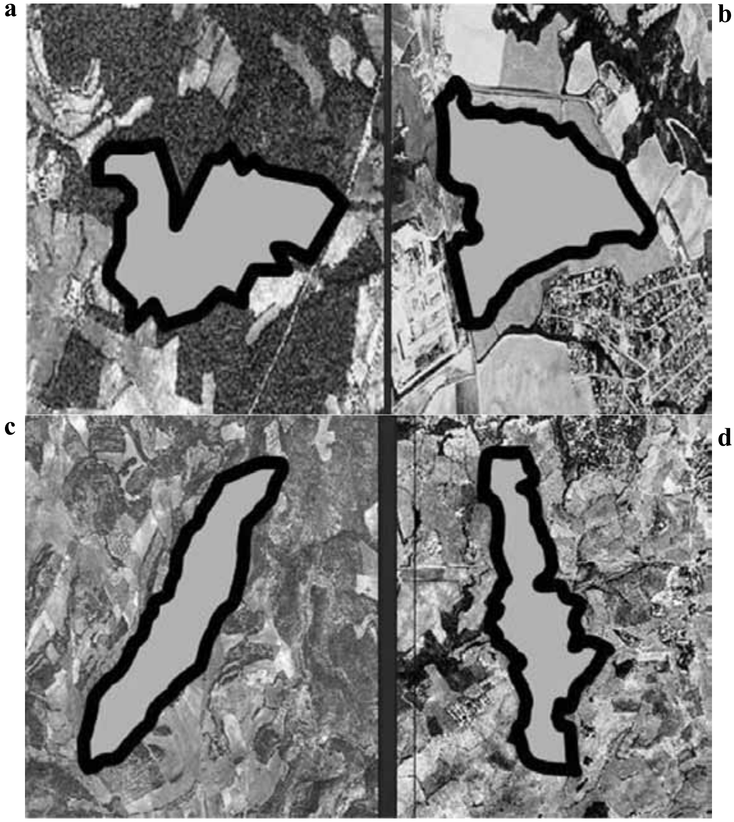


Figure 3. The same synoptic weather situation implied different patterns of fire spread depending on the macroscopic relief. The first two fires occurred near the coast in Banyoles (a) and Masquefa (b). They are displaying a rounded shape, and their perimeters are affected by the daily shift of land and sea breezes. Meanwhile the fires near Les Avellanes (c) and Sant Pedor (d), occurred in the interior. Their perimeter patterns are not affected by sea breezes and they have an elongated shape. Understanding these patterns has a great influence on the selection of tactics.

strategies, new tools, and to pass this information on to others, supplementing and strengthening a person's experience (Alexander and Thomas 2003). So, it is not only an organization's task to create a platform to keep records, it also means to track the results of decisions taken, and analyze these results in ways that reveal their key lessons (Alexander 2002; Sagarzazu Ansaldo and Defossé 2009).

Transferring knowledge throughout the organization (Garvin 2000).
The objective is to anticipate problems before a wildfire occurs and to discuss lessons learned after a fire (same day and during the next season), or after a whole

fire season (Castellnou et al. 2007). This is particularly applicable when promoting fire analysis training through case examples throughout the whole organization.

Exchanging information and personnel with other countries, regions and organizations.
This should include especially decision-makers, stakeholders and fire specialists of countries, regions or organizations with similar present or future problems. This will not only improve operational procedures, but will also enable learning from best practices of other organizations allowing to include local or foreign expertise, and to increase the range of possible solutions to similar problems (Garvin 2000; Castellnou et al. 2008). The creation of platforms to exchange information (e.g. web platforms and web forums for fire professionals) is fundamental.

5.2.6 From individuals to organizations

The last step after understanding the road towards management and understanding the new focus on knowledge, is looking at people not as workers, but as information keepers. Putting all this together allows a global vision of what is going on, what is coming and what is needed. The whole team should take part of the process of decision-making, each one at its level of responsibility. Individuals are keepers of the information which they acquire and which they create and this is the most valuable asset.

Accordingly, including fire intelligence at different levels of the organization (Garvin 2000) means to train all personnel at different levels of fire behaviour analysis. Furthermore, it also means consolidating Fire Specialist groups with a high capacity of analysis (see chapter by Molina et al.). Thus new job positions must be promoted, i.e. the Firing Specialist and Firing Operations Leader at the fire front, the Firing Tactics Commander in a fire division, and the Fire Behavior Analyst for the whole of a fire (see chapter by Miralles et al.). The ability of any organization to listen to experts is the key: experts who can apply new techniques in new situations, who are able to recognize patterns, to separate noise from a real signal, with long-time, landscape vision, recognized by their own people, recommended by other mentors (Saveland 2008).

The use of fire during fire suppression operations can become a complex task, since it adds another risk factor to the regular suite of risks in fire fighting. In complex emergencies, any organization must respond in a flexible, scalable way through a standard management hierarchy and standard procedures in order that there is a common framework within which people from different organizations can work together effectively (such as the Incident Command System, developed in the USA). The attitude and mental model of providing standards, policies and directives is an important part of the issue, but it is only part of the story (Saveland 2008). In complex systems – operating in a chaotic environment where the need to manage the unexpected arises – the organization does not only require the structure of command and control. It also needs a learning culture, to enhance and sustain safe and effective work practices.

Box 1. Identification of different types of wildfires escaping extinction control (fire generations) and best strategies and response from different organizations.

Large fires can be uncontrollable for different reasons: from continuous surface fires, to fast spotting surface fires, to crown fires and wildland-urban interface crown fires, to simultaneous wildland urban interface large-fires (Table 1). Obviously different types of large fires, with different socio-economic contexts, need different responses, and in Europe we have seen and experienced multiple extinction systems, with different regulations, different competences (forest/fire services), and even different fire fighting tools (e.g. suppression based on use of hose lines, or on use of defence lines). These differences in response to fire - used by different organizations and regions working together in fire suppression applications - provide a great capacity to adapt to a changing environment. This is the most important decision: to identify exactly what is the fire situation (fire generations: Table 1) and to adapt a response to it in a local context (but taking into account the lessons learned by others that have experienced similar situations).

New large wildfires and global seasonal change are forcing the identification of specific requirements for each area and to respond to them, with organizations that are capable of adapting to local conditions but with the capacity to learn and share experiences with others.

The response and strategy to fight fires, and thus the type of fire specialist requires some changes. These specialists have to adapt to a range of large fire-types, and the socio-economic pressure of extinction of such fires is serious. Thus expert decisions need to be taken at different scales (front, sector or whole fire area), from different levels of expertise (managing one drip torch, or a group of torches, or managing fire interaction as a whole).

However, the more investment in 'response capacity', the more fuel will accumulate and a new generation of large fires will be created. So the fire extinction response must be accompanied by measures to reduce fuel load, continuity, vulnerability of the forest, and measures to promote self-protection of people and infrastructures.

Table 1. Description of generations of large fires with potential to escape the capacity of extinction due to: fuel continuity, rate of spread, maintained crown fire behaviour, high intensity wildland urban interface (WUI) spread and simultaneously occurring large fires. Best strategy and response from different organizations and the type of fire specialist (see chapter by Miralles et al.) involved.

	1 – Fuel continuity
Landscape	Continuous fuel distribution allows long perimeters. Farmlands abandoned.
Fire behaviour	Surface fires consume fine fuels, and spread on dry grasses and/or litter. Mainly wind-driven fires with lack of anchor points.
Strategy	Direct attack, based on local resources.
Response	• Local response, reinforced with seasonal fire fighters. • Linear infrastructures, accessibility and building water points.
Fire specialist groups involved	BRIF (Spain). Basic fire specialists (technical fire support, level 2) with non-specialized unit commander (level 4):
Operations available	• Backfires and burn out operations, especially perimeter definition with burn out operations; • Improve safety in fire management operations; • Combined operations.

	2 – Rate of spread
Landscape	Fuel build-up allows faster spread rates of fires and spotting.
Fire behaviour	Wind- and topography-driven fast surface fires, mainly spreading in shrubs and tall dry grasses, with occasional crown fires. The speed of the fires overruns the holding lines.
Strategy	Fast dedicated and efficient attack, based on local expert input and aerial support.
Response	• Dense detection and suppression net to ensure a fast and powerful dispatch of fire engines/crews and helicopters. • Wider range of combined suppression techniques: fire, hand tools and machinery, hose lines and aerial attack, combined operations. • Fire analysis to anticipate small-scale opportunities
Fire specialist groups involved	Example GRAFF (France). Wildland fire ignition specialists (level 3) with technical fire support (level 2) and non-specialized unit commander (level 4).
Operations available	Additional competencies: • Tracking opportunities associated to windows of opportunities; • Greater ability to operate drip torches; • Broader range of objectives and techniques to manage wildfires; • Greater ability of combined operations.

Table 1. Continued.

	3 – Maintained crown fire.
Landscape	Fuel build-up to crown continuity results in high intensity active crown fires with convective plumes that are beyond capacity of control.
Fire behaviour	Active crown fires and long spotting distances during extreme heat waves, with very few opportunities to control. Fire changes behaviour faster than information is passed on in the chain of command.
Strategy	Slowing down the fire front and confinement strategies.
Response	• Reinforcement of logistics units. • Directing or delaying fire spread to reach specific resource management objectives. • Introduce fire regime concept in forest planning. • Include fire analyst to anticipate opportunities, increasing the adaptability of the organization to changes of fire behaviour.
Fire specialist groups involved	Example GAUF (Portugal), GRAF (Catalonia). Wildland ignition specialists (level 3) with technical fire support (level 2) and technical fire specialist (level 4). Supervised by a Fire Analyst.
Operations available	Additional competencies: • Directing or delaying fire spread to reach specific resource management objectives; • Prioritizing windows of opportunities; • A greater ability to manage groups of drip torches combined with other techniques, with a broader range of objectives.

	4 – WUI fires
Landscape	The WUI becomes involved in the forest fire environment. Residential and industrial areas are increasingly affected by wildfires.
Fire behaviour	Fires that can start and be stopped inside the WUI.
Response	New landscape situations are forcing a change from attacking fires to defending houses and people in a new defensive situation. • Fire specialist groups as mobile units inside the residential areas, trained to take tactical decisions on the basis of general strategies. • Simulators, GPS and mapping technologies to track resources in real-time. • Professional logistics units.
Strategy	Lowering tactical decision level, and command taking strategic decisions
Fire specialist groups involved	Same fire specialist as for maintained crown fire generations.

Table 1. Continued.

	5 –Large fires.
Landscape	Zones at risk are faced with simultaneous large and fast spreading, extremely intense wildfires.
Fire behaviour	Simultaneous crown fires involving wildland urban interfaces, mainly during heat waves.
Response	• New skills are needed to respond to simultaneous large fires. • The answer is sharing resources, on a larger scale. This implies: • standardized training systems; • logistics organization for regional assistance. • Cooperation and exchange of information and experience is required.
Strategy	Pool resources distribution to help on a regional scale
Fire specialist groups involved	Same fire specialist as for maintained crown fire generations.

5.2.7 Conclusions

Creating a set of procedures for fire extinction within fire management means incorporating knowledge into the system, and to transform from a hierarchical organization to an organization adapted to learning. This is a complex, time-consuming and expensive task. European policies should rather strengthen investments in:

- Training fire analysis, fire behaviour and fire ecology for all staff fighting fires, as in fast-spreading fires, tactical decisions are taken by lower ranks in the structure, and must be based on knowledge.
- Exchanging information and experts in promoting learning organizations that currently are clearly insufficient. Experience must be easily transferrable and any operation performed should form part of the knowledge-base.
- Appointing fire analysts to help detecting and prioritizing windows of opportunity.
- Creating fire specialist groups to perform suppression fire operations. This means not only long training and exchange programmes for individuals, but also for those that can form part of teams which can extrapolate the results for a wider audience.

Large fires are an increasing problem, which must be addressed at a landscape scale:

- Fire as an operational technique can be regarded as a first step, but fire management ideas must also be developed further, from being a technique to manage fuel to become a technique to manage the landscape.
- Finally, promoting a wise use of fire means initiating, promoting and expanding public awareness policies, which stop “selling” all fires as emergencies to the public, and rather attempt to explain fires as an integral part of landscape dynamics.

References

Alexander, M.E. and Thomas, D.A. 2003. Wildland fire behavior case studies and analyses: value, approaches, and practical uses. Fire Management Today 63: 4–9.
Alexander, M.E. 2002. The staff-ride approach to wildland fire behaviour and fire fighter safety awareness training: a commentary. Fire Management Today 62: 25–30.
Cassagne, N., Mantzavelas, A., Dupuy, J.L., Lazaridou, T., Pimont, F., Partozis, T., Fernandes, P., Loureiro, C. and Rigolot, E. 2009. Report on the effects of broad scale and long-term application of prescribed burning on fire risk components. Deliverable D5.3-1 of the Integrated Project "Fire Paradox", Project no. FP6-018505. European Commission. 88 p.
Castellnou, M., Iglesias, N., Guarque, J., Perna, J., and Lleonart, S. 2007. Experiencias de formación continuada en Cataluña durante las campañas 2003, 2004, 2005 y 2006. Proceedings of the IV Internacional Wildfire Conference. Sevilla. Spain.
Castellnou, M., Mira, N., Castellarnau, X., Miralles, M., Loureiro, C., Lorca, M., Salgueiro, A., Binggeli, F., Gibson, S., Lambert, B., Grau, G., Solivellas, P., Cendra, J. and Quílez, R. 2008. Guideline for exchanges between fire managers. Deliverable D10.4-1 of the Integrated Project "Fire Paradox", Project no. FP6-018505. European Commission. 58 p.
Finney, M., McHugh, C.W. and Grenfell, I.C. 2005. Stand- and landscape-level effects of prescribed burning on two Arizona wildfires. Canadian Journal of Forest Research 35: 1714–1722.
Garvin, D.A. 2000. Learning in action. Harvard Business School Press. Boston, MA, USA.
Lázaro, A., Solana, J., Montiel, C., Goldammer, J.G., Kraus, D. and Rigolot, E. 2008. Collection, classification and mapping of the current prescribed fire and suppression fire practices in Europe. Deliverable D7.1-3-1. of the Integrated Project "Fire Paradox", Project no. FP6-018505. European Commission. 47 p.
Nasiatka, P. 2003. Southern California Firestorm 2003. Report for the Wildland Fire Lessons Learned Center. 70 p.
Nasiatka, P. 2008. Building the foundation for a learning culture. Fire Management Today. 68: 5–7.
Piñol, J., Castellnou, M. and Beven, K.J. 2007. Conditioning uncertainty in ecological models: Assessing the impact of fire management strategies. Ecological Modelling 207: 34–44.
Rifà, A. and Castellnou, M. 2007. El modelo de extinción de incendios forestales catalan. Proceedings of the IV Internacional Wildfire Conference. Sevilla, Spain.
Rigolot, E., Fernandes, P. and Rego, F. 2009. Managing Wildfire Risk, Prevention, Suppression. In: Birot, Y. (ed.). Living with wildfires, what science can tell us. EFI Discussion Paper 15. European Forest Institute. Pp. 49–52
Sagarzazu Ansaldo, M.S. and Defossé, G.E. 2009. Study of a 2nd set of largest past fires. Deliverable D8.3-1 of the Integrated Project "Fire Paradox", Project no. FP6-018505. European Commission. 82 p.
San-Miguel, J. and Camia, A. 2009. Forest Fires at a Glance: Facts, Figures and Trends in the EU. In: Birot, Y. (ed.). Living with Wildfires: what science can tell us. 15. European Forest Institute. Pp. 11–18.
Saveland, J. 2008. Making sense of organizing for high reliability and learning. Fire Management Today. 68: 8.
Seijo, F. 2009. Who framed the forest fire? State Framing and peasant counter-framing of anthropogenic forest fires in Spain since 1940. Journal of Environmental Policy and Planning. 11: 103–128.
State of Victoria. 2003. Report of the Inquire into the 2002–2003 Victorian Bushfires. Australia.

Van Wagtendonk, J.W. 2007. The history and evolution of wildland fire use. History 3:3.
Van Wilgen, B.W. 2002. Changing paradigms in conservation: Lessons from six decades of fire management in a large African national park.

5.3 Improving Suppression Fire Capacity

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5.3.1 Introduction

The use of fire during fire suppression operations can become a complex task, since it adds another risk factor to the regular suite of risks in fire fighting: if not carefully executed it may 'fuel' the main fire instead of containing it. However, it definitely has the potential to create new opportunities in front of large wildfires that are beyond the control of any available fire fighting system when using a direct attack approach. In order to reduce risk and improve efficiency, fire use is a management tool to be placed in few skilful hands only, with extensive and on-going training and broad experience.

Fire has been used as a technique to control wildfires for a long time. However, given the dramatic changes of European landscapes during the last half of the 20th century, fire behaviour and associated fire risk has been worsening, and using fire to change the behaviour of a wildfire in our 21st century landscapes, does not only mean to light a fire. It means predicting fire behaviour, using fire as a management tool and conducting combined fire fighting operations. The capacity of applying these three main pillars of fire use qualifications, is the key to an efficient fire management, and should therefore be the main focus of training.

5.3.2 Types of Suppression Fire

There are several ways in which fire is used to fight fire – collectively these are termed suppression fire.

- Burn out or burning out is defined as removing fuel between a constructed fireline and the edge of a fire. Often this is done at the rear or on flanks of the fire continuously with fireline construction
- Backfire is similar to a burn out except it is ignited to take advantage of the convective indraft ahead of an oncoming fire. Backfiring is relatively uncommon because it is typically performed directly ahead of the advancing head of an intense fire. Timing is critical to allow for the reversal of wind direction associated with the blocking of ambient wind by the main front and indrafts to the headfire.

- Back burn is defined as an ignition intended to spread in a backing direction into the wind or down slope. Back burning may be done in prescribed fire or on wildfires.

5.3.3 Combined fire fighting operations

When executing backfiring operations during a large wildfire, the key to success is the appropriate combination with other fire fighting techniques, since fire use has by far a broader range of applications when combined with other techniques. Anchoring an operation with fire involves significant changes in hose line or defence line construction, and even requires distinct aerial support. Consequently, safety protocols must be established accordingly, and organizational procedures must be integrated in these operations. All organizational changes and adaptations to a suppression fire operation must be controlled by the fire chief or Incident Commander and advised by specialized fire analyst technicians.

5.3.4 Predicting fire behaviour: logical analysis language

The first Fire Analyst in Europe was contracted in 1999 in Catalonia, and was completely linked to the use of fire as a technique to fight fires. Fire was introduced as a tool to reduce the spread of the head of large and fast fires moving through the crowns of the trees, with massive long distance spotting. This allowed more time for hose line construction and hand tools to contain the flanks. However, to safely achieve a decrease in fire spread and to apply efficiently a confinement strategy, an appropriate anticipation of fire behaviour and a deep knowledge of fire operations are needed (Castellnou and Miralles 2009).

Consequently fire analysis became a useful tool not only in slowing down head fire spread and applying confinement strategies, but also to increase efficiency and safety in backfiring and burn out operations. More recently, other regions and countries were introducing fire as a technique and hiring fire analysts (in Gran Canaria and in Portugal), or training ignition specialists in fire analysis (in Sardinia). Slowly, even in wildfire scenarios in which suppression fire is not used, fire analysis has been introduced to direct suppression efforts in the most efficient and safe way (Castilla La Mancha, Galicia, Valencia, Aragon) (see Molina et al. in this book).

In order to change wildfire behaviour with a suppression fire, it is not only important to understand what the fire will do, but also how operations might change the behaviour. Every minor decision involving suppression fires must be constantly adapted to minor changes in topography (slope, aspects, canyons), fuel characteristics (flammability, fuel load, fuel distribution), weather forecasts (winds, temperature, humidity) and changes in fire spread pattern related to fuel availability, fire front and smoke plume dynamics.

Some quantitative and qualitative methods exist to anticipate fire behaviour (Andrews 1986; Finney 1996; Clarke et al. 1994; Piñol et al. 2005). Quantitative

Figure 1. A deep understanding of plume-fire dynamics is needed to perform fire operations in a plume dominated fire; the fire is not a continuous front but many different plots joining in a large convection air mass. In plume dominated fires, without a deep understanding of fire behaviour and plume dynamics, suppression fire operations can have the same effect as additional spot fires, and exacerbate, instead of reduce, the effects of the wildfire.

methods are mainly used for political decision-making, training, prevention and pre-suppression. During suppression operations, however, they are far from fast or accurate enough. "During a real wildfire, if you are watching the computer you are losing what fire is doing: there is too much information to be reviewed and processed, and you can't lose it" (Richard Rothermel, pers. com.).

Fighting fires does not only mean following protocols and applying training; it goes beyond behaving like a "drill-ground commander"(Douglas Campbell, pers. com.). Every fire situation is unique, and therefore no training or protocol will be an exact fit to every fire situation. When confronted with a real fire under various circumstances, a fire fighter must intelligently adapt to the situation. Experience helps the fire fighter to recognize when the situation is unique. Consequently a rather large base of experience is required since any new size of fire, in a new fuel type, in a different landscape and with a different meteorology is a new set of information to be stored and to be used under similar conditions (Alexander and Thomas 2003). This is a lot of information to be in one's mind, and a way to organize this mental database of every fire fighter is fire analysis language (Campbell 1995; Castellnou 2000).

This knowledge is not only empirical, since in addition to experience it is also based on the acquisition of scientific knowledge and its integration in the analysis of situations. Fire analysis is a semi-empirical qualitative tool that integrates scientific knowledge and experience. Its main purpose is to anticipate fire behaviour changes.

A fire analysis language system (Campbell 1995) becomes a key tool during suppression fire use because it helps to:

- learn to see and observe;
- communicate information and tactics; and
- increase safety.

Box 1. Fire anthropology

The technical use of fire mainly consists in knowing the behaviour of the fire, in order to understand its logic and to manipulate its behaviour to serve one's objectives. Formalizing the fire control skills of traditional and institutional practitioners is a challenge, because the technical nature of these skills is invisible, since they basically rest on a sensory culture carried through the memory and the body.

The art of hazards management: geography and wildfire knowledge
In similar conditions and in familiar places, the behaviour of the fire shows certain patterns. Repetition of wildfires provides traditional and institutional practitioners the opportunity to gain experience of signals related to different fire behaviour in a certain area. The hazards, the knowledge of geography and of the previous wildfires is part of the technical skills, as far as the relative stability of geography and fire behaviour in these particular places makes up for meteorology instability and uncertainty.

The traditional techniques can be described as a 'dry' culture of fire (meaning techniques that do not use water) with few people using very simple ignition devices. So, ignition patterns traditionally used are less complex than the ones carried out by institutional practitioners, and are adapted to a more limited wildfire behaviour range and to a limited geographical area.

Sharp-eye: having seen, seeing, foreseeing, reacting
The ability to control a fire does not rely on sleight-of-hand but on sharp-eye. Vision is at the heart of technical knowledge, yet vision is not only the use of the visual faculty, it also requires a specific intellectual ability. It means observing at the time and establishing comparisons between previous situations and the current situation (Weick1993; Hutchins 1995).. The behaviour of an ignition reflects the consequences of the practitioners' actions, so they need to observe many times these consequences to infer the choices to be made. While the important things are invisible to the eyes of the neophyte, seeing and having seen are essential skills for the practitioner to be able to foresee, and thus to ponder and act in an appropriate way.

In a moving reality such as a wildfire, "we need to recognize places, ways and opportune moments; and that knowledge becomes the key to an efficient action" (Trédé 1992). Knowing how to catch the opportune moment to act is about being able to anticipate the right circumstances, recognize them, immediately update previous deliberations and use them.

All these skills cannot be trained, must be experienced. These experiences can be acquired through decades following an expert, as done by traditional practitioners, or through some years of prescribed burning some training and some years of following teams of experts as done by institutional practitioners.

Learn to see and observe. Observing a fire from the air allows a unique view of the fire environment. Fires as a whole, however, do not need to be watched from the air to be understood and to take strategic or even small tactical decisions. Everyone making decisions in a fire situation needs to learn to extract all possible information of fire behaviour from every scene watched and a lot of information must be quickly registered: not only relevant flame characteristics for parts of the fire affected by different factors, but especially where these factors will change. Based on observed fire behaviour and foreseen changes of factors, forecasts of where and how fire behaviour will change are done. The decisions taken are only as good as the quality of data available: the quality of the information extracted from the observed fire behaviour, past observations of fire behaviour in similar situations, one's ability to identify key factors, as well as the quality of weather forecasts and maps. Large fires offer very few opportunities for containment and to forecast opportunities in advance, a key will be the ability to analyse which factors affecting fire behaviour will change in the fire front. Consequently, anyone taking (small or large) decisions at the fire front, should know how to observe and extract information and not only to describe changing factors (relevant factors affecting fire behaviour and their alignment, relevant aspects of an smoke column, of fuel availability, identify the key factor that is speeding up a fire, the fire spread). Additionally, fire fighters have to relate changing factors with opportunities. This means relating real fire behaviour affected by a current set of factors, and predicting fire behaviour under forecasted combination of the same factors, as well as relating fuel availability forecasts to changes in extinction capacity of a fire and relating changes in main factors driving the fire to changes in existing opportunities. A decision should also be based on the quality of data available, especially in weather forecasting, mapping, and fire behaviour associated with fuels.

Communicate information and tactics. Intuition cannot be explained, but an adequate fire analysis allows explanation of and discussion about how an opportunity of control at the fire perimeter is related to forecast fire behaviour changes, and therefore, how to relate tactics to efficiency. This has an added benefit in prevention: the use of a common fire analysis language helps to explain and discuss best fire prevention plans to fight the expected fire behaviour type and prepare the predicted opportunities to fight fire or to use fire.

Increase safety. Safety is a primary consideration in any wildfire operation, and that is particularly important when managing fire as a technique. Fire analysis provides key information not only about real time fire behaviour, but especially about forecast fire behaviour.

However, the behaviour of large wildfires is a complex phenomenon. The relations between fire environment factors change in a complex, non-linear manner as the spatial and temporal scales change, due to complex interactions at different scales of fire environmental variables (Holling 1981). Fire behaviour has too many components to account for the behaviour and interactions of all the parts, but too few components to permit the assumption of uniform behaviour of the whole system (McCormick et al. 2000). So, subtle shifts in environmental variables cause qualitative changes in fire behaviour, and the system's behaviour changes its scale (McCormick et al. 2000).

5.3.5 Capacity of analysis

The study of historical fires provides a vocabulary that assists in identifying phenomena individuals may not have seen before. Fire analysis language adapts to fire behaviour complexity through describing multiple factors that can be relevant at different scales, and through describing the most frequent system behaviour at each scale (examples in Campbell 1995; Castellnou et al. 2009). However, when predicting fire behaviour, extrapolating fire analysis factors up-scale or down-scale results in losing predictive power. In a wildfire with complex fire behaviour, sharing a language is not enough, just as existing quantitative fire models are not enough. What is needed is the capacity to identify the critical factors that explain most of observed fire behaviour, to predict changes and identify indicators to re-evaluate fire behaviour. Only real fire observation can help predict when a component or process may enter into feedback and comes to dominate system behaviour (Alexander and Thomas 2003). Real experience provides tools to decide which factors are selected, when based on a personal mental database of experience. This is what North American professionals call 'slide-tray'. Only a mental database of thoughtful experience provides analysis capacity. Wildfire is a clear case of complex behaviour. Experience allows a better approximation to compare, scale and understand the role of the different factors considered when analysing a fire. When just counting on fire suppression experience without a sound learning and training framework, the learning-period for the individual will become longer. Instead, only an unrealistic insight based on similar experiences to face past-experience situations is available. Adding a language-based logic, the fire fighter is forced to organize their own mental database. This serves as a tool then to share knowledge, benefiting from the experience of others as well as their own experience, and we need fire professionals able to cope with new types of fire spread, sometimes in different geographical regions than their own home environment.

For good capacity of analysis it is important to have some personal skills such as being able to read a map easily, to move in a landscape without getting lost, to store and maintain a large mental database with the significant information on previous wildfires observed, to identify key factors in such a complex landscape where a large fire is burning and identify models or patterns between situations. Thus, spatial reasoning, systematic thinking or conceptual reasoning might enable fire analysts to build the most suited model for the fire they eventually face.

Balance between language of analysis, technical knowledge, experience and know-how provides capacity of analysis, that is vital in increasing efficiency and safety in any operation with fire.

5.3.6 Managing the ignition: experience as a base

The ability to manage a single drip torch or a team of fire ignition specialists, defines the ability to adjust the ignition pattern in order to control fire behaviour. When a suppression fire operation must be performed, many decisions related to fire ignition are to be taken: number, size and distribution of the ignitions at any moment. Experience is required to get trained in the management of drip torches or other ignition devices.

The following objectives should be promoted to have trained personnel ready to perform technical fire operations:

Encourage training on European specifics. Training in the specifics of the European situation should be made available through joint training courses attended by future trainers, and through available e-learning processes. This includes training a group of trainers from different countries and services in logical fire analysis to improve knowledge transfer between professionals, and to increase the safety and efficiency of fire operations. Training fire managers for the fastest and largest fires is of major importance. Some past large fires can already serve as a model of what can be expected in future large fires, and some lessons must be learned from the past and shared (Alexander and Thomas 2003). Studying past fires from other regions is strengthening this kind of analysis (Sagarzazu Ansaldo and Defossé 2009) and when a similar situation is experienced by other people, whose training was based on these fires, the probability of a successful operation increases significantly. Also joint training during fire suppression demonstrations has allowed techniques and experiences to be exchanged between different European Fire Specialists (Castellnou et al. 2008).

Work towards a common qualification system. Europe is facing enormous fires, simultaneously-occurring large fires showing fast, extreme fire behaviour in wildland urban interfaces as we have seen in, for example, Greece in 2007 and in Portugal in 2003. This is a reality that we know for sure will happen again in not too distant future. No country can successfully face such fires alone since no resources of a single fire service will be enough for such a 'large fire' event. Furthermore, large fire situations are experienced only once in a while in each country. These events must be faced from a European perspective. However, nowadays in Europe, every region and country uses different tools, different training techniques and different qualifications for its fire professionals. A first step towards standardizing training involves a common qualification system for Europe.

Accordingly, the Fire Paradox project has developed core competences for fire specialists, levels 2 to 5 of the European Qualification Framework.

Level 1: Introduction – Assist
Level 2: Operator – Support
Level 3: Basic – Do/Apply
Level 4: Team boss – Manage
Level 5: Commander – Decide

This common qualification system serves to:

- standardize qualifications without interfering with national/local decision making about training;
- make exchange and collaboration between countries easier through shared competences;
- develop performance based training with shared competences as a critical component.

Thus a list of abilities, skills, competences and qualifications for every job role, should be directly related to the management of fire (see table 1). This common qualification system is:

- a guidance for new organizations;
- a guidance for every organization in Europe, following a recommendation

Table 1. Specific Job Positions proposed directly related with technical fire:

Level	Title	
2	Technical Fire Support	
3	Prescribed Burning Ignition Specialist	In rangelands, heathlands and understory burning
4	Prescribed Burn Boss	In rangelands, heathlands and understory burning
3	Firing Specialist	
4	Firing Operations Leader	
5	Firing Tactics Commander	

Table 2. Scheme of proposal of competences for Level 3 and Level 4 wildland fire specialists.

Level 3. Firing Specialist (FS)	Level 4. Firing Operations Leader (FOL)
• L2 – Ensure that your actions in vegetation management reduce the risk to yourself and others • L3 – Apply techniques and tactics to suppress wildfire, in relation to fire behaviour • L3 – Improve safety in fire management operations • L3 – Help fire contain operations with suppression fire use (following a specified fire plan). • L3 – Carry out ignitions in a prescribed burning in rangelands and heathlands • L3 – Carry out ignitions in a prescribed burning in understory burning • L3 – Carry out ignitions to manage wildfires in Mediterranean Ecosystems • L3 – Identify opportunities associated to changes of fire behaviour to propose tactics to prevent and fight wildfires in Mediterranean Ecosystems	The competences of a Firing Specialist plus: • L4 – Prioritize opportunities associated to changes of fire behaviour to propose tactics and strategies to prevent and fight wildfires in Mediterranean Ecosystems • L4 – Control of operations with technical fire in a prescribed burning in rangelands and heathlands • L4 – Control of operations with technical fire in a prescribed burning in understory burning • L4 – Control of operations with technical fire, to manage wildfires in Mediterranean Ecosystems • L4 – Coordinate look-out operations, in a team performing technical fire • L4 – Coordinate data recording and monitoring in a prescribed burning
Optional competences (Minimum 4) L2 – Use water with light weight portable pumps to suppress and or control wildfires L2 – Use of heavy machinery to suppress wildfires L2 – Use of aerial support to suppress wildfires L2 – Use water from engine pumps and hoses to suppress and/or control wildfires L2 – Use of hand tools to suppress and or control wildfires	

Recommended experience		Recommended experience added to FS	
Prescribed Burning or Wildfire Hours	100 h	Prescribed Burning or Wildfire Hours	100 h
Prescribed Burning (PB)	30 h	Prescribed Burning (PB)	30h
PB in Rangelands	10 h	PB in Rangelands	20h
PB in Understory	10 h	PB in Understory	20h
Wildfire Hours as Fire Specialist	50 h	PB boss	50h
TOTAL FS	200 h	Wildfire Hours as Fire Specialist	180 h
		TOTAL FOL	400 h
		TOTAL FS + FOL	600 h

to develop these qualifications and competences in the frame of National qualification systems;
- a basis for exchanges and help between countries (to be included when writing mutual assistance agreements).

However, there are many different kinds of fire behaviour experienced all over Europe. The skills needed to perform fire operations may vary depending on the complexity of the operation and the fire regime characteristics. Thus, some added competences are needed to be competent in high intensity, plume dominated fires with independent crowning, characteristic of Mediterranean summers.

Additionally, it is clear that performing as a Firing Specialist (FS) in a specific ecosystem, it is required to acquire some extra know-how specific to other fire regimes when performing under different conditions.

Each qualification has a series of related competences (see Table 2)

Create opportunities for maintaining and sharing expertise. The main problem with the use of fire for suppression is to maintain capacity of managing fire. Consequently, if we cannot keep operational teams active, they cannot keep adding experience hours, which holds a rather expensive problem, since not in all fires, burn out operations can be performed. This is especially important in countries with low-frequency, but fast and intense (large) fires threatening forest areas. Many fire professionals are only exposed once or twice in their professional career to the highest intensity – fastest and largest – fire experiences. People based in state fire services (both structural and forest service based) cannot accumulate enough experience to be prepared for such big events. It will always be a new situation, which needs a different response (more anticipation and working in advance) than the usual direct attack approach.

Consequently, emphasis is put on creating opportunities for accumulating and transferring knowledge and experience, allowing the sharing of expertise and training capabilities. However, providing experience in all different types of fires, fire intensities and fire behaviour is sometimes difficult if we only look at countries or regions individually. Of course, working and experience hours under different situations are required to have the ability to perform burn outs afterwards. In this context it is sometimes difficult to achieve the high expectations, especially if we don't look at Europe as a global wildfire area. The exchange of practitioners in large fire events in Europe allows more people to have the opportunity of participating in backfiring actions. Thus, the promotion of exchanges, both of people and information from all over Europe should be targeted and a series of best exercises and best practices are proposed to enrich exchanges.

Best exercises during exchanges. Exchanges with the purpose of sharing exercises have proven to be very useful because they are a great opportunity to share different approaches to a common problem. Best exercises shared during exchanges have been suppression fire demonstrations, analysis and priorities of opportunities in small scenarios and tracking opportunities in a landscape.

Best practices during exchanges. Best practices are the ones that allow learning from the tools and operations that the host organization is operating and performing, e.g. participating in a prescribed burning or constructing a line with the host tools, including the ones that allow learning from the type of fires, fuels, opportunities and capacity of extinction in the host organization (e.g. analysis of past fires).

Box 2. Lessons learned through exchanges

Fire fighters only experience a large wildfire episode in their area once to three times in their career. Only exchanging people during periods of risk in other areas can guarantee having experts ready to face a large fire episode, such as those occurred in Portugal (2003, 2005) or Greece (2007). Exchanging people and information have also benefits for the professionals who are hosting their colleagues, because both groups can share new approaches to the same old problems.

Figure 2. Zone where a burnout was started in l'Aude (France) in August 2007 in Armissan. The opportunity to control this flank could be used only through a fire suppression operation, and the presence of a Catalan fire specialist (in a Fire Paradox exchange) provided the French fire fighters the needed expertise to perform successfully this operation, and to acquire needed experience in their own ground.

Figure 3. Catalan fire specialist team working in a north Atlantic European ecosystem in Scotland, to get more experience in a light fuels fire, to be prepared for a wildfire in their region in the Pyrenees.

Figure 4. Training the use of the torch in prescribed burning: learning to look back (Catalan example). Regulating the distances between ignitions and distances of discontinuous fire fronts, with the same fuel means different behaviour.

5.3.7 Prescribed burning as a basic tool to train in the use of suppression fire

The most efficient way to increase opportunities of learning a technique to manage fire is participating in the performance of prescribed burning. Performing fire operations during a wildfire in Mediterranean areas requires many skills that are also necessary to perform prescribed burning both in rangelands and heathlands (without limitation of avoiding crown scorch but with larger fire fronts to control), and also the ones needed to perform understory burning (with more control of ignition patterns in a detailed scale due to crown scorch limitations).

Improving individual capability of analysis and drip torch management is a long process, but allows:

- to increase the capacity of lower levels to take informed tactical decisions;
- to improve the quality of strategic decisions, increasing the efficiency in the use of resources when there is a real opportunity;
- to improve the leadership towards other organizations participating in fire extinction;
- to plan in advance fire suppression operations.

5.3.8 Conclusions and recommendations

By definition, fire suppression techniques are used in a changing and unstable context. As a consequence, in any wildfire scenario, and especially in a scenario involving fire management, fire services must use all techniques and abilities available to read the clues given by fire behaviour, and to anticipate moments, places and ignition patterns, critical for the success of the operation. That means that building up an experienced fire service and maintaining knowledge and experience of fires in all its different conditions, is as important as a good training. This implies investing in well trained fire specialists, providing opportunities for experienced crews and fire analysts to experience large fire events, and investing in tools to increase and share knowledge and experience. During the large fires in Spain, Portugal, France and Greece, these investments in fire-experienced fire services had not been in place. In fact, policies of the European Union were repeatedly impeding factors to this development, since a request for massive aerial means for cooperation and assistance is still the common procedure, rather than asking for well trained crews and experienced fire analysts. To achieve the required changes in Europe, the needs are:

- Training, training and training about each fire. We need to ensure that everybody knows a good range of past fires and to create thereby a ‘common experience’;
- Use analysis to determine where to attack and when, so we use our resources at their maximum capacity;
- The same knowledge can be used in prevention during a no fire situation;
- Using fire as a suppression technique means getting experience through prescribed burning;
- Send fire professionals working outside their own fire service area and comfort zone, so they can pick up more experience to be used back home.

Box 3. Prescribed burning to improve fire specialist abilities in Portugal.

It is important that the fire professionals become more involved in forest fuel management, outside the fire season, mainly during prescribed burning operations. Prescribed burning is the most suitable scenario to provide training opportunities outside a wildfire. Some large prescribed fires can be used as training situations for the use of fire and to test best ignition patterns in suppression fire. This has been done in Portugal, where fire analysts and fire specialists must have prescribed fire training, certification and practice before starting to participate in wildfire analyses and suppression fire use.

The prescribed burning program included shrublands (1 318 ha in the last two years) but also forested stands (173 ha). Such a complete prescribed burning program is a needed step to train technicians and burning teams.

Some of these technicians are part of the fire analysis and fire use team (GAUF – Grupo de Análise e Uso do Fogo) that provide support to wildfire fighting during the fire season.

The activity of this group during the prescribed fire season provided the possibility for different actors to be involved in fire fighting, creating experience and knowledge that is useful during the fire season.

This strategy was also used to establish international exchange. The Lousã Summer Bases in 2007 and 2008, and the Prescribed Burning Practitioners Meeting, in February 2009, are examples of this exchange.

The participation of this highly experienced fire analysts and fire specialists was also a benefit for the prescribed burning program, namely through:

- Support to local burning teams needing the support of more experienced elements.
- Support to local burning teams, in their training, allowing to extend and to increase the efficiency of burning operations, using more wide prescription windows, and burning in more diverse situations,
- Application of this management technique in regions where there are not qualified technicians or hand crew teams with prescribed burning training.

These actions allowed a better expansion of prescribed burning, a larger implementation and more efficient fire management actions. This were also good opportunities to develop experience and exchange between teams, and also initial attack and suppression fire training, in situations close to the wildfire environment.

References

Alexander, M.E., and Thomas, D.A. 2003. Wildland fire behavior case studies and analyses: value, approaches, and practical uses. Fire Management Today 63: 4–9.

Andrews, P.L. 1986. Behave: fire behavior prediction and fuel modeling system - BURN subsystem Part 1. USDA Forest Service, Intermountain Research Station, Ogden, UT, USA. 130 p.

Campbell, D. (ed.) 1995. The Campbell Prediction System: A Wild Land Fire Prediction System & Language. 129 p.

Castellnou, M. 2000. Nuevas Metodologías de Prevención de Grandes Incendios. Congreso Forestal Ibérico. Castelo Branco, Portugal.

Castellnou, M., Mira, N., Castellarnau, X., Miralles, M., Loureiro, C., Lorca, M., Salgueiro, A., Binggeli, F., Gibson, S., Lambert, B., Grau, G., Solivellas, P., Cendra, J. and Quílez, R. 2008. Guidelines for exchanges between fire managers. Deliverable D10.4-1 of the Integrated Project "Fire Paradox", Project no. FP6-018505. European Commission. 58 p.
Castellnou, M and Miralles, M. 2009. The great fire changes in the Mediterranean - the example of Catalonia, Spain. Crisis Response 5: 56–57.
Castellnou, M., Miralles, M., Pages, J. and Pique, M. 2009 Tipificación de los incendios forestales de Cataluña. Elaboración del mapa de incendios de diseño como herramienta para la gestión forestal. Proceedings of the 5th Congreso Forestal Español. Ávila, Spain.
Clarke, K.C. Brass, J.A. and Riggan, P.J. 1994. A cellular automation model of wildfire propagation and extinction. Photogrammetic Engineering & Remote Sensing 60: 1355–1367.
Finney, M. 1996. FARSITE: Users Guide and Technical Documentation Systems for Environmental Management. Missoula, MT, USA.
Holling, C.S. 1981. Forest insects, forest fires and resilience. USDA Forest Service General Technical Report WO 26: 445–464.
Hutchins, E. 1995. How a cockpit remembers its speed. Cognitive Science 19: 265–288.
McCormick, R.J. Brandner, T.A. and Allen, T.F.H. 2000. Toward a theory of meso-scale wildfire modeling - a complex system approach using artificial neural networks. In: LF Neuenschwander, K.C., Ryan, G.E., Gollberg and Greer J.D., (eds.). Proceedings from the Joint Fire Science Conference and Workshop. University of Idaho and the International Association of Wildland Fire. Moscow, ID, USA. Pp. 3–15.
Piñol J., Beven K and Viegas D.X. 2005. Modelling the effect of fire-exclusion and prescribed fire on wildfire size in Mediterranean ecosystems. Ecological Modelling 183: 397–409
Sagarzazu Ansaldo, M.S. and Defossé, G.E. 2009. Study of a 2nd set of largest past fires. Deliverable D8.3-1 of the Integrated Project "Fire Paradox", Project no. FP6-018505. European Commission. 82 p.
Trédé, M. 1992. Kairos : L'à-propos et l'occasion. Editions Klincksieck, Paris. 338 p.
Weick, K.E. 1993. The collapse of sense making in organizations: the Mann Gulch Disaster. Administrative Science Quarterly 38: 628–652.

6. Solving the Fire Paradox – Regulating the Wildfire Problem by the Wise Use of Fire

6. Solving the Fire Paradox – Regulating the Wildfire Problem by the Wise Use of Fire

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6.1 Introduction

"Fire is a bad master but a good servant" is a Finnish proverb which illustrates the paradox of fire, as it reflects the detrimental effects when it runs out of control and the beneficial effects when it is mastered suiting human interests. However fire should be understood beyond an anthropocentric perspective, as it is associated with many natural ecosystems in the world, therefore playing a role in their conservation. Despite this general understanding shared by many ecologists, we are far from knowing what is 'good for nature'. On the contrary we have a quite clear perspective of what is 'good' for human societies. However, where fire is concerned there are contradictory perspectives of master and servant, which lead to the paradox of fire.

Understanding the detrimental and beneficial effects of fire is fundamental for a more comprehensive view of the Fire Paradox and constitutes the optimal conceptual basis for integrated fire management policies and practices. Considering this integrated perspective, the set of coherent actions required to minimize the net social costs of fires include: the mitigation of fuel hazard, the reduction of unwanted ignitions and the suppression of wildfires. In turn, this set of actions must be translated into policies and disseminated to all participating agents. The structure of the present chapter follows this framework, including different developments and solutions to solve the paradox of fire.

6.2 Minimizing the net social costs of fires

The objective of minimizing the social impacts of forest fires implies in the first place, the need of quantifying the social costs and benefits of fire regimes. This is a problem which is common to many aspects of forests and wildland areas, given the difficulties to determine the value of externalities, for example. Despite the methodologies which were developed to tackle this problem (see Mavsar et al. in this volume) there are major drawbacks which have to be solved or minimized, such as the absence of common criteria for data collection on costs and expenses associated with wildfires.

Minimizing the social costs of fire implies the assessment of fire effects on vegetation, people and infrastructures. With this purpose, research efforts were developed in order to determine fire effects on trees using experimental and numerical studies of fire behaviour and effects (Guijarro et al. (2009), including a review on the state of the art of pine resistance to fire (Fernandes et al. 2008). Another contribution to the assessment of fire effects was performed by Hostikka et al. (2008) and Torero (2008) including the simulation of fire brands (i.e. burning particles such as twigs or leaves carried by wind and capable of starting fires) travelling into houses (Sikanen 2009). Wildland urban interfaces are both an important source of ignitions and an important concern due to the values at risk in terms of human lives and property. The strategy to tackle this important problem includes the characterization and the mapping of wildland urban interfaces and the assessment of vulnerability and potential damages (Lampin et al. 2008).

Another important aspect regarding the social costs of fires has to do with the traditional use of fire in some European regions. Traditional fire use practices constitute an influencing factor which has to determine and guide the strategies and recommendations to be applied within a given social context. Recognizing the benefits of traditional fire by integrating these practices instead of systematically suppressing them, may contribute to fuel management and may save the resources spent in unnecessary fire fighting (Lázaro et al. 2008). Nevertheless European countries present contrasting situations in terms of traditional fire use: in Central Europe and Baltic countries there has been a general abandonment of rural fire practices but in other countries, particularly in the Mediterranean Basin, fire is a deeply rooted tool for rural activities.

Minimization of wildfire costs is also influenced by the characteristics of the vegetation which burns. Different works have approached the problem of fire selectivity (Bajocco and Ricotta 2008; Moreira et al. 2009) allowing the conclusion that land use may definitively influence fire incidence and therefore the social costs from wildfires. Another related issue is the capacity of vegetation to continue assuring the benefits and services to the society and its role in the ecosystems, after the fire has passed. Some vegetation types are more resilient than others, which means they are capable of contributing to reduce the negative effects of wildfires by quickly recovering after burning. This may contribute to strongly reduce the cost of wildfires from both economic and ecological perspectives (see Mavsar et al. in this volume and Krivtsov et al. 2008). Therefore, integrated fire management should consider not only the use of fire to modify fuels and to fight fires, but also to drive the ecological succession towards less fire prone and more resilient vegetation, in order to minimize the costs of wildfires.

6.3 Managing fuels with prescribed burning to reduce wildfire hazard and severity

Proper fuel management requires sound knowledge of fuel characteristics for the different fuel types. Accurate characterization and mapping of fuels can provide useful information to be used in pre-fire planning, and therefore in the construction of forest fire management plans. Remotely sensed data have already been used to directly identify and map fuel types or to obtain vegetation maps, which were later translated into fuel models. The objective of fuel type classification is to define vegetation associations with similar potential fire behaviour. With this purpose several recent studies were produced aiming at developing fuel typology and fuel characterization systems, using remote sensing (Mårell et al. 2008). Additionally, fire hazard maps are needed to assist the spatial planning of prescribed burning. A sequence of mapping exercises was conducted in study areas in South Africa and Portugal for integrated fire management on a regional level (De Ronde 2009a). These can be used with advantage in other European countries to develop optimized fire protection systems, and to select where to apply prescribed burning and fuel treatments in general.

The study of fuels has different aims, one of the most important being the use of fuel characteristics as inputs to fire behaviour models and systems. Recent works have allowed the development of a fuel editor aiming to be, on one hand, a management tool for manipulating fuel complexes and on the other, an application that enables fire simulations and the generation of vegetation post fire succession steps (Lecomte et al. 2009). Since fuel conditions are constantly changing, the dynamic side of fuel characterization is undoubtedly a challenging domain, given the difficulties of forecasting scenarios of fuel development, and the usefulness of having this information for fuel and fire management planning, including the use of prescribed fire. Therefore some attempts have been performed in order to model the temporal variation of fuel accumulation and fuel structure, with the general aim of evaluating prescribed fire regimes (Krivtsov et al. 2008; Krivtsov et al. 2009a,b). The use of prescribed burning has to be thoroughly assessed in order to allow evaluation of its effectiveness in reducing fire hazard. In the absence of the required long-term information, fire modelling and analysis of the fire regime dependency on fuel age, can be used as a surrogate to ascertain the relevance of prescribed burning (Cassagne et al. 2009).

A positive side effect of prescribed burning is the possibility to mitigate CO_2 emissions by reducing the potential fire hazard of wildlands. However, prescribed burning in Europe can only make a significant contribution in those countries where fire incidence is high (Narayan et al. 2007). Over a 5-year period, the emissions from wildfires in Europe were estimated to be approximately 11 million tonnes of CO_2 per year, while with extended prescribed burning programs this was estimated to be 6 million tonnes, a potential reduction of almost 50%. This means that for countries in the Mediterranean region it may be worthwhile to account for the reduction in emissions obtained when such techniques are applied.

As a final consideration regarding the importance of prescribed burning as a key issue to solve the Fire Paradox, we should add the need of international cooperation. This has been achieved through the knowledge exchange between different European countries but also with non-European countries. A good example was the establishment of guidelines for the integration of prescribed burning in Europe, using the experience from South Africa (De Ronde 2009b). Although very different from Europe, the South African situation can be extrapolated to some European countries, especially those which share similar tree species used in industrial plantations such as *Pinus* spp. and *Eucalyptus globulus*.

6.4 Decreasing unwanted ignitions and integrating the traditional use of fire

The study of ignitions starts with the basic characterization of forest fuel pyrolysis, and the process of ignition and combustion. From the fuel perspective, the processes controlling ignition and flame spread are the degradation chemistry and the different heat and mass transport processes. Given the complexity of these processes new developments have recently been introduced by comparing different methods for studying and modelling the pyrolysis process of forest fuels (Rein et al. 2008).

Fuel moisture content (FMC) is a critical parameter that affects fire ignition, fire behaviour and fire severity. However, FMC modelling is still a challenge. In fact, FMC is a necessary input for all existing physical, semi-physical and empirical fire behaviour prediction models as well as ignition probability models. Besides that, FMC, or its surrogate in the form of an index, is a key factor in most fire danger rating systems. From the operational point of view, FMC estimates are also required for prescribed burning planning and for suppression activities. Recent studies have provided new data for the prediction of fuel moisture using remotely sensed data (Todone et al. 2009), methods for estimating ignition probability of fine fuels (Kazakis et al. 2007), and relationships between ignitability and fuel bed characteristics (Curt et al. 2007).

Besides the physical and biological mechanisms related to ignitions, the basic problem to solve, in order to decrease the number of unwanted ignitions, deals with the relationships between fire starts and land use, particularly in the European context. According to different studies it is known that ignition probability is closely related with human presence and human activities (see Catry et al. in this volume). Agricultural practices are known to be an important source of ignitions in different European regions. Also road networks and wildland urban interfaces have a positive relationship with ignition probability. Therefore the identification of these situations is of crucial importance for decreasing the number of unwanted ignitions (Bajocco et al. 2008).

Consequently the development of public awareness strategies is a fundamental aspect if we want to mitigate the problem of unwanted ignitions and to have a conscious use of fire. The achievement of these objectives depends on a proper use of recent information and communication techniques adapted to the different specific situations (Badillo and Bourgeois 2008). In this field we are far from having satisfactory solutions in terms of outcomes obtained from the communication process. Therefore it is important to analyze the communication process, in order to develop a more effective communication and dissemination strategy (Badillo et al. 2009).

6.5 Reducing the extent of wildfires through suppression fire

The further objective is to decrease wildfire sizes, costs and damages. One main approach is the use of suppression fire. This is a very challenging practice requiring in-depth knowledge of fire behaviour, including the interaction between fire fronts, which has been poorly addressed by past research. Numerical simulations on suppression fires can be performed with existing 3D physical-based models such as Firetech and WFDS (Linn et al. 2002). Numerical simulations of a fully-physical model are an alternative to obtain information on fire propagation. These models provide detailed information such as the temperature of the gaseous phase, the temperature of the different components of the vegetation, fuel moisture content of the vegetation, heat fluxes, as a function of spatial position and time. Given that these quantities cannot be determined through experiments, numerical simulations are a powerful tool to study the mechanisms of fire behaviour and effects. Recent developments have contributed to, and improved, the scarce body of numerical studies of wildfire behaviour using full-physical models, addressing the interaction between fire fronts and fire impact on trees.

An additional source of knowledge is the recording of large past fires. It is worth noting that the implications of wildfire case studies done in one country can be extended to others. The reconstruction and analysis of fires can be based on historical fire databases, reports, journals, satellite images and interviews, including the description of time and cause of ignition, meteorological and topographic conditions, main vegetation types present in the region, fire suppression strategies and tactics applied, fire behaviour characteristics (rate of spread, length of flame, spotting, etc.), and difficulties encountered by fire suppression. Detailed information about past wildfires are valuable not only in assisting training but also as sources of research data (Sargarzazu and Defossé 2009).

Temporary field bases located in areas historically subject to wildfire are also an interesting source of knowledge and experience. These multidisciplinary summer laboratories were a meeting point for fire research in Europe with the objective of accelerating the collection and sharing of knowledge for subsequent dissemination. The overall objectives of field bases were the follow-up and monitoring of wildfires and the analysis and interpretation of aerial documentation. Aerial observations recorded by airplanes above wildfires allowed for a continuous follow-up of fire propagation. The use of infrared and laser technologies provided data allowing deeper understanding of the mechanisms involved. This information together with ground-based observations was shared between scientists, students and fire managers from different countries (Binggeli 2009).

The availability of information on fire propagation issued with the support of simulation software is another crucial aspect of fire fighting. Image analysis software is capable of extracting fire lines and spotting from infrared images, and a ‘regional centre of resources’ is able to put them in a geographical system and to send this information. Moreover, the simulation of fire spread running on a remote dedicated server can supply extra information about fire propagation and this information can be used to generate a prevision fire map in real time. The transmission of this data can be used by fire commanders (on a laptop or PDA) in real time, to run fire simulations and fire spotting assessment (Orabona et al. 2007).

6.6 Policies and knowledge dissemination

The general concept of integrated fire management is particularly relevant in the dissemination of knowledge and recommendations to policy makers, fire managers and university students, given the integrated perspective which has necessarily to be introduced in these different approaches to the paradox of fire. These approaches may come in the form of scientific outputs, technical guidelines, and policy documents to support the implementation policies and practices, and the academic and professional training.

It is important to assess the main benefits and limitations of the legislation and policy outputs in order to consider their contributions to integrated fire management, before making proposals for new legislation. Although the European legislation has contributed to homogenize national legal frameworks, there are still important differences among countries. On the other hand most forestry-related documents hardly ever mention wildfire management. Also, there is clearly a lack of an effective coordination among the different units dealing with fires. Further, problems of coordination are exacerbated by the fact that many countries have federal systems or are undergoing decentralization trends. Regarding community-based cooperation, organized groups of local stakeholders are emerging especially in Mediterranean countries. These groups contribute to fire management as a result of instrumental motivation, or self-interest. Furthermore, some common ecological and socio-economic patterns have been recognized at the regional level, which can be used to provide recommendations for the future and to set the basis for new legislation and policy measures relative to integrated fire management, adapted to each territorial context (Agudo and Montiel 2009; Herrero et al. 2009). Apart from sector policies which have the responsibility for national fire management (forest and civil protection), it is considered necessary to analyze other public policies, which are outside of the sector scope. The assessment performed by Lázaro et al. (2009) has identified some common findings about the role that territorial policies should play concerning integrated fire management at the national and European level.

Integrated fire management also deals with cooperation policies. Cooperation mechanisms, from the regional to the international scale, emerge as an evident answer to the problem of wildfires and fire use. In most countries the coordinating institutions in fire prevention are the agricultural, forest and environmental government services, with only a few countries assigning that responsibility to civil protection related institutions. The majority of cooperating entities in prevention are public institutions, but in some cases private entities, such as volunteers, private companies, and forest owners associations also participate in prevention programs. In most countries the coordination of fire extinction activities is the responsibility of the civil protection, but in some countries the coordination is the responsibility of forest or environmental services. International cooperation is more often associated with mutual assistance protocols for fire extinction, such as bilateral agreements, and European Union's Community Civil Protection Mechanism. Bilateral agreements are usually related to aerial means, but some countries also have agreements for the intervention in common border areas. European Union's Community Civil Protection Mechanism is the most important mechanism at the European scale, conveying wildfire disaster relief requests to the community countries (Correia et al. 2008).

With regard to knowledge dissemination, we must distinguish the professional training of managers and fire fighters and the academic training level. Both should include an integrated fire management approach in order to know how to analyze and understand fire in its dual perspective: i.e. as both master and servant. Prescribed fire and experimental fires must be considered as an obligatory part of any training for fire professionals. The extensive practice of prescribed burning is a very effective training for fire professionals who have an important role in fuel management, simultaneously with their training for fire fighting. Formal knowledge dissemination is far from being sufficient to prepare fire professionals. Training is a fundamental aspect in assuring effectiveness in fire fighting efforts. The training of fire professionals strongly benefits from the exchange of knowledge between crews from different countries during the occurrence of large wildfires (Castellnou et al. 2008).

Concerning university and post-graduate level training, not many initiatives have been particularly focused on integrated fire management. In Europe, fire academic training is not responding to the increasing number of issues in forest and nature management that are formulated, implemented, and co-ordinated at a level above that of the nation state. This situation provides a whole range of new challenges and demands for policy and management at the European level. This situation calls for the implementation of post-graduate studies on fire management. The educational goals of such a post-graduate program should provide the students with an effective, quality learning experience. Science-based education must be balanced with application of that science, and providing advise that is tailored to help students to meet their long-term career and educational goals. Further, such graduate programs should seek to attract and support students who have the potential to become leaders within the fire community, and to foster a culture of diversity, community and global citizenship. An initiative with these characteristics has recently been launched under the form of an International Fire Master Program based on an agreement between four universities from Europe and the USA, as an outcome of the Fire Paradox project.

6.7 Final considerations

As a closing remark, it is important to retain a message which is crucial for solving the paradox of fire: there is no single solution to this complex problem. Solving the paradox of fire should make use of a whole range of attributes, from fuel management to public awareness; from professional training to science informing policy. The Fire Paradox project has produced a variety of fire science goods and services including: scientific papers, technical reports, technological tools, training programs and training materials. This diversity of outputs is necessary if we want to introduce changes in fire management, rather than just stating principles. The outcomes of the Fire Paradox project provide an integrated solution to a complex problem in fire management. In the present day the complex trade-offs between fire as a bad master and as a good servant, have necessarily to be played by agents that have the knowledge and the training required under the principles of integrated fire management and wise use of fire. The preparation of these agents, from policy makers to fire managers, under this integrated approach is the core of our proposal to solve the Fire Paradox.

References

Agudo, J. and Montiel, C. 2009. Basis to start the process for a proposal of a new legislation at EU level. Deliverable D.7.1-1.3 of the Integrated project “Fire Paradox”. European Commission. 45 p.

Badillo, P.-Y. and Bourgeois, D. 2008. Report to the European Commission: synthesis of the state of the art. Deliverable D11.1-5 of the Integrated Project “Fire Paradox” , Project no. FP6-018505. European Commission. 51 p.

Badillo, P.-Y., Bourgeois, D., Marciano, J-P. and Asdourian, B. 2009. Seminar with experts. Internal Report 11.3-5 of the Integrated Project “Fire Paradox” , Project no. FP6-018505. European Commission. 18 p.

Bajocco, S. and Ricotta, C. 2008. Evidence of selective burning in Sardinia (Italy): which land-cover classes do wildfires prefer? Landscape Ecology 23(2): 557–567.

Bajocco, S., De Angelis, A., Rosati, L., Ricotta, C., Mouflis, G.D., Gitas, I.Z., Silva, J.S., Moreira, F., Vaz, P., Catry, F., Ferreira, P.G., Pezzatti, G.B., Torriani, D. and Conedera, M. 2008. Publication describing wildfire regimes distribution in selected European study areas. Deliverable D4.1-1b of the Integrated Project “Fire Paradox”, Project no. FP6-018505. European Commission. 79 p.

Binggeli, F. 2009. Bulletins of the bases. Internal Report IR8.1-1 of the Integrated Project “Fire Paradox”, Project no. FP6-018505. European Commission. 7 p.

Cassagne, N., Mantzavelas, A., Dupuy, J.L., Lazaridou, T., Pimont, F., Partozis, T., Fernandes, P., Loureiro, C. and

Rigolot, E. 2009. Report on the effects of broad scale and long-term application of prescribed burning on fire risk components. Deliverable D5.3-1 of the Integrated project “Fire Paradox”, FP6-018505. European Commission. 88 p.

Castellnou, M., Mira, N., Castellarnau, X., Miralles, M., Loureiro, C., Lorca, M., Salgueiro, A., Binggeli, F., Gibson, S., Lambert, B., Grau, G., Solivellas, P., Cendra, J. and Quílez, R. 2008. Guidelines for exchanges between fire managers. Deliverable D10.4-1 of the Integrated Project “Fire Paradox”, Project no. FP6-018505. European Commission. 58 p.

Correia, A., Colaço, C., Rego, F., Solana, J., Herrero, G., Montiel, C., Sesbou, A. and Kraus, D. 2008. A review of the existing cooperation mechanisms between departments dealing with fire management at the European and national level. Deliverable 7.1-4 – 1 of the Integrated Project “Fire Paradox”, Project no. FP6-018505. European Commission. 58 p.

Curt, T., Ganteaume, A., Jappiot, M., Lampin, C., Borgniet, L., Baudel, J., Esteve, R., Martin, W., N’Diaye Boubacar, A., Madrigal, J., Díez Galilea, C., Marino, E., Guijarro, M. and Hernando, C. 2007. Empirical modelling of fuel flammability and initial fire propagation: First results. Deliverable D3.1-6 of the Integrated Project “Fire Paradox”, Project no. FP6-018505. European Commission. 23 p.

De Ronde, C. 2009a. Recommendations for prescribed burning mapping in Mediterranean-type natural vegetation and forests. Deliverable D5.4-2 of the Integrated Project “Fire Paradox”, Project no. FP6-018505. European Commission. 17 p.

De Ronde, C. 2009b. Guidelines for the integration of prescribed burning in the Fire Paradox environment: within natural vegetation, industrial forest land and the urban interface. Deliverable D13.1-2 of the Integrated Project “Fire Paradox”, Project no. FP6-018505. European Commission. 26 p.

Fernandes, P.M., Vega, J.A., Jiménez, E. and Rigolot, E. 2008. Fire resistance of European pines. Forest Ecology and Management 256: 246-255.

Guijarro, M., Madrigal, J., Marino, E., Hernando, C., Díez, C., Mendes-Lopes, J.M., Ventura, J., Santos, N., Meléndez, J., López, F., Aranda, J.M., Díaz, F., Defossé, G., Godoy, M.M., Sagarzazy, M.S., Bianchi, L., Bravo, S., Kunst, C., Ledesma, R. and Godoy, J. 2009. Fire impact on trees and shrubs: methods and first results. Internal Report

IR2.3-3 of the Integrated Project "Fire Paradox", Project no. FP6-018505. European Commission. 45 p.
Herrero, G., Montiel, C., Agudo, J. and Aguilar, S. 2009. Assessment document on the main strengths and weaknesses of the legislation and policy instruments concerning integrated wildland fire management in the EU, in European Member States and in North African countries. Deliverable D7.1-1-2 of the Integrated Project "Fire Paradox", Project no. FP6-018505. European Commission. 117 p.
Hostikka, S., Mangs, J. and Mikkola, E. 2008. The effect of three-dimensionality on the building response to a forest fire. Deliverable D2.5-2 of the Integrated Project "Fire Paradox", Project no. FP6-018505. European Commission. 53 p.
Kazakis, G., Ghosn, D., Xanthopoulos, G. and Dimitrakopoulos, A. 2007. Probability of ignition modelling in forest fuels – First results. Deliverable D3.1-5 of the Integrated Project "Fire Paradox", Project no. FP6-018505. European Commission. 42 p.
Krivtsov, V., Fernandes, P., Higham, B., Pezzatti, G.B. and Legg, C. 2009a. Release of prototype software for allometric modelling of fuel structure with provisional case studies. Deliverable D3.3-5 of the Integrated Project "Fire Paradox", Project no. FP6-018505. European Commission. 33 p.
Krivtsov, V., Legg, C., Vigy, O., Rigolot, E., Lecomte, I., Curt, T., Jappiot, M., Lampin, C., Fernandes, P. and Pezzatti, B. 2008. Prototype of biophysical models of fuel accumulation using empirical data. Deliverable D3.3-3 of the Integrated Project "Fire Paradox", Project no. FP6-018505. European Commission. 30 p.
Krivtsov, V., Vigy, O., Legg, C., Curt, T., Rigolot, E., Lecomte, I., Jappiot, M., Lampin-Maillet, C., Fernandes, P. and Pezzatti, G. 2009b. Fuel modelling in terrestrial ecosystems: An overview in the context of the development of an object-orientated database for wild fire analysis. Ecological Modelling 220:2915–2926.
Lampin, C., Long, M., Jappiot, M., Morge, D., Bouillon, C., Mantzavelas, A., Apostolopoulou, I., Lazaridou, T., Partozis, T., Topaloudis, T., Galiana, L., Herrero, G. and Solana, J.L. 2008. Guide for end-users to characterize and to map wildland urban interfaces. Deliverable D5.2-2 of the Integrated Project "Fire Paradox", Project no. FP6-018505. European Commission. 18 p.
Lázaro, A., Galiana, L., Aguilar, S., and Sesbou, A. 2009. Assessment document on the main strengths and weaknesses of the legislation and spatial policy instruments concerning wildfire integrated management in the EU, in European member states and in North African countries. Deliverable D7.3-1 of the Integrated Project "Fire Paradox", Project no. FP6-018505. European Commission. 81 p.
Lázaro, A., Solana, J., Montiel, C., Goldammer, J.G., Kraus, D. and Rigolot, E. 2008. Collection, classification and mapping of the current prescribed fire and suppression fire practices in Europe. Deliverable D7.1-3-1 of the Integrated Project "Fire Paradox", Project no. FP6-018505. European Commission. 47 p.
Lecomte, I., de Coligny, F., Griffon, S., Pimont, F., Rigaud, E., Rigolot, E. and Vigy, O. 2009. Fire Paradox fuel manager: software and user's manual. Product P6.1-6 of the Integrated Project "Fire Paradox", Project no. FP6-018505. European Commission. 85 p.
Linn, R., Reisner, J., Colman, J.J. and Winterkamp, J. 2002. Studying wildfire behavior using FIRETEC. International Journal of Wildland Fire 11:233-246.
Mårell, A., Abdelmoula, K., Allgöwer, B., Borgniet, L., Cassagne, N., Curt, T., Ganteaume, A., Ghosn, D., Gitas, I., Jappiot, M., Jimenez, E., Kazakis, G., Koetz, B., Lampin, C., Machrouh, A., Morsdorf, F., Pimont, F., Rigolot, E., Sesbou, A., Vega, J.-A. and Wellani, W. 2008. Fuel description: first results. Deliverable D3.4-3 of the Integrated Project "Fire Paradox", Project no. FP6-018505. European Commission. 80 p.
Moreira, F., Vaz, P., Catry, F. and Silva, J.S. 2009. Regional variations in wildfire susceptibility of land-cover types in Portugal: implications for landscape management to minimize fire hazard. International Journal of Wildland Fire 18:563-574.

Narayan, C., Fernandes, P.M., van Brusselen, J. and Schuck, A. 2007. Potential for CO_2 emissions mitigation in Europe through prescribed burning in the context of the Kyoto protocol. Forest Ecology and Management 251:164–173.
Orabona, V., Mazzoleni, S. and Giannino, F. 2007. Report on the type of data collection. Deliverable D6.4-1 of the Integrated Project "Fire Paradox", Project no. FP6-018505. European Commission. 12 p.
Rein, G., Torero, J., Guijarro, M., Esko, M. and Castro, A. 2008. Methods for the experimental study and recommendations for the modelling of pyrolysis and combustion of forest fuels. Deliverable D2.1-1 of the Integrated Project "Fire Paradox", Project no. FP6-018505. European Commission. 83 p.
Sagarzazu, M.S. and Defossé, G.E. 2009. Study of a 2º set of largest past fires. Deliverable D8.3-1 of the Integrated Project "Fire Paradox", Project no. FP6-018505. European Commission. 82 p.
Sikanen, T. 2009. Fire safety analysis around targets using FDS: Final achievements - Transport of firebrands and attack on buildings. Deliverable D2.5-4 of the Integrated Project "Fire Paradox", Project no. FP6-018505. European Commission. 24 p.
Todone, J.F., Bianchi, L.O. and Defossé, G.E. 2009. First field sampling results of dead and live fuel moisture prediction in Patagonia. Internal Report IR3.1-7b of the Integrated Project "Fire Paradox", Project no. FP6-018505. European Commission. 24 p.
Torero, J.L. 2008. Criteria for building material ignition and assessment of burn injuries in wildland fires: model development. Internal Report IR2.5-3 of the Integrated Project "Fire Paradox", Project no. FP6-018505. European Commission. 58 p.

Important Concepts and Terms

Integrated fire management: A concept for planning and operational systems that include social, economical, cultural and ecological evaluations with the objective of minimizing the damage and maximizing the benefits of fire. These systems include a combination of prevention and suppression strategies and techniques that integrate the use of technical fires and regulate traditional burning.

Fire management: All activities required for the protection of burnable forest and other vegetation values from fire, and the use of fire to meet land management goals and objectives.

Traditional burning (or traditional fire use): The use of fire by rural communities for land and resource management purposes based on traditional know-how.

Appropriate traditional fire use: The use of traditional burning under legal regulations and good practices.

Technical fire: The controlled use of fire carried out by qualified personnel under specific environmental conditions and based on an analysis of fire behaviour. Technical fires are divided into prescribed fires, wildfires within prescription and suppression fires.

Fire within prescription: A prescribed fire or a wildfire that burns within prescription.

Prescribed burning (or prescribed fire): The application of a fire under specified environmental conditions, which allow the fire to be confined to a predetermined area and to attain planned resource management objectives.

Wildfire within prescription: A wildfire that is confined to a predetermined area and produces the fire behaviour and the fire effects required to attain the planned fire treatment and/or resource management objectives.

Wildfire: Any unplanned and uncontrolled vegetation fire which, regardless of the ignition source, may require suppression response or other actions according to agency policy.

Suppression fire: The application of a fire to accelerate or strengthen the suppression of wildfires.

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The approach taken in the Fire Paradox project was based on the paradox that fire can be "a bad master but a good servant", thus requiring the consideration of the negative impacts of current wildfire regimes (understanding fire initiation and propagation) and the beneficial impacts of managed fires in vegetation management and as a planned mitigation practice (prescribed burning together with some traditional fire uses) and for combating wildfires (suppression fire). These were the four integration pillars of the project.

This Research Report reflects the structure of the project, corresponding to its integration pillars – initiation, propagation, prescribed burning and suppression fires – and including a closing chapter which synthesizes and combines the main project outcomes. The book provides science based knowledge that can assist policy makers to develop the necessary 'common strategies' to elaborate and implement integrated fire management policies. It makes extensive use of the science and technology findings from the Fire Paradox project, focusing on policies and best management practices, as well as providing guidelines for the future.

The Fire Paradox project (2006–2010) was funded by the European Commission Research and Development 6th Framework Programme. The project included 30 partners from eleven European countries and six partners from Africa, South America and Asia, with close support from an International Advisory Committee formed by nine specialists from the USA, Canada and Australia. Fire problems and solutions are found all over the world, and we see the knowledge exchange and benefits of Fire Paradox will extend far beyond Europe.

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