FIREfficient
Operational tools for improving efficiency in wildfire risk reduction in EU landscapes

This project is co-funded by the European Union

Methodology for incorporating large fire risk into landscape management decision making

Authors:

Jordi Pagès[1], Andrea Duane[2], Marc Castellnou[1] and Lluís Brotons[2]

Advisory board:

Marta Miralles[1], Edgar Nebot[1], Asier Larrañaga[1], Mariona Borràs[3]

Contributors:

Etel Arilla[1], Xavier Castellarnau[1], Jordi Guarque[1], Josep Pallas[1], Matthew Bushby[4], Pere Frigola[5], Assu Gil-Tena[2], Núria Aquilué[2]

1 Department of Interior from the Government of Catalonia; Bombers GRAF, INT-GRAF
2 Forest Science Centre of Catalonia, CTFC
3 Pau Costa Foundation
4 Mourne Heritage Trust
5 Generalitat de Catalunya

Bellaterra, April 2015

Forest Sciences Centre of Catalonia · Generalitat de Catalunya Departament d'Interior · PAU Costa Foundation · EFI · King's College London University of London

INDEX

1. Introduction

Goals

Landscape evolution in Europe has been closely linked to anthropic factors for centuries. These factors have been of different nature and have been changing along history. However, from the second half of 20th century, transformations are more intense and changes are accelerating. Land abandonment and agriculture and livestock farming intensification (Moreira *et al.* 2001), urban economic concentration, wildland-urban-interface sprawl, forest expansion (Améztegui *et al.* 2010) and protection, and lack of forest management, are the main drivers of change in Europe in the last decades, and all them are increasing wildfire occurrence risk, fire intensity and population exposure. During last years, wildfire extreme events have been recorded in several areas from Europe: Portugal (2003 and 2005), South-East France (2003), Spain (2006, 2009 and 2012) and Greece (2000, 2007 and 2009), and even in more unusual regions as Sweden in 2014.

The response from governments and public administrations to this challenge has been focused on the reinforcement to suppression policies, understanding forest fire as unforeseeable civil emergencies affecting randomly the landscape. Suppression policies have been quite successful with most of fires ignited. Very few of them, only the fastest and more intense ones, behave out of capacity of control for fire services. But those few large wildfires (LWF) are the ones that burn most of the landscape, and get people and communities feeling threatened and vulnerable. Large wildfires of the last decades show repeated fire patterns (Costa *et al.* 2011). Thus, large fires are no longer stochastic, unforeseeable processes, and so wildfire risk can be further integrated on land planning.

Landscape planning seems to be one of the potential solutions to the large wildfires problem (Loepfe *et al.* 2012). Wildfire extinction policies have not been able to eliminate forest fire, but it has increased the importance of large wildfires (Piñol *et al.* 2007). Landscape planning can modify fire regime:

1. by managing the fuel, increasing the frequency and reducing intensity of disturbances
2. by helping fire brigades contain the fire where landscape is favourable, accepting the rest of the landscape will burn

Thus, wildfires become a multi-sectorial issue relating forest managers, civil protection bodies and urban and land-use planners, which should interrelate and collaborate aiming at reducing European landscape vulnerability to large wildfires.

Mediterranean ecosystems are particularly affected by global change, and tipping-points might be reached during this century with the predicted increase of both the frequency and the intensity of disturbances associated to climate change, land-use change and lifestyle (FAO 2013). Similar challenges may also appear in peripheral areas, specifically in Europe in northernmost limits. Given fire intrinsic presence in the ecosystems, the challenge does not consist in its final eradication of the systems, but in anticipate and reduce fires capacity of spread out of control capacity, and thus reduce goods and people damage. The solution has been manifested to not depend on the direct investment on suppression efforts,

but considering an integrative landscape planning that incorporates potential wildfire occurrence and spread into landscape socioeconomic dynamics.

The purpose of the present guide is to develop a methodology for incorporating wildfires risk in decision-making landscape management, aiming at facilitating easier choices between alternative management actions and fuel treatment, and thus reduce landscape vulnerability to large wildfires from a cost-effectiveness perspective.

Approach

The first part of the guide presents the background and state of the art in terms of fire and landscape planning, as well as a brief review on Europe fire situation.

Given the wide-possibility potential user of this guide, the character adopted by the same is quite general. Firstly it aims to help decision-makers at the landscape planning and forest management level to situate and adapt their potential management actions, aiming to reduce the spread of possible fires in the different regions. Finally, it aims to help the discussion of the potential policy measures that agencies can adopt to reduce fuel load in the landscape, and at the same time, reduce large wildfires vulnerability.

By this guide the aim is to reduce landscape vulnerability to large wildfires by:

- Reduce intensity and impact of LWF
- Increase security, efficiency and effectiveness of suppression bodies
- Reduce risk on goods, people and economy
- Increase cost-effectiveness ratio in investments for fire risk reduction.

We propose to translate forest management into landscape ordination through the knowledge of the spread and behaviour of fires. Usually this potential fire spread has been assessed by fire analyst within firefighters' brigades. Firefighters are able to stop small wildfires, and control damage to people. In front of a large wildfire, landscape and forest planners are the ones that could reduce the negative impact of the fire, by technical decisions conducted to facilitate firefighters' operations and reduce fire potentials. Hence, bringing up together the different agencies of the public administration is a challenging goal presented in the guide.

During the guide, a European context is considered for the proposed methodology. However, some examples of specific regions of different parts of Europe will be used as case studies for illustrate the management actions proposed or the limitations on the implementation. More specifically, Catalonia will be the most redundant region used as case study, since it is one of the most advance regions in terms of fire prevention, management and extinction at the European level.

2. Background and State of the art in Europe

Land planning and fire regulation: historical perspective

Commonly in Europe, wildfire risk planning has been approached from the view of urban and territorial planning, mostly delimitating protection strips or, as a most, identifying certain risk zones where edification is forbidden. Mainly, wildfire risk planning has been centred in Wildfire-Urban-Interfaces (WUI). Although many other risk have been incorporated in land planning, as earthquakes or floods, wildfires have historically not been considered, both for its low risk perception in many regions, and for the difficulty associated to its more stochastic behaviour.

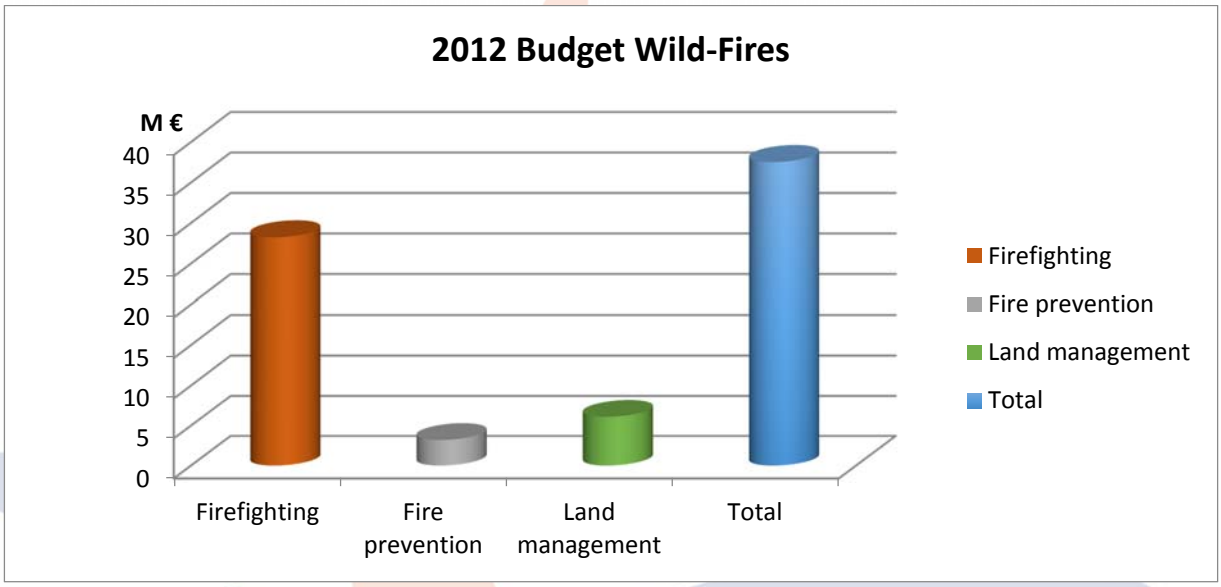

FIGURE 1: BUDGET FOR PREVENTION AND FIREFIGHTING WILDFIRES IN CATALONIA IN 2012 (SOURCE: WEBSITE OF THE FORESTRY AND INTERIOR DEPARTMENT OF THE CATALAN GOVERMENT).

Public investment in forest management, prevention and fire-fighting are closely linked. Last years trend has been the focus on investments in wildfire prevention and extinction. Nowadays most part of investments dedicated to prevention are bound to build extinction support infrastructures, more than managing fuel loads at stand and/or landscape scale (Figure 1). Paradoxically, studies show that this policy tends to perpetuate large wildfires more than prevent in high fire recurrence areas. On the contrary, forest management investment (with a fuel reduction associated) is one of the suitable actions capable to reduce large wildfires incidence.

Stakeholders involved

Wildfire risk issue has several actors involved in the active and passive prevention and extinction within the wildfire management. From a public administration point of view, the three most common departments involved in land planning and emergencies are: Civil Protection Department: aims to protect populations in front of several risks and mainly acts in the active extinction process; Environmental Department: represents the competence on forest management, thus acting at a passive prevention

scale; and Land-use Department, which integrates multi-sectorial land-use planning to actively prevent wildfires.

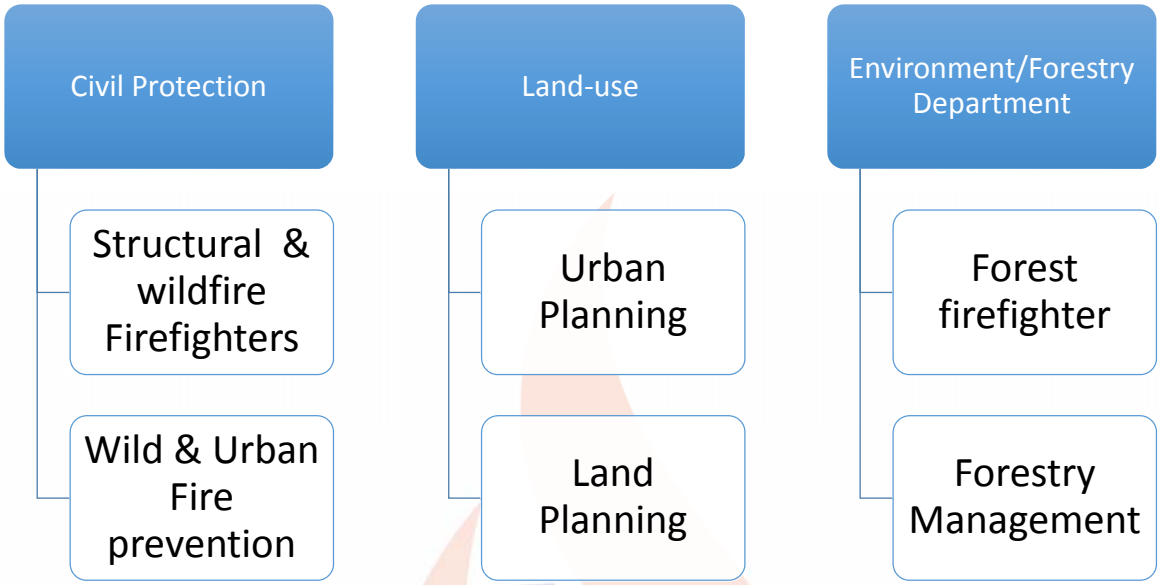

FIGURE 2: COMMON DEPARTMENTS INVOLVED IN FIRE FIGHTING PREVENTION AND EXTINCTION

For instance, fire prevention infrastructures usually need to be located in areas with different kind of properties (public or private). Such infrastructures are of public interest and therefore the administration could exercise its right of expropriation to execute them. In other cases, well-located agriculture lands offers the best opportunities to stop the large fires, and incentives should be regulated to promote these activities. So, many stakeholders, including private owners, are involved in fire fighting issues.

Wildfires and the problematic with Wildland-Urban interface (WUI) is a problem of territorial scale often tackled from sectorial logics. Without a transverse scale perspective, the solution becomes an arduous problem. Land planning strategy has to overcome a double paradox: the inadequacy of the institutional structure and landscape dynamics.

Multi-scale forest planning: crucial integration

Further than a multi-sectorial competences issue, wildfire has also a multi-scale perspective. Similar to other planning problems, wildfire risk can be faced from a stand-level operational planning, to a regional-scale long-time policy planning. The integration of this multi-scale integrative context is crucial in a successful reduction of landscape vulnerability to large wildfires.

Land planning usually works from a nested model where each level defines precise prevention policies. Planning goes from strategic levels planning (at country/region) to tactical level planning (local/Property).

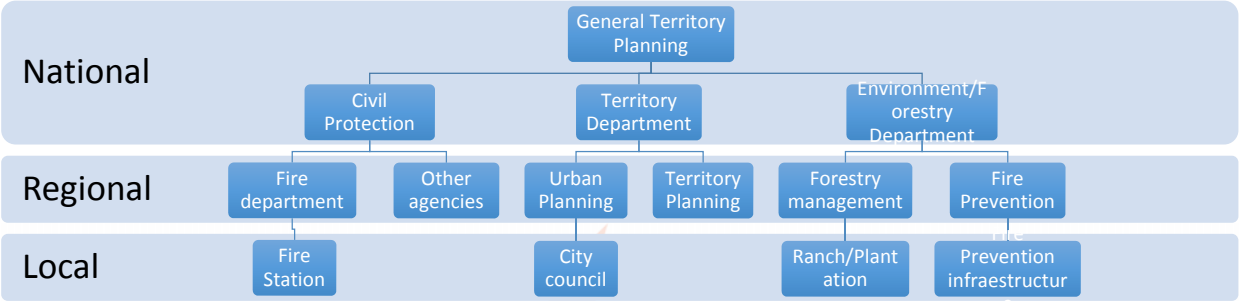

FIGURE 3: EXAMPLE OF A STEPPED MODEL PLANNING STRUCTURE.

In Catalonia, (NE Spain), different levels of planning have been nested to integrate wildfire risk in forest planning instruments. The following scheme (Figure 4), from Plana-Bach 2011, resumes the proposed model to integrate wildfire risk in forest planning at a multi-scale level.

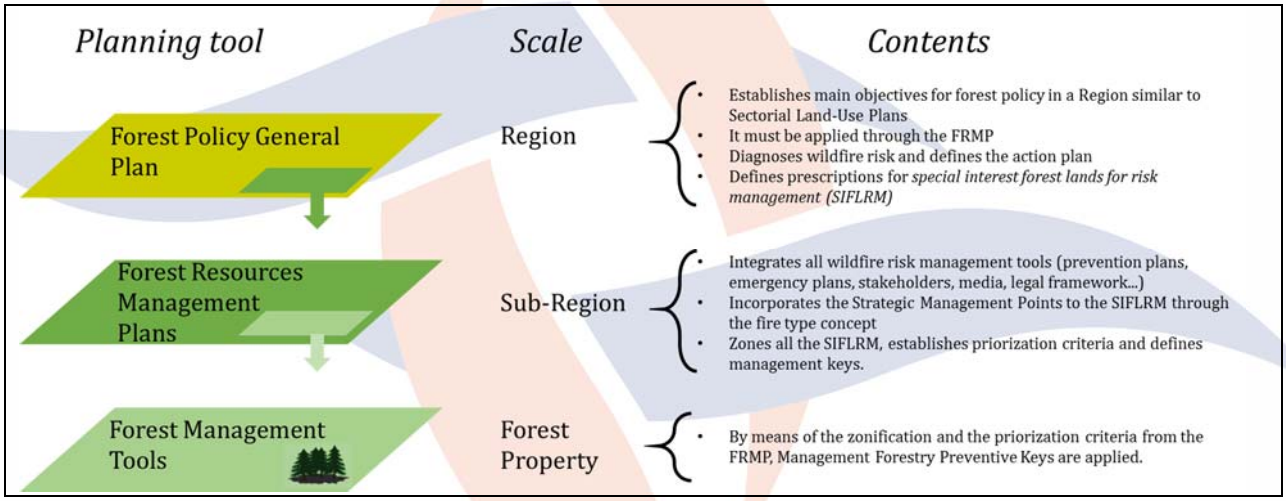

FIGURE 4: MODEL OF INTEGRATED LEVELS OF FOREST PLANNING IN A EUROPEAN REGION (CATALONIA) (SOURCE: PLANA 2011)

Fire planning must be on the same scale (spatial and temporal) as the fires affecting the territory:

- At the landscape scale, we can influence the fire regime
- At the mountain range scale, we can define wildfire prevention infrastructures
- At the local level, we can reduce people vulnerability to catastrophic wildfires.
- At the property level, we can reduce wildfire forest vulnerability

Due to the poor perception of the forest fire risk and to the perceived stochastic nature of this risk, in landscape planning there is a prevalence of local planning that unwittingly determines decisions on a regional scale.

Fire types as a landscape management tool and Strategic Management Points: context

For the last decades, an increment on the incidence and impact of wildfires in Europe has created an inherent need to better understand fires and the processes behind them, to help predict both the occurrence and the spread of new fires. Furthermore, from an operational point of view, an anticipation need of the decision-making during fires has contributed to create a fire classification into different fire spread patterns and fire types. It has been through this classification that suppression brigades have become capable to make decisions during the same fire event, based on previously studied fires, and thus winning extinction-time and enhancing fire suppression strategies.

As a result of the analysis of hundreds of fires, firefighters are currently able to know which spatial points are the ones where fires run away and exceed extinction capacity rates. Therefore, the challenge is to transform this knowledge into landscape management actions aiming at producing new opportunities, and finally reducing landscape vulnerability to large wildfires. The publication of the Fire Types Classification (Castellnou *et al.* 2009) has served to plan extinction strategies by firefighters and try to improve its efficiency. It has also become a great tool for infrastructure planning to prevent wildfires. Furthermore, this classification has allowed societies to define the capabilities of the extinction systems, acknowledging the own weaknesses points and thus being able to identify the critical points in large wildfires spread (Costa *et al.* 2011). Hence, fire extinction limits have been identified and started to transform to forest and land planning (Figure 5). The characterization and classification of wildfires has bring together operational firefighting systems, forest planners and land planners, since this classification provides valuable information for land planners to integrate the prediction of future wildfires in defining strategies for landscape use. Hence, by the increment of knowledge on the potential spread of fires, the uncertainty can become risk, which enables the transfer of emergency management into landscape and forest planning.

FIGURE 5: EVOLUTION OF THE WILDFIRE PREVENTION. SOURCE: (COSTA ET AL 2011)

Each of the types of fires can be described by common characteristics. From these specific characteristics, fire and land managers can begin to define exactly how defence infrastructures could be. Explicitly, the classification presented by Castellnou *et al* 2009 has allowed to design the type, size and location of prevention infrastructures for each kind of fire, leading to adjusted management actions for each fire affectation and landscape characteristics.

Europe situation

In Europe, wildfires impact more than half a million hectares of forest every year (Khabarov *et al.* 2014). Nonetheless, Europe has shown to have different fire regimes characterizing the regions (Joint Research Centre 2014). The spatial wildfire situation in Europe diverges in the different regions and countries, and should be tackled distinctly at the regional and national levels, taking into account wildfire incidence and fire processes, as well as past, present and future socio-economic conditions.

The approach given to wildfire issue around the different countries in Europe has taken different formulations. Depending on the risk severity of wildfires in the national contexts and the different political and administrative systems existing in each country, wildfires receive distinct consideration within the national policy instruments. For instance, in northern countries, wildfires are a subject of growing concern while in Mediterranean countries the concern has already been treated as a major natural risk. Policy measures in each country are influenced by the perceived level of threat, which varies with the evolution

of the intensity and scale of fire-related problems. The Mediterranean Basin countries have more and more significant policies contemplating different levels of wildfires as a threat, as well as an extended implementation of regulations about fire prevention. In the rest of Europe (especially in Northern countries) forest production goals are more important than forest fire prevention in forestry management, thus in national prevention policies.

Furthermore, and as a general rule around the continent, fire policies affronting wildfires have been usually characterized by the adoption of new political measures based on fast post-reaction to a past catastrophic situation, rather than proactive mitigation before an emergency arises.

Fire issue in Europe: different structures, analogous functions

Structural department in Europe is specific from each region. Nonetheless, competences are identical in all regions even they are located in different departments. Aiming at contributing to a specific regional view, the following conceptual schemes should be transposed to each region institutional structure. When considering wildfire prevention and extinction at the European level, two big typologies of institutional organization systems arise:

- **Type 1: Civil Protection Perspective:** Civil Protection Department usually has the competences for wildfire extinction, while wildfire prevention usually falls in forest department. This kind of institutional structure highly integrates all wildfire respond services for fires affecting WUI, and it uses to work with an integral emergency perspective. But on the other hand, it usually presents difficulties to influence in wildfire prevention policies, since these prevention measures are usually dissolved among several forest management programs. Then, suppression efficiency pressures are not translated to forest planning, which are the ones designing prevention infrastructures.
- **Type 2: Forest Perspective:** Forest Department can have both the competences on wildfire suppression and wildfire prevention, and it is structurally different to Civil Protection and other emergency agencies (Firefighters, Medical staff, etc.). This kind of institutional structure highly integrates prevention infrastructures design with its future use by the extinction system bodies, and it usually has integrative policies including wildfires in forest planning structures. However, having two wildfire extinction systems (Structural-Protection and Forestry-Firefighters), generates biases when working on an emergency in a WUI including both target defending items (houses and forests).

FIGURE 6: MULTI-AGENCIES INVOLVED IN A FIRE INCIDENT. (SOURCE: CATALAN FIREFIGHTERS)

FIGURE 7: WILDFIRE ENTERING IN A WILD-LAND URBAN INTERFACE AREA. (SOURCE: CATALAN FIREFIGHTERS)

In fact, institutional structures architecture tend to approach between them aiming at providing a better response to a complex problem, which requires a transversal contribution between the different departments.

Climate change in Europe: past, present and future

A wide set of global changes are affecting currently the European environment at landscape levels. Specifically, socio-economic changes and climate change are driving fire regimes changes at the European level (Amatulli *et al.* 2013; Raftoyannis *et al.* 2014). Data over recent decades points to sharp changes in fire recurrence, intensity and severity (Díaz-Delgado *et al.* 2004; González-Olabarria *et al.* 2007) associated with widespread land abandonment and fuel accumulation (Moreira *et al.* 2001; Pausas and Fernández-Muñoz 2011), global warming (Terradas *et al.* 1998; Pausas 2004) and fire suppression activity (Brotons *et al.* 2013; Moreno *et al.* 2014). Land-use changes have also shown a high incidence on fire dynamics: land-use changes have aggravated fire hazards in terms of fire intensity reached (land abandonment processes leading to higher build up fuel accumulation rates (Ursino and Romano 2014) and people exposition (Wildland-urban-interfaces increment during last decades (Lampin-Maillet *et al.* 2011; Syphard *et al.* 2013)).

FIGURE 8: AFFORESTATION IN AN AGRICULTURAL ABANDONMENT AREA (SOURCE: FOREST SCIENCES CENTER OF CATALONIA)

FIGURE 9: WILDFIRE SPREADING LOOSELY IN A CONTINUOUS FOREST AREA (SOURCE: CATALAN FIREFIGHTERS)

Climate change reported during last decades has shown to have effects on the occurrence, spread and size of fires in several regions of the world (Moritz *et al.* 2012). These effects have been documented to range from minor changes on fire distribution (Terrier *et al.* 2014) to potential changes on fire sizes and frequencies (Terradas *et al.* 1998; Pausas 2004; Batllori *et al.* 2013).

Historically, fire has been present all around Europe (Costa *et al.* 2011). However, wildfire's devastating associated events are more related to Southern European Countries, the ones with Mediterranean climate, since the intensity achieved and urban configuration have threaten more people than in Northern countries. Therefore, suppression and prevention policies have received more investments in Southern European countries.

During last years, an increasing concern has been arising in Northern European countries. An increment of the number, intensity and size of fires in many regions (Sweden 2014, etc.), has shown a progressive colonization of devastating LWF phenomena in countries not used to these events. Wildfires are showing changes in their behavior (crown fires, high intensity fires, large wildfires, etc.), which has provoked an ad hoc reaction from European institutions. Even further, in front a climate change situation, wildfires imply a major concern in a Europe context.

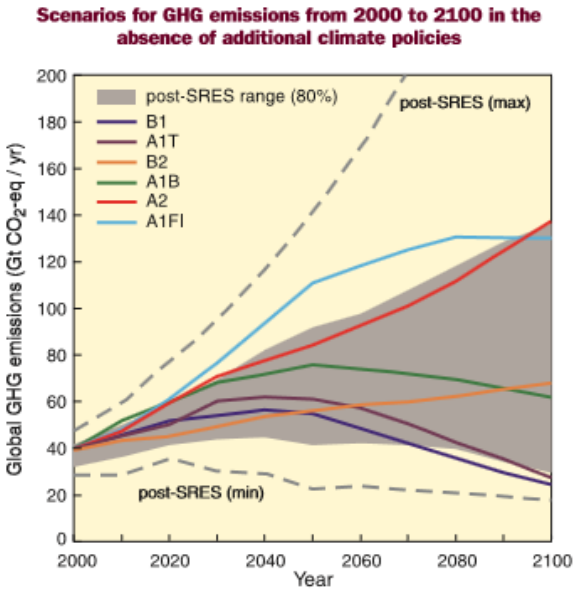

Figure 3.1. Global GHG emissions (in $GtCO_2$-eq per year) in the absence of additional climate policies: six illustrative SRES marker scenarios (coloured lines) and 80th percentile range of recent scenarios published since SRES (post-SRES) (gray shaded area). Dashed lines show the full range of post-SRES scenarios. The emissions include CO_2, CH_4, N_2O and F-gases. {WGIII 1.3, 3.2, Figure SPM.4}

FIGURE 10: PROJECTED GHG EMISSION FOR 2100 ACCORDING THE DIFFERENT CLIMATE CHANGE SCENARIOS. (SOURCE: IPCC REPORTS)

Fire weather conditions are predict to increase under climate change predictions in European countries (Moriondo *et al.* 2006; Flannigan *et al.* 2009; Batllori *et al.* 2013). However, the potential evolution of fire regimes is still uncertain and under discussion. Here we present some of the main ideas that are projected to happen in Europe, separating broadly among Mediterranean and non-Mediterranean regions:

- *Mediterranean EU-regions*

  Mediterranean ecosystems occupy a sensitive portion of global fire occurrence, and show a high fire-climate relationship, in particular for precipitation-related variables (Batllori *et al.* 2013). Precisely, precipitation trends predictions to the future are more uncertain compared to temperature changes. Despite it is no clear, an increase in rainfall variability is expected (Servei Meteorològic de Catalunya 2012), which may prolong and intensify summer drought, and also enhance the occurrence of intense rainfall events (de Luis *et al.* 2010; Servei Meteorològic de Catalunya 2012), which would lead to more often and severe droughts. These could point to a desertification of current Mediterranean ecosystems, which could directly lead to profound changes in vegetation patterns. Thus, two main vegetation changes are predicted to happen under a climate change situation: one the one hand, changes in species composition, rolling over a more drought adapted vegetation. And on the other hand, less build up capacity from forests and shrublands due to low humidity rates. This could lead to less biomass available to burn in these ecosystems.

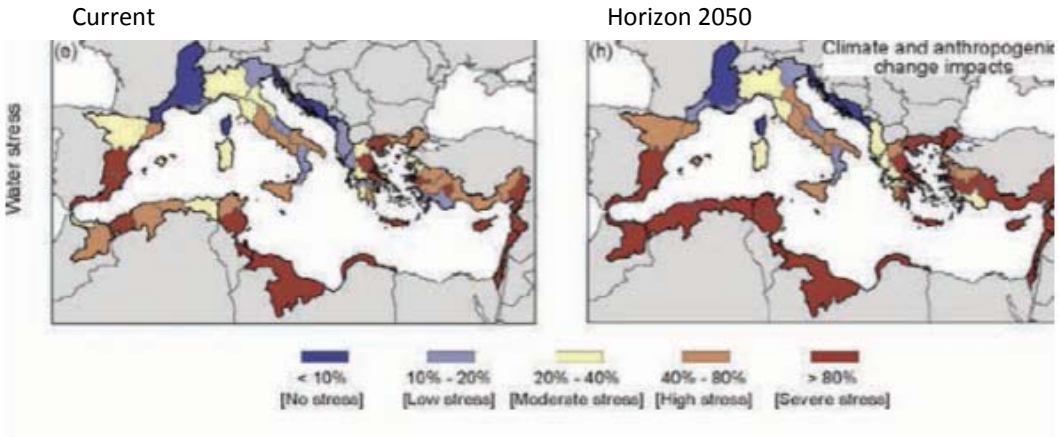

FIGURE 11. A WATER STRESS PROJECTION TO 20150 IN THE MEDITERRANEAN BASIN. (SOURCE: FAO 2013)

Fire weather danger is expected to increase in Mediterranean Europe (Mouillot *et al.* 2002; Moriondo *et al.* 2006). A substantial decrease in summer precipitation (up to 70 %) is projected for 2070–2099 in some areas of southern Europe, increasing the frequency and severity of forest fires (Alcamo *et al.* 2007). More often droughts, worst and more frequent extreme conditions, as well as a temperature increase and a moisture decrease are all factors that are related to an increase of fire events and catastrophic fire events.

The trade-offs between these two phenomena (vegetation desertification and more prone fire weather conditions) is not well known how they would evolve. To this, many social and human factors have to be taken into account. An increase of fire suppression efforts could lead to a homogenization of vegetation masses at landscape level (Minnich and Chou 1997; Brotons *et al.* 2013). Agricultural abandonment is also increasing fuel biomass in these areas (Moreira *et al.* 2001). And finally urban planning is changing both how vegetation is located in the space and how humans are in front fire risk (Syphard *et al.* 2014).

High intensity fire are predicted to be less common if vegetation gets more arid, with less fuel load on the landscapes. Even though, the transition between current forests to deserted vegetation landscapes is going to be long. The time of bypass could represent a deterioration of high intensity fires, since weather conditions will be more prone to fires and vegetation will still being the one characterized in a more humid climate. Even more fire and landscape management should be implemented in a worsen wildfire scenario.

- *Other non-Mediterranean regions in Europe*

At a European level, several changes are affecting current forest situation (Fares *et al.* 2015). Most of them are related to social and economic pressures with an uncertain future for fire regime evolution, and even further when mixed with the climate change threat. Forest evolution at a European level has two sides: new forests are gaining ground and pushing up overall forest area, but existing stands are becoming less productive with age and damage. To this, an increase of fire

weather situation in northern latitudes has to be summed to the situation, leading to novel fire situations faced by northern European countries.

In northern parts of Europe, the fire risk is likely to increase (Khabarov *et al.* 2014). Global simulations of future fire regimes point to an increase of the probability of fires in the future in Central and Northern Europe, which mixed with social and economic changes affecting forest and landscape dynamics, could worse wildfire population exposure in front more devastating fire scenario.

3. Proposed Methodology

First: Fire regime diagnosis

The methodology proposed starts from the premise that with the same topography and meteorology, fire spreads following similar scheme propagation (Castellnou *et al.* 2009; Costa *et al.* 2011). Fire changes its intensity depending on fuel availability, which depends mainly on accumulated hydric stress and fuel amount and structure. To know the fire types and the fire regime affecting a particular area, one must analyse the historical track of wildfires in the region.

FIGURE 12: HISTORICAL SEQUENCE OF THE SAME FIRE SPREAD PATTERN AND THE SAME METEOROLOGICAL SYNOPTIC SITUATION IN DIFFERENT YEARS IN L'ALBIOL (CATALONIA). (SOURCE: COSTA ET AL 2011)

For instance, Figure 12 shows three similar wildfires that have burned in different years in the same area in the same synoptic meteorological situations (Catalonia, NE Spain). The three perimeters are very similar and hint that they are governed by the same pattern. The key to understand this pattern is the interaction between the topography and similar meteorology. The identification of fire-spread patterns in a region is a crucial step for reducing fire vulnerability at a landscape scale.

Fire typology identification in the regions

In general, the identification of fire types is done by analysing spread patterns and synoptic situations, and observing the relevant and repeated aspects that allow the classification of forest fires (Pique *et al.* 2011).

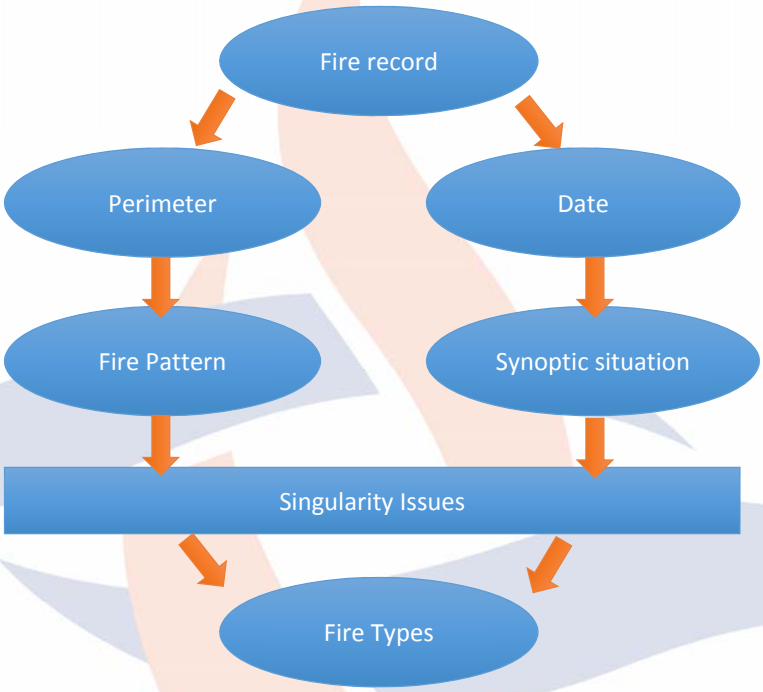

FIGURE 13: CATEGORIZATION PROCESS OF HISTORICAL WILDFIRES (PIQUE, 2011).

Fire spread patterns and Synoptic weather situations

Related with physical phenomena that occur in a forest fire, fire spread is governed by the interaction between fuel, weather and topography.

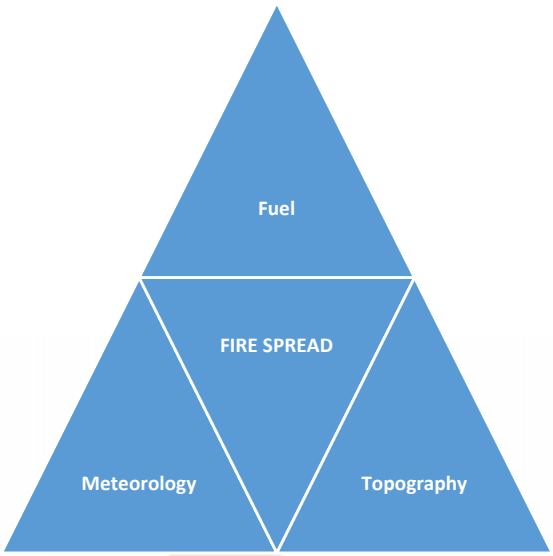

FIGURE 14: FIRE SPREAD TRIANGLE

According to the driving forces dominating fire spread, forest fires are classified into four groups (Rothermel 1972):

- Topographic fire
- Wind driven fire
- Plume dominated fire
- Storm driven fire

Synoptic weather situation is the responsible for establishing which spread pattern is assigned to each fire, depending on the most prominent meteorological aspects and on the influence of these conditions on fuel:

- Heat
- Wind
- Drought
- Storm

FIGURE 15: FIRE SPREAD PATTERNS AND SYNOPTIC WEATHER SITUATIONS RELATED TO EACH FIRE SPREAD PATTERN (SOURCE: COSTA *ET AL* 2011)

Fire types

In order to classify wildfires into specific fire typologies, distinct local-relief configurations must be identified. These configurations are associated with the interaction between the meteorological synoptic situation and relief:

- Sea breeze: Rotating wind regime associated with land-sea interaction
- Venturi Effect: Channelling and speeding winds in some narrow gorges
- Turbulence: Counter winds generated by the interaction between strong winds and abrupt relief
- Subsidence: changing direction wind regime in subsidence zones with descending winds. General atmospheric wind blow along the surface at night and local relief-wind rises up during daytime.
- Pyrocumulus Phenomenon associated to a collapse of a Pyrocumulus cloud produce by a high intensity wildfire.
- (...)

In Catalonia, ten different fire types according to these criteria have been identified. However, noteworthy is that all these fire types can occur all around the world, but translating general patterns to local conditions.

TABLE 1: FIRE TYPES IN CATALONIA.

Topographic	Standard topographic fires
	Coastal topographic fires
	Topographic fires in main valleys and canyons
Wind driven	Wind-driven fires in flat land
	Wind-driven fires in mountainous terrain
	Wind-driven with subsidence

Plume dominated	Standard convection dominated fires
	Convection dominated fires with wind
	Convection dominated fires producing pyrocumulus clouds
Storm driven	Storm-driven fires

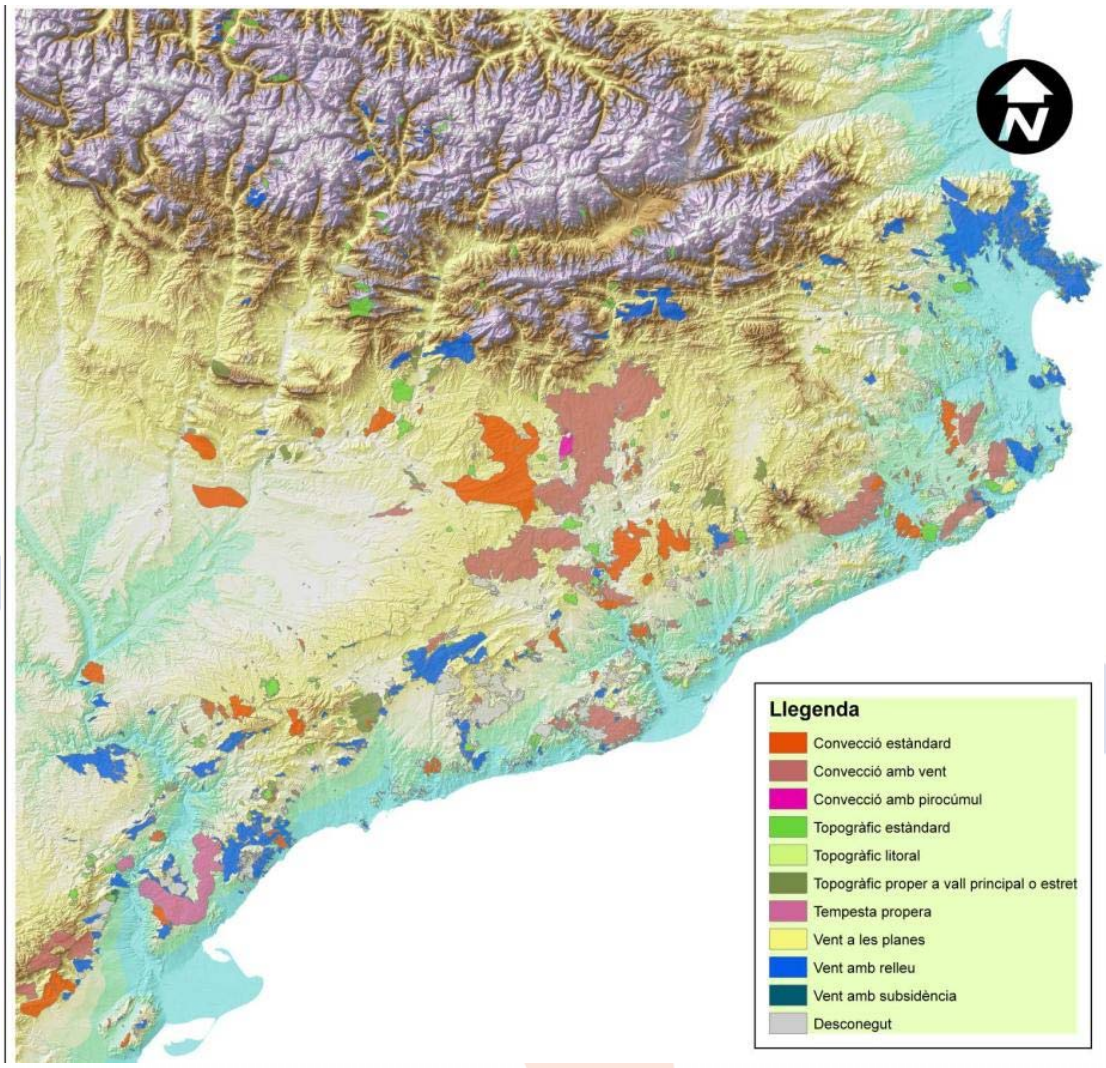

FIGURE 16: MAP OF WILDFIRES CLASSIFIED TO THE DIFFERENT FIRE TYPES IN CATALONIA (SOURCE: CASTELLNOU ET AL 2009)

This classification has provided a deeper knowledge into how wildfires move above the land and how they interact with weather. Hence, firefighter systems are able to deduce how wildfires will exceed the ability to extinction and where they could find extinction opportunities. This is the basis for landscape planning to reduce vulnerability of large fires. To transform this knowledge into landscape planning it is crucial to know where the different fire types will occur and which frequency they will have.

Homogeneous zones

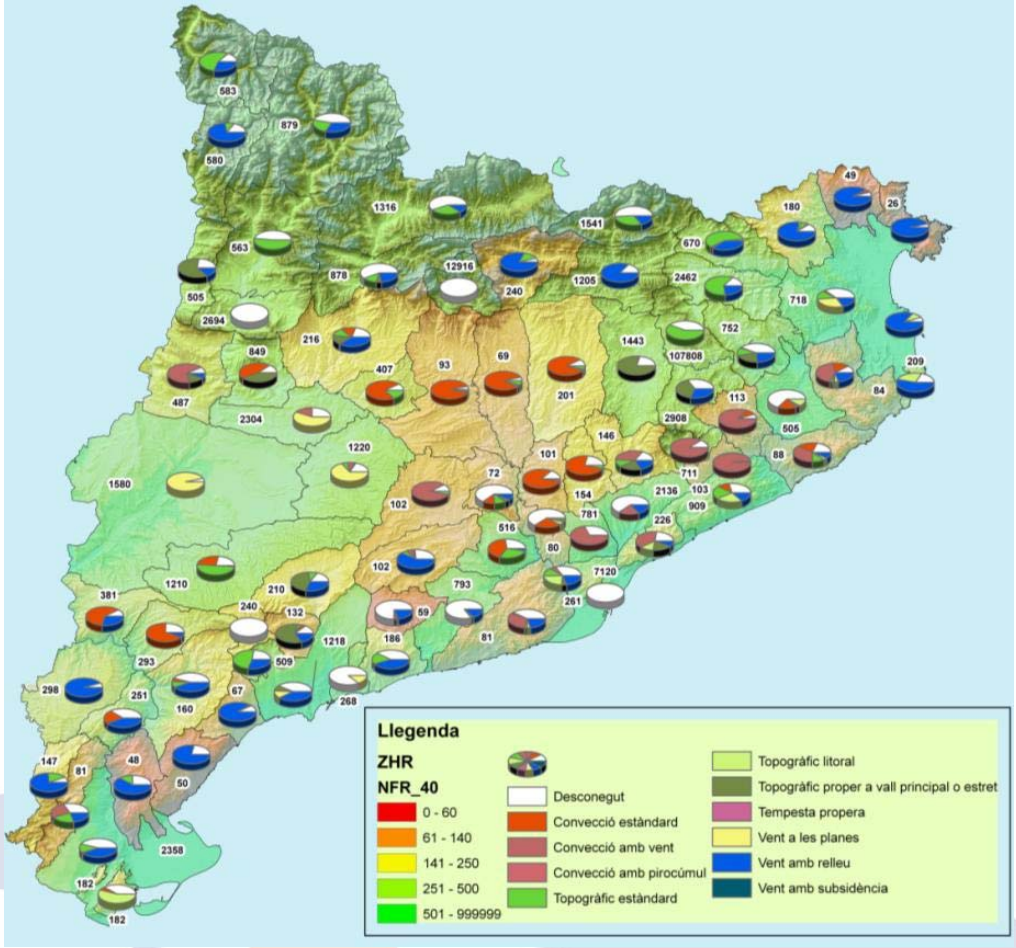

FIGURE 17: MAP OF HOMOGENEOUS REGIME ZONES AND THE DISTRIBUTION OF WILDFIRE TYPES IN CATALONIA (SOURCE: CASTELLNOU ET AL 2009)

According to the identified fire types in a region, a map regarding fire type frequency in each "Homogeneous Zone Regime" (Pique *et al* 2011 for more information) should be built. With this map, a spatial distribution of high fire danger area is identified, and infrastructures for each fire type can be planned.

Critical points

Once acknowledged for the fire type regime situation in a region, the results allow to observe locations where fire can accelerate and decelerate, changing also its intensity. As the fire passes these points, those act as gateways to new potentials. These points are called "Critical Points". This knowledge has turned up from the experiences of firefighting departments. After years of experience, suppression bodies have been observing changing fire behaviour points (for speed and/or intensity), and therefore the places that optimizes cost-efficiency in terms of effort of suppression against unburnt protected area.

Critical points are usually located in abrupt relief changes and can be located making a geomorphology analysis of the relief, seeking ravine junctions, crest line junctions and mountain passes.

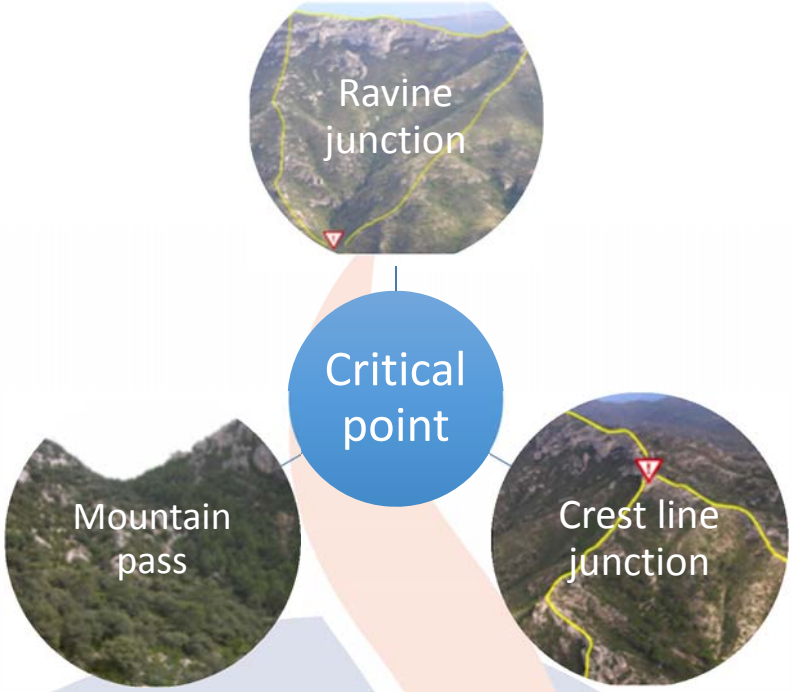

FIGURE 18: CRITICAL POINT TYPES

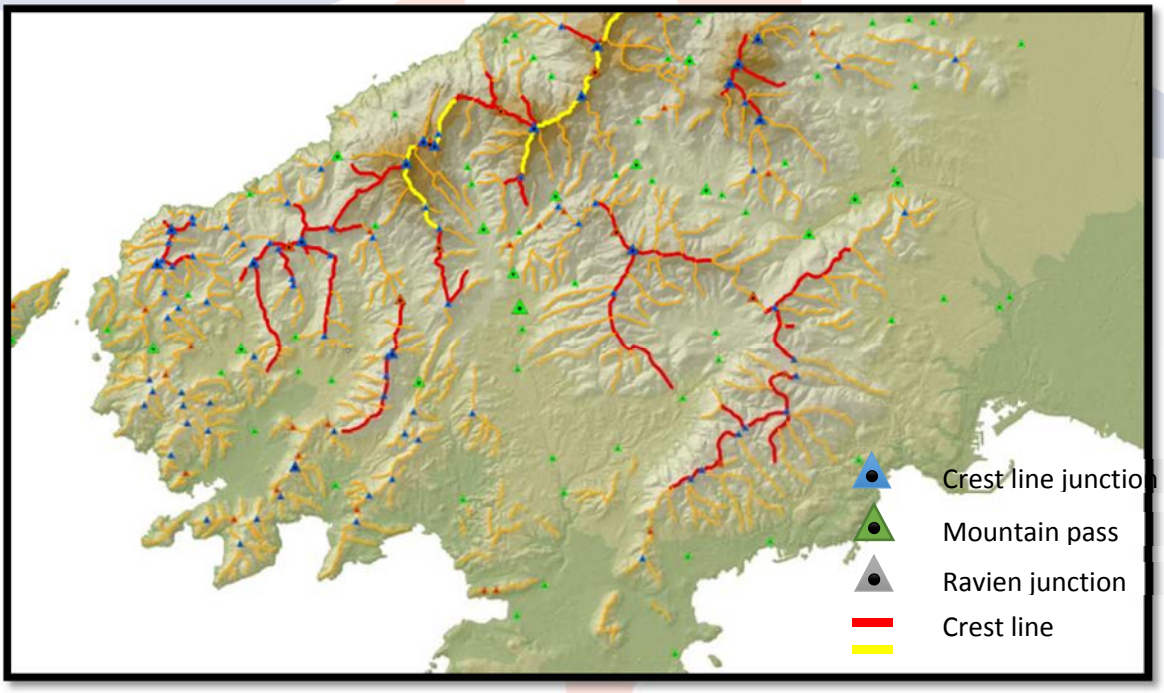

FIGURE 19: CRITICAL POINTS (SOURCE: GOVERN DE LES ILLES BALEARS)

Critical points can be associated to the different fire types. The behaviour of the different fire types is different in each of the different critical points according to the dynamics of its spread. Topographic fires, usually spreading uphill, can exponentially increase its potential burnt are when they find a ravine junction than when they find a crest line junction. Thus, the previous knowledge of each fire type incidence in the "Homogeneous Zones" can help to identify critical points according to the most common Fire Type in the region. To provide an example of a critical point within a wildfire, Figure 19 shows an image sequence of the 2014 Andratx Fire reaching one of the critical points (*Pla de S'Avangèlica*), in a slowly and low intensity way. Once the fire reaches the mountain pass, the fire grows quickly and burns all new potential with high intensity related to the critical point.

FIGURE 20: ANDRATX 2014 FIRE; PLA DE S'AVANGÈLICA CRITICAL POINT (SOURCE: GOVERN DE LES ILLES BALEARS)

Second: Prevention

The cost-effective vision: Strategic Management Points

After fire regime diagnosis and the deep knowledge in the incidence of fire types and the identification of critical points in the landscape, a cost-effective management action can be related to this knowledge. Along with the planning of the different fire prevention infrastructure options, a reliable analysis that considers the efficiency of these measures compared to its cost should be contemplated. The most high cost-efficiency prevention action according to a Firefighting department point of view are the Strategic Management Points (SMP). SMP are a tool for land and/or forest managers that has a high suppression efficiency compared to its cost. They also allow a multi-sectorial management for their own maintenance, and that can be adjusted to the dynamics of economic and social uses of the territory where the SMP are located. SMP are feasible in all regions in Europe, although its development has been mostly in accomplished Mediterranean Spanish areas.

Strategic Management Points have shown to be one of the optimal tools for the cost-effectiveness problems joining prevention, extinction and management. Firefighter systems have demonstrated that the suppression work when applied in a small area (that is the gateway to a great potential) is much more effective than spreading resources all around the perimeter of the fire. Their identification is mostly related to the critical points where fires overpass fire suppression capabilities, and their goal is to reduce fire spread speed and intensity, to ensure a secure point for firefighters and to provide suppression resources, as anchor points or water tanks.

This prevention management strategy can also satisfy most of the requirements in terms of reliability and safety. Compliance with these requirements should be given to the infrastructure because it can be used successfully for these proposes.

Furthermore, traditionally the main forest management action aimed at forest fire prevention has had conflicts with other uses. However, for the last years, a new perspective has raised, which promotes the inclusion of a variety of compatible uses for this kind of infrastructure, where the only requirement is to maintain a fuel load below a certain threshold. The multi-use function could allow an economy linked to the execution and maintenance related to the primary sector. These could be a feasible tool and way to reduce landscape vulnerability to fire regimes with a low cost and a sustainable maintenance. Maintaining SMP to generate a local economy is linked to the maintenance of these infrastructures. For this, SMP could be the link between different worlds involved in land management:

- Forest fire resources
- Forest management
- Territorial Planning
- Landscaping
- Public/private territory use

However, other fire reduction policies and actions aimed at reducing the fuel on a large scale are not discarded. Some authors as Piñol *et al* 2007, suggested that in a Mediterranean landscape as Catalonia, reducing a 10% of its forest surface could significantly reduce large wildfire risk. In this way, the forward section *Long-term planning* (page 26) discusses possibilities of large-scale territorial measures (such as promoting local forest economy). However, their costs must be deeply evaluated, since in case their implementation has to be paid by the administration, the cost could be very high, and thus it could compromise its successful performance. Consequently, SMP are proposed as one of the most optimal tools to reduce the vulnerability of landscape fires.

Wild-land fire department

Strategic Management Points, more than places where fuel reduction can be concentrated, are also related to suppression operations that allow firefighters to better control the fire. The main activities projected to be performed in a Strategic Management Point are exposed in Figure 21.

FIGURE 21: FIREFIGHTING SUPPRESSION ACTIVITIES TO BE EXECUTED DURING A FIRE IN THE STRATEGIC MANAGEMENT POINTS

When planning any wildfire prevention action, it is meaningful to accurately know which extinction operation is expected for each infrastructure. Hence, aiming at achieving a successful implementation,

the needs and impediments for each extinction operation must be identified and controlled. The main suppression operations planned to be performed in a SMP are the ones summarized in Table 2, as well as the needs of the infrastructure.

TABLE 2: MAIN SUPPRESSION OPERATIONS PLANNED IN A STRATEGIC MANAGEMENT POINT

OPERATION	PICTURE	INFRASTRUCTURE NEEDS
Water hose		• Low fuel load to generate surface fire • Access route for a large truck • Turning area for trucks • Water supply point
Heavy machinery		• Shrublands vegetation type (not trees) • Road access for the hoist
Back fire		• Low fuel load, but with fine fuel to ignite quickly • Anchor line • Security zone nearby
Direct attack with manual tools		• Low fuel load area • Surface/understory fire with low intensity • Security zone nearby

The "Auto-Regulate System" proposal

The successful implementation of the SMP at large spatial scales and long temporal scales is a challenge per se. The high number of stakeholders involved in its definition, the implementation, the maintenance

and the use implies many agencies and administrative bodies that must interact at different levels of the decision-making process. It is crucial thus to build a system which is able to have success and to be perpetuated through the time in the correct implementation of this planning tool.

For this, an auto-regulate system is proposed as a valid approach to develop SMP. These kinds of systems have been propitiously applied to other complex protocols in emergency planning. The system aims to adopt an enough flexible structure of agents that ensures the implementation of the SMP at different levels of decision, space and time.

The structure defines the what (SMP to be implemented), the who (the ones that will execute the SMP and the ones that will keep their maintenance), the how (normative that will define the whole implementation) and the transfer of knowledge (ensures the maintenance of the same structure through time).

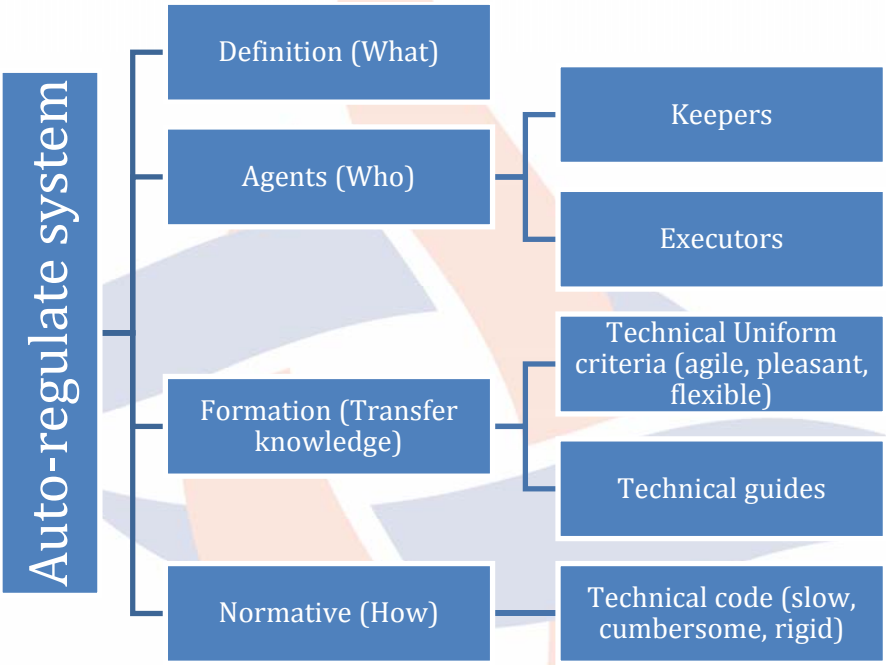

FIGURE 22: DIAGRAM OF THE STRUCTURE OF THE AUTO-REGULATE SYSTEM FOR THE STRATEGIC MANAGEMENT POINTS

Administrative implementation

Implantation limitations of the SMP

One of the problems for the implementation of the SMP is implementation stems on the fact that forest products and forest land value is very low. Even if the costs of forestland expropriation and fire prevention infrastructure building are low, these works have a high maintenance cost. For the forest administration is easy to get the budget for the construction of new infrastructures, but it is difficult to get the annual budget for their maintenance, then taking the risk of becoming obsolete. Then, this model calls into question the fact that the infrastructures are declared of public interest. There could be intermediate models where property should be involved. One possible solution could be the construction of public-

private partnerships, where the administration generates the main investment and attends infrastructure maintenance, and by contrast the owner retains the ownership. For a successful and holistic fire prevention, it is necessary to involve private property responsible for fire prevention. In Europe we find examples of organizations (Wildfire Groups in UK, and Coordination Group for wildfire prevention in Girona (Spain)) that are leaders in integrating all stakeholders in land management (public and private) and to develop action plans prevention of wildfires. These can be an example of implementation. For a successful implementation of the SMP, a social perspective should be prioritized. It is important that local society has a feeling of belonging and of common good defence for the success of these initiatives.

Regulations

Although it may be feasible to expropriate lands for urban planning, it is difficult to talk about expropriations in the forest world, since budget allocations that should accompany the implementation and maintenance of these infrastructures are often not effective. We must think on other "less aggressive" ways of planning in order to implement these measures in a practical way. Following, some proposals are listed:

- *Particular forest consortium*: This is a simple compromise between the owner (whether an individual, or a city council or other public agency) and the administration that is responsible for a certain time to manage the consortium property. Public administration usually makes the reforestations and establishes the necessary technical program management; in addition, it reserves the right to extend its operation until it has recovered its investment.
- *Land stewardship:* this is a set of strategies and techniques designed to preserve the natural, cultural and landscape values of a territory and make a responsible use (of the territory and its resources). It is a procedure of voluntary agreement between the owner and custodian entities, by one of the possible custody agreement possible, with or without legal basis (stewardship agreements).

A main recommendation of this guide to ensure the success of the implementation of the present methodology is the creation of fire groups.

Third: Long-term planning

Fire policies at long term under different scenarios

Forecasting fire regimes changes, related to area burnt, fire event allocation, fire spread, and fire frequency, is one of the challenges facing current decisions when considering climate change at the European level, in order to help policy making in fire management, prevention and extinction. European policies dealing with fire issues have usually been proposed after catastrophic events, proposing solutions after new fire catastrophic events, not before, and usually being ineffective under new situations. Moreover, the evolution of future fire regimes, under a climate change situation, can entail cause 'novel' or 'no analogue' environmental conditions, which presents new challenges for management, policy and planning. The use of model projections under different scenarios is a key step for understanding system's evolution and reduce uncertainty.

Scenarios for decision making

A valuable and frequently applied technique to help to decide under the complex uncertainties associated with future changes and their impacts is scenario analysis. Scenarios have been characterized as the "… plausible and often simplified descriptions of how the future may develop based on a coherent and internally consistent set of assumption about key driving forces and relationships" (Rounsevell *et al.* 2006). Climate simulations produced by the United Nations Intergovernmental Panel on Climate Change (IPCC) and regional downscaled data have been a primary source for climate projection and policy decision making in terms of energy and climate.

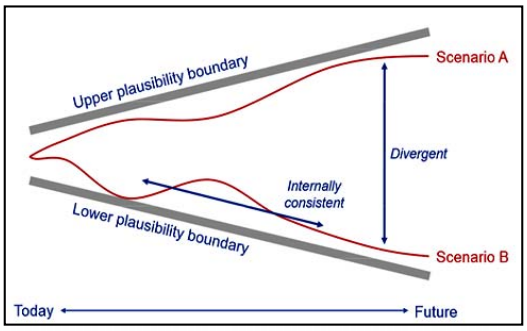

FIGURE 23: SCENARIO CONCEPT FOR DECISION MAKING UNDER UNCERTAIN FUTURES (SOURCE: ROUNSEVELL ET AL 2006)

Forest and landscape evolution, and consequently fire regime evolution, can also benefit from the use of scenarios to help policy makers to build decisions based on plausible futures and reducing a part of the uncertainty associated. Even more, the use of scenarios may be used under a modelling framework to better understand consequences of current decisions made at large temporal and spatial scales.

Thus, it is important to consider different scenarios of change for landscape management and planning. The elaboration of conceptual frameworks to generate global change scenarios for the different regions is crucial for a long term assessment. Scenarios may integrate socioeconomic storylines using a structured framework and should identify their associated drivers of environmental change with specially impact on landscape dynamics. Special attention might be devoted to climate changes, changes in forest management and social impacts to help wildfire decisions.

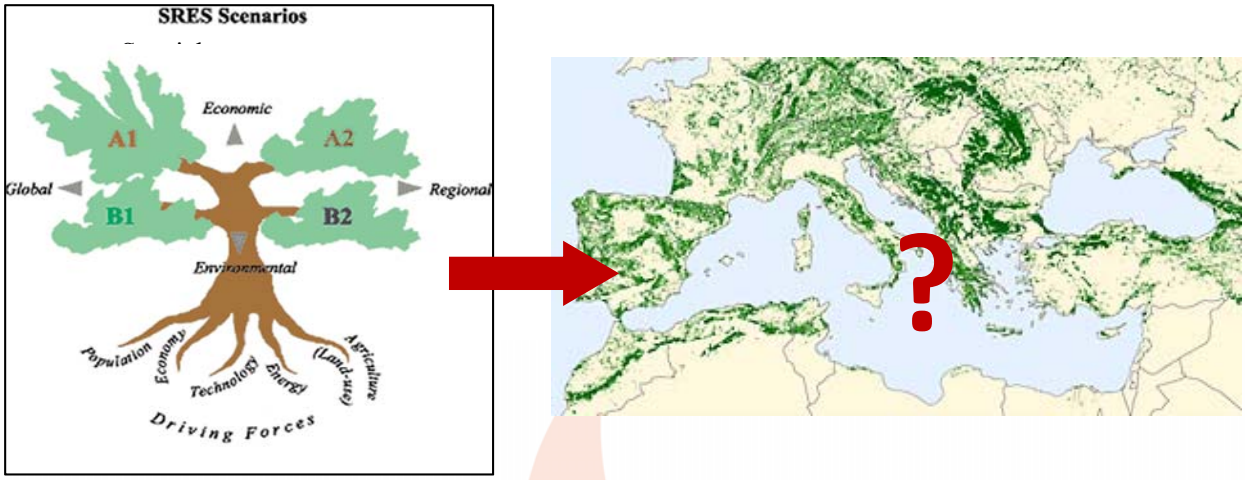

FIGURE 24: SOCIO-ECONOMIC SCENARIOS THAT MAY AFFECT EUROPEAN FOREST WITH UNCERTAIN FUTURE.(SOURCE: IPCC REPORTS AND OWN ELABORATION).

Once under a conceptual framework of how systems will evolve, it is then recommended to adopt and define adaptive management strategies according to the goals set for each of the different EU regions. Not a unique recommendation is done, but the important is to set the goals, understand the system, deal with possible futures to reduce uncertainties and decide under quantitative criteria.

Modelling framework for decision making

Forest management has benefited from recent research effort on methodologies and decision tools, towards a more science-based approach. The use of models in the assessment of fire regime changes can be used as a basic tool to quantify potential changes and to evaluate the complex interaction between factors affecting the different components of fire regimes (Miller and Ager 2013). With many ecological processes that still unknown (ie. fire spread stills in the frontier of research; (Keeley *et al.* 2012)), and many unknown evolution socio-ecological factors affecting large scale phenomena (land abandonment, outsourcing economic sectors, etc.), the complexity of fire regimes entails a very difficult assessment of the consequences of current policies on the evolution of landscape systems. Complex systems as the ones characterizing the fire process usually require from mathematic models to better understand potential ecosystem evolutions under different pressures of change. Thereby, uncertain evolutions can become more accurate, helping the process of decision making.

Furthermore, quantifying the implications of a set of different suppression policies is crucial in the long-term assessment of current decisions with usually uncertain consequences. For instance, a greater investment on fire suppression for the last decades has not been shown to stop the intensity and devastating effects of fires nowadays (Tedim *et al.* 2013). Some experiments have shown important and significant effects of different fire suppression strategies on area burnt in Catalonia at a landscape scale and for long-term periods. The work done by Regos et al. 2014 actually showed how letting fires burn in mild weather conditions could increase suppression opportunities for suppression in large fires during

adverse weather conditions. This is just one optional strategy that can be adopted at large scales and that can be implemented by policy measures at a European level when quantifying appropriately its effects at a long term period.

Climate Change and fire suppression: scenarios and projections in EU landscapes examples

For the present guide, some examples of climate projections have been built aiming at presenting a range of possibilities to assess future scenarios of change in European landscapes. We display the projection and reproduce some of the most important changes on fire regimes in different parts of Europe according to climate change scenarios and different fire suppression scenarios. We have applied the MedFire model (Brotons *et al.* 2013) to the Iberian Peninsula, and we have compared two regions with different fire regimes in terms of total annual area burnt and fire sizes distribution. The two studied regions are Andalusia (South Spain), and Galicia (North-west Spain). The greater difference between the fire regimes in the two regions is the amount of total area burnt that is burnt in large fires. While in Andalusia total area burnt is smaller, the percentage of area burnt in large fires is bigger than in Galicia.

We defined landscape scenarios according to climate variations and firefighting treatments to assess fire regime evolution of the two regions. We proposed two simple climate treatments: (C0) the percentage of severe years in the 50-year period is equal to the percentage of the observed period (from 1968 to 1999), and (C1) this percentage is double. We established two firefighting treatments: the first one did not involve any fire suppression strategy, whereas the second involved active fire suppression extinguishing any fire that burn agriculture covers, or fires burning sclerophyllous forest in not ascending conditions, or wind-back fires in pine and shrub forests (70% of efficiency). These scenarios start in 2000 year with the same initial conditions, and project the fire regime and the effects on landscape composition over a 50-year period. We ran 50 replicas of each scenario.

TABLE 3: THE FOUR SCENARIOS CONSIDERED.

Scenarios		**Climate Scenarios**	
		Same climate	**Double Severe Climate Years**
Fire suppression strategies		**C0**	**C1**
No firefighting	**0**	0-C0	0-C1
Active fire suppression at 70%	**70**	70-C0	70-C1

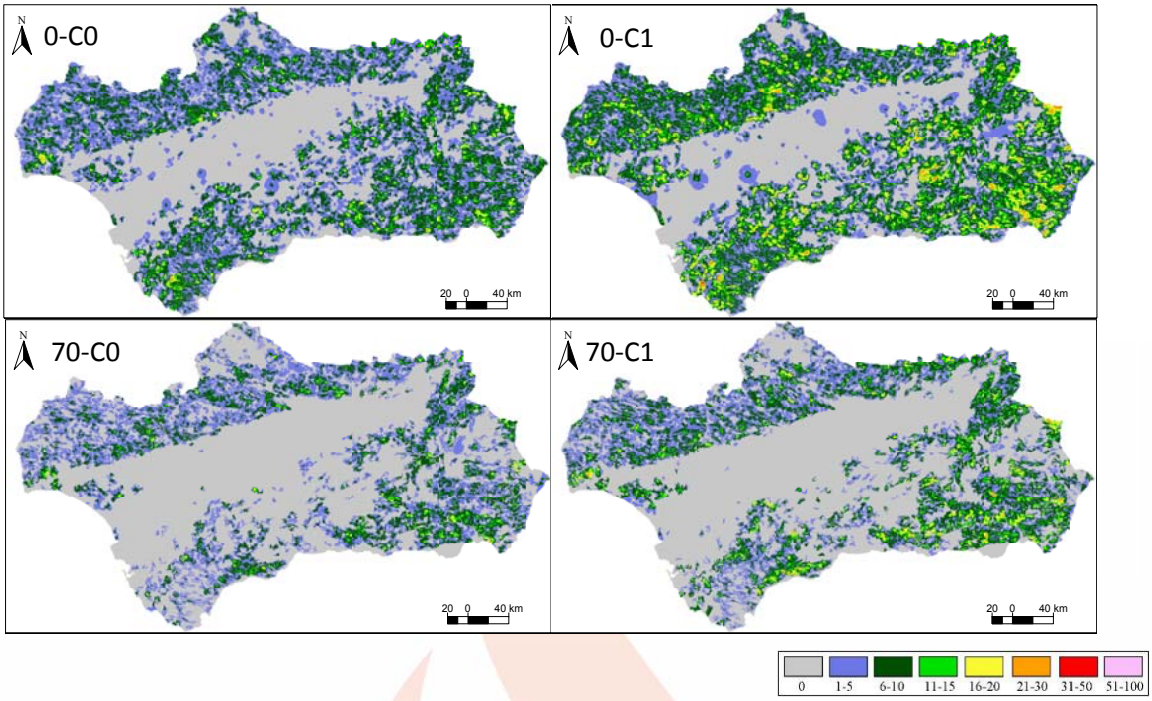

FIGURE 25: FREQUENCY OF BURNING IN LARGE FIRES (EXTENSION GREATER THAN 500 HA) AT LEAST ONE TIME OVER A 50-YEAR PERIOD UNDER THE (0-C0), (70-C0), (0-C1), AND (70-C1) SCENARIOS IN ANDALUSIA.

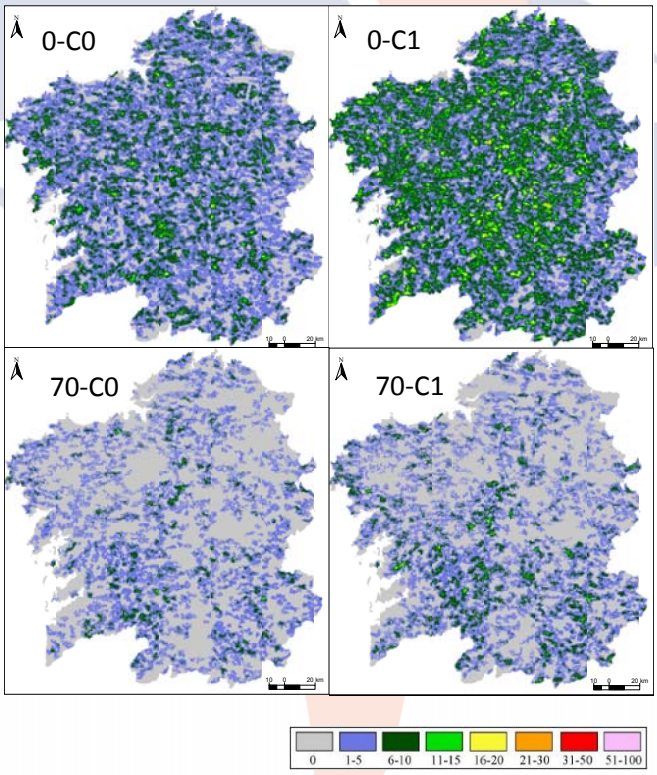

FIGURE 26: FREQUENCY OF BURNING IN LARGE FIRES (EXTENSION GREATER THAN 500 HA) AT LEAST ONE TIME OVER A 50-YEAR PERIOD UNDER THE (0-C0), (70-C0), (0-C1), AND (70-C1) SCENARIOS IN GALICIA.

The greater difference between the two fire regimes described is the amount of total area burnt that is burnt in large fires. While in Andalusia total area burnt annually is smaller, the percentage of area burnt in large fires is much bigger than in Galicia. In contrast, Galicia has a very low number of large fires. Galicia has a particular fire regime governed largely by social constrains related to a traditional use of fire (Catry *et al.* 2010). A very traditional rural population stills using fire as a management tool, which combined with a more flammable landscape because changes in species composition product of forests plantations are the main causes of a high fire incidence. However, the landscape spatial pattern present in the region, characterized by very small patches of the different land covers, may influence in the low capacity of fires to spread and become large fires. Consequently, and similarly to other regions as northern Portugal, fires are not very large. In contrast, in Andalusia, fire events are less common, but as a consequence of traditional forest management abandonment and land abandonment, fuel build up accumulation has induced a fire prone landscape. Fire spread is more devastating than decades before, and wildfires are usually very large.

These differences have different implications for the run scenarios. In Galicia the landscape structure does not allow fires to get big, even increasing fire suppression efficiency. Fire suppression policy decisions can lie on this kind of evidences: an increment on fire suppression efforts in Galicia will not be translated in a decrement of large fires. Thus, efforts should be focused on understanding the main problematic of each region, and on preforming the appropriate experiments aiming at decreasing negative fire impacts under climate change scenarios.

Thus, using the same data source, a different range of fire regimes (in terms of area burnt, severe years and fire size distribution) can have direct consequences on the evolution of the system under the same drivers of change. Consequently, when regarding landscape planning aiming at reduce predicted fire impacts at a landscape scale under a climate change scenario, an exhaustive work on understanding the processes governing fire regime in the different areas should be done before making decisions. Fire suppression changes aiming at minimize fire effects at a landscape effects cannot be the same in Galicia or in Andalusia. The same can be applied to other regions of Europe. Hence, the regionalization of the fire phenomena, bound to more local processes (both socio economic processes and climatic local changes), is a crucial step towards a better policy adaptation in a European context.

4. References

Alcamo J, Moreno J, Nováky B, Bindi M, Corobov R, Devoy R, Giannakopoulos C, Martin E, Olesen J, Shvidenko A (2007) Chapter 12: Europe. "Climate Change 2007: impacts, adaptation and vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on on Climate Change." (Ed HC (eds) Parry ML, Canziani OF, Palutikof JP, van der Linden PJ)(Cambridge University Press: Cambridge)

Amatulli G, Camia A, San-Miguel-Ayanz J (2013) Estimating future burned areas under changing climate in the EU-Mediterranean countries. *The Science of the total environment* **450-451**, 209–22. doi:10.1016/j.scitotenv.2013.02.014

Améztegui A, Brotons L, Coll L (2010) Land-use changes as major drivers of mountain pine (Pinus uncinata Ram.) expansion in the Pyrenees. *Global Ecology and Biogeography* **19**, 632–641. doi:10.1111/j.1466-8238.2010.00550.x

Batllori E, Parisien M-A, Krawchuk M a., Moritz M (2013) Climate change-induced shifts in fire for Mediterranean ecosystems. *Global Ecology and Biogeography* **22**, 1118–1129. doi:10.1111/geb.12065

Brotons L, Aquilué N, de Cáceres M, Fortin M-J, Fall A (2013) How fire history, fire suppression practices and climate change affect wildfire regimes in mediterranean landscapes. *PloS one* **8**(5), . doi:10.1371/journal.pone.0062392

Castellnou M, Pagés J, Miralles M, Pique M (2009) Tipificación de los incendios forestales de Cataluña. Elaboración del mapa de incendios de diseño como herramienta para la gestión forestal. InSECF (ed) "5º Congreso Forestal Español," Ávila. pp 1–16. (Sociedad Española de Ciencias Forestales: Ávila)

Catry F, Rego FC, Silva JS, Moreira F, Camia A, Ricotta C, Conedera M (2010) Fire Starts and Human Activities. "Towards integrated fire management - outcomes of the European Project Fire Paradox."

Costa P, Castellnou M, Larrañaga A, Miralles M, Kraus PD (2011) "Prevention of Large Wildfires using the Fire Types Concept." (U GRAF, Ed.). (Departament d'Interior de la Generalitat de Catalunya)

de Luis M, Brunetti M, Gonzalez-Hidalgo JC, Longares LA, Martin-Vide J (2010) Changes in seasonal precipitation in the Iberian Peninsula during 1946-2005. *Global and Planetary Change* **74**(1), 27–33. doi:10.1016/j.gloplacha.2010.06.006

Díaz-Delgado R, Lloret F, Pons X (2004) Spatial patterns of fire occurrence in Catalonia, NE, Spain. *Landscape Ecology* **19**(7), 731–745.

FAO (2013) State of the Mediterranean Forests. (Rome)

Fares S, Scarascia G, Corona P, Palahí M (2015) Five steps for managing Europe's forests. *Nature Comment* 7–9.

Flannigan M, Krawchuk M, de Groot WJ, Wotton BM, Gowman LM (2009) Implications of changing climate

for global wildland fire. *International Journal of Wildland Fire* **18**(5), 483–507. doi:10.1071/WF08187

González-Olabarria JR, Palahí M, Pukkala T (2007) Modelling the risk of forest fires in Catalonia (North-East Spain) for forest management planning purposes. In "4th International Wildfire Conference," Sevilla.(Sevilla)

Joint Research Centre (2014) Forest Fires in Europe , Middle East and North Africa 2013. doi:10.2788/99870

Keeley JE, Bond WJ, Bradstock RA, Pausas JG, Rundel PW (2012) "Fire in Mediterranean Ecosystems. Ecology, Evolution and Management." (Cambridge University Press: New York)

Khabarov N, Krasovskii A, Obersteiner M, Swart R, Dosio A, San-Miguel-Ayanz J, Durrant T, Camia A, Migliavacca M (2014) Forest fires and adaptation options in Europe. *Regional Environmental Change*. doi:10.1007/s10113-014-0621-0

Lampin-Maillet C, Long-Fournel M, Ganteaume a., Jappiot M, Ferrier JP (2011) Land cover analysis in wildland–urban interfaces according to wildfire risk: A case study in the South of France. *Forest Ecology and Management* **261**(12), 2200–2213. doi:10.1016/j.foreco.2010.11.022

Loepfe L, Martinez-Vilalta J, Piñol J (2012) Management alternatives to offset climate change effects on Mediterranean fire regimes in NE Spain. *Climatic Change* **115**(3-4), 693–707. doi:10.1007/s10584-012-0488-3

Miller C, Ager A a. (2013) A review of recent advances in risk analysis for wildfire management. *International Journal of Wildland Fire* **22**(1), 1. doi:10.1071/WF11114

Minnich RA, Chou YH (1997) Wildland fire patch dynamics in the chaparral of southern California and northern Baja California. *International Journal of Wildland Fire* **7**, 221–248.

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

Moreno MV, Conedera M, Chuvieco E, Pezzatti GB (2014) Fire regime changes and major driving forces in Spain from 1968 to 2010. *Environmental Science & Policy* **37**, 11–22. doi:10.1016/j.envsci.2013.08.005

Moriondo M, Good P, Durao R, Bindi M, Giannakopoulos C, Corte-Real J (2006) Potential impact of climate change on fire risk in the Mediterranean area. *Climate Research* **31**, 85–95. doi:10.3354/cr031085

Moritz M, Parisien M-A, Batllori E, Krawchuk M, Van Dorn J, Ganz D, Hayhoe K (2012) Climate change and disruptions to global fire activity. *Ecosphere* **3**(June), 1–22. doi:10.1890/ES11-00345.1

Mouillot F, Rambal S, Joffre R (2002) Simulating climate change impacts on fire frequency and vegetation dynamics in a Mediterranean-type ecosystem. *Global Change Biology* **8**(5), 423–437. doi:10.1046/j.1365-2486.2002.00494.x

Pausas JG (2004) Changes in fire and climate in the eastern Iberian Peninsula (Mediterranean Basin).

Climatic Change **63**, 337–350.

Pausas JG, Fernández-Muñoz S (2011) Fire regime changes in the Western Mediterranean Basin: from fuel-limited to drought-driven fire regime. *Climatic Change* **110**(1-2), 215–226.

Piñol J, Castellnou M, Beven KJ (2007) Conditioning uncertainty in ecological models: Assessing the impact of fire management strategies. *Ecological Modelling* **207**(1), 34–44. doi:10.1016/j.ecolmodel.2007.03.020

Pique M, Castellnou M, Valor T, Pagés J, Larrañaga A, Miralles M, Cervera T (2011) Integració del risc de grans incendis forestals (GIF) en la gestió forestal Incendis tipus i vulnerabilitat de les estructures forestals al foc de capçades. (Barcelona)

Plana Bach E (2011) Integració del risc d ' incendis en la planificació forestal estratègica i l ' ordenació del territori. **2011**, 71–72.

Raftoyannis Y, Nocentini S, Marchi E, Calama Sainz R, Garcia Guemes C, Pilas I, Peric S, Amaral Paulo J, Moreira-Marcelino A, Costa-Ferreira M, Kakouris E, Lindner M (2014) Perceptions of forest experts on climate change and fire management in European Mediterranean forests. *IForest - Biogeosciences and Forestry* **7**(1), 33–41. doi:10.3832/ifor0817-006

Regos A, Aquilué N, Retana J, De Cáceres M, Brotons L (2014) Using unplanned fires to help suppressing future large fires in mediterranean forests. (JA Añel, Ed.). *PloS one* **9**(4), e94906. doi:10.1371/journal.pone.0094906

Rothermel RC (1972) "A mathematical model for predicting fire spread in wildland fuels." (USDA Forest Service, Intermountain Forest and Range Experiment Station, Research Paper INT-115: Odgen, UT)

Rounsevell MD a., Reginster I, Araújo MB, Carter TR, Dendoncker N, Ewert F, House JI, Kankaanpää S, Leemans R, Metzger MJ, Schmit C, Smith P, Tuck G (2006) A coherent set of future land use change scenarios for Europe. *Agriculture, Ecosystems & Environment* **114**(1), 57–68. doi:10.1016/j.agee.2005.11.027

Servei Meteorològic de Catalunya (2012) Projecte ESCAT. http://www20.gencat.cat/docs/meteocat/Continguts/Climatologia/Canvi climatic/projectes/pdf/resum_executiu_ESCAT.pdf

Syphard AD, Bar Massada A, Butsic V, Keeley JE (2013) Land use planning and wildfire: development policies influence future probability of housing loss. *PloS one* **8**(8), e71708. doi:10.1371/journal.pone.0071708

Syphard A, Brennan T, Keeley J (2014) The role of defensible space for residential structure protection during wildfires.

Tedim F, Remelgado R, Borges C, Carvalho S, Martins J (2013) Exploring the occurrence of mega-fires in Portugal. *Forest Ecology and Management* **294**, 86–96. doi:10.1016/j.foreco.2012.07.031

Terradas J, Piñol J, Lloret F (1998) Risk factors in wildfires along the Mediterranean coast of Iberian Peninsula. "Fire Management of Pinus halepensis and P. brutia forest ecosystems in the Mediterranean Basin (eds. G.Ne'eman & L. Trabaud)." pp.297–304

Terrier A, de Groot WJ, Girardin MP, Bergeron Y (2014) Dynamics of moisture content in spruce–feather moss and spruce–Sphagnum organic layers during an extreme fire season and implications for future depths of burn in Clay Belt black spruce forests. *International Journal of Wildland Fire* **23**(4), 490. doi:10.1071/WF13133

Ursino N, Romano N (2014) Wild forest fire regime following land abandonment in the Mediterranean region. *Geophysical Research Letters*(41), 1–10. doi:10.1002/2014GL061560.Received

5. Annexes

Wildfire Case Study

The Mourne Mountains, Co. Down, Northern Ireland

Background

The Mourne Mountains are subject to wildfires and are one of the worst affected sites in Northern Ireland, for example, wildfire damaged between 8–10 square kilometers of upland heath in the Mournes in April/May 2011.

FIGURE 27: WILDFIRE ON SLIEVE LAMAGAN, MOURNE MOUNTAINS, MAY 2011.

The *Mournes* consist of a compact range of granite mountains forming the highest ground in Northern Ireland and are situated in the southeast of the Province in County Down (see **¡Error! No se encuentra el origen de la referencia.**).

FIGURE 28: LOCATION OF THE MOURNE MOUNTAIN RANGE INDICATED BY THE RED ARROW.

Within the Mountain range, 12 peaks extend to over 600m, with Slieve Donard rising to 852m. It is characterised by thin peat soils and areas of blanket bog and is designated as a Special Area of Conservation (SAC) and Area of Special Scientific Interest (ASSI) due to its unique combination of upland habitats and associated vegetation communities including the largest extent of European dry heaths in Northern Ireland. The area provides a range of ecosystem services including agriculture, biodiversity,

carbon sequestration, forestry, health and well-being, mineral extraction, recreation, tourism and water catchment.

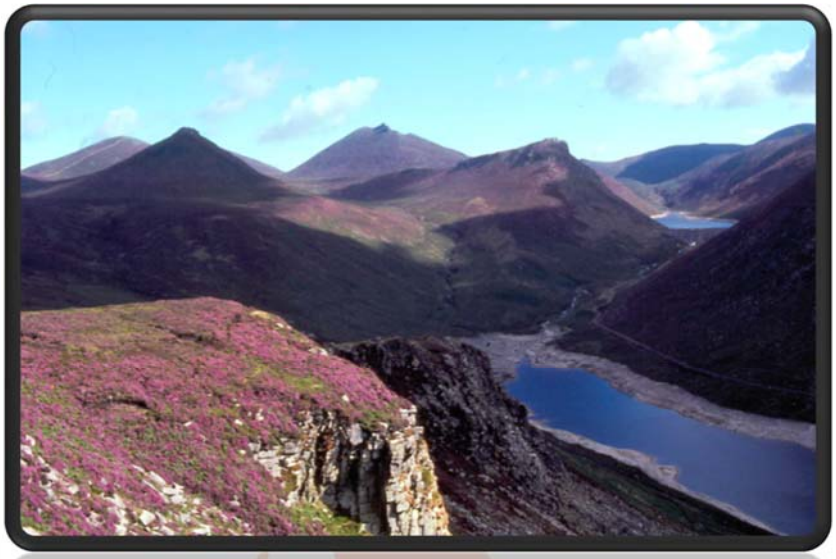

FIGURE 29: VIEW OF THE EASTERN MOURNES MOUNTAINS SHOWING THE HEATHLAND AND RESERVOIRS

Previous efforts by a broad stakeholder group called the Safer Mournes Partnership to reduce the incident of wildfire following increased wildfire activity in the 2000s had stalled, and following the 2011 fires interested parties realised an insurmountable problem would develop if mitigation methods continued in the same way.

The situation was deadlocked with government departments acknowledging the issue but unable to identify a lead department to establish a strategic cross departmental plan and NI Wildfire Forum. A solution needed to be found that was innovative and presented a workable, cost effective option to break the deadlock.

This happened when Mourne Heritage Trust facilitated an initiative where Northern Ireland Environment Agency, Northern Ireland Fire and Rescue Services (NIFRS) and Northern Ireland Water jointly commissioned Wildfire Advisory Services (WAS) to produce the Eastern Mournes Wildfire Report (2012).

The Eastern Mournes Wildfire Report 2012 – Main Findings

Wildfire Advisory Services was commissioned to deliver advice on how to reduce the impact of wildfire in the Eastern Mourne Mountains (EMM). The study area was approximately 7000 hectares and included a water catchment of 3000ha within the ring of high peaks in the Eastern Mournes owned by NI Water, and 4000ha on the outer slopes owned by NI Water, Private Mountain Trustees, private landowners, Forest Service and the National Trust (all within the SAC/ASSI).

The focus of the proposal submitted by Wildfire Advisory Services was aimed at limiting as far as possible the vulnerability of the landscape and water resources to disturbance caused by wildfire, either as a direct result of fire or by the damage caused to the soil layer within the water catchment area.

The threat of wildfire cannot be eradicated, therefore the realistic approach adopted within the project was to provide recommendations on how the number, likelihood and size of wildfire incidents could be reduced. This included an appraisal of how effective intervention response was by both the Fire and Rescue Service and the rural land management sector.

The project recognised the importance of establishing a collaborative problem solving approach between land managers, the fire service, relevant agencies and other stakeholders, and to this end a cross section of local stakeholders and government bodies were interviewed in the development of its recommendations.

The Report analysed weather, terrain, fuel availability and fire history and identified two critical weather patterns that featured in the largest wildfire incidents in the Eastern Mournes:

- Type A; High pressure building from the European continent causing a strong drying environment with high easterly winds.
- Type B; High pressure causing a drying environment but with lower easterly winds.

Type A scenarios would create conditions that threatened the whole Eastern Mourne area, while Type B conditions would generally spread fires along the valleys, especially the main ones.

Computer simulations using *NEXUS* and *Wildfire Analyst* were run to ascertain fire behaviour over the Eastern Mournes (under Type A and B scenarios), which identified the links between the various parts of the terrain and disclosed the routes or fire paths that were available for a fire to move across the landscape.

The main vegetation types present across most of the EMM consisted of heathers and grasses, which provided substantial quantities of 'fine fuel`. The fuel was arranged with connectivity and continuity over the landscape, providing some fires with the potential to spread across what was a 'flammable landscape` for considerable distances causing significant damage (see Photos 1 and 2).

Therefore, the reduction in the size, scale and impact of wildfire primarily depended on how well the above vegetation was managed. In particular, it was important to put in place a plan that broke fuel continuity and reduced fuel loading. The report identified the critical locations (Strategic Management Points - SMP) where fuel/vegetation should be managed to have the maximum effect on limiting the potential of a fire to spread. This totalled approximately 143ha or 2% of the study area.

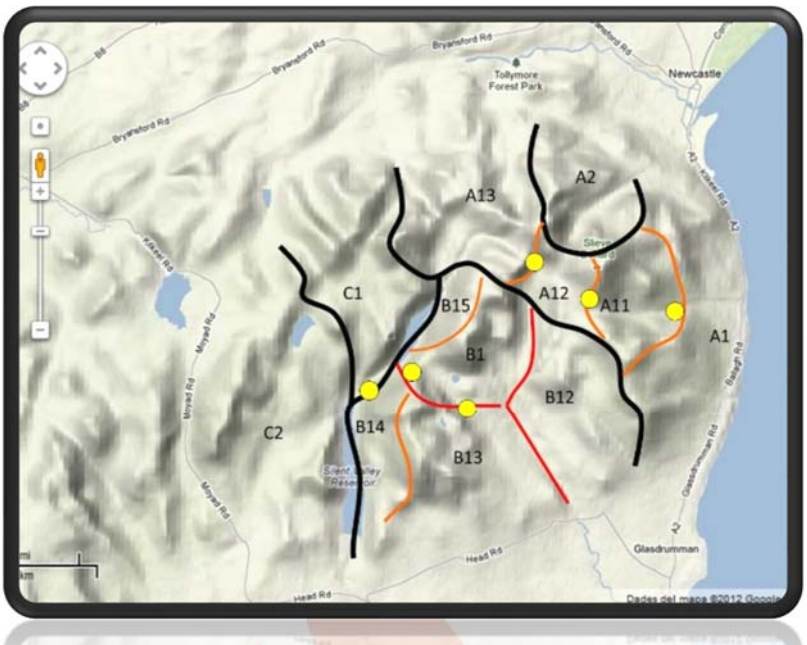

FIGURE 30: SHOWING THE LINKAGE POINTS BETWEEN DIFFERENT LANDSCAPE AREAS IN THE EASTERN MOURNES AND THE CRITICAL LOCATIONS WHERE FUEL LOADING SHOULD BE REDUCED (SMPS).

The report also assessed the capacity for emergency response and concluded that NIFRS was largely unsupported by the rural sector and arrangements were not in place to enable it to effectively cooperate/communicate with land managers, which had a significant impact on the effectiveness of fire-fighting operations but also impinged on FRS preparedness and planning. Moreover, although well trained the FRS lacked the tactical ability to suppress or contain parts of a fire that demonstrated high intensity, and lacked specific weather and wildfire knowledge and equipment. The lack of management of the fuel/vegetation by land managers resulted in a situation where there were few opportunities to prevent the spread of high intensity fires.

The results of the research demonstrated that the land sector and NIFRS were involved in a form of crisis management that at times overwhelmed their resources. The number, size and intensity of historical fires provided evidence that the current approach was failing and the EMM remained under severe threat from landscape sized wildfire incidents. To reduce the risk it was essential that action was taken that limited a fire's potential to spread across the EMM, which could only be achieved by managing the fuel/vegetation that was available to burn. The actions outlined would significantly reduce the risk of fire spreading over large areas, and from one part of the landscape to another, reduce the size and impact of all fires that occur, and also provide the means to establish a long term and sustainable fuel management plan that could eventually be extended into other parts of the EMM.

It was of the utmost importance that a greater understanding of wildfire, and its environment, be developed both within NIFRS and the rural/land sectors. Only then could partners work together effectively and make informed decisions. There was a great deal of evidence to suggest that the threat posed by wildfire in the UK would increase in the future. By addressing the issues now, members of any fire group and the organisations that they represented could build up knowledge of the phenomena; this would permit an improved response in future years.

Actions Following the Report

As a result of the report the **Mourne Wildfire Group** was established in October 2014 and has three sub-groups tasked with developing actions on Land Management (including the recommended SMP), a Strategic Wildfire Plan, and Emergency Response.

Initial actions under the Mourne Wildfire Group focused on carrying out a 5ha prescribed burn at one of the report's recommended SMP between the Ben Crom and Silent Valley Reservoirs, and was regarded by government departments as a pilot exercise to inform further similar work on ASSIs, and also wildfire policy. MHT prepared the prescribed burn plan, commissioned a habitat survey and achieved Government assent for carrying out the work on an SAC/ASSI. N.B. currently controlled burning is not permitted on an ASSI, and in particular on peat bogs, so NIEA were very cautious about this proposal. NI Water monitored impact on water quality.

The burn was carried out by MHT and NIFRS personnel in March and April 2015 (Photo 3). MHT led the burn, which had a joint aim of establishing the required fuel reduction and also enabling recovery of the heathland to a good habitat condition. Of important note is that the resources needed to carry out the burn were made available through a working partnership between NIFRS and MHT (with consents from NIW and NIEA), where specialist equipment was shared and staffing numbers achieved to ensure the burn was managed in a controlled way and to a specific prescription. Moreover, the exercise was also regarded as a training opportunity for NIFRS and MHTs wider staff.

FIGURE 31: PRESCRIBED BURN AT SILENT VALLEY, MOURNE MOUNTAINS MARCH 2015

As it is a pilot exercise, recovery management of the heathland following the burn will be critical to demonstrate whether it provides an adequate SMP and does not reduce the habitat quality. MHT is managing the site recovery including liaising with the farmer who grazes the mountain with sheep to ensure the appropriate stocking density is achieved to supress the *graminoids* and allow the heather and broader biodiversity to recover.

The burn has illustrated the need for land managers and emergency services to work together to learn about their local environment, their capabilities, to increase knowledge and skills, and to maintain momentum (where a lack of practical management may risk the initiative becoming stalled as a paper exercise).

Challenges

There is still no designated lead government department in Northern Ireland and no National Wildfire Forum or resourced Strategic NI Wildfire Plan.

MHT & NIFRS have much broader remits and lack the resources to properly commit personnel to drive the initiative and carry out the practical work as required. (For example the pilot prescribed burn took 8

days, which equated to 83 staff days at a staff cost of approximately £9300, which does not include the broader planning, management and equipment costs that were involved).

Austerity policies in the United Kingdom have impacted significantly on the resources available to the Northern Ireland Executive. This in turn has badly affected MHT, which is at risk of losing a significant proportion of its core funding from July 2015. The various government departments and agencies, including NIFRS, have also suffered cuts, which raises the question of how to sustain this new initiative. However, it also provides an opportunity to demonstrate the value in the proposed approach including SMPs, which require relatively small resources to ultimately avoid the greater costs of treating fire damaged catchment water, the loss in tourism and agricultural land and timber value etc., particularly as disturbances to upland areas are predicted to increase (FRISK Go – see below).

Broader Aspects

The EMWR aligns well with other initiatives including an earlier study on the heathland in the Eastern Mournes that identified the increasing threat of wildfire and the need to consider actions that were not currently routinely carried out on heathland in the UK. In particular, it recommended managing fire breaks and establishing diverse micro habitats (e.g. re-wooding river valleys and raising the water table in certain locations), **as part of building resilience into the landscape.**

MHT and NIFRS are working hard to network with wider practitioners to profile the Mournes initiative and to develop understanding of the international wildfire context & opportunities. This has involved:

- NIFRS and MHT personnel attending tactical burning training in Catalonia.
- NIFRS and MHT personnel carrying out demonstrations on controlled burning to wide stakeholder groups including farmers and NGOs, under an NIEA led series of events to raise wildfire awareness.
- Participation in the European Forest Risk initiative (FRISK Go) including a workshop in Catalonia, and a study visit to Norway to establish understanding and networking across northern European countries.
- NIFRS Commander attending a knowledge exchange visit to South Africa (via FRISK Go)
- Participation in the European POFISmart initiative aiming to establish post fire recovery modelling tools, and the European FIREfficent initiative.
- Close working with representatives of the Dept of Agriculture in the Republic of Ireland aiming towards a coordinated broader island of Ireland wildfire initiative.
- Exploring partnerships with academic institutions including Kings College London and Edinburgh University to develop modelling and stakeholder value assessment profiles.

Matthew Bushby

Mourne Heritage Trust

The Albera and Creus cap, Alt Empordà, Catalonia.

In *Albera and Cap de Creus* mountains (26000 ha of forest land), in the Alt Emporda county (Catalonia, NE Spain), prevention of wildfires is focused on adapt some areas for firefighters' use. The goal is focused on firefighters' availability to restrain wind-driven fires from the North, very common in the region, both in winter and summer seasons. Wind driven fires can win firefighter systems if the fire propagation speed (2-4 km/h) is greater than the fire extinction speed (0.5-2 km / h). It can also happen that the speed with which events occur is greater than the speed at which orders, implementation and firefighting monitoring flow. In this area, wind driven fires from the North have such a homogeneous spread over the landscape that the movements and spread patterns are repeated for the same weather conditions.

According to the fire type classification, in this region the most common fire spread pattern is wind-driven fire in abrupt relief. Historically, fires have demonstrated the following characteristics:

- Head propagation:
    - Rate of speed 2 km/h.
    - Away spotting firebrands distance of 200 meters.
    - Fire behaviour with crown fire activity
    - Flame length greater than 6 meters.
- Flank propagation:
    - Fire behaviour with medium-high intensity
    - Flame length of about 2-4 meters.

With these technical fire characteristics, we will identify areas where the terrain allows to plan the operations to be carried out during the fire. We will adapt the land for achieve more effective planned operations. Those are the Strategic Management Points. This wildfire prevention planning helps firefighters to explain the actions needed to owners and managers, and implementing fuel management work in the best conditions and plan maintenances. In these points firefighters will be able to work with greater safety and efficiency. Furthermore, it will be easier to calculate the land potential protected in each SMP. This is a way to justify the investment in fire prevention with measurable results. The process to apply this methodology is not simple and it should be suited for each region.

In 2012 the Fire Prevention Plan in *Albera-Cap de Creus* massif was updated, and it further included this methodology to design SMP opportunities for fires greater than 5000 ha. Based on meetings between administration technicians, (Alt Emporda, Natural Park and Firefighters), owners representatives , local municipality representatives, hunters and ecologist groups, a consensus proposal of SMG was defined, including:

- Identification of treatment areas
- Definition of the planned manoeuvre extinction
- Definition of fuel treatments

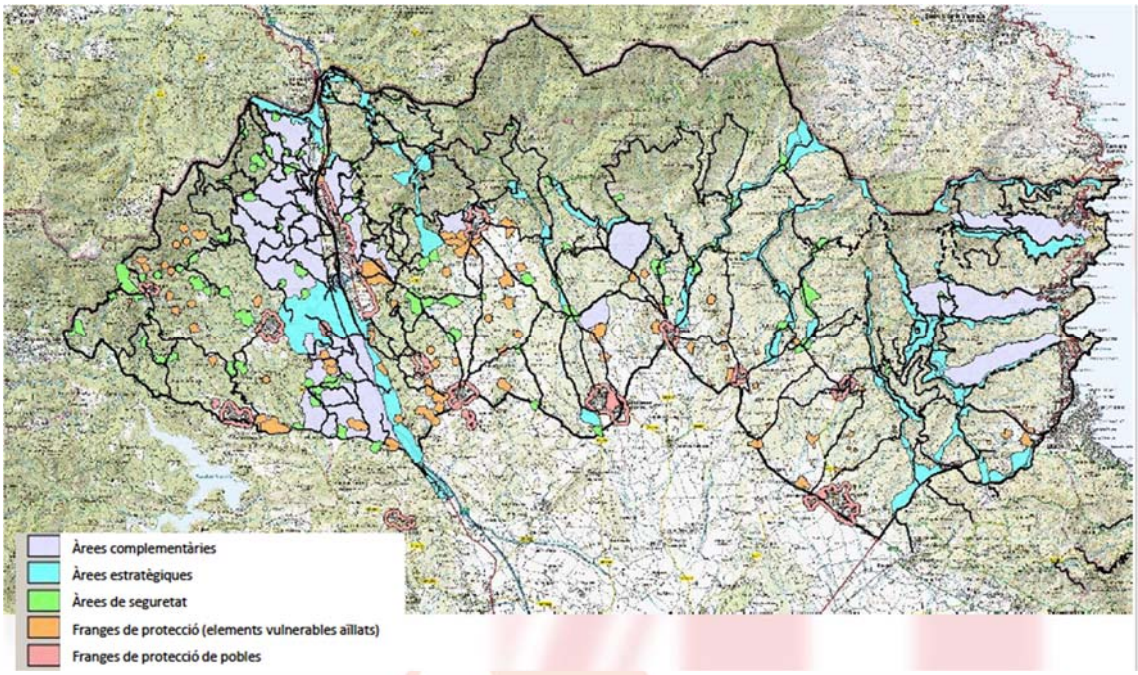

FIGURE 32: FIRE PREVENTION CARTOGRAPHY FOR THE ALBERA-CAP DE CREUS MASSIF

Currently planned jobs are under execution (November 2015). These works include most of the conditions requested and take into account the needs of local economic activities related to their maintenance:

- Hunting
- Pasture
- Maintaining favourable habitats protected species

FIGURE 33: SMP OF COLL DE BANYULS.

FIGURE 4: SMP COLL DE BANYULS; MAKING AN INFRASTRUCTURE FOR PRESCRIBED BURN

For the last two years, fire commanders are being formed to learn the main manoeuvres planned in each point. This way, when a fire will occur, the analysis, evaluation and execution of the manoeuvre will be very fast. And it also will match what was planned, so that the use of fire prevention infrastructures could work as efficiently as possible and allow to achieve operational objectives expected by fire departments.

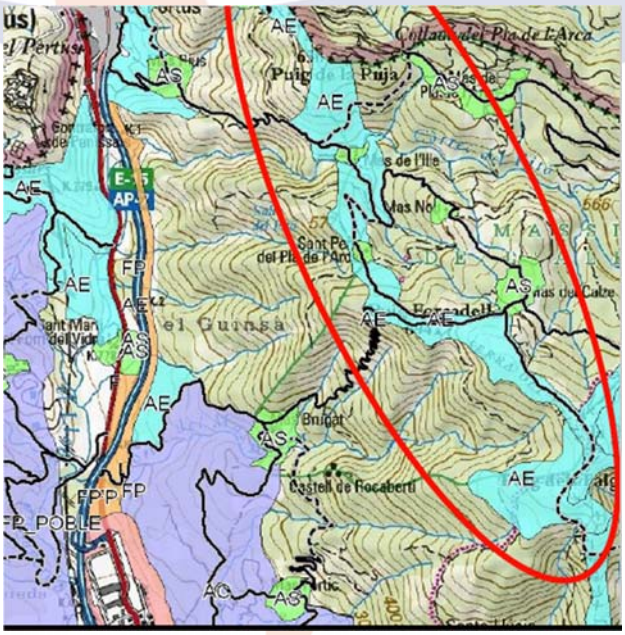

FIGURE 35: SMP PLA DE L'ARCA. INFRASTRUCTURE PLANNING

FIGURE 36: SMP PLA DE L'ARCA. EXECUTED INFRASTRUCTURE

FIGURE 37: SMP PLA DE L'ARCA. JONQUERA FIRE JULY 2012 REACHING THE SMP.

FIGURE 38: SMP PLA DE L'ARCA. SUCCESSFUL INFRASTRUCTURE USED BY FIREFIGHTERS ON JONQUERA 2012 FIRE SUPPRESSION.