Managing Forest Ecosystems

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Post-Fire Management and Restoration of Southern European Forests

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Post-Fire Management and Restoration of Southern European Forests

Managing Forest Ecosystems

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Aims & Scope:

Well-managed forests and woodlands are a renewable resource, producing essential raw material with minimum waste and energy use. Rich in habitat and species diversity, forests may contribute to increased ecosystem stability. They can absorb the effects of unwanted deposition and other disturbances and protect neighbouring ecosystems by maintaining stable nutrient and energy cycles and by preventing soil degradation and erosion. They provide much-needed recreation and their continued existence contributes to stabilizing rural communities.

Forests are managed for timber production and species, habitat and process conservation. A subtle shift from *multiple-use management to ecosystems management* is being observed and the new ecological perspective of *multi-functional forest management* is based on the principles of ecosystem diversity, stability and elasticity, and the dynamic equilibrium of primary and secondary production.

Making full use of new technology is one of the challenges facing forest management today. Resource information must be obtained with a limited budget. This requires better timing of resource assessment activities and improved use of multiple data sources. Sound ecosystems management, like any other management activity, relies on effective forecasting and operational control.

The aim of the book series ***Managing Forest Ecosystems*** is to present state-of-the-art research results relating to the practice of forest management. Contributions are solicited from prominent authors. Each reference book, monograph or proceedings volume will be focused to deal with a specific context. Typical issues of the series are: resource assessment techniques, evaluating sustainability for even-aged and uneven-aged forests, multi-objective management, predicting forest development, optimizing forest management, biodiversity management and monitoring, risk assessment and economic analysis.

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Cover picture legend: Typical scene in the State of Durango where forests are managed by communities known as Ejidos: management is by selective tree removal, clear-felling is not allowed. Animals (ganado) are part of the multiple use system practiced there. (Photo by K.v. Gadow, autumn 2009)

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Foreword

In spite of the huge areas affected by wildfires every year in Europe, the post-fire management of burned areas has been given much less attention than fire management. Even from a scientific research perspective, priority has been given to fire management, with the most relevant EU project in recent years, FIRE PARADOX (http://www.fireparadox.org/), focusing on the important issue of the use of fire as a tool to combating wildfires.

However, the high relevance of post-fire management has been recognized in several political contexts, such as the EU Forest Action Plan, which in its Key Action 9 (Enhance the protection of EU forests) asks for the support for the restoration of forests damaged by natural disasters and fire, or a FAO review on international cooperation in fire management, which identifies post-fire rehabilitation and management of invasive species as priority topics for cooperative action (FAO 2006). Though relevant scientific knowledge on these specific topics is available in some countries, mainly of Southern Europe, research innovations have not been sufficiently transferred to the management practice yet, especially at the European level. The EU project EUFIRELAB (http://www.eufirelab.org) was a significant starting point to this, by making a preliminary assessment of the state-of-the-art concerning post-fire management techniques and restoration efforts, but much remains to be done. Ongoing initiatives consist of networks of research institutions, such as the PHOENIX Project Centre (www.phoenixefi.org/) created in the frame of the European Forest Institute, and the COST Action FP0701 "Post-Fire Forest Management in Southern Europe" (http://uaeco.biol.uoa.gr/cost/), established in the frame of the European Science Foundation, aiming at gathering research efforts on post-fire management topics and at identifying the best management practices for post-fire ecosystem rehabilitation in Europe. This book has been written in the framework of the PHOENIX and COST initiatives.

Why is this book needed? Firstly, because post-fire management and restoration of burned areas is a relevant topic that has not received much attention in Europe. Secondly, because there is a lack of information on restoration approaches and assessment of currently applied post-fire management practices and techniques for post-fire ecosystem rehabilitation in Europe. Finally, because information on the legal and social implications of wildfires is scarce, and so are the methods for the economic assessment of their impacts.

The main objective of this book is to assemble and disseminate scientifically based decision criteria for post-fire forest management and restoration, by reviewing the results of previous and ongoing scientific research. It aims at transferring this scientific knowledge into management practices, by bridging the gap between science and practice in post-fire management. It covers a wide range of spatial scales, from stand to landscape level planning, thus the main target users of this book include not only forest managers but also landscape managers and policy makers at national and regional levels. In fact, several practices for restoration are implemented on a large landscape scale and go beyond forest policies, stretching to agricultural and socio-economic policies. Nevertheless, the book uses a scientific language and approach that makes it suitable also for a broader audience including scientists, university lecturers and graduate students. It is primarily based on a review of the most relevant scientific literature, but it also includes previously unpublished scientific information, with the aim of offering a timely synthesis and novel elements for guiding research and monitoring programs, management guidelines and policy, concerning the restoration of burned lands. The short term expected result is to increase the scientific basis for undertaking appropriate post-fire management practices in Europe, whereas the long term expected result is to improve our ability to effectively restore burned areas and reduce fire hazard in European forests and landscapes. Although focused on Southern Europe, where fire hazard is currently higher, the outcome is also highly relevant for central and northern European countries as well, as climate change is increasing fire hazard in these regions.

The book begins with an introduction, where key questions and concepts related to post-fire management are placed. Chapter 2 deals with the relationships between recent land-cover changes and fire regime in Europe. The economic, legal and social aspects of post-fire management are considered in Chap. 3. Chap. 4 provides an overview of the fire hazard of different forest types. Chapter 5 addresses the main questions related to the post-fire management, common to all forest types. The last chapters (6–12) present distinctive post-fire management issues related to different forest types in Europe. Following the classification of forest types made by the European Environmental Agency, we focused on relevant fire-affected forest types (serotinous pine forests, non-serotinous pine forests, cork oak forests, other Mediterranean broadleaved forests, forests of exotic species, newly fire affected threatened forest types) and shrublands. These chapters are roughly similar in structure, each including the ecological context, the current post-fire management practices, the main management alternatives, and some relevant post-fire management case studies.

We are grateful to external reviewers, Dimitrakopoulos Panayiotis (University of the Aegean), Francisco Rego (Technical University of Lisbon), Filipe Catry (Technical University of Lisbon), Giovanni Bovio (University of Turin), for their valuable contribution for the improvement of the quality of the book.

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The editors

COST: European Cooperation in the Field of Scientific and Technical Research

COST – the acronym for European Cooperation in Science and Technology- is the oldest and widest European intergovernmental network for cooperation in research. Established by the Ministerial Conference in November 1971, COST is presently used by the scientific communities of 36 European countries to cooperate in common research projects supported by national funds.

The funds provided by COST – less than 1% of the total value of the projects – support the COST cooperation networks (COST Actions) through which, with EUR 30 million per year, more than 30,000 European scientists are involved in research having a total value which exceeds EUR 2 billion per year. This is the financial worth of the European added value which COST achieves.

A “bottom up approach” (the initiative of launching a COST Action comes from the European scientists themselves), “à la carte participation” (only countries interested in the Action participate), “equality of access” (participation is open also to the scientific communities of countries not belonging to the European Union) and “flexible structure” (easy implementation and light management of the research initiatives) are the main characteristics of COST.

As precursor of advanced multidisciplinary research COST has a very important role for the realisation of the European Research Area (ERA) anticipating and complementing the activities of the Framework Programmes, constituting a “bridge” towards the scientific communities of emerging countries, increasing the mobility of researchers across Europe and fostering the establishment of “Networks of Excellence” in many key scientific domains such as: Biomedicine and Molecular Biosciences; Food and Agriculture; Forests, their Products and Services; Materials, Physical and Nanosciences; Chemistry and Molecular Sciences and Technologies; Earth System Science and Environmental Management; Information and Communication Technologies; Transport and Urban Development; Individuals, Societies, Cultures and Health. It covers basic and more applied research and also addresses issues of pre-normative nature or of societal importance.

Web: http://www.cost.eu

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Chapter 1
Setting the Scene for Post-Fire Management

Francisco Moreira, Margarita Arianoutsou, V. Ramón Vallejo, Jorge de las Heras, Piermaria Corona, Gavriil Xanthopoulos, Paulo Fernandes, and Kostas Papageorgiou

1.1 Introduction

Every year, around 45,000 wildfires occur in Europe, burning an area of 0.5 million hectares (San-Miguel and Camia 2009). Between 1995 and 2004, more than four million hectares were burned in the Mediterranean region alone, corresponding to an area larger than the Netherlands. In addition to social and environmental impacts, wildfires also produce considerable economic damages due to: (i) the huge amount of resources spent in fire suppression and prevention; (ii) the loss of commercial value of damaged wood products; (iii) the costs related to loss of public non-market services (i.e., biodiversity protection, water cycle regulation, supply of recreational areas, soil protection, carbon sequestration, etc.).

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The post-fire management of burned areas has been given much less attention than fire suppression and prevention in Europe and elsewhere. However, important questions raise public concern and require scientifically-based 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 relevant not only in a southern European perspective, where wildfires are more frequent, but all over Europe. In fact, climate change and land-use trends are expected to increase fire incidence in Central and Northern Europe (Lindner et al. 2010), and new geographical areas (and forest ecosystems) where wildfires were infrequent are likely to become more fire-prone. Thus, further knowledge is needed on how to manage the millions of hectares burned in Europe, including planning of post-fire management, short-term intervention techniques to minimise soil erosion and runoff, and longer-term ecosystem recovery and restoration.

1.2 Wildfires in Europe

Fire is an integral part of many terrestrial biomes including the Mediterranean ones, but is also a major factor of disturbance (Pausas et al. 2008). Natural fire regimes have been increasingly changed by man for many thousands of years, so that in many regions of the world human-caused fires have become more frequent than natural sources of ignition (Goldammer and Crutzen 1993). During the last decades, an increase in the number of fires and the area burned is observed (Flannigan et al. 2009; Moreno et al. 1998; Piñol et al. 1998). In the Southern European Mediterranean countries, the major driving forces behind this change in the fire regime are land abandonment and afforestation of former agricultural land, leading to fuel accumulation and landscape-level connectivity of flammable patches.

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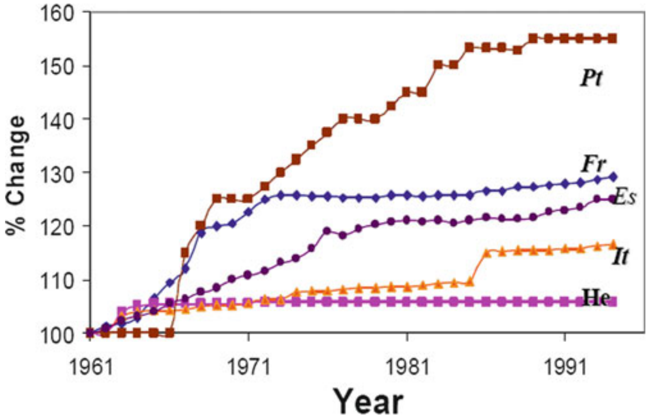

Fig. 1.1 Change (%) in forest area in some Mediterranean countries of Europe during the second half of the twentieth century. *Pt* Portugal, *Fr* France, *Es* Spain, *It* Italy, *He* Hellas (Greece). (Source: FAOSTAT)

By the second half of the twentieth century, the process of extensive land use was halted and reversed in most regions of Europe. Rural exodus (Hill et al. 2008), mechanization of agriculture, reduced livestock grazing, afforestation in many marginal areas and changes in life styles caused important changes in land-use and land-cover patterns (Arianoutsou 2001; Lehouerou 1992; MacDonald et al. 2000; Moreira et al. 2001, 2009a, 2011). Poorly vegetated landscapes gave rise to others which gradually accumulated vegetation biomass, with growing trees or shrubs, and in which active management became occasional. This tendency to increase forest and non-managed land, that is, of increasing fuel loads in the landscape, has been observed in most countries (Fig. 1.1).

In addition to land cover changes, the influence of climatic changes upon shifts in fire regime cannot be ruled out (Pausas 2004; Pausas et al. 2008; Piñol et al. 1998). In fact, climatic extremes, that are more frequently observed nowadays (Founda and Giannakopoulos 2009; Tolika et al. 2009), may be more critical than fuel accumulation in controlling fire behaviour (Cumming 2001). Pausas and Fernandéz-Muñoz (2011) suggest that fire regime changes in the western Mediterranean were different before the 1970s, where fires were mostly fuel-limited, from the present, where they are mostly drought-driven. However, the effects of climate change on increased fire occurrence are not always obvious. For example, in Eastern Iberian Peninsula, Pausas (2004) found a positive correlation between summer rainfall and the area burned two years later, suggesting that this rainfall increases fuel loads for the subsequent fire seasons. In this perspective, warmer and drier summers could decrease fuel loads and, thus, fire hazard, which is supported by process-based simulations of fire activity under future climates (Thonicke et al. 2010).

Although forest fire statistics are incomplete for the first part of the twentieth century, available data indicate that wildfires were not important until the middle of

Table 1.1 Number of fires and burned area in the five Southern States in the last 30 years

Number of fires	Portugal	Spain	France	Italy	Greece[a]	Total
2009	26,119	15,391	4,800	5,422	1,063	52,795
% of total in 2009	49	29	9	10	2	100
Average 1980–1989	7,381	9,515	4,910	11,575	1,264	34,645
Average 1990–1999	22,250	18,152	5,538	11,164	1,748	58,851
Average 2000–2009	24,949	18,337	4,406	7,259	1,569	56,645
Average 1980–2009	18,194	15,335	4,951	9,999	1,569	50,047
Total (1980–2009)	545,805	452,848	148,531	299,977	47,058	1,501,409
Burned areas (ha)	**Portugal**	**Spain**	**France**	**Italy**	**Greece[a]**	**Total**
2009	87,416	110,783	17,000	73,355	35,342	323,896
% of total in 2009	27	34	5	23	11	100
Average 1980–1989	73,484	244,788	39,157	147,150	52,417	556,995
Average 1990–1999	102,203	161,319	22,735	118,573	44,108	448,938
Average 2000–2009	150,101	125,239	22,342	83,878	49,238	430,798
Average 1980–2009	108,956	177,115	28,078	116,534	48,587	478,910
Total (1980–2009)	3,257,886	5,313,457	842,332	3,496,005	1,457,624	14,367,304

[a]Provisional data for 2009
Source: EFFIS report 2009

the century, at least in forested areas, which were the ones for which statistics were compiled. By the late 1960s wildfires started to occur at an increasing rate in the Euro-Mediterranean countries (Alexandrian and Esnault 1998). The number of fires has continued rising, although part of this trend is due to a change in the compilation of statistics (Moreno 2010). Additionally, an increase in ignition sources due to changes in socioeconomic and land-use cannot be excluded (Vélez 2009). Therefore, while a climate effect cannot be ruled out, certainly other factors came into play (Moreno 2010). Area burned, which is less sensitive to compilation procedures, increased during the 1970s and into the 1980s, by which time Spain and Italy had reached maximum values. Greece and Portugal followed with some delay (Moreno et al. 1998). This increase occurred while fire suppression was being strengthened in all the Euro-Mediterranean countries.

Around the Mediterranean most fires (≈95%) are caused by humans, either by accidents or intentionally (EFFIS 2009). During the last decades the area burned in Spain, France and Italy has decreased, but that is not the case for Greece and, much less so, for other Balkan countries and Portugal, where the area burned per year has markedly increased. During 2009, fires in these five countries burned a total area of 323,896 ha (Table 1.1), which, although almost doubling the area burned in 2008, is still below the average for the last 29 years. The number of fires that occurred (52,795) is also slightly below the average of the last two decades. Since the area of each country is different, and the area at risk within each country is also different, comparisons among countries are not straightforward. Fires also occur in other parts of Central and northern Europe, although with a much lower significance (EFFIS 2009).

Large fires represent a small fraction of the total number of fires, but are responsible for a large percentage of the total land area burned in the Mediterranean basin (Diaz-Delgado et al. 2004; Bermudez et al. 2009). Large fires are relatively new in the recent history of the Mediterranean Basin (Lloret and Marí 2001). The recent exceptional fire-seasons (e.g. 1978/79 and 1994 in Spain, 1998, 2000 and 2007 in Greece, 2005 in Portugal, 2003 throughout Europe) contributed to highlight the importance of large fires in the Euro-Mediterranean (e.g. Oliveras et al. 2009; Pausas 2004; Piñol et al. 1998; Xanthopoulos 2007).

A more detailed analysis of current fire regimes is made in Chap. 2.

1.3 What to Do After Fire?

The traditional strategy for the management of burned areas, and other degraded lands, in the Mediterranean region was based on afforestation or reforestation with conifers, particularly since the nineteenth century. Massive plantations covering millions of hectares were carried out in many Mediterranean countries, mostly using pines, and reforestation rates have been further promoted by EU agricultural policies that aimed to convert marginal agricultural land into forested areas (Pausas et al. 2004; Vallejo 2005a). These plantations provided jobs in rural areas, and aimed to increase forest productivity, protect watersheds and in some cases stabilize coastal dune systems. This strategy also assumed that the restoration of degraded areas involved a first stage in which a pioneer conifer was used, followed by the posterior introduction of late-successional hardwoods (Pausas et al. 2004). This traditional view ended up having a very low level of application, due to the cost of implementing it. In addition, changes in fire regime since the last decades of the twentieth century strongly compromised the effectiveness of this strategy.

Nowadays, the range of alternatives, in terms of management objectives for burned areas and techniques available for restoration, is much wider, and the usual political response of "planting trees in 5,000 ha if 5,000 ha were burned" is a simplistic approach no longer justified. Previously, restoring a burned area was equivalent to carrying out a reforestation or afforestation. But in fact, depending on the local conditions and objectives for the burned areas, these are often not the best management alternatives.

1.3.1 Major Questions and Some Answers

After a wildfire, forest managers and stakeholders face a series of questions that may not have an easy answer: should afforestations or reforestations 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

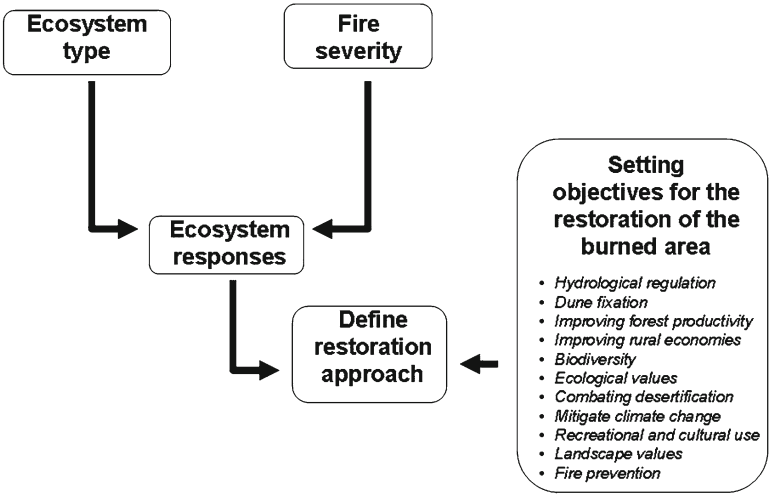

Fig. 1.2 The definition of a restoration approach for a burned area depends on the expected ecosystem responses, which will be determined by ecosystem type and by fire severity, and on the objectives determined for the burned area. These are mostly set at on a local scale

questions, the key question is probably: "for which purpose?". Which are the objectives defined for the burned area and its management?

The answers to these questions depend on two fundamental topics: (i) our capacity to predict how affected ecosystems will react to fire; (ii) the definition of management objectives for the burned area (Vallejo 2005b). Both will determine the restoration approach and techniques that can be used (Fig. 1.2).

Ecosystem responses to fire are dependent on the regeneration capacity of its plant species. But predicting how plant communities will respond to fire is also dependent on the characteristics of the fire itself. Even for the same vegetation type different response patterns are expected whether a fire is quite intense and severe, or of low intensity and severity (e.g. Bond and van Wilgen 1996; Belligham and Sparrow 2000; Moreira et al. 2009b).

The management objectives for a burned area may be quite variable depending on the local situation. "Traditional" objectives included soil erosion prevention, water regulation, or increase forest productivity, but these have been replaced by new objectives such as biodiversity conservation, carbon storage, enhancing landscape values or reducing wildfire hazard (Fig. 1.2). These objectives are mostly local and can be quite variable from place to place, depending on the severity of impacts, the geographic and climate context, and socio-economic and cultural drivers. In the case of woodland restoration in the Mediterranean, Vallejo et al. (2006) suggested that the main priorities should be soil and water conservation, improving the resistance and resilience of vegetation to fire, increasing mature forests, promoting biodiversity and fostering the re-introduction of key species that might have disappeared.

1.3.2 Key Concepts in Restoration Ecology

These concepts have been addressed in several publications and books (e.g. Society for Ecological Restoration International Science and Policy Working Group 2004), thus we review them shortly with a focus on burned area restoration.

1.3.2.1 Restoration, Rehabilitation and Replacement

Restoration is the "process of assisting the recovery of an ecosystem that has been degraded, damaged or destroyed" (SER 2004). This definition is applicable to native forest ecosystems that were degraded or destroyed. Restoration aims to return an ecosystem to its historical condition, although setting this base reference is often difficult in a Mediterranean context where human management has been shaping landscapes for thousands of years. However, in the case of burned area management, our goals may not include restoration at all, in particular if we aim to change the ecosystem type that was burned (e.g. because it had no conservation value, or if we intend to reduce the fuel load in a particular location, independently of the previous land cover).

Rehabilitation shares with restoration a fundamental focus on historical or pre-existing ecosystems as a reference, but the two activities differ in their goals and strategies. Rehabilitation emphasizes the reparation of ecosystem processes, productivity and services, but not necessarily the re-establishment of the pre-existing biotic integrity in terms of species composition and community structure.

In *replacement*, or re-allocation (Aronson et al. 1993), the objective is to build up a new, productive ecosystem, often simpler than the original.

Forest restoration is a global concept that may have different degrees and intensities of management intervention, depending on the degradation stage of the forest and the specific management objectives considered. In the past, forest restoration has been mostly interpreted as planting trees, that is, afforestation or reforestation. Nowadays, this view is being replaced by a more holistic one, considering a wide set of restoration alternatives and approaches.

1.3.2.2 Active and Indirect Restoration

Active restoration uses techniques including plantations and direct seeding. These are relatively expensive tools for restoration, as they require site preparation, equipment, man-power, seedlings from nurseries, transport to the area, fertilizers, tree shelters, etc. (e.g. Moreira et al. 2009c). The survival of planted seedlings is quite variable, and often quite low in the case of broadleaved trees (Pausas et al. 2004). Direct seeding usually has lower costs compared to tree planting (Lamb and Gilmour 2003; Mansourian et al. 2005), but often only a low proportion of seeds is able to germinate and thrive (e.g. Pausas et al. 2004).

Indirect restoration implies the use of natural regeneration, and it can be either passive or assisted. *Passive restoration* is based on protecting the area from further disturbances and let ecological succession work (Lamb and Gilmour 2003). In burned areas regeneration may occur from seeds (e.g. Pausas et al. 2004), from resprouting of burned trees and stumps (mostly basal resprouting) (e.g. Espelta et al. 2003) or resprouting of burned shrubs or herbs. Tree resprouts, in particular, have significant advantages over seedlings or planted trees because they have an established root system which may confer higher probability of survival and better growth (e.g. Moreira et al. 2009c; Simões and Marques 2007). Further stages in natural regeneration management imply *assisted restoration* and may involve thinning, the selection of shoots in coppices, and the control of unwanted vegetation or protection from grazing animals (e.g. Lamb and Gilmour 2003; Moreira and Vallejo 2009; Vallejo et al. 2006; Whisenant 2005). The use of indirect restoration has been often neglected by managers and policy makers, and some regional and national governments have even subsidised active restoration in burned areas where natural regeneration was occurring.

Mediterranean-type ecosystems are highly resilient to fire when dominated by shrub and tree species that have the ability to resprout or produce seedlings after fire. Thus, these traits should be used in post-fire restoration, mainly through assisting natural regeneration that will likely result in less costly interventions and higher rate of vegetation recovery (Moreira and Vallejo 2009).

1.4 A Framework for Planning Post-Fire Restoration

In this section we describe a framework that can be used in post-fire management and restoration. It is based on five major steps (Fig. 1.3).

1.4.1 Predicting Vulnerable Areas

Even before fires occur, forest and landscape managers have the tools to map area vulnerability to wildfires, and to identify priority areas for fire prevention and intervention after fire. The key data to build these maps include soil information, topography (slope in particular), vegetation type, and also the location of values-at-risk (infrastructures, buildings, valuable ecosystems). One example is the work done by Alloza and Vallejo (2006) for the region of Valencia (over two million hectares). Using a Geographic Information System (GIS), these authors have mapped vulnerable areas based on the joint evaluation of the potential regeneration capacity of the vegetation and of the degradation risk (the environmental factors that condition the regeneration potential). Regeneration capacity was based on the combination of autosuccession potential (the ability to recover the pre-fire vegetation type) and the rate of plant recovery, which determines how quickly vegetation recovers to protect

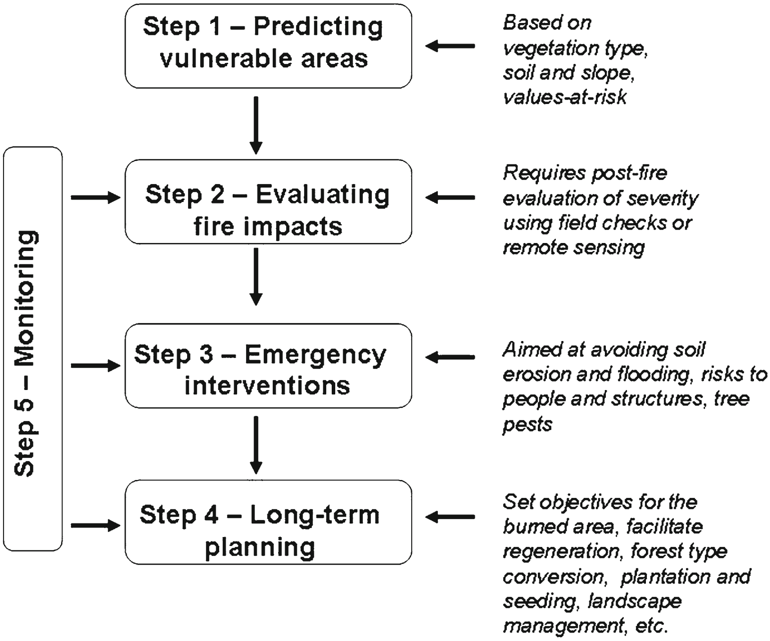

Fig. 1.3 Framework to planning post-fire management and restoration in burned areas

the soil and decrease excessive erosion and runoff risk, for different vegetation types. The degradation risk was estimated based on the erosion potential (based on the Universal Soil Loss Equation) plus the drought risk (an estimator of the length of the dry period). At the end, the combination of the regeneration capacity and degradation risk yielded a map of ecosystem vulnerability that enabled the identification of priority areas for post-fire intervention, in the event of wildfires. These authors have found that 14% of the Valencia region is highly vulnerable in relation to forest fires, i.e. in the event of a forest fire some degradation of the vegetation cover can be expected in the short term. In Cape Sounion National Park, Central Greece, ecological and landscape data have been also integrated with decision-support techniques in a Geographic Information Systems (GIS) framework to evaluate the risk of loosing post-fire resilience in *Pinus halepensis* forests (Arianoutsou et al. 2011). Criteria related to the significance of several indicators (bio-indicators: plant woody cover, pine density and geo-indicators: fire history, parent rock material and slope) were incorporated within a weights coefficient and then integrated into a multicriteria rule that was used to map the risk of loosing resilience. This map is useful for identifying 'risk hotspots' where post-fire management measures should have priority.

This type of approach can be used all over Europe, in order to identify vulnerable areas and prioritise fire prevention and post-fire intervention actions after wildfires.

1.4.2 Evaluating Fire Impacts

Even if a given area was identified as highly vulnerable to wildfires, post-fire soil erosion and degradation might be negligible if a wildfire had low severity. The impact of a fire upon a site will depend on fire characteristics, and the key variable to evaluate how a given ecosystem will respond to fire, fire severity (Fig. 1.2), can obviously be assessed only after a wildfire has occurred. It is, therefore, important to evaluate severity levels as soon as possible after fire, and this can be done either by field inspections, by using remote sensing at high resolution (e.g. satellite images), or a combination of both. The use of remote sensing to evaluate fire severity will only be effective if the information is available for the forest managers in the short-term. Additionally, this technique has some inaccuracies (Lentile et al. 2006), for example in forest areas remotely sensed burn severity is often highly correlated with fire effects on the tree canopy but exhibits low correlation with ground and soil severity. Often, it is more practical to do field checks in the first couple of weeks after the fire, to visually evaluate fire severity. Several guidelines exist (e.g. USDI 2003) that can be used to quickly evaluate fire severity and identify areas for emergency interventions.

1.4.3 Emergency Interventions

These emergency interventions, sometimes called first-aid rehabilitation, aim to stabilise the affected area, prevent degradation processes and minimise risks for people (Robichaud et al. 2000). They may aim at soil protection to avoid erosion and decrease water runoff and risk of flooding, to decrease risks to people and property (e.g. hazard from falling burned trees), or to the prevention of tree pests and diseases. They should be undertaken as soon as possible, at most a few months after the fire, and preferably before the first autumn rains when in the Mediterranean region.

1.4.4 Long-Term Planning

This is related to setting the objectives for the burned area and the actions needed to accomplish these objectives. Depending on the situation, it may include facilitating the natural regeneration, carry out conversion to other forest types, afforestation or reforestation, landscape management to promote specific land covers, etc.

1.4.5 The Importance of Monitoring and Evaluation

Restoration projects are traditionally weak in monitoring and evaluation. This limits the opportunities to learn from past successes and failures (Vallejo 2005a). A properly planned restoration project or management action should attempt to fulfil clearly stated objectives. Assessing whether objectives were fulfilled, or how far we are from attaining these objectives, is only possible through monitoring and evaluation. What cannot be measured and monitored in an objective and unbiased way cannot be effectively managed (Corona et al. 2003). Thus, objectives, performance standards, and protocols for monitoring and for data assessment should be incorporated into restoration schemes prior to the start of a project.

Post-fire monitoring and evaluation is essential to gain understanding of forest ecosystems successional pathways after fire and, accordingly, to plan appropriate restoration actions. It will also allow re-directing restoration actions in an adaptive management context.

According to SER (2004), there are three strategies for conducting an evaluation: direct comparison, attribute analysis, and trajectory analysis. In direct comparison, selected parameters are measured in the reference and restoration sites. One example is to assess the plant composition of a post-fire recovering forest and compare it with that of an adjacent unburned plot of the same forest type. In attribute analysis, a set of desirable characteristics for the project result are defined at the beginning and the measured parameters are compared with this set. In trajectory analysis, data are collected periodically and trends examined to confirm that the project is following the intended trajectory.

Independently of the followed strategy, two major points should always be taken into account. The first is the knowledge of the *baseline situation*. As an example, consider how to assess the success of a given action in increasing soil cover if we did not measure it at the start? This implies assessing the current status of our parameter of interest before the start of the management action or experiment. The second point concerns the *monitoring of untreated control plots*, which provide the only way of evaluating the net effect of our action. For example, the meaning of a 50% increase in soil cover after a given treatment is totally different according to whether this increase in an untreated plot, during the same time period, was 5% (our treatment was highly effective, compared to the control) or 45% (denoting low effectiveness of the treatment, just 5% higher than the control).

Finally, the social impacts of any restoration project should also be taken into account in the evaluation of its outcomes as, beside the ecological objectives, there are always more or less explicit social and economic objectives and implications. Bautista and Alloza (2009) have recently developed a protocol for evaluating Mediterranean forest restoration projects considering both biophysical and socio-economic criteria. See also Table 3.5 (chapter 3).

1.5 Spatial Scales for Management and Restoration: From the Forest Stand to Land Use Planning

Post-fire management and restoration actions can be taken at a variety of spatial scales, from the forest stand level to landscape regional planning (Fig. 1.4).

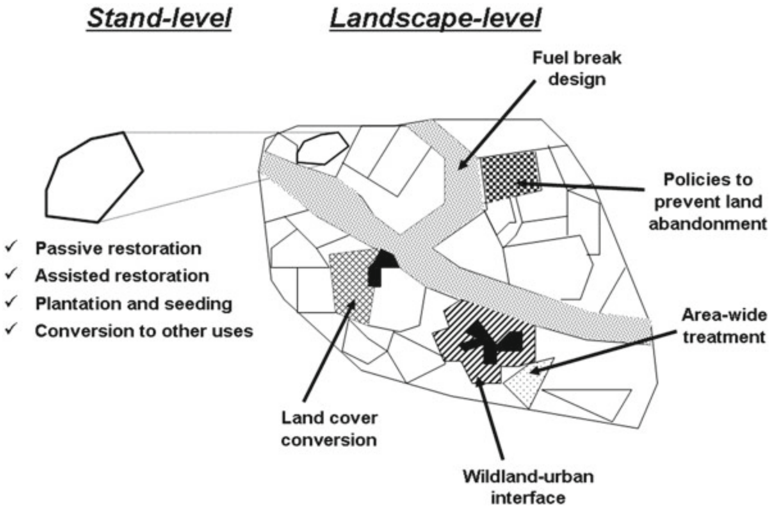

Fig. 1.4 Spatial scales to carry out post-fire management and restoration. At landscape level, it may include the definition of landscape-scale fuel breaks or area-wide treatments, implementation of policies for preventing land abandonment or keeping specific land covers, land cover conversion to less fire-prone cover, specific regulations for the wildland-urban interfaces. At stand level, different options include passive restoration, assisted restoration, plantation and seeding (of the same forest species or converting to another tree species), or conversion to other non-forest uses

1.5.1 Stand-Level Silvicultural Practices

The planning and implementation of restoration actions in burned forest areas need to be spatially framed according to the stand-level variability in terms of fire affected forest types and levels of fire severity. In fact, restoration strategies should be put into place depending on fire damage levels and post-fire ecology of affected forest types, notably the post-fire regeneration strategies (seeders, resprouters). Current post-fire management practices and recommendations are proposed in the Chaps. 6–12 for the relevant fire-affected forest types in Europe.

First of all, it is recommended to accurately plan the post-fire harvest of trees, if needed. The pros and cons of salvage logging have been addressed in several studies (e.g. Lindenmayer and Noss 2006). Once emergency interventions have been completed, there are basically three possible options for the restoration of forests impacted by fire.

Indirect restoration techniques are applicable where forest stand functional/structural damage is limited and resilience is high. The first option is the management of burned forest (or shrubland) areas through natural regeneration (passive restoration). The exclusion or restriction of some land use activities (e.g. livestock grazing) for some years and the implementation of measures to prevent further degrading events (e.g. additional fires) is generally enough to ensure satisfactory post-fire regeneration. Management thus involves careful monitoring of the dynamics of recovery and verifying their coherence with the management objectives set in terms of forest structure and composition. The second option of indirect restoration is assisted restoration, with the application of appropriate silvicultural techniques to support post-fire natural regeneration in order to promote faster achievement of the mature stages of development. However, it has to be decided when to apply restoration interventions: soon after the fire or wait until the natural regeneration is established? Early silvicultural interventions aim at creating favourable conditions for the establishment of natural regeneration, while latter interventions are intended to support the development of already established regeneration. Different approaches can be used: (i) to favour vegetative regeneration through stump undercutting and selection of shoots, namely when fire affects wooded lands dominated by resprouting species like broadleaved evergreen or thermophilous deciduous oaks (coppices); (ii) to support regeneration of new individuals through pruning and thinning to stimulate seeding, by giving more light and potential growing space to dominant branches and crowns of dominant standing trees, whose seed production is generally higher than the other trees, and subsequent localised cleaning to favour seedling survival and growth, and, when necessary, localized planting to restore tree cover.

The third option is active restoration, through active seeding and plantation in stand-replacing fires. For a number of reasons (e.g. high fire severity, post-fire ecology of the affected vegetation, juvenile forest stand) natural regeneration may not guarantee the self-restoration of the fire affected forest types, mainly in the case of pine stands. In these cases seeding or planting are suitable techniques to ensure long-term restoration, and may include the use of a wide variety of species, depending on the objectives. For example, if forest conversion, e.g. to a less fire-prone composition, is an objective, plant species that did not exist before the fire may be planted or sown.

One last alternative of management is the conversion to other non-forest uses, usually within the scope of planning at a larger spatial scale (see Sect. 1.5.2).

As mentioned, several tree forest species, particularly Mediterranean ones, have high intrinsic resilience to fire, and therefore are potentially capable of guaranteeing an efficient natural recovery after fire. Yet, the post-fire woodland restoration methods currently practised in Europe mostly follow conventional practices and administrative regulations that do not always take into consideration the fire ecology of affected forest types, as will be illustrated in the specific chapters (see Chaps. 6–12); thus they are often not the most suitable to facilitate the natural ability of the vegetation to return to the pre-disturbance stage, through the autosuccessional process.

1.5.2 Landscape Management Planning

Planning at the landscape-scale aims to reduce fire hazard in order to produce landscapes that are less fire-prone (Fig. 1.4).

At landscape level, wildfire initiation and spread result from the interaction among ignition sources, weather, topography and land cover (e.g. Mermoz et al. 2005; Rothermel 1983). From a management perspective, land cover (related to vegetation composition and flammability) is the only variable that can be manipulated by man. In general, agricultural areas and deciduous broadleaved forests are the least fire-prone land cover, whereas shrublands and pine woodlands are the most fire-prone in the Mediterranean basin (e.g. Moreira et al. 2009a). A straightforward application of this knowledge lies in the definition of landscape-scale fuel breaks and area-wide (block) treatments, whose main objective is to reduce fuel loads or change the spatial arrangement of fuels (i.e. the landscape structure), so that when a wildfire ignites in a managed landscape, it spreads more slowly, burns with less intensity and severity, and is less costly to suppress. Thus, the main objectives of landscape fuel treatments are to break up the continuity of hazardous fuels across a landscape, and to reduce the intensity of wildfires, providing broad zones within which fire-fighters can conduct suppression operations more safely and effectively. In addition, these areas can also be used to provide other types of benefits (e.g. habitat diversity, landscape scenery, protection of heritage sites) (Agee et al. 2000; Cumming 2001; Rigolot 2002; Weatherspoon and Skinner 1996).

The management implications of understanding the landscape-fire relationships are not restricted to fuel break or block treatment designs. The definition of land use management rules and the design and implementation of policies to achieve specific landscape objectives, ranging from forest to agricultural, rural development or urban policies (mainly in the wildland-urban interface), all contribute to "making" landscapes with lower fire hazard. For example, the "rural exodus syndrome" (Hill et al. 2008) is causing a widespread increase in vegetation biomass over large areas of the Mediterranean Europe, mainly in mountain areas, and a subsequent increase in fire hazard. Population decline, agricultural and pastoral land abandonment (and the subsequent natural regeneration of forests), and policies promoting forest cover, particularly in former agricultural land, are the main driving forces of this process. This trend can only be counteracted effectively through policies enabling the improvement of the socio-economic conditions of people living in rural areas, promoting new immigration to these regions, and implementing rural development policies that foster activities contributing to reduce fire hazard, such as agriculture and livestock grazing. These policies are mainly related to agricultural, rural development and economic issues, rather than forest management.

In the absence of other fuel treatment drivers, prescribed fire or controlled occupational burning (used by shepherds to renew pastures) can be useful tools to reduce fire hazard. In this perspective, energy policies supporting the environmentally compatible use of renewable bioenergy potential from agriculture and forestry products (agricultural waste, crop mix for biomass production, complementary fellings and residues from silvicultural activities and/or fuel treatments) may also contribute to decrease fire hazard, while providing job opportunities to rural populations.

At regional/local levels, these policies should be implemented mainly in areas where landscape-level planning to reduce fire hazard identified priority sites for fuel treatments, such as wildland-urban interface areas surrounding villages. In fact, one of the most serious consequences of the abandonment of traditional practices is that villages in mountain areas, traditionally surrounded by a belt of farmland that acted as a landscape fuel break, nowadays have forests and shrublands in the vicinity of houses and other infrastructures, which greatly increase fire hazard.

Under moderate to severe fire weather conditions, fuel management should be focused on increasing the fire suppression options and effectiveness by limiting fire ignition and fire spread in strategic locations. However, under exceptional fire weather conditions, fire may propagate throughout a whole landscape regardless of land cover and fuel management. Prevention strategies should therefore include self-protection options to limit fire intensity and damages on both ecosystems and human assets, under the assumption that fire fighting will not always be possible in these circumstances. This implies a major shift in the way fire management is seen, and a cross sectorial approach integrating agricultural, forest and urban planning policies. Currently, the unbalanced fire management being practiced in Europe, with too much resources being allocated to pre-suppression and suppression actions compared to poor fuel management measures (e.g. Fernandes 2008), is increasingly questioned. Simultaneously, the "learning to live with fire" objective is increasingly shared (Birot and Rigolot 2009), by recognising that fire cannot be excluded from the Mediterranean environment (Rego et al. 2010). Under this objective, fuel management is not only devoted to limiting wildfire spread, but also to lower fire impacts on human resources and assets.

Land ownership may be a problem when implementing landscape-scale management. In situations where most of the land is private and property size is small, it may be difficult to coordinate the management of different land owners in order to achieve a spatial dimension that suits management objectives. In countries or regions where fragmented private property prevails, the only way of assuring effective management is to promote coordinated action among land and forest owners. In Portugal, for example, the government is promoting the association of land owners with contiguous properties, so that a joint management plant is implemented to achieve this objective.

1.6 Key Messages

- The restoration of a burned area is not just a matter of how to carry out reforestations. The post-fire management approaches and techniques that can be used are quite variable and depend on (1) our capacity to predict how affected ecosystems will react to fire and (2) the definition of management objectives for the burned area. It is also important to adopt of an adaptive management approach which systematically integrates results of previous interventions to iteratively improve and accommodate change by learning from the outcomes of experimented practices;
- The management objectives for a burned area are mostly local and can be quite variable from place to place, depending on the severity of impacts, the geographic

and climate context, and the socio-economic and cultural context. But the main priorities should always be soil and water conservation;

- Ecosystems dominated by shrub and tree species that have the ability to resprout or produce seedlings after fire are usually highly resilient to fire. These traits should be used in post-fire restoration, mainly by assisting natural regeneration that will likely result in less costly interventions and higher rate of vegetation recovery;
- We suggest a framework for planning post-fire management and restoration based on five steps: (1) identifying vulnerable areas, (2) evaluating fire impacts, (3) carrying out emergency interventions, (4) long-term planning, and (5) monitoring;
- Spatial scales for post-fire management range from the forest stand to landscape management. At the landscape level, besides fuel break or area-wide treatment designs, the implementation of policies to achieve specific land management objectives, ranging from forest to agricultural, rural development or urban policies (mainly in the wildland-urban interface) is essential to promote landscapes which are less fire prone;
- The unbalanced fire management being practiced in Europe, with too much resources being allocated to pre-suppression and suppression actions compared to poor fuel management measures, needs to be changed to a greater focus on fuel management. Adoption of correct post-fire management practices is the first step towards adequate fuel management to decrease the damage caused by subsequent fires.

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