Evaluation of Alternative Post-fire Strategies

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Abstract

Over the last decades, areas burned by wildfires have been significantly increasing along with the costs associated with forest fire management (FFM) practices. Post-fire management teams face difficult trade-offs in choosing among a variety of alternatives after a wildfire incident. Therefore, it is crucial to monitor and evaluate the strategies available to help in the process of decision making.

In most cases, ecosystems are resilient to fire disturbance and the no intervention scenario should be weighted. However, in some specific areas that are more susceptible to degradation, post-fire management techniques should be carried out. This work needs to be done carefully as the management options chosen can emphasize or reduce the positive and negative impacts on the burned site.

The present dissertation studies and evaluates some post-fire management alternatives along with the advantages and disadvantages of their use. In order to understand the impacts of choosing one strategy over another the costs of each one were presented and analysed together with the application to real distinct scenarios. This allowed, besides the obvious theoretical conclusions, to have actual values associated with the alternatives that serve as a support for future management decisions.

To achieve the best results possible it is critical that both the top management and the operational teams keep controlling and improving the process daily in a culture of continuous improvement.

Keywords: Forest fire prevention, Post-fire management, Cost analysis

Resumo

Avaliação das estratégias alternativas pós-fogo

Nas últimas décadas, as áreas queimadas por incêndios florestais aumentaram significativamente juntamente com os custos associados às práticas de gestão de incêndios florestais. As equipas de gestão pós-fogo enfrentam dificuldades para escolher entre uma variedade de alternativas após uma ocorrência de incêndio florestal. Portanto, é fundamental monitorizar e avaliar as estratégias disponíveis para auxiliar no processo de tomada de decisão.

Na maioria dos casos, os ecossistemas são resilientes à perturbação do fogo e o cenário sem intervenção deve ser ponderado. No entanto, em algumas áreas específicas que são mais suscetíveis à degradação, técnicas de gestão pós-fogo devem ser aplicadas. Este trabalho deve ser feito com cuidado pois as opções de gestão escolhidas podem enfatizar ou reduzir os impactos positivos e negativos no local queimado.

A presente dissertação estuda e avalia algumas alternativas de gestão pós-incêndio e as vantagens e desvantagens do seu uso. Para compreender os impactos da escolha de uma estratégia em detrimento de outra, os custos de cada uma foram apresentados e analisados juntamente com a aplicação a cenários reais distintos. Isto permitiu, além das óbvias conclusões teóricas, ter valores reais associados às alternativas que servem de suporte para futuras decisões de gestão.

Para alcançar os melhores resultados possíveis é fundamental que tanto a alta administração quanto as equipas operacionais mantenham o controlo e a melhoria diária do processo numa cultura de melhoria contínua.

Palavras-chave: Prevenção de incêndios florestais, Gestão pós-fogo, Análise de custos

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Lastly, to my sister, Maria, that is always present in every moment of my life.

To All, a huge thank you.

"If you find a path with no obstacles, it probably doesn't lead anywhere."

Frank A. Clark

Contents

Acronyms and Symbols

BAER	Burned area emergency response
FB	Forest biomass
FM	Fire managers
FFM	Forest fire management
MB	Mediterranean basin
PM	Policy makers
WUI	Wildland-urban interface

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Chapter 1

Introduction

The present curricular dissertation project, part of the 5th year cicle in the masters degree in Engenharia e Gestão Industrial, has its focus on the evaluation of the various post-fire management alternatives and the costs associated with each one.

In this section follows the presentation and context of the project developed. Here are also described the objectives defined and the methodology to achieve them.

1.1 Context and motivation of the project

Over the past few years, the sites burned by wildfires have been increasing along with the costs associated with forest fire management (FFM) practices. This problematic also has indirect effects on society as many human lives are lost, property values put at risk, natural resources and ecosystems are affected and cultural resources destroyed. It is of paramount importance that these negative effects are mitigated and to achieve so, some alternatives are evaluated in order to minimize the negative effects of wildfires.

Post-fire management and, in particular, fire managers (FM) face difficult trade-offs in choosing among a variety of alternatives after a wildfire incident. Practices regarding post-fire management can fluctuate from passive management, which allows natural regeneration to happen, to undertaking various levels of intervention. The decisions concerning FFM are made under a great amount of uncertainty due to uncontrollable factors like meteorological and economic conditions and also the impact of the diverse strategies on each other. In order to be effective, and because there is a finite budget, management also needs to balance suppression and prevention activities.

The present thesis, arises from this context as a tool to define methodologies to apply to and better control the decisions that concern fire management.

1.2 The wildfire scenario in Portugal

Every summer, Portugal is the scene of terrible wildfires that destroy tens of thousands of hectares of forest. Looking back at the years of 2003, 2005 and 2017, it is easy to recognize the importance that wildfires have acquired in Portugal. Although this matter has always had much attention from our community, the referred years, in particular, have showed us that this matter requires deep, structuring solutions and methods in order to effectively manage it.

Two thirds of Portugal are composed by forested spaces that provide paper, cork, furniture and thousands of jobs. Furthermore, a number of factors such as climate, topography, distribution of tree species and population density contribute to the fact that Portugal is the number one European country when it comes to fire occurrence. An enormous population migration from the rural interior to the coastal urban areas has led to land and agriculture abandonment. Also, we have a Mediterranean-type climate which makes for mild, humid winters and warm, dry summers. Besides that, climate is changing and bringing more extreme weather and drought events. The vegetation that covers most of our lands is highly flammable instead of fire-resistant. The predominant tree species are Maritime Pine, Eucalyptus and Cork Oak. The highly combustible Maritime Pine and Eucalyptus, are found essentially in the central north part of the country where high rural fire activity has been recorded. The Cork Oak, which offers an elevated resistance to fire, is predominant in the southern part of the country. Besides, Portugal is the European country with more forest under private control which makes it hard to properly manage them. It is important to note that the high population density is related to the fact that wildfires in Portugal are mainly of human origin. Another key characteristic is the topography. The northern half of the country is considerably more mountainous, which helps fire to spread faster, compared to the southern half mainly consisting of flat areas.

This set of factors put Portugal at an extremely high risk of occurrence of wildfires. The changes that we need to make to deal with this thematic must be sustainable with collaboration from all levels of government and the civilians. Wildfires are inevitable so it is of paramount importance to find strategic ways to manage it adequately.

1.3 Aim of the project

The impacts that wildfires have on so many levels, such as environmental, societal, cultural and so on, demand several strategic upgradings in the next few years in order to significantly reduce them.

Taking into account the aim of this project, it is intended to answer some pivotal questions:

- What are the different post-fire management strategies being currently used and are there other options to consider?
- What factors influence the proper post-fire alternatives to choose after a wildfire?
- What is the methodology to apply in order to choose the adequate strategy and properly manage every wildfire incident?
- What are the future positive and negative impacts of the actions undertaken regarding FFM?

- How can the costs of choosing one alternative over another be calculated?

Having answered all of these questions, there is a possibility to develop a strategic plan of action to help FM deal with the uncertainties involved in this thematic and to effectively manage the consequences of wildfires.

1.4 Methodology

The methodology followed in this study was based on qualitative and quantitative techniques that were explored with the objective to respond to the research questions. The global perspective of the methodology applied starts with a conceptual framework that is basically qualitative and ends with an action plan that is based in a quantitative approach.

This project was divided in three phases that are described as follows:

- The first phase consisted of a theoretical involvement of the theme, the problems that are of greatest concern relating to wildfires and the description of the different alternatives being currently used in FFM and the advantages and disadvantages that come from their use.
- In the second one, the state of the art of what is being done was described. Furthermore, the costs of some post-fire management techniques were collected and organized in tables in order to facilitate the analysis that enabled to find efficient solutions for future management teams to apply.
- The last phase refers to the actual implementation of some post-fire management alternatives in different situations. The ones that were identified as the more adequate to minimize total costs were applied and then the attempt to normalize the process was made to help guide future solutions design.

1.5 Dissertation structure

This dissertation consists of 6 chapters where a more detailed explanation of the context and methodology of the project can be found and is organized as follow.

In the present chapter there is an introduction to the project, to its objectives and the methodology defined. It is also done a brief context of the wildfire scenario in Portugal.

Chapter 2 refers to the literature review where there is a theoretical framework of the concepts and methodologies that served as a support to the development of this project.

In chapter 3 the state of the art of the theme is characterized along with the identification and description of the problem.

Chapter 4 specifies the problem, allowing for an extended knowledge of the theme and the hypothesis analysed. There are also described some restraints arising from the investigation of the application of the different alternatives.

Chapter 5 describes the solutions proposed to the resolution of the problem, so as the main results that emerged from its application.

Lastly, in chapter 6, the solutions studied and some suggestions for improvement to apply in a future perspective are presented.

Chapter 2

Literature review

In the present chapter, the theoretical concepts that were studied and served as a basis to the development of this thesis are presented.

2.1 Wildfire management

Wildfire emergency management consists of four different phases that generate the management process, as illustrated in Figure 2.1. These phases are mitigation, preparation, response, and recovery. Every phase has a different role in the emergency management process but, in some aspects, they connect with each other. If a management process does not include one of the four phases it could be judged as imperfect and inappropriate (Sylves, 2019). According to Drabek Thomas (1986) mitigation is usually defined as prevention and preparedness is the act of changing behaviors or processes to minimize the impact that a calamity may have on a population or crowd. Again, Sylves (2019) says that response is gathering teams of emergency service to the local of disaster and recovery aims to restore the place affected by the accident to its condition before the accident.

In the face of fire risk, the process of forest management is a tough problem not only because fire propagates across a landscape but also because of the unpredictability of its occurrence. For

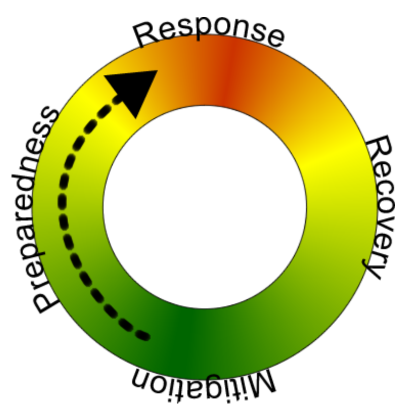

Figure 2.1: The four phases in emergency management

determining optimal management it is crucial to account for the existence of random occurrences that create spatial interactions in the context of a dynamic decision process. Fire is a natural process that can be necessary to the health of forest ecosystems but, on the other hand, it can also threaten values on the landscape such as timber, homes in the WUI, watershed health, air quality, and wildlife habitat (Lauer et al., 2017).

Another impasse related to FFM is clarified by Minas et al. (2012) and resides in the fact that FM act in a very challenging decision atmosphere characterised by complexity, numerous contradictory objectives and uncertainty.

To confront the challenges set by these incidents San-Miguel-Ayanz et al. (2013) recognized that appropriate forest management is fundamental to decrease fire hazard, improve the prevention of wildfires and avoid extreme fire events, also referenced as "mega-fires".

2.2 Prevention and suppression of wildfires

To effectively manage the risk of forest fires it is necessary to balance suppression and prevention activities. As defined by Collins et al. (2013) suppression is the action to terminate fires already ignited, while prevention tries to put limits to the severity of fires through fuel reduction, for example prescribed fire.

Policy makers (PM) and FM, although sometimes have to deal with imperfect and incomplete information and limited financial funds, need to make decisions on the most efficient and effective attribution of funds to different FFM options (Pacheco et al., 2015). As the financial funds are limited, budget balancing at policy, restoration and operational resources—levels is mandatory (Collins et al., 2013).

The Mediterranean basin (MB) includes the lands that in Europe, Africa and Asia border the Mediterranean Sea and have moderate winters and very hot, dry summers, that is, are characterised by a Mediterranean-type clime. Fernandes (2013) came to the conclusion that, in the MB, the actual fire management policies privilege fire suppression and tend to disregard land management problems, which may contribute to a more fire-prone future and enhance the issue. FFM in the MB relies deeply on fire suppression and do not sufficiently handle the socio-economic and land management questions behind the inception and propagation of wildfires (Fernandes, 2008).

Due to the fact that the fire policies in the MB give more importance to fire suppression than prevention it makes them unsustainable, almost with a counterproductive behavior because they do not get to the source of the issue. It is now acknowledged that short-term and reactive fire management policies should give way to “longer-term policies aimed at acting on the structural causes of fires and integrating fire and forest management strategies” (Fernandes, 2010).

Furthermore, Collins et al. (2013) review denotes that a management policy emphasizing suppression can diminish the long-run effectiveness of FFM. By moving away efforts from preventative actions like fuel reduction, it aggravates fuel accumulations and favors the occurrence of larger wildfires, which additionally enhance suppression budgets. In the business management literature this issue is referred to as the "firefighting trap", while focusing on solving problems deviates attention from preventing them and, therefore, leading to worse results.

As one can see nowadays, the growing investment in fire suppression did not decrease the amount of large fires, with mega-fires becoming even more common (Fernandes et al., 2016), WUI fires (that are a hazard for populations and their goods) are responsible for 95% of the suppression costs in comparison to remote fires (Schoennagel et al., 2017), all leading to permanent budget deficits.

2.3 Fuel management

The spreadness of wildfires is based on the sort and amount of the fuel that encloses it. Fuel can comprise lots of things from trees, underbrush and grassy fields to houses. The quantity of fiery material that surrounds a wildfire is referred to as the fuel load. A low fuel load will lead to a small intensity fire spread. On the other hand, if there is a lot of fuel, the fire will spread faster. The drought of the combustible also affects the way the fire behaviours. A very dry fuel is consumed much quicker and generates a fire that is extremely hard to extinguish.

A large part of the forested areas in the MB that were previously cultivated have been forsaken for the last decades. The absence of management during this shifting era from cropping to forest recolonization has led to a cumulation of fuel, resulting in harsh wildfires in some places (Cerdà and Mataix-Solera, 2009). Pausas and Paula (2012) and also Moreira et al. (2011) identified land desertion and fuel accumulation as the major elements that facilitate the occurrence of mega-fires.

The purpose of fire management is to alter the fire regimen, which is a consequence from the interaction between ignitions and other environmental factors like topography, climate and vegetation. By handling the accumulation of fuel, FFM can actually reduce the area burned both directly and indirectly, respectively by retarding fire propagation and by increasing the meteorological conditions under which wildfire control is possible (Fernandes, 2013). Therefore, the goal of forest management in areas prone to fire should be to reduce fuel accumulation through, for example, prescribed fire, thinning and the elimination of forest debris after forest harvesting actions (Xanthopoulos et al., 2006).

Taylor et al. (2013) reviewed two goals of fuel treatments. The first is that the purpose of these treatments is to decrease fuel accumulation in order to attenuate wildfire harshness which, in consequence, reduces the expected costs of damages. Secondly, fuel treatments try to reinstate health and resiliency to ecosystems. Public agency endeavors and expenses still give emphasis to wildfire suppression and post-fire restoration, neglecting pre-fire combustible treatment. Also, Taylor et al. (2013) concluded in his work that a relevant implication of having undervalued the benefits of fuel treatments is that although treatment is economically efficient in certain conditions, it may not be so efficient in others.

2.4 Post-fire management

The post-fire management of burned sites has been given much less attention than fire suppression and prevention in Europe and all over the world. Vallejo et al. (2012) lifted some significant questions of public interest and that demand scientific knowledge: "How can we accurately evaluate fire damages in economic terms? What are the most suitable short-term intervention techniques to minimise soil erosion and runoff? How should burned trees be managed? What is the best approach to long-term planning for the rehabilitation of burned areas? Along side the damage they incur, wildfires can also be regarded as an opportunity to plan and establish less flammable and more resilient forests and landscapes in recently burned areas. What information is available on these topics and how should administrations and stakeholders react after large fires?" These questions are pertinent all over the world but, even more so, in a southern European context, where wildfires are more common.

In order to properly manage forest ecosystems, FM and PM need to adopt post-disturbance interventions that are intended to achieve management objectives and to restore the necessary ecosystem services (Marcolin et al., 2019). In order to avoid further fire associated damages, which can be exceptionally harsh to the environment, and to impulse regeneration, different post-fire management strategies are used to recover the burned areas and to mitigate new fires (Wittenberg et al., 2019). However, some post-fire management techniques can impact soils on a negative way, which can be even more damaging than the fire itself (Mataix-Solera et al., 2015).

Pereira et al. (2018) came to the conclusion that ecosystems can be resilient to wildfires and, thus, a scenario of no intervention should be taken into account. This also happens in the MB, where the post-fire restoration of burned forests generally involves planting or direct seeding, often overlooking the use of natural recovery (Moreira et al., 2009). Post-fire management should only be performed in some particular areas, the ones that are more sensible to degradation. Throughout history, it is known that ecosystems adapted to count on fire perturbation and created mechanisms of protection from it. However, the growth of fire occurrence and the gravity of these fires has been reducing the ability of ecosystems to recuperate.

Passive restoration usually implicates a smaller financial cost, even if some intervention to support this natural regeneration is used. Moreira et al. (2009) recognized that conflicts between the active and passive strategies for rehabilitation can happen, specially if governments subsidise active restoration in places where natural regeneration is already happening.

Forest administrations usually have to make decisions that are subject to a particular context and that depend on the concrete circumstances of the fire, primarily the extent of the burned area, the costs of management operations and the commercial value of the burned wood (Taboada et al., 2017). According to Moreira et al. (2009) post-fire management actions in the MB areas are of great concern to national and regional governments and also to FM but there is yet a significative absence of knowledge on the best strategies to use.

The impacts of wildfires are dependant on a set of factors and, thus, the post-fire management techniques used should be adjusted to local and fire features. The adequacy of these techniques depends on some elements correlated to fire like dimension, magnitude, harshness and reappearance of the fire as well as on the land use, topography, weather and the sort of soil (Hosseini et al., 2017). "As fire behaviour and impacts are site-specific, the appropriate post-fire management strategies ought to be site-specific as well" (Wittenberg et al., 2019).

2.5 Uncertainties in wildfire management

Wildfire management is subdued to several sources of uncertainty. Besides the obvious unpredictable behaviour of wildfires, uncertainty also derives from inaccurate or missing data, fire behavior response to treatments, restricted resource value measures, an defective scientific understanding of ecological reaction to fire and spatiotemporal dynamics involving perturbation regimes and weather modification (Thompson and Calkin, 2011).

Forest fire management challenges are complex as they depend on interactions between ecological, social, economic, and policy factors. Pacheco and Claro (2018) developed a study on how to manage a portfolio of a set of FFM options with a restricted budget, taking into account uncertainties in meteorological and economic conditions and the impact of the diverse strategies on each other in order to mitigate post-fire consequences.

Weather previsions, performance of suppression resources, and fire behavior, spread and outcomes are some of the extremely unpredictable factors that serve as a basis for fire management and policy decisions, so uncertainty in the results is an eminent characteristic of wildfire management alternatives at policy and operational levels (Pacheco et al., 2015). Thompson and Calkin (2011) emphasized that it is of paramount importance to identify and characterize uncertainties to be able to better quantify and manage them. Taking advantage of the most suitable decision assistance tools can favor the assessment of wildfire risk and also enrich the decision-making process.

2.6 Flexibility in wildfire management

Whenever uncertainty is present, operational flexibility is of high importance for the majority of FFM decisions Pacheco and Claro (2018). “Flexibility is the ability to adapt to change and may take many forms” (Chod et al., 2010), thus, if a system is projected using a variety of different sources of flexibility, it reinforces its ability to adapt to various future events, subject to various sources of uncertainty and consequently its capability to reach its main goal (Cardin et al., 2015).

Forest management is a dynamic issue and the actions taken today have significant effects on the forthcoming worth of the forest land. The search for the optimal management is aggravated by unpredictable ecological perturbations, like wildfires, that occur in many forested landscapes. Fire is a natural disturbance that can be vital to the health of forest ecosystems but it can also endanger values on the landscape like wood, houses in the WUI, watersheds, air quality, and habitats (Lauer et al., 2017). Therefore, the need of flexibility in the process of wildfire management is crucial.

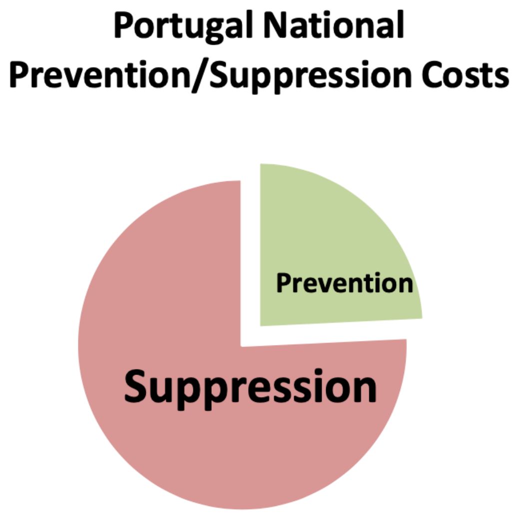

Figure 2.2: Prevention and suppression costs

2.7 Wildfire management in Portugal

Fire management in Europe is highly concentrared on fire suppression (Fernandes, 2008), for example, expenditures with fire fighting in Portugal surpass by a factor of three those with fire prevention (Mateus and Fernandes, 2014), as illustrated in figure 2.2. This happened as a reaction to the increase of fire occurrence in the 1970s following forest and shrubland augmentation that resulted from afforestation and agriculture abandonment (Pausas and Fernández-Muñoz, 2012). Although fire suppression efforts did mitigate the area burned (Moreno et al., 2014), it did not succeed in decreasing the quantity of large (more that 500 ha) fires (San-Miguel-Ayanz et al., 2013), which became more common in the last twenty years (Cardil et al., 2015).

The main goal of fire management in Portugal is to reduce the area burned (Lourenço et al., 2005), and, according to Moreira et al. (2010), the largest wildfires in Portugal take place especially where population density is lower and forest dominates land cover, corresponding to mountainous sites and possibly indicating associated effects of great fuel accumulation, unfavorable topography and low pre-suppression preparation.

Pacheco and Claro (2018) concluded in their analysis that “no prevention” can be connected to the “abandoned forest” (characteristic of the center and north regions of Portugal, where the majority of forest is divided between multiple small proprietaries), “prevention focus” to the “planted forest” (owned or rented, but mostly managed by companies for wood production), and “suppression dominance” to the WUI. Even though the Portuguese law demands every fire to be fought, the “let burn” policy still happens in shrublands (distant from populated areas).

Portugal, like most Mediterranean-type ecosystems, is controlled by shrub and tree species and they have the capability to resprout after fire (Pausas, 1999) which grants an excellent resiliency to these ecosystems. However, FFM needs to always consider alternatives for the afforestation of burned areas and the prevention of wildfires.

Figure 2.3: Districts of Portugal

2.8 Administrative divisions of Portugal

The actual administrative divisions of Portugal are the 18 districts and the 2 autonomous regions, Azores and Madeira. Figure 2.3 shows the 18 districts of continental Portugal.

The partition of Portuguese districts is nominally homogeneous but there are some outliers (Beja, for example, is 4.6 times larger than the smallest district, Viana do Castelo). However, there are a lot of shortcomings and discrepancies within the country: the division of population and gross domestic product between territorial units is greatly distinct. Again, the district of Beja, for example, represents nearly 11.5% of the surface of Portugal, while Viana do Castelo is fewer than 2.5%, but Beja represents only 1.6% of the population of Portugal.

Portugal is essentially a seafaring nation and in tradition human settling has gathered along the coastal line so much so that the seaboard districts, while being fairly small, are disproportionately overpopulated. The six greatest districts (with the exception of Santarém) are the six ones with the lowest populations and have a communal characteristic: a border with Spain. These interior districts represent 63.8% of the population of Portugal and have less than two million inhabitants which is only marginally inferior to the population of the district of Lisbon.

The district is the most important and historically meaningful subdivision of the country's territory. It presents a basis for a range of administrative divisions, such as electoral constituencies or district football associations, as well as being a publicly acknowledgeable territorial partition of the nation. In 1976, Portugal was sectioned into 18 districts and 2 autonomous regions (Azores and Madeira) consisting of 308 municipalities (concelhos), which in turn were parted into 4257 local government authorities (freguesias) (Ramos and Silva, 2007).

Chapter 3

Problem description

In this chapter, it is presented a detailed analysis of the problem that leads to a better grasp of the project and that has a direct impact in the design of the solutions.

3.1 Characterization of the problem

The fresh and moist winter creates great conditions to the development of countless plant species that, in most cases, originate continuous and homogeneous mantles of vegetation. This elevated fuel load together with the hot and dry conditions of summer facilitate the occurrence of wildfires.

For a long time, the discussion around this matter focused mostly on fire suppression. Lately, prevention has been gaining prominence essentially through fuel management, controlled fire and the formation of teams of sappers.

However, what happens after a wildfire receives little attention by the competent authorities. The issues related to post-fire in Portugal are essentially focused in the investigation because in practice there is barely visible any action in this area. Although many owners and associations have some concerns about this regard, there is still a lack of structure that indicates how and when to proceed. There are also many hectares that belong to nobody, where in most cases the respective owners do not even know that it burned. It is for all of these reasons that there is still not a good structured post-fire management in Portugal.

With a critical view over what could be improved and what remains to be done, this project intends to characterize the actual post-fire management practices in Portugal and develop a strategic plan of action.

3.2 Study site

Some countries are more affected by wildfires than others and Portugal is at the top of that list when it comes to number of incidences. The countries with more wildfires are the following:

- EUA

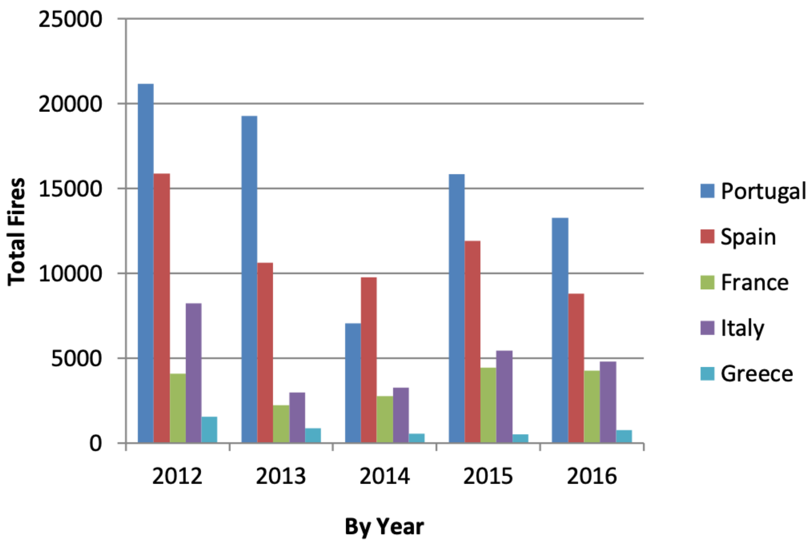

Figure 3.1: Wildfires in European countries

- Canada
- Portugal
- Australia
- Spain
- Greece
- Chile

Portugal is localized in the southwesterly extreme of Europe and is one of the European Mediterranean countries that is more attacked by wildfires, including Spain, France, Italy and Greece as demonstrated in figure 3.1. It is, therefore, a good study object to analyse in the present thesis.

3.3 Characteristics of Portugal

There are a series of factors that make Portugal very susceptible to wildfires, especially in the northern and central parts of the country. The wildfire susceptibility in continental Portugal is demonstrated in figure 3.2.

Figure 3.3 shows the 18 districts, their correspondent municipalities (278 counties) and also the population density distribution for each district.

The urban area types in Portugal shown in figure 3.4, present a very resembling distribution pattern to the population density map, as expected, because population tends to concentrate in the predominantly urban areas.

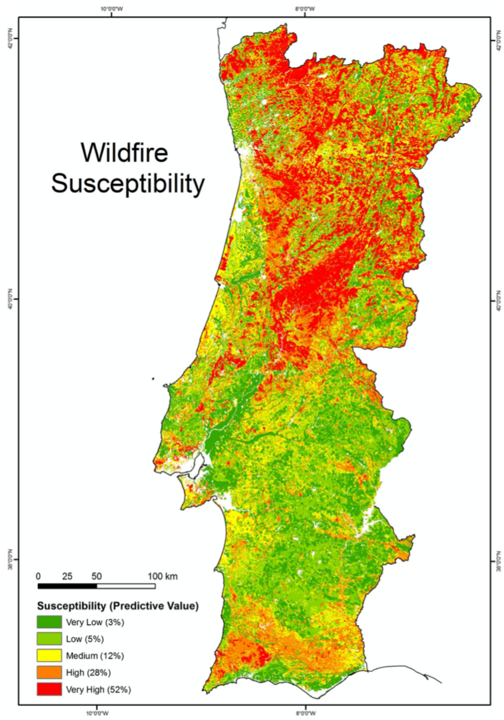

Figure 3.2: Wildfire susceptibility in Portugal from (Verde and Zêzere, 2010)

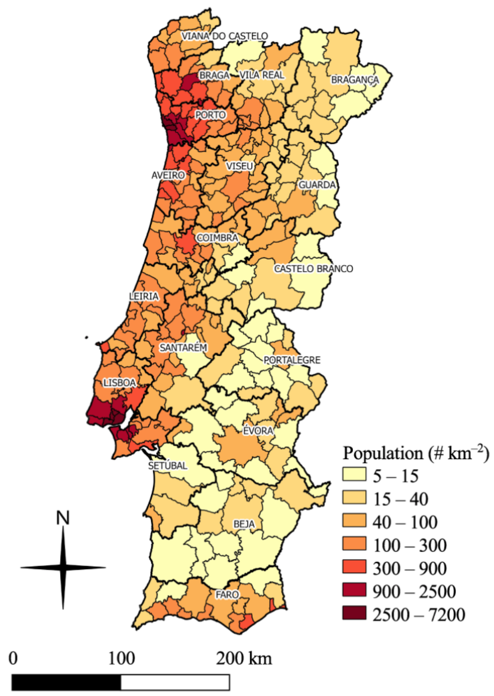

Figure 3.3: Population density from (Pereira et al., 2011)

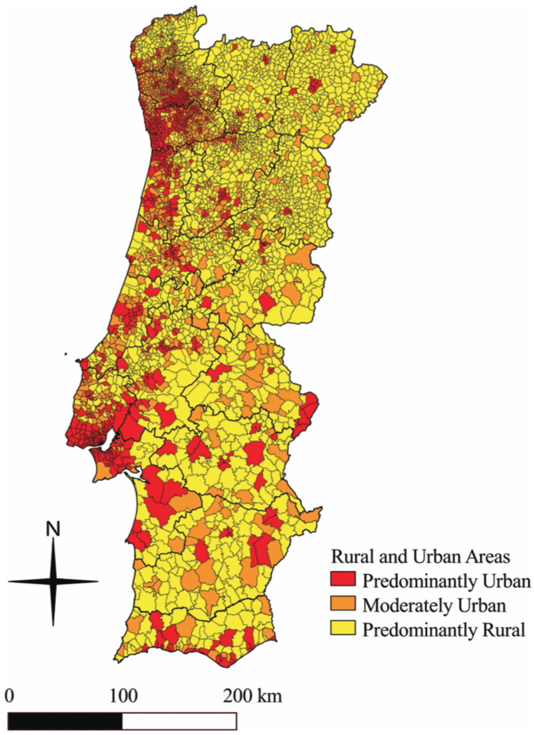

Figure 3.4: Rural and urban areas from (Pereira et al., 2011)

In the areas where there are more people, there are also more wildfires. 98% of all Portugal ignitions are human caused as figure 3.5 illustrates. However, it is relevant to note that only 27% of fire occurrences in Portugal have an identified cause.

Elevation is one of the wildfire conditioning factors. Elevation “controls temperature and rainfall” (Ventura and Vasconcelos, 2006), which will, in turn, influentiate the kind and availability of fuel, as well as its humidity. It is not homogeneous in Portugal and the greater values are found in the central and northern part of the nation, as presented in figure 3.6.

The power of slope on fire propagation is well noted. The greater the slope, the quicker fire advances by heating the combustible uphill. Slope is also an element that commands the wind velocity (Viegas, 2006). The spatial standard of slope distribution in Portugal is resemblant to that of elevation, shown in figure 3.7. The slope gradient is generally higher in the north and central parts of Portugal.

The unique mix of vegetation that covers the country’s land has made Portugal very prone to wildfires. Furthermore, many rural community farm lands that once mitigated fire spread are now abandoned due to rural depopulation and marginally productive lands converted to forest plantations are increasingly left unmanaged because they are too expensive to sustain (about 80% of forests are unmanaged). These abandoned rural areas and unmanaged forests are then invaded by dense shrubs and trees making vast landscapes prone to wildfires and the recently burned areas are quickly invaded by highly flammable trees and shrubs making much of Portugal very susceptible to wildfire.

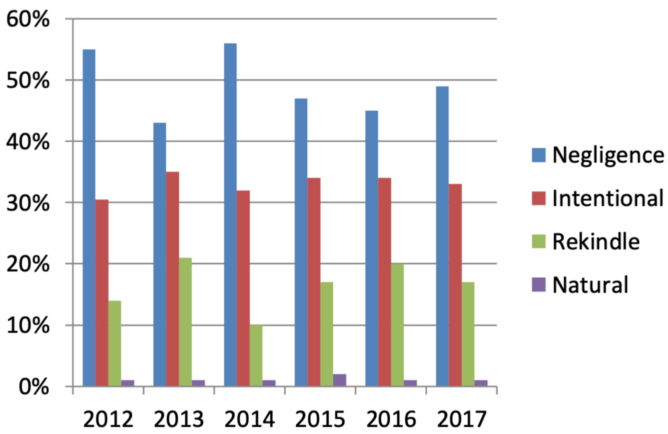

Figure 3.5: Causes of wildfires

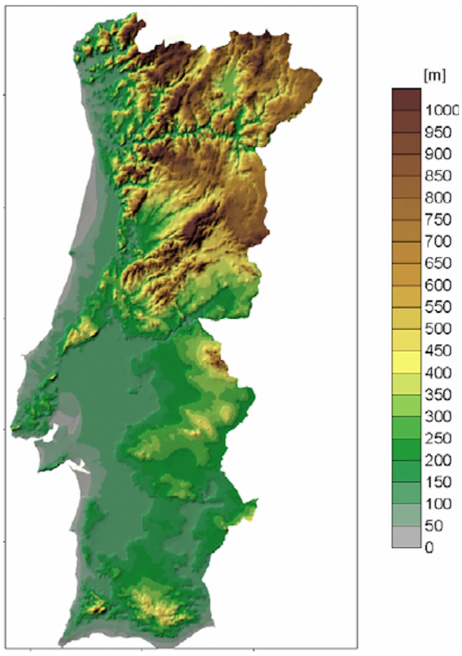

Figure 3.6: Elevation map

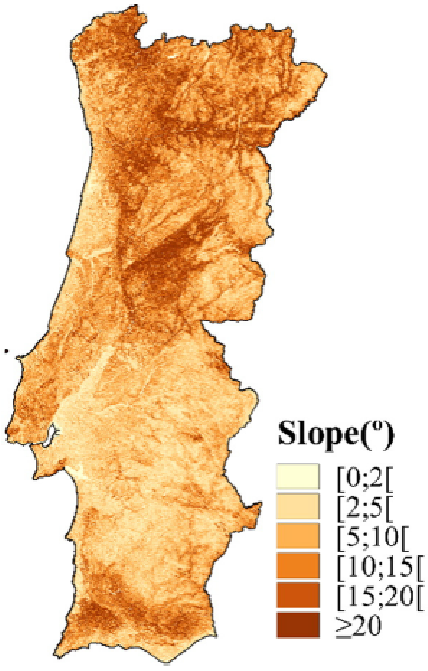

Figure 3.7: Slope map

As represented in figure 3.8, the predominant tree species are Maritime Pine (Pinus pinaster), Eucalyptus and Cork Oak (Quercus suber). This distribution of vegetation types is highly connected to the wildfire susceptibility in continental Portugal. Pinus pinaster is essentially found in the central and north parts of Portugal and is particularly successful because it is adapted to high-intensity fires, it regenerates from seeds that it releases as a recovery mechanism. Eucalyptus is also mostly present in the central and north parts of the country and is well adapted to fire as it resprouts after fire or has seeds which survive fire. However, these two species, Pinus pinaster and Eucalyptus, are highly flammable. Quercus suber, on the other hand, is mainly present in the southern part of the continent and it is also adapted to tolerate forest fires because its bark allows it to simply regrow branches to fill out the canopy. This tree, however, does not burn as easily as the other two species mentioned above because it has a higher content of humidity.

3.4 Definition of the goal

Having characterized the problem, the objective is to find the best line of action on how to proceed after the occurrence of a wildfire. Taking into account the costs associated with each post-fire management alternative, the main goal is to develop a strategic post-fire plan that allows FM to promptly act in any situation.

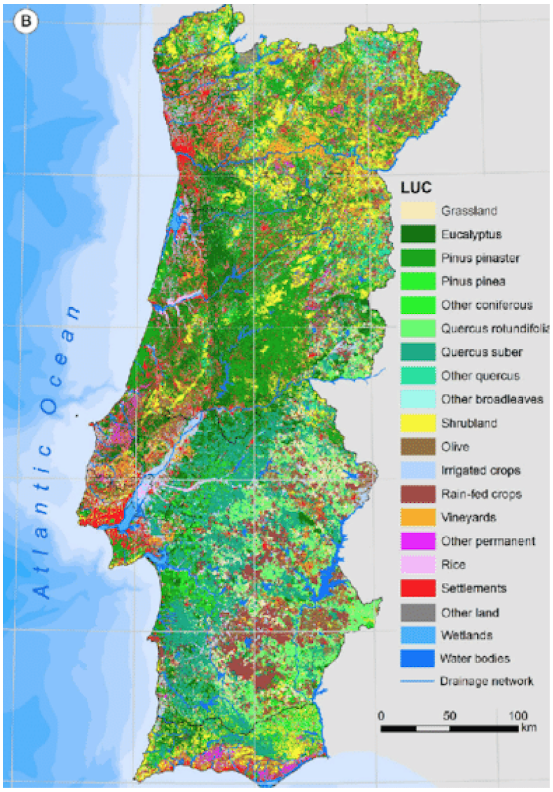

Figure 3.8: Vegetation types map

3.5 Post-fire management strategies

As important as the appropriate description of the problem and the study object is the knowledge of all of the different strategies that can be applied to solve the problem in order to cover all possibilities.

After a very serious perturbation, forest regeneration can be hampered by rough microclimatic conditions emerging from the incident. In the lack of particular plant features associated with the occurrence of disturbances and in the aftermath of a wildfire, the status may become specially unfavorable, strongly restraining the establishment and survival of tree recovery. "FM and PM need to be aware of the importance of properly managing these ecosystems, adopting post-disturbance interventions designed to reach management goals, and restoring the required ecosystem services" (Marcolin et al., 2019).

However, according to García-Orenes et al. (2017), not all post-fire management strategies have positive influences on the regeneration of ecosystems, especially, when WUI fires are concerned.

No intervention (natural regeneration)

Passive forest regeneration strategies are a solid approach when ecosystem structural or functional damage is little and resilience is high (Vallejo et al., 2006). However, even when natural regeneration is expected to happen and forms a practicable choice, post-fire restoration plans in the MB often do not take into account this alternative, focusing efforts only in active restoration

Figure 3.9: No intervention scenario from (Marcolin et al., 2019)

techniques (which can, in some cases, ruin natural regeneration while being carried out). Besides, some conflicts between active and passive restoration techniques are possible, particularly if governments subsidise active strategies in areas where natural revegetation is already happening (Pausas et al., 2004).

According to Abella and Fornwalt (2015), post-fire natural regeneration relies on ecosystem endurance, resilience and the gravity of the perturbation and there are several advantages associated with it. First of all, resprouts have lots of potential advantages over seedlings or planted trees due to the fact that they have an already settled root system and great stocked energy reserves, which may grant higher chances of plant survival and recuperation (Simões and Marques, 2007). Furthermore, the costs are lower, as less weighty or no equipment at all is needed, and often local preparation is not necessary (Whisenant, 2005). Soil mobilization and sequential erosion hazard are also minimized. Plant survival and development are highlighted as the resprouts have a good established root system, and an ensuing faster vegetation coverage is reached, although with substantial implications for avoiding soil erosion (Vallejo et al., 2006). Further phases in natural regeneration management, depending on the goals, may implicate thinning, the selection of sprouts and the control of unwished vegetation (Holz and Placci, 2005), and these will have associated costs.

On the other hand, one of the disadvantages of the natural regeneration technique is that frequent big harsh fires farther result in narrowed or failed natural tree regeneration (Tapias et al., 2001) and, in the medium-term, strong proliferation of pioneer shrubs (Baeza et al., 2007) creating homogeneous settings with great fuel accumulation (Loepfe et al., 2010).

In conclusion, the fact that Mediterranean-type ecosystems are commonly overpowered by shrub and tree species that have the capability to resprout after fire (Pausas, 1999) confers a lot of resilience to these systems. Therefore, some post-fire scenarios may allow no intervention to be considered while others may need different levels of intervention (Pereira et al., 2018).

An example of a post-fire no intervention scenario is given in figure 3.9.

Salvage logging

Figure 3.10: Salvage logging scenario from (Marcolin et al., 2019)

Salvage logging is a commonly used post-fire management technique, which implicates the removal of burnt wood from the ground after a wildfire. The extraction of the charred logs, is often done using weighty machinery that lugs the logs over the burned land. This action can increase the sensibility of the soil to erosion and degradation due to the pressure that logging equipment has on soil (García-Orenes et al., 2017). The modifications caused by logging equipment such as compaction, furrowing and damage of macropores can impact rough soils and vegetation recuperation for many decades after logging actions. Subsequently, downstream areas are put at great danger of land flows and sedimentation (Wagenbrenner et al., 2016).

Some post-fire management alternatives can indeed have a negative impact on soils and this impact is even more harmful than the fire itself (Mataix-Solera et al., 2015). Salvage logging, sometimes, can negatively influence the burned site and additionally exacerbate the post-fire effects. As Marcolin et al. (2019) concluded, it can alter the abiotic environment, triggering surface erosion and runoff, and stimulating snow-mass displacements. Furthermore, cutting off and taking away burnt trees can act as an additional perturbation, with potential unwished implications on many ecosystem processes.

However, despite some severe disturbances associated with salvage logging, the prevailing management technique, is yet frequently used to save the economic value of wood by extracting the dead or affected trees, frequently by civil request (Marcolin et al., 2019). Besides, the utilization of the timber from the affected trees can decrease the necessity to cut off other trees (Marques and Mora, 1998). These are some benefits brought by the use of this technique, together with the objective of lowering the hazards emerging from gradual snag fall in very frequented places. Nevertheless, when the logged wood has a small value, salvage logging also becomes controversial from an economic viewpoint because of its large costs.

An example of a post-fire salvage logging scenario is given in figure 3.10.

Cut and release

According to Marcolin et al. (2019), treatments that are intermediate between salvage logging and no intervention can be used and one of them is called cut and release. This strategy involves

Figure 3.11: Cut and release scenario from (Marcolin et al., 2019)

the cutting of the snags and the releasing of all deadwood on the ground.

This management option could maintain and generate microsites for regeneration, accelerating and imitating the natural process of snag downfall (Molinas-González et al., 2017). Placing deadwood on the soil supplies enhanced microclimatic conditions, thus, attenuating the severe post-fire ambience. Deadwood also has an important function in defining regeneration standards. Its presence can augment the availability of adequate places for seedling settlement and survival, interacting as a cover or shield against numerous restraining elements. Especially when lying on the ground, deadwood debris can influence heat transfer at the surface of the soil, affecting its temperature over the day and seasonally, and also humidity patterns (Pichler et al., 2012). Moreover, deadwood has an essential role in winter because of its elevated assimilation of shortwave irradiation, accelerating snow fusion and, thus, extending the growth period in the surrounding vicinity (Devine and Harrington, 2007). Laying deadwood on the ground leads to additional heterogeneous snow cover conditions and cumulation, in comparison to salvaged areas, generating more structural diverseness of the settled forest stand, as a secondary and welcome outcome (Schönenberger, 2001).

A possible downside of this post-fire management strategy is the greater fuel accumulation, specially from the big quantity of weighty fuels left on site, with possible consequences on fire danger in the medium term (Marcolin et al., 2019).

An example of a post-fire cut and release scenario is given in figure 3.11.

Seeding

Wildfires consume live and dead fuels, destabilize physical and ecological landscapes and affect humans and socio-economic processes (Pyne, 2017). Post-fire seeding was primarily utilized to keep soils stable. Lately, it is being used to restore some plant species after wildfires, manage invasive and non-native plants and help settle valuable vegetation structures.

Post fire seeding developed from the aspiration to secure hillslope soils in mountainous lands after a wildfire and to avoid downstream floods and mud outflows. In arid places, post fire seeding attempts to minimize the deposition and the erosion caused by windy days.

Several unexpected effects have been noticed from post fire seeding. Seed mixtures, even "certified weed free" seed mixtures, have been polluted with invasive species and started new infestations (Hunter et al., 2006). The prosperous development of seeded grasses has dislocated native or naturalized species, including shrub and tree seedlings (Beyers, 2004). The preparation of seeds and the seeding process itself has favored the development and augmentation of several non-native species (Erickson, 2007). Furthermore, the types of machines utilized during the seeding procedures, for example, drill seeders and chains, affect surviving native plants and perturb the soil (Shaw et al., 2005).

Mulching

Mulch is a material that can be spread above the soil surface to avoid particles from dislocation caused by rain drop impact and land outflow (Robichaud et al., 2013) and simulate natural erosion debris encountered on site, such as pine needles (Pannkuk and Robichaud, 2003).

Mulch is more effective if used in the crucial first year after the occurrence of the wildfire when the soil is more susceptible to erosion and it is designed to stabilize it till plants can recover (Kruse et al., 2004). Nevertheless, as mentioned by Robichaud et al. (2003) its influence on the reaction of vegetation for more than one year after the fire is widely unrecognized. There are a great variety of mulch materials that can be used like agricultural straw, wood chips, wood shreds that have proven to be powerful in decreasing post-fire erosion and improve soil conditions.

Right after being applied, mulch is a powerful ground cover which makes it an appealing option for stabilising post-fire hillslopes. This technique is frequently used in combination with seeding to give ground cover in hazardous sites and to increment the success of seeding by enriching humidity conservation. Nevertheless, mulch is a fairly costly post-fire treatment and this limits its utilization to the areas with great potential for soil erosion and important values at risk in the vicinity (Bautista et al., 2009).

Reforestation

Forest reforestation is suitable whenever biodiversity recovery is the principal objective of restoration, such as for wildlife preservation, environmental safety, eco-tourism or to provide a large diversity of forest products to near communities (Brancalion et al., 2019). Burned forests can be recovered under many circumstances but affected places within secured areas are of high priority. The pressure that humans exercise upon landscapes has been increasing causing the need of reforestation to be practiced within a range of different forms of forest management, for instance, to meet the economic needs of local communities.

The goal of post-fire reforestation is to improve vegetation coverage and, in consequence, decrease soil and water losses (Cerdà and Doerr, 2005). The choice of plant species during the rehabilitation of burned sites defines the future phase of the affected ecosystem (Cerdà et al., 2017). Reforestation actions are frequently prosperous but in several situations they might lead to increased runoff and soil erosion as some tree species, like pines, augment the water repellency of the soils (Cerdà et al., 2017). Besides, the use of very inflammable trees raises the danger of future persistent wildfires (Hosseini et al., 2017).

Reforestation operations have certain disadvantages as they disturb the soil and have high costs associated. However, the consequences are simply handled by picking different vegetation species and planting standards (Wittenberg et al., 2019). In addition, the homogenized ash and soil decreases the soil water repellency (Wittenberg et al., 2019).

Erosion barriers

Erosion barriers, created from a variety of natural and made up materials, are an usual post-fire treatment that aims to avoid sediment sliding to downstream watersheds by catching sediments and discontinuing flow tracks. According to Rulli et al. (2012) some examples of barrier models are contour-felled logs, straw sticks, contour trenches or straw burdens.

Right after being instaled, erosion barriers proportionate their best performance but the setup process can perturb and liberate soil particles making it prone to erosion. Another drawback of this method is that it can be powerful for average intensity precipitations but their effectiveness is highly diminished for intense rains (Wagenbrenner et al., 2006). Erosion barrier success is equally dependent on the installation process and diminishes over the years as the deposit areas above the logs get stuffed and the barrier can no longer trap more sediment. The consequence of these outcomes has been a diminution in the utilization of erosion barriers for hillslope stabilization, particularly when the potential tempest dimension is considered (Robichaud, 2009). Besides, the erosion barriers start to lose their effectiveness if they are not preserved or regularly washed (Rulli et al., 2012).

As erosion barriers are mostly fighting traces of the damages caused after a wildfire, this technique should be used in association with others (Wittenberg et al., 2019).

Coconut fibre webs

Coconut fibre webs can be defined as carpets and rolls made of natural coconut and are primarily utilized to attenuate soil losses and to assist vegetation growth and settlement on human-modified hillslopes, such as highway and railroad bankings and construction areas (Bhattacharyya et al., 2010).

This post-fire treatment retards the time to runoff and enhances infiltration capability, in comparison to the uncovered surface. Furthermore, it reduces the impact of splash erosion and diminishes the speed of land overflow as an outcome of augmented surface rugosity (Sutherland and Ziegler, 2007).

This strategy, however, as concluded by Wittenberg et al. (2019) obtained a brief amount of attention in urban burned landscapes.

3.6 Summary

Facing the growing necessity to properly manage the wildfire scenario, it seemed appropriate to develop a plan of action, taking into account the actual costs, for managing the post-fire affected sites.

To actually achieve positive results is going to be a challenge as the human factor has a great influence on this matter and because of the highly and numerous unpredictable factors that are at the origin of wildfire occurrences.

Portugal was the study site selected for the development of the strategic plan due to its unique characteristics and history around this matter. Furthermore, as a way of understanding what could be done after a wildfire incident to help prevent future disasters, it became pertinent to describe some different post-fire management strategies and the advantages and disadvantages associated with the use of each one.

In the next chapter, the actions taken in post-fire management are going to be analysed. For this purpose, data about the strategies were previously collected in order to compare them and make informed decisions about the most efficient ones to use.

Chapter 4

Post-fire analysis

An accurate analysis of the problem becomes imperative in order to better grasp the complexity of it and the approach to be followed in a posterior intervention. For this purpose, here are going to be studied some specific measures to take after the occurrence of a wildfire, along with the costs associated with some of the post-fire management alternatives.

4.1 Burned Area Emergency Response

Burned area emergency response (BAER) is an emergency risk management action to deal with post wildfire problems that pose dangers to human life and property or could additionally destabilize the burned territories. Although wildfires are natural occurrences, the existence of people and human made constructions adjacent to the burned site often demands continuous emergency risk management actions. Great severe wildfires pose a continuing hazard of flood, debris overflow and mudflow to the people living close to a burned watershed as well as a possible loss of many watershed values (Parsons, 2003).

Three phases of wildfire recovery

According to (Napper, 2006) there are three stages of recuperation immediately after wildfires and they are mentioned below:

- Fire Suppression Repair is a sequence of instant post-fire actions taken to fix damages and reduce possible soil erosion and impacts coming from fire suppression actions and commonly starts prior to fire containment and before the demobilization of an Incident Management Team. This task mends the dozer fire lines, roads, trails, staging places, safety sites and drop points utilized during fire suppression actions.

- Emergency Stabilization is a quick evaluation of affected watersheds by a BAER team in order to recognize impending post-wildfire dangers to human life and safety, property, and crucial natural or cultural resources on National Forest System lands and take instant actions to implement emergency stabilization measures prior to the first post-fire damaging events. Wildfires have some negative consequences such as loss of vegetation, exposure of soil to erosion and increased water leakage that may lead to floodings, increased sediment, debris outflows, and harm to critic natural and cultural resources. BAER actions like mulching, seeding, assembly of erosion and water leakage regulation structures, barriers to secure recovering sites and installation of warning signals may be carried out. BAER work should also substitute security facilities, take away safety hazards, avoid permanent loss of habitat for threatened species, prevent the propagation of toxic weeds and secure crucial cultural resources.

- Long-Term Recovery and Restoration uses non-emergency actions to upgrade the harmed areas that are improbable to regenerate naturally and to fix or substitute facilities harmed by wildfires that are not crucial to life and safety. This step may comprise restoring affected habitats, afforestation, planting or seeding, monitoring fire outcomes, substituting damaged barriers, interpreting cultural places, healing toxic weed infestations and implanting interpretive signals.

Limitations

While many fires cause minimum damage to the ground and pose very few menaces to the land or people in the vicinity, some others result in harm that demands particular efforts to minimize impacts afterwards. Some of the unintended negative effects are the loss of vegetation that exposes soil to erosion, water leakage that may augment and cause floodings, rocks may move downstream and harm goods or occupy reservoirs putting community water provisions and threatened species at danger.

"The BAER program is designed to identify and manage potential risks to resources on National Forest System lands and reduce these threats through appropriate emergency measures to protect human life and safety, property and critical natural or cultural resources. BAER is an emergency program for stabilization work that involves time-critical activities to be completed before the first damaging storm event to meet program objectives" (Napper, 2006).

Objectives

Parsons (2003) in his investigation work described the main objectives of BAER projects:

- Define whether impending post-fire menaces to human life and security, property, and crucial natural or cultural resources on National Forest System lands exist and take instant actions, as suitable, to manage the unacceptable hazards;

- If emergency circumstances are found, minimize important menaces to human life and safety, Forest Service property and other critical natural and cultural resource values;

- Determine emergency response conducts to secure and prevent unacceptable degradation to natural and cultural resources, to mitigate menaces to life or property that result from the outcomes of a wildfire or to build physical advances needed to avoid degradation of land or resources;

- Implement emergency response actions to support in the stabilization of soils, control water and debris movement and possibly mitigate menaces to the BAER critical values encountered above when an analysis demonstrates that planned actions are susceptible to minimize hazards within the first years after the containment of the fire;

- Monitor the implementation and also the effectiveness of emergency actions that were carried out on National Forest System lands.

Process

"BAER assessment teams are staffed by specially trained professionals that may include: hydrologists, soil scientists, engineers, biologists, botanists, archaeologists and others who evaluate the burned area and prescribe temporary emergency stabilization actions on National Forest System lands to protect the land quickly and effectively. BAER assessments usually begin before a wildfire has been fully contained" (Parsons, 2003).

A BAER team leads field researches and utilizes science-based templates to quickly evaluate the affected site and define emergency stabilization steps. The team creates a Soil Burn Severity chart by using satellite imaging which is then validated by BAER team field surveys to evaluate watershed status and model possible watershed reaction to the fire. The chart recognizes places of soil burn severity by classes of very low, low, moderate, and high which may coincide with a projected augmentation in watershed response. The greater the burn severity, the less the soil will be capable to assimilate water when it rains. Without absorption there will be increased leakage with the possibility of floodings.

The BAER team presents these discoveries in an assessment report that acknowledges instant and emergency actions necessary to address post-wildfire threats to human life and safety, property, cultural and crucial natural resources. This comprises initial detection and quick response techniques to avoid the propagation of toxic weeds into native plant species. The BAER report depicts pre and post-fire watershed reaction data, places of concern for life and property and recommended short-term emergency stabilization actions for affected Forest Service lands.

In the majority of the situations, only a part of the burned site is effectively treated. Seriously burned sites, steep slopes and areas where water leakage will be excessive and may affect relevant resources are focus areas and depicted in the BAER assessment report if they impact critical values. Response action timing is essential to ensure that the emergency stabilization conducts are effective. BAER treatments are preventative in nature but cannot avoid all harm, specially debris flows in places that are prone to sliding and have lost crucial root structure from plants.

What BAER Can Do

- Install water or erosion control devices.

- Seed or mulch for erosion control or stability reasons.

- Install erosion control measures at critical cultural sites.

- Install provisional fences to secure treated or recovering sites.

- Install warning signals.
- Substitute protection related facilities, like burned guard rails.
- Install proper-sized drainage features on roads and trails.
- Withdraw crucial safety hazards.
- Avoid permanent loss of endangered habitats.
- Monitor BAER actions.
- Implement initial quick response actions to minimize the propagation of toxic weeds into native plant communities.

What BAER Cannot Do

- Prevent all flooding and debris flows.
- Replant forests or grass for forage.
- Dig and interpret cultural areas.
- Substitute burned pasturage barriers.
- Install interpretive signals.
- Substitute affected buildings, bridges and corrals.
- Substitute roads harmed by floods after wildfire.
- Remove all hazard trees.
- Substitute damaged habitats.
- Monitor fire outcomes.
- Manage pre-existing toxic weeds.

Funding

Special Emergency Wildfire Suppression funds are authorized for BAER actions and the quantity of these expenditures fluctuates with the gravity of the fire season. Some years see small BAER action while others are highly occupied.

Preparing the BAER Plan/Report

Usually, it is a local BAER team that will elaborate the BAER Plan/Report. In its preparation, the team should work with the staff in the field to take the next actions:

- Ascertain the availability and cost of the treatment or activity provisions;

- Start making adjustments for the cultural and threatened species appointments;
- Ascertain the availability and make preliminary adjustments for needed hardware;
- Coordinate with the agency administrator and with concerned parties about suggested emergency stabilization measures;
- Coordinate with the National Office on complicated emergency stabilization funding problems or technical issues.

The data necessary to finish the report may contain:

- Agency review and consents;
- Brief wildfire activities and treatments necessary;
- Fire localization and background data;
- Sort of plan (early submission or amendment);
- Values at danger;
- Values to be secured and their localization;
- Emergency stabilization goals;
- Plans for team organization and membership;
- Treatment specifications;
- Emergency stabilization funding requirements;
- Appointments made by the planning team;
- Burned site evaluations;
- Environmental observance documentation;
- Explication of treatments with respect to values at danger;
- Maps, photo documentation and supporting documents;
- Monitoring goals and protocols.

Planning of Treatment Effectiveness Monitoring and Evaluation

BAER Plans/Reports must include provisions for monitoring and evaluation of treatments.

Monitoring and evaluation of post-fire treatments are critical for understanding and improving them. The goal of treatment effectiveness is to assess if plan objectives were met. Effectiveness monitoring is utilized to assess whether the used treatment had the desired result. This data is utilized to adjust management techniques and actions for the present and future projects to augment effectiveness.

Monitoring magnitude should be proportional to the complexity of the emergency stabilization strategies and the level of concern connected to the emergency stabilization treatment. The effectiveness monitoring specifications should document the concrete monitoring goals for that project, the monitoring protocol, the equipment necessary and the funding needed. Those actions that have been recognized for effectiveness monitoring must have monitoring provisions and proceedings detailed.

4.2 Utilization of forest biomass

The last decade has seen an increasing interest in renewable energies. Although this interest gained tremendous prominence in the 1970s, when the world experienced two oil crises that acted as an incentive to use new sources of primary energy, few countries have really changed their energy model.

The forest biomass (FB) market has been developing in recent years in Europe. Portugal, despite having considerable development through its forestry industry, only in the last few years has it begun to face the opportunities that this resource can offer.

The forest biomass, is defined as the products and leftovers from forestry (Ribas et al., 2008), it can have several uses, namely in energy production, thus contributing to the reduction of fuel accumulation in the soil. This reduction contributes to the minimization of the risk of wildfire, as well as in the creation of a market that promotes the use of this material and reduces the net cleaning costs of forest stands adding value to forestry operations only considered as a cost, for example, thinning, clearing, sanitary pruning and remnants (branches and pecks) of the final cut (DGRF-Direcção-Geral, 2007).

The National Strategy for Forests refers to the recuperation of forest exploitation leftovers as a source of renewable energy, encouraging the use of FB directed to its use outside the areas of influence of the plants, provided that the material consumed is FB from fuel management in the scope of preventive silviculture and forestry measures. Other possibilities are mentioned for the use of FB, which lack adequate research, such as localized energy production systems (for example, the heating of a school) (DGRF-Direcção-Geral, 2007).

The use of the country's natural resources, as a source of renewable energy, may be the key to the reduction of energy dependence, as it compensates the natural from non-renewable sources, by reducing the consumption of fossil and non-renewable energies that contribute to the increase of greenhouse gas emissions.

The valorization of FB, as a renewable energy source, contributes to the limitation of the costs of forestry operations, leftovers, and environmental impacts when compared to non-renewable energy sources (Ferreira et al., 2009).

The times and costs of FB extraction operations need to be analysed and recorded, and the costs and energy consumption associated with each of these operations estimated, in order to assess their feasibility and assist in the decision-making by economic agents.

It is of paramount importance to estimate the productivity of the operations realized in the FB extraction process. This will lead to some conclusions that would not be possible without analysing the different alternatives because each area has many technical itineraries, different physiographic characteristics, different transport distances from the plant material to the consumption center and different forms of extracted biomass (bales and chips).

The calculation of not only the economic but also the energy balance will allow an assessment of the feasibility of extraction of FB, based on the specific properties of each area (type of biomass, machinery used, technical itinerary used, etc).

4.3 Analysis of post-fire operations

Each post-fire action has a different cost associated and some are more effective than others. Every situation needs to be thoroughly examined before starting to take any action and, in this section, the phases of the FB recharge and transport are going to be presented to make it simpler to understand the study of the costs. There are some points that should be taken into consideration when analysing a post-fire situation and they are the following:

- Promotion of the use of biomass from forestry operations;
- Dissemination of the management methodologies best suited to the forestry reality, which allow the restoration of forestry potential;
- Prevention of risk factors, biotic and abiotic, through the promotion of interventions in forest stands;
- Promotion and enhancement of forest biomass, ensuring an increase in income for the rural world;
- Increase in technological development related to the use and enhancement of FB, through the establishment of innovative experiences in this field.

Working times

The study of the working times of forest operations is an essential tool in determining the productivity and cost of each operation, allowing also the diagnosis of vulnerabilities and the optimization of forestry operations and the elements that interact with it.

Used in each of the operations required to extract forest biomass from the site, these studies are important because they allow to assist in the preparation of energy and economic balances.

They demand extreme care to achieve adequate levels of productivity, quality and safety at work as well.

Figure 4.1: Forest truck with crane

4.3.1 FB Recharge

In the filling operation, the stages of work are the following:

- The collection of residual material;
- The movement of the vehicle;
- The discharge of FB into a loader, to the soil. For this operation, the companies generally resorted to the same type of equipment used to pick up woody material: the forest truck with crane, as illustrated in figure 4.1, the forwarder, as figure 4.2 demonstrates, and the agricultural tractor (with forest trailer and crane), as seen in figure 4.3.

Figure 4.2: Forwarder

Figure 4.3: Agricultural tractor with forest trailer and crane

4.3.2 FB Transport

For the transport of FB, the tractor with semi-trailer, seen in figure 4.4, the truck with trailer, as illustrated in figure 4.5, and the truck, as figure 4.6 demonstrates, were used. The main tasks of this operation include:

- Loading times;
- Cargo arrangement;
- Movement of the transport vehicle to the consumer unit and the time spent in this unit.

4.3.3 Management of the operations

The use of FB, with a view of the optimization of the operations and the increase of the economic income, involves its integrated exploitation with all forestry activity.

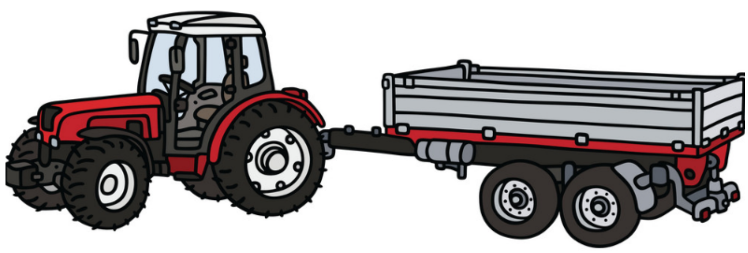

Figure 4.4: Tractor with semi-trailer

Figure 4.5: Truck with trailer

Figure 4.6: Truck

In fact, the distance to travel is not the only factor that directly interferes with the costs obtained, and other parameters should be considered in this type of analysis, namely the type of equipment to be allocated to operations, the correct management of human and material resources and advance planning of operations, such as those that most affect the cost structure.

The factors limiting the optimization of operations are directly related to planning, so it is necessary to take measures at the level of operational planning and implement them, before the start of the forestry operation itself.

These measures should not be seen as additional costs, as these are usually recovered by reducing operational costs, thus increasing the commercial margin for the forestry operator.

4.4 Summary

The post-fire analysis fell on the study about the emergency risk management actions taken and the process followed after a wildfire occurrence, including the monitoring and evaluation of the treatments that were chosen in order to verify the effectiveness of each one.

The utilization of the FB was explored as a benefit, mainly for energy production, that comes from managing post-fire sites and that also reduces the accumulation of fuel in the soil.

Analysing some of the main operations revealed the need to evolve to an integrated exploitation of FB with all forestry activity in order to optimize them.

The next phase will focus on a deeper study of the costs to try to normalize the post-fire management process and to achieve the best results possible.

Chapter 5

Solution proposal

There are two ways to obtain precise scientific answers: theoretical knowledge - rarely available for the particularity of the case in question - or experimentation. It could be argued that a third way is through experience, but experience is just the accumulation of knowledge based on experimentation, even if conducted in an unconscious way, over a long period of time.

5.1 Normalization of the process

As Egging and Barney (1979) referenced, an advanced post-fire management policy should follow some basic principles:

- be driven by land and forest management goals;
- combine all the accessible biological, ecological, physical and technological sources of information related to the fire to achieve the management objectives;
- mix the fire element in land management planning straight from the beginning of the process;
- take into consideration various techniques to adapt different land management goals through zoning.

Integrated FFM converts into a logical series of complementary techniques that try to reduce the net social costs of wildfires (Rego et al., 2010).

Currently, the variety of alternatives concerning management goals for burned sites and strategies accessible for rehabilitation is much broader and the regular answer of "planting trees in 5,000 ha if 5,000 ha were burned" is a very simple approach no longer justified. Formerly, recovering a burned place was the same as executing a reforestation but, actually, depending on the local requirements and goals for the burned sites, these may not be the best management strategies (Moreira et al., 2012).

FFM is a complicated notion that has several degrees and magnitudes of management interference depending on the degradation degree of the area and the particular management goals taken

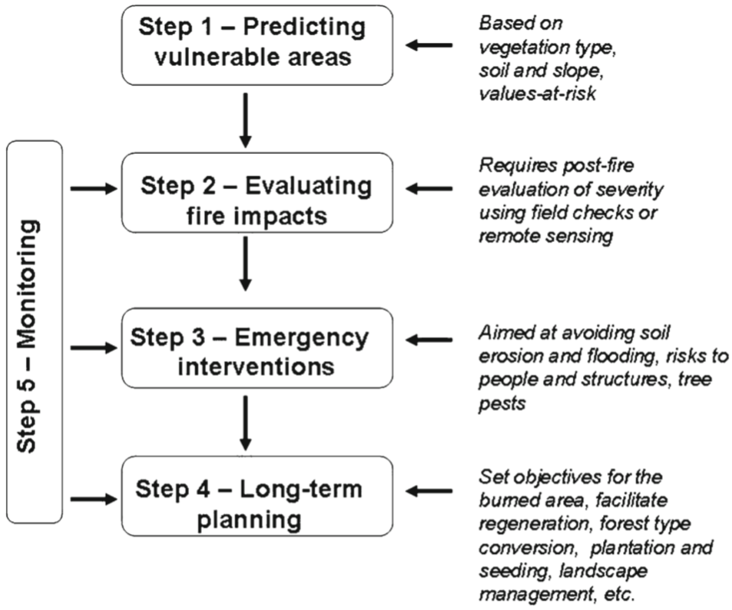

Figure 5.1: Structure to plan post-fire management from (Moreira et al., 2012)

into account. In past years, forest rehabilitation has been mainly understood as planting trees, that is, reforestation. Presently, this perspective is being substituted by a more holistic one, considering a large series of recovery techniques.

Moreira et al. (2012) proposed a plan to used in post-fire management that considers five steps that are depicted below and shown in figure 5.1.

Predicting vulnerable areas

Prior to a fire occurrence, forest and landscape managers already have the tools to find areas more vulnerable to wildfires and to recognize fire-prone sites that need to be prioritized in terms of prevention and intervention after wildfires. The most important data for these tasks includes soil, topography, vegetation type, and the localization of values that are in danger zones.

This kind of approach can be used all over the world in order to recognize vulnerable places and prioritise fire prevention and also post-fire intervention actions.

Evaluating fire impacts

Even if a certain local was identified as very vulnerable in the face of a wildfire, post-fire soil erosion and degradation could be insignificant if the fire had low gravity. The impact that a wildfire has on an area depends on its features and the key variable to assess how a certain ecosystem will react to fire can evidently be evaluated only after a wildfire occurrence. So, it is very relevant to measure severity levels as soon as practicable after fire and this can be done either by ground supervisions, by utilizing remote sensing at high resolution or an association of both. The use of remote sensing to estimate the severity of fires will only be powerful if the data is accessible for the forest managers in the short-term. Furthermore, this strategy has many inaccuracies (Lentile et al., 2006), for example, in forest locals remotely sensed, burn gravity is frequently highly correlated with fire effects on the tree coverage but displays low correlation with land and soil severity. Commonly, it is more convenient to do field examinations in the first weeks after the wildfire to visually assess fire gravity. Many guidelines already exist that can be used to promptly measure fire severity and recognize sites for emergency interventions.

Emergency interventions

Emergency interventions, occasionally referred to as first-aid rehabilitation, aim to secure the burned place, avoid degradation processes and reduce hazards for people (Robichaud et al., 2000). They also have some objectives such as soil protection, prevention of erosion and diminishing water runoff and danger of flooding, reducing risks to people and property and the prevention of tree plagues and illnesses. They should be undertaken preferably in a few months after the wildfire and also before the first autumn rainfalls when in the MB.

Long-term planning

Long-term planning is connected to establishing the goals for the burned site and the actions needed to achieve these objectives. Depending on the case, it may comprise the facilitation of natural recovery, the transformation to other forest models, the reforestation and the landscape management to foment particular land coverages.

Monitoring

Restoration plans are usually weak in the monitoring and evaluation components. This limits the chances to learn from past successes and failures (Mansourian and Vallauri, 2005). A correctly structured rehabilitation scheme or management action should try to satisfy plainly stated goals. Evaluating if objectives were satisfied or how far we are from reaching these goals is only feasible through monitoring and evaluation. "What cannot be measured and monitored in an objective and in an unbiased way cannot be effectively managed" (Corona et al., 2003). Therefore, goals, performance patterns and protocols for monitoring and for information assessment should be incorporated into rehabilitation plans before the beginning of a project.

Post-fire monitoring and evaluation is fundamental to acquire knowledge about forest ecosystems' pathways after wildfires and to project suitable recovery actions. It will also permit redirecting restoration conducts in an adaptable management context.

Lastly, the social impacts of any rehabilitation plan should also be taken into consideration in the estimation of its results as, besides the ecological goals, there are always more or less explicit social and economic goals and implications.

5.2 Cost analysis

After a wildfire occurrence, FM and PM encounter a set of questions that may not have a simple response: "should reforestation be carried out? If so, in the whole area or just in part of it? Or is it better doing nothing? And if action is decided, when should it be taken? Using which techniques? Planting or seeding? Or wait for natural regeneration? But, more important than all the previous questions, the key question is probably: for which purpose? Which are the objectives defined for the burned area and its management?" (Moreira et al., 2012).

Ecosystem responses to fire are dependent on a set of factors, one of the most important ones being the recovery capability of its plant species. However, predicting how plant species will react to wildfires is also dependent on the features of the fire itself. Even for the identical vegetation types, distinct reaction models are expected whether a fire is highly severe or of low intensity (Bellingham and Sparrow, 2000).

As table 5.1 and table 5.2 show, there are some management options that can be done manually, others that are a mix of manual and mechanical operations as demonstrated in table 5.3 and in table 5.4 and, lastly, some that are carried out mechanically, as table 5.5 illustrates.

These costs are going to be applied to two different real post-fire scenarios considering three strategies: a manual one, a mechanical one and also a mix between these two.

Situation 1

Work conditions:

- Area burned: 2 ha;
- Maximum slope: 5%
- Height of the vegetation: 0,5 m
- Fuel load: 5 t/ha
- Degree of stony: 5%
- Good accesses

In table 5.6 are presented the costs for the situation 1 for the three strategies used: manual, mixed and mechanical operations.

Situation 2

Work conditions:

- Area burned: 2 ha;
- Maximum slope: 30%
- Height of the vegetation: 2,5 m
- Fuel load: 20 t/ha
- Degree of stony: 60%
- Bad accesses

In table 5.7 are presented the costs for the situation 2 for the three strategies used: manual, mixed and mechanical operations.

In order to be able to compare them, the results were obtained assuming that, in both situations, the same amount of operations were performed and to calculate the costs of the manual operations there were 2000 units in the two cases.

Table 5.1: Costs of manual operations

Type of operation	Observations	Minimum cost (euros)		Maximum cost (euros)	
		cost/unit	work conditions	cost/unit	work conditions
Scrolling	Undifferentiated labor	0.20	a) slope of 0 to 5% b) number of plants to roll/ha > 100 c) diameter of the stems at the base < 2,5 cm	0.39	a) slope > 25% b) number of plants to roll/ha < 50 c) diameter of the stems at the base > 5 cm
Training pruning	Labor specialized in young trees	0.45	a) slope of 0 to 5% b) circumference at chest height < 15 cm	1.12	a) slope > 25% b) circumference at chest height > 30 cm
Pruning	Labor specialized in young trees	0.29	a) slope of 0 to 5% b) pruning height < 1,5 m c) diameter of the branches in the cervix < 1,5 cm	1.12	a) slope > 25% b) pruning height > 3,0 m c) diameter of the branches in the cervix > 3,0 cm
Weeds and heaps	Undifferentiated labor	0.20	a) slope of 0 to 5% b) degree of stony < 10%	0.29	a) slope > 25% b) degree of stony > 50%
Collection and burning of waste from sanitary pruning	Undifferentiated labor	1.95	a) slope of 0 to 5% b) % of the infected canopy < 20% c) diameter of the canopy projection < 5,0 m	5.85	a) slope > 25% b) % of the infected canopy > 50% c) diameter of the canopy projection > 9,0 m

Table 5.2: Costs of other manual operations

Type of operation	Observations	Minimum cost (euros) cost/unit	Minimum cost (euros) work conditions	Maximum cost (euros) cost/unit	Maximum cost (euros) work conditions
Selection of future trees	Specialized labor (senior technician)	46.74	a) slope of 0 to 5% b) herbaceous and/or shrub vegetation with height < 0,8 m c) number of trees to select/ha < 200	140.21	a) slope > 25% b) herbaceous and/or shrub vegetation with height > 1,5 m c) number of trees to select/ha > 350
Signaling of natural regeneration	Undifferentiated labor	29.26	a) slope of 0 to 5% b) herbaceous and/or shrub vegetation with height < 0,8 m c) number of trees to signal/ha < 100	117.02	a) slope > 25% b) herbaceous and/or shrub vegetation with height > 1,5 m c) number of trees to signal/ha > 250
Control of invasive woody plants	Undifferentiated labor for densities < 3000 invasive plants/ha, the area to intervene should be calculated by reference to this density - young tree	175.53	a) slope of 0 to 5% b) number of invasive woody plants/ha < 10 000	351.06	a) slope > 25% b) number of invasive woody plants/ha > 20 000
Controlled fire	Specialized labor (senior technician) does not include the elaboration of controlled fire plans and burning plans, nor the opening of containment strips		Populations		Populations
		93.47	a) slope of 0 to 5% b) area > 4 ha c) fuel load < 12 t/ha	467.35	a) slope > 25% b) area < 2 ha c) fuel load > 12 t/ha
			Bushlands		Bushlands
		93.47	a) slope of 0 to 5% b) area > 6 ha	373.88	a) slope > 25% b) area < 2 há

Table 5.3: Costs of mixed operations

Type of operation	Observations	Minimum cost (euros)		Maximum cost (euros)	
		cost/ha	work conditions	cost/ha	work conditions
Control of spontaneous vegetation on the line or in a localized manner	Specialized labor, including equipment	47.92	a) slope of 0 to 5% b) degree of stony < 10% c) herbaceous and/or shrub vegetation with height < 0,5 m d) number of lines/ha < 15 or area to intervene < 15%	575.04	a) slope > 25% b) degree of stony > 50% c) herbaceous and/or shrub vegetation with height > 1,5 m d) number of lines/ha > 25 or area to intervene > 25%
Control of local spontaneous vegetation	Specialized labor, including equipment	383.36	a) slope of 0 to 5% b) degree of stony < 10% c) herbaceous and/or shrub vegetation with height < 0,5 m	1150.08	a) slope > 25% b) degree of stony > 50% c) herbaceous and/or shrub vegetation with height > 1,5 m
Control of invasive woody plants (cut)	Undifferentiated labor including equipment for densities < 3000 invasive plants/ha, the area to intervene should be calculated by reference to this density - young trees	287.52	a) slope of 0 to 5% b) degree of stony < 10% c) invasive plants with height < 0,5 m d) number of invasive plants /ha > 10 000	575.04	a) slope > 25% b) degree of stony > 50% c) invasive plants with height > 1,5 m d) number of invasive plants /ha > 20 000
Excessive density control	Specialized labor, including equipment - young trees	95.84	a) slope of 0 to 5% b) degree of stony < 10% c) herbaceous and/or shrub vegetation with height < 0,5 m d) number of plants/ha < 3 000 e) plants with height < 1 m	1150.08	a) slope > 25% b) degree of stony > 50% c) herbaceous and/or shrub vegetation with height > 1,5 m d) number of plants/ha > 10 000 e) plants with height > 2 m

Table 5.4: Costs of other mixed operations

Type of operation	Observations	Minimum cost (euros) cost/unit	Minimum cost (euros) work conditions	Maximum cost (euros) cost/unit	Maximum cost (euros) work conditions
Training pruning	Specialized labor, including equipment	0.64	a) slope of 0 to 5% b) circumference at chest height < 25 cm	1.60	a) slope > 25% b) circumference at chest height > 50 cm
Pruning	Specialized labor - young trees	0.42	a) slope of 0 to 5% b) pruning height < 1,5 m c) diameter of the branches in the cervix < 3 cm	1.60	a) slope > 25% b) pruning height > 3 m c) diameter of the branches in the cervix > 5 cm
Sanitary pruning	Specialized labor, including equipment	2.40	a) slope of 0 to 5% b) % of the infected canopy < 20% c) diameter of the canopy projection < 5 m	4.79	a) slope > 25% b) % of the infected canopy > 50% c) diameter of the canopy projection > 9 m
Selection of eucalyptus sticks	Specialized labor, including equipment	0.16	a) slope of 0 to 5% b) number of sticks < 5 c) age of sticks < 3 years b) herbaceous and/or shrub vegetation with height < 40 cm	0.38	a) slope > 20% b) number of sticks > 7 c) age of sticks > 4 years b) herbaceous and/or shrub vegetation with height > 80 cm
Traps for Monochamus (not including monitoring)	Senior technician and undifferentiated labor	7.60	a) slope of 0 to 5% b) proximity between locations c) good accesses d) trees near the paths e) clean stands	30.40	a) slope > 20% b) locations away from each other c) bad accesses d) trees far from paths e) stands with bush
Density reduction in medium developed (> 8 years): hardwood stands, pine trees, other resinous	Specialized labor, including equipment	0.48	a) slope of 0 to 5%	0.80	a) slope > 25%
		0.64	b) degree of stony < 10%	0.96	b) degree of stony > 50%
		0.38	c) circumference at chest height < 15 cm	0.48	c) circumference at chest height > 50 cm

Table 5.5: Costs of mechanical operations

Type of operation	Observations	Minimum cost (euros)				Maximum cost (euros)			
		hours	cost/hour	total cost	work conditions	hours	cost/hour	total cost	work conditions
Control of spontaneous vegetation	Farm tractor and offset grid with 24" discs	1.50	59.34	89.01	a) slope of 0 to 5% b) degree of stony < 10% c) vegetation with height < 0,30 m d) number between lines > 25/ha or area to intervene < 75%	2.50	59.34	148.35	a) slope > 25% b) degree of stony > 50% c) vegetation with height > 0,50 m d) number between lines < 15/ha or area to intervene > 85%
Phytosanitary treatments	Agricultural tractor with double traction and sprayer with 600 lts fan, not including phytopharmaceutical	0.50	51.99	26.00	a) slope of 0 to 5% b) degree of stony < 10% c) height < 5 m d) number of passes < 15/ha	1.00	51.99	51.99	a) slope > 10% b) degree of stony > 50% c) height > 10 m d) number of passes > 25/ha
Total fertilizer application	Agricultural tractor with double traction and centrifugal fertilizer spreader, assembled, of 600 lts, not including fertilizer	0.42	44.51	18.69	a) slope of 0 to 5% b) degree of stony < 10%	0.75	44.51	33.38	a) slope > 10% b) degree of stony > 50%
	Farm tractor and centrifugal fertilizer spreader, assembled, of 600 lts, not including fertilizer	0.47	46.74	21.97	a) slope < 15% b) degree of stony < 10%	0.84	46.74	39.26	a) slope > 25% b) degree of stony > 50%
Fertilizer application in line, in depth	Agricultural tractor with double traction and furrow fertilizer spreader, assembled, 600 lts, 1 iron	0.63	44.14	27.81	a) slope of 0 to 5% b) degree of stony < 10% c) soil with plain texture d) number between lines < 15/ha	1.12	44.14	49.44	a) slope > 10% b) degree of stony > 50% c) soil with clayey texture d) number between lines > 25/ha
	Farm tractor and furrow fertilizer spreader, assembled, 600 lts, 1 iron	0.76	45.10	34.28	a) slope < 15% b) degree of stony < 10% c) soil with plain texture d) number between lines < 15/ha	1.35	45.10	60.89	a) slope > 25% b) degree of stony > 50% c) soil with clayey texture d) number between lines > 25/ha
Irrigation located and carried out during the first years after planting (5 lts/plant)	Agricultural tractor and 4 000 lts cistern, undifferentiated labor	0.94	57.39	53.95	a) slope < 5% b) degree of stony < 10% c) soil with plain texture d) 300 to 450 plants/ha e) distance from the water < 500 m	1.88	57.39	108.91	a) slope > 10% b) degree of stony > 50% c) soil with clayey texture d) 650 to 850 plants/ha e) distance from the water > 2 000 m

Table 5.6: Costs for situation 1

Type of strategy	Total costs (euros)
Manual operations	6 180,00
Mixed operations	1 533,44
Mechanical operations	430,92

In both situations the manual operations' strategy comes at a much higher cost and that should be taken into consideration when choosing the post-fire management alternative to treat a specific burned area.

5.3 Summary

In the present chapter, an attempt to theoretically normalize the process was made and it resulted in a structured plan to manage the areas that are more prone to fire.

The costs of the different management techniques were applied to some examples of post-fire sites with distinct characteristics and, although some conclusions were obvious from the start, it allowed to have access to values that can serve as a basis for comparison for future management decisions.

The culture of continuous improvement should continue to be, for FFM, the necessary support for the pursuit of the best results. To achieve this purpose, it is critical that both the top management and the operational teams control and improve the process daily.

Table 5.7: Costs for situation 2

Type of strategy	Total costs (euros)
Manual operations	17 540,00
Mixed operations	5 750,40
Mechanical operations	784,14

Chapter 6

Conclusion

FFM is dependent on several sources of uncertainty, inciting great variability in the outcomes and thus making it hard to have an efficient response when an event occurs.

The project developed with the aim to evaluate the costs of some of the post-fire management alternatives that can be used and to create a methodology to act promptly after a wildfire.

6.1 Main contributions

Natural regeneration is, as expected, the most economical way in the short term but, on the other hand, planted forest helps to reduce the severity of future wildfires and has a lower cleaning cost over the years due to the order in which the tree species are planted and also the predetermined spacing between them.

There are restrictions on available labor, that is, the maximum number of teams that can be formed (the availability of human resources is limited) and the productivity of these teams also depends on the technology used (greater or lesser degree of mechanization).

Analysing different post-fire sites does not give direct answers on how to react when faced with a future wildfire occurrence - some factors like the severity of the fire, the vegetation cover that burned, the slope of the land, etc, are always different. This project and the investigation behind it allowed the development of a simple methodology to guide FM in their decisions towards post-fire management.

The analysis of the post-fire management techniques allowed the obtention of different tables with the organization of the costs of some alternatives and also a calculation sheet that shows the total costs of treating a certain burned area.

Furthermore, some of the most important theoretical conclusions that emerged from this investigation work and that are based on the findings of Moreira et al. (2012) are described below:

- The recovery of a burned site is not just a matter of how to perform reforestation actions. The post-fire management strategies that can be utilized are fairly distinct and are dependent on not only our ability to forecast how affected ecosystems will respond to wildfire but also on the determination of management goals for the affected site. It is also fundamental to embrace of an adaptable management approach which systematically instates outcomes of prior treatments to continually upgrade and adjust change by acquiring knowledge from the results of tested actions;

- The management goals for an affected place are mainly local and can be very different from site to site depending on the gravity of the impacts, the geographic and climatic contexts and also the socio-economic and cultural contexts;
- In the MB, the ecosystems are controlled by shrub and tree species that have the capability to resprout or produce seedlings after wildfires and that are generally very resilient to them. These features should be utilized in post-fire rehabilitation, especially by helping natural recovery that will probably result in cheaper interventions and better vegetation regeneration;
- The unbalanced FFM currently being used in Europe, with a lot of resources distributed to suppression actions in comparison to little fuel management measures, must be altered to a higher focus on fuel management. A selection of the right post-fire management strategies is the main step towards proper fuel management to reduce the harm provoked by sequential wildfires.

6.2 Perspectives for future work

As a future extension of this work it is imperative to create a more realistic simulation model with more situations that can be adapted to different locations and that optimizes forest treatment costs in the long term.

As a way for the rest to be analyzed at a later stage, the present thesis had its core on the theoretical investigation of the theme, an organization of ideas and methods and a calculation sheet to serve as a basis to a deeper analysis of the problem and the questions raised.

At last, during this project, it was identified as an opportunity for improvement, at a national level, to assess conditions responsible for the costs of the operations, in order to create a model to support decision making.

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