

# Shrubland and Woodland Restoration in the Mediterranean Basin<sup>1</sup>

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## Abstract

Landscapes and ecosystems in the Mediterranean basin (MB) have been profoundly modified after a long history of land use and deforestation, which has caused extensive land degradation. In the last third of the 20th century, extensive land abandonment occurred in European Mediterranean countries, which dramatically increased fuel load and continuity in landscape and, consequently, large wildfires. As a response to land degradation, the forest services of MB countries already promoted large afforestations in the late 19<sup>th</sup> century. After the breakout of large wildfires and the new social perception of wildlands, new approaches for land restoration were called for. We present an approach and decision support system for assessing post-fire restoration. Short-term rehabilitation is considered to mitigate post-fire soil degradation and excessive runoff, while short- and mid-term restoration focuses on recovering keystone species. Long-term restoration is considered to recover the integrity of reference ecosystems and their services, together with a reduced fire hazard. The protocol and decision support system proved applicable to most of the characteristic vegetation types in the MB. However it is still uncertain how applicable they can be to other Mediterranean type ecosystems, such as the Californian chaparral.

Keywords: Mediterranean basin, resprouters, seeders, restoration, post-fire, shrubland, plantation, drought.

## Introduction

Landscapes and ecosystems in the Mediterranean basin (MB) have been profoundly modified by long-term land use (Thirgood 1981), which often causes irreversible degradation. The main land transformation causes include cultivation, grazing (often overgrazing), fuel wood collection, forest overexploitation, mining and forest fires. Fire is known to form an essential part of Mediterranean plant evolution and natural ecosystem dynamics (Keeley et al. 2012). Therefore, most Mediterranean plant species present specific adaptations to withstand fires. However, excessively high fire frequency and extreme fire severity may overcome ecosystem fire resilience, especially when other disturbances contribute to ecosystem degradation. Recent widespread land abandonment in European Mediterranean countries has triggered wildfire occurrence (Pausas and Fernández-Muñoz 2012). Burned forests and shrublands are now the main subject of restoration projects in the MB. For that reason, this paper mostly focuses on post-fire restoration.

Afforestation of degraded lands is quite an old practice in the MB (fig. 1), and

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has become especially significant since the 19<sup>th</sup> century (Vallejo and Alloza 2012). The main afforestation objectives were watershed protection, increased forest areas and timber productivity, dune fixation and providing employment to marginal regions (Vallejo and Alloza 1998). The traditional management strategy of burned and other degraded areas in the Mediterranean region was based on afforestation with conifers, mostly pines. This strategy assumed that the restoration of degraded areas first required the introduction of pioneer conifers, followed by the introduction of late-successional hardwoods (Pausas et al. 2004). This traditional approach has been applied by default for decades in the MB to restore degraded ecosystems. However, the high cost to completely implement this strategy, and the changes in fire regime in the last few decades of the 20<sup>th</sup> century, have strongly compromised the effectiveness of this strategy.



Figure 1—Example of old afforestation in Sierra Espuña (SE Spain). The project started in 1892 (left) after devastating floods caused by head-waters catchment deforestation. Pine plantations were successful in the long-term (right). Vallejo 2005.

In the present-day, new objectives for land restoration are added to traditional ones, such as increasing biodiversity, combating desertification, carbon fixation, fire prevention, and landscape recreational, cultural and aesthetical values (Vallejo and Alloza 2012). These new forest restoration goals should be reflected in the restoration strategies and techniques to be applied. In many Mediterranean countries, especially lowland forests with low timber productivity, fire prevention has become the first forest management priority. Advances in fire and restoration ecology in recent decades, along with the new social demands for preserving and improving ecological values, have led to new approaches in forest and shrublands management in general, and in post-fire restoration in particular. In this context, the definition of a restoration approach for a burned area must consider not only the expected ecosystem responses on a local scale, which will be determined by ecosystem type and by fire severity, but also the management objectives for the burned area (Moreira et al. 2012).

Ecosystem responses to fire are dependent on the regeneration strategy of dominant plant species (Vallejo and Alloza 1998). However, plant communities' response to fire is also dependent on the characteristics of the fire itself (e.g., fire intensity and frequency) and, what is even more unpredictable, the post-fire weather conditions. For one same vegetation type, different response patterns are expected for distinct fire intensities and severities (e.g., Bond and van Wilgen 1996, Belligham

and Sparrow 2000, Moreira et al. 2009).

Specific forest management objectives can be extremely diverse depending on local ecological and socio-economic conditions. However, assuming post-fire land use changes is neither allowed nor considered, few baseline management objectives can be taken as a reference for most burned ecosystems in the MB (Vallejo and Alloza, 1998; Vallejo & Alloza 2012): 1) Soil conservation and water regulation. 2) Increasing fire-resilience in fire-prone ecosystems; 3) Recovering natural forests and tall shrublands.

In this article, we summarize the rationale and approaches for post-fire assessment and restoration in MB ecosystems developed by CEAM since the early 1990s in close collaboration with regional and national forest services. The background research has been mostly carried out in Eastern Spain (the Valencian Region) in dry sub-humid to semi-arid Mediterranean climates, including areas that have suffered large, frequent wildfires. The approaches have been also tested in other MB countries (Moreira et al. 2012, Vallejo et al. 2012).

## Main Characteristics of Fire-Prone Vegetation in the MB

In the MB, wildfires affect mostly shrublands (more than 50% of the burned area), and pine woodlands and forests (Moreno et al. 2013). Most shrublands are successional, except those thriving in a semi-arid climate and in extreme habitats. Figure 2 provides a simplified overview of the main MB ecosystems types and their response to fire.

Hardwoods and sclerophyllous tall shrubs (fig. 3) are resprouters. Resprouting vigour can be very diverse depending on species, and sometimes on age and fire regime (Reyes and Casal 2008, Lloret and Zedler 2009). Most sclerophyllous MB trees and tall shrubs are extremely vigorous resprouters under current, and even severe (high intensity or frequency), fire regimes. Pine forests and woodlands are abundant in landscapes because of their good colonization ability and the extensive artificial plantations carried out since the 19<sup>th</sup> century. Most Mediterranean pines are obligate seeders, except *Pinus canariensis*, which is a vigorous resprouter and originally from the Canary Islands. Some pine species are very sensitive to crown fires (e.g., *Pinus nigra*, *P. sylvestris*, *P. pinea*). Serotinous pine species (*P. halepensis*, *P. brutia*, *P. Pinaster*, dependent on provenance) usually regenerate after crown fires when trees are mature, but are sensitive to crown fires with short fire-return intervals (around 15 years, or shorter) that imply an immaturity risk; that is, the regenerate does not have time to reach sexual maturity and there is no seed bank for regeneration after the second fire (Pausas et al 1994).

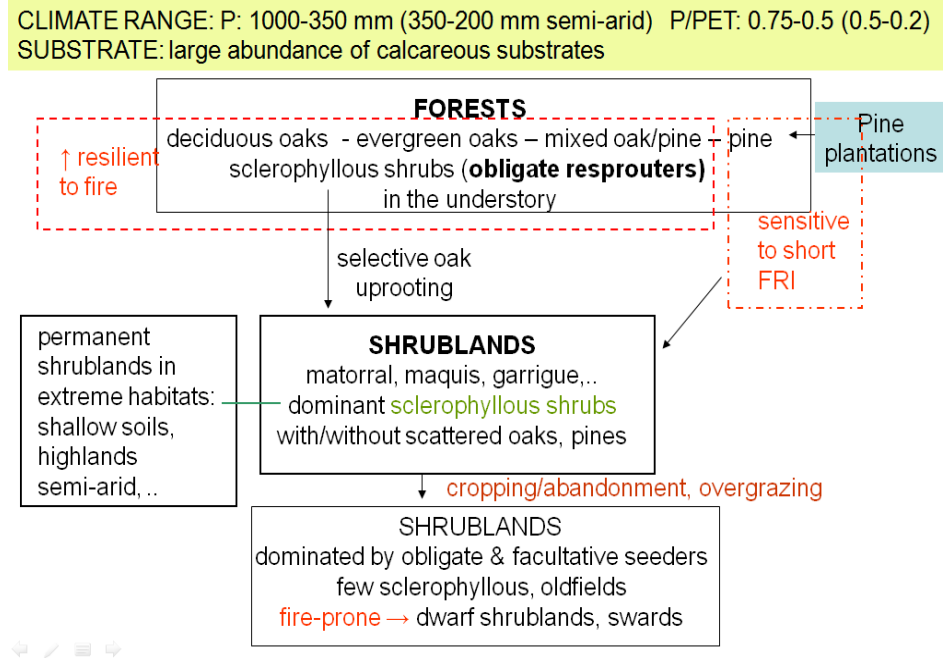


Figure 2—Simplified overview of the main ecosystem types affected by wildfires in the Mediterranean Basin and their dynamics. P: precipitation. PET: Potential Evapotranspiration. P/PET: Aridity index (UNESCO 1979). FRI: Fire Return Interval. More details in the text.

Permanent shrublands growing in a semi-arid climate are seldom affected by fire because of insufficient fuel load and continuity. If the climate is dry sub-humid, successional shrublands can group in those dominated by sclerophyllous species (fig. 3), maquis, kermes oak garrigue), which are vigorous resprouters, from those dominated by obligate seeders which are fire-prone and provide little protection to soil shortly after fire (fig. 4), Vallejo and Alloza 1998). These latter shrub communities especially develop in old fields (fig. 5) and may trigger short-term fire cycles, leading to ecosystem degradation loops. Therefore, recurrent fires may trigger catastrophic shifts in ecosystem state and resilience, especially in old fields and erodible soils.

Less disturbed, and never cultivated oak forests (in a dry sub-humid climate), are often considered reference ecosystems for restoration. Some, especially holm oak forests, were traditionally called “chaparral” in Spanish from Spain (deriving from the Basque language word txaparro, RAE 2001). The term chaparral refers to the low stature and shrubby form of trees, often resulting from coppicing and/or canopy fires.

In summary, knowledge of plant species’ post-fire regeneration strategies is essential to predict fire impacts and to assess species selection in restoration programs which aim to increase ecosystem fire-resilience. A database of fire-related traits for species in the MB is already available (Paula et al. 2009) and a larger initiative is ongoing (Kattge et al., 2011).

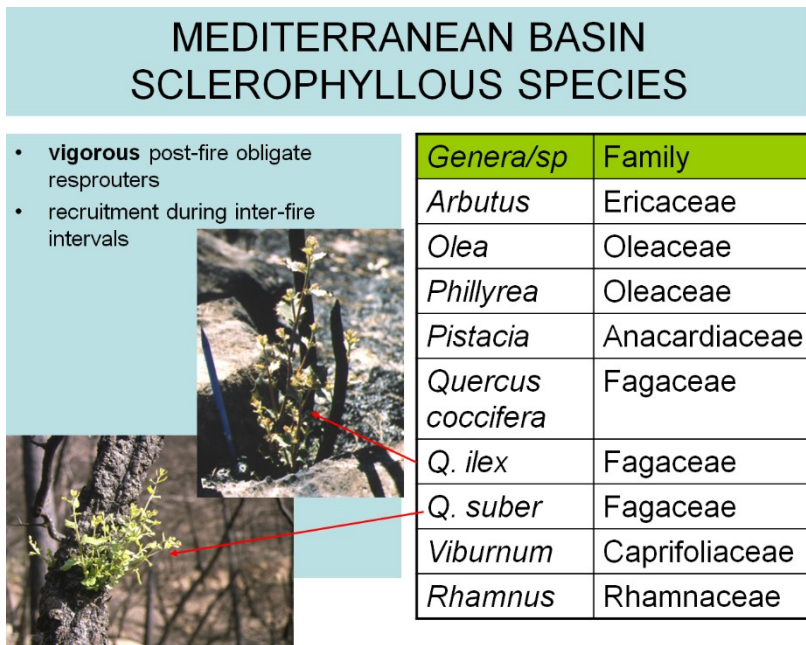


Figure 3—Representative MB sclerophyllous genera and species (for *Quercus*). Several of these genera are also native in North America. *Quercus suber* (cork oak) is the only species in the list to have insulating cork and to show epicormic resprouting after crown fires. The rest resprout from stumps and/or roots.

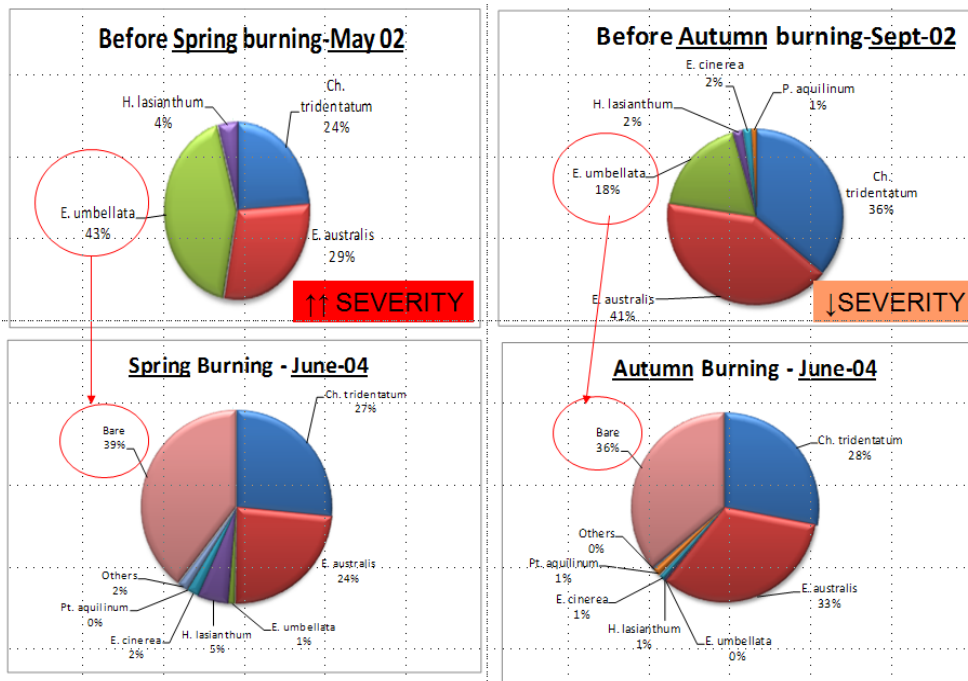


Figure 4—Shrubland regeneration after experimental fires set up in spring (high severity) and autumn (low severity), Gestosa (Portugal). The dominant resprouter shrubs (*Chamaespartium tridentatum* and *Erica australis*) quickly recovered their pre-fire plant cover. *Erica umbellata*, an obligate seeder, did not recover its pre-fire plant cover after 22-24 months since burning, which largely contributed to the persistence of bare soil (hence erosion risk) for both fire severities. Serrasolses (unpublished).



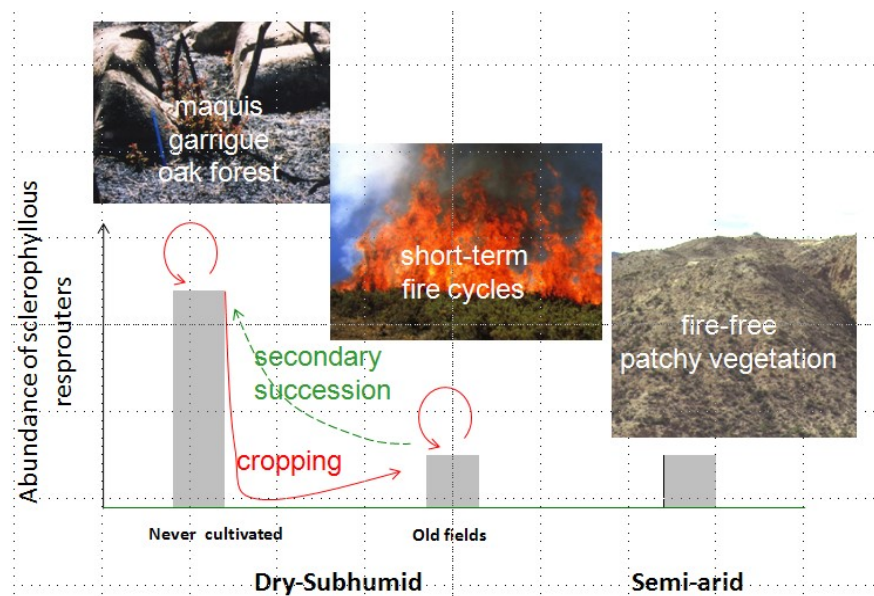


Figure 5—The role of cropping-abandonment in the abundance of sclerophyllous species in shrublands, woodlands and forests. Cropping drastically reduces the abundance of sclerophyllous species, which are poor colonizers to old fields. The dominant succession model after fire is autosuccession (Hanes 1971, Trabaud 1994); i.e., recovery of the same plant community after a relatively short time, a few years.

## Assessing Post-fire Restoration Needs

Current restoration practices very much depend on the media impact of a given fire, which is related to fire size and social damages, and also on public budget availability. In an attempt to provide a comprehensive post-fire restoration strategy, and to optimise the investment of limited available economic resources, we have developed a protocol and a Decision Support System to help post-fire management decision making (Vallejo and Alloza 2012).

The main steps considered are:

- Defining management objectives, such as avoiding damage (erosion, flash floods), increasing fire-resilience and ecosystem/landscape biodiversity, and preventing new fires. According to the socio-economic and biophysical conditions of the burned area, more site-specific objectives can be considered.
- Identifying fire-vulnerable ecosystems
  - ⇒ Predicting runoff and soil erosion risk
  - ⇒ Predicting the regeneration capability of dominant species (resilience, regeneration rate) according to fire severity and to land and ecosystem characteristics
- Recommending specific techniques to mitigate degradation and to assist regeneration at different time steps.

The operational protocol includes four time steps according to timing of risks (fig. 6), Vallejo and Alloza 2012): 1) Preliminary GIS assessment of the vulnerable areas based on topography, vegetation and soil erosion risk maps; 2) Short-term assessment of soil erosion and excessive runoff risk based on Step 1 and the field survey immediately after fire occurrence – recommendation of emergency

rehabilitation actions; 3) Short-term assessment of the regeneration of keystone species and possible recommendations to assist natural regeneration; 4) Long-term assessment of ecosystem restoration, often forest restoration, by considering the provision of ecosystem services and fire prevention. Long-term restoration should include climate change projections according to the state-of-the-art knowledge on the projected changes in climate and the fire regime, and also on the species adaptation potential to change. All the operational steps, from 2 to 4, include the quality control of restoration works (stewardship during implementation), and monitoring and assessment according to the set objectives. The objectives, performance standards and protocols for monitoring and for data assessment should be incorporated into restoration schemes before a project starts. Post-fire monitoring and assessment is essential to gain an understanding of forest ecosystems' post-fire successional pathways and, accordingly, to plan appropriate restoration actions. It will also allow the re-direction of restoration actions in an adaptive management framework (Vallejo & Alloza, 2012). The participation and involvement of relevant stakeholders in all the project phases is critical to help incorporate local knowledge and to stimulate adoption. The protocol has been fully developed using standard data collection forms and general guidelines to assist forest managers in post-fire management (Alloza et al. 2014, in Spanish).

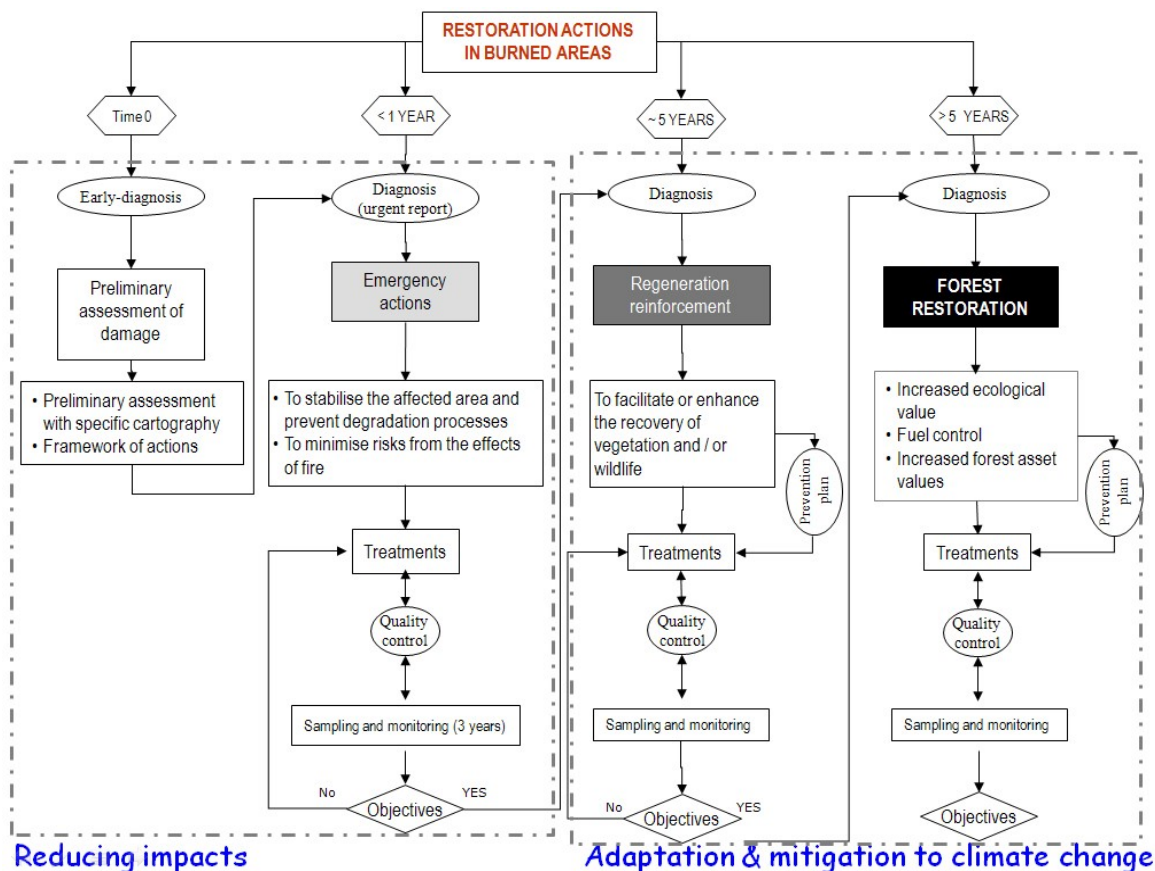


Figure 6—Scheme for assessing post-fire restoration in the Mediterranean Basin. Details in the text.

## Post-fire Decision Support System (POSTFIRE-DSS)

Based on the previous protocol, we have developed a Decision Support System to help post-fire decision making for MB conditions (Vallejo and Alloza 2012). The application, called the POSTFIRE-Decision Support System, includes four steps: 1) Identifying vulnerable areas, 2) Assessing fire impacts and emergency interventions, 3) Short- and mid-term planning and 4) Long-term planning. All the steps are not necessarily required depending on the stakes focussed on, the general objectives and level of risk,

### Identifying Vulnerable Areas

Forest and land managers need tools to identify priority areas for fire prevention and post-fire intervention. Using a Geographic Information System (GIS) and thematic cartography, vulnerable areas can be mapped on the basis of assessing not only the potential regeneration capacity of the vegetation, but also the post-fire degradation risk (Alloza and Vallejo 2006; Duguy et al. 2012, (fig. 7). The main factors considered are: 1) Estimating the vegetation regeneration capacity by using the combination of autosuccession potential (the ability to recover the pre-fire vegetation type) and the plant recovery rate, which determines how quickly plant cover will recover to protect soil against excessive erosion and runoff risk; 2) Assessing the short-term degradation risk based on the potential soil erosion risk; 3) Combining the regeneration capacity and soil degradation risk to produce a map of ecosystem vulnerability that enables the identification of priority areas for pre-fire prevention and post-fire intervention when a wildfire occurs. This type of approach can be used on different scales; for example, in the European Union (Duguy et al, 2013) or on a regional scale (Duguy et al. 2012).

### Assessing Fire Impacts and Emergency Interventions

The ecological impact of a fire partly depends on fire severity. It is critical to assess severity levels as soon as possible after fire. This can be done by either field surveys or using high resolution remote sensing, or a combination of both. Several published guidelines can be used to quickly assess fire severity and to identify areas for emergency interventions (e.g., USDI, 2003; Napper, 2006; Lutes, 2006; Pike & Ussery, 2006; Stella et al, 2007; Robichaud and Ashmun, 2012). The field survey protocol has been developed using standard forms (Alloza et al. 2014) to assess fire impacts. Depending on site conditions and fire impacts, emergency interventions may be required.



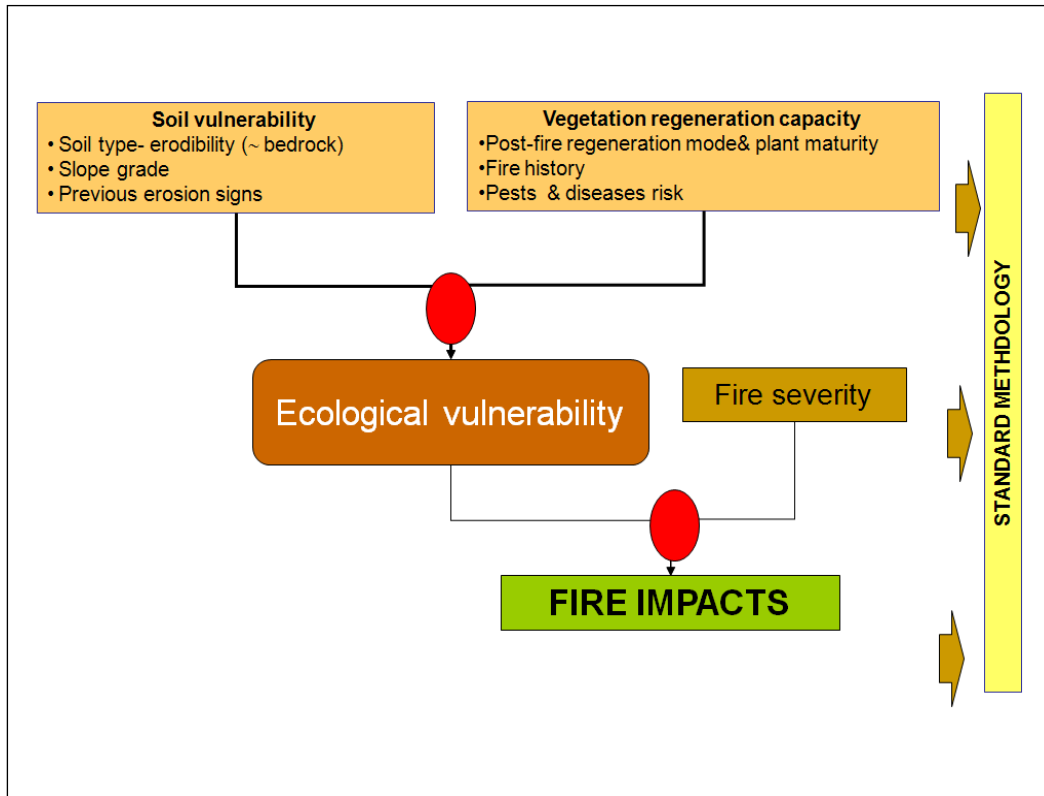


Figure 7—Outline of the criteria used to assess ecological vulnerability and fire impacts.

Emergency interventions, sometimes called first-aid rehabilitation, aim to stabilize the affected area, to prevent degradation processes and to minimize risks for people (Robichaud et al. 2000). They focus on soil protection to avoid erosion and to decrease water runoff and risk of flooding, to reduce risks to people and property (e.g., hazard from falling burned trees), and/or to prevent tree pest and disease outbreak. They should be carried out as soon as possible, in a few weeks, or a few months after the fire at the most, and preferably before the first (often heavy) autumn rains in the Mediterranean region. In principle, early emergency approaches should not essentially be modified because of climate change as only moderate rain intensities immediately after fire may produce already serious erosion, whereas mid- to long-term restoration should very much consider climate change projections.

The Decision Support System displays a screen with the variables needed to characterize site conditions and fire characteristics. Variables are grouped into four blocks: site conditions, vegetation (composition and cover) before fire, fire severity, and early post-fire soil conditions (fig. 8). The most unfavourable site conditions are: 1) high risk of heavy autumn rain; 2) poor resprouters cover before fire; 3) erodible soils; 4) steep slopes. These risk situations can be exacerbated for high severity fires.

**Emergency actions**

**SITE CONDITIONS**

Risk of intense precipitation ( Return period 30 mm maximum precipitation in 24-h)

Return period  $\geq 5$  years  
Return period  $< 5$  years

Previous symptoms of erosion

None / Low  
Moderate  
High  
Severe

Slope

$< 15\%$   
 $15 - 30\%$   
 $31 - 45\%$

Aspect

North  
South

Soil bed rock

Limestones with marls: Flysch; Calcareneites or sandstones,  
Marls and limestones calcarenites or dolomites  
Clay; Marls; Granites; Siltstone; Clay with silt or marls  
Sands; Boulders

Terraces

No terraces or terraces in good condition  
Scattered landslides  
Widespread landslides

Pest outbreak

Slight or none  
Moderate  
High

Number of fires in the last 20 years

0  
1  
>1

**VEGETATION**

Canopy cover of mature serotinous pines (e.g. *P. halepensis*, *pinaster*,...) or resprouter trees (e.g. *salix*,...)

High ( $>60\%$ )  
Medium ( $30 - 60\%$ )  
Low ( $0-30\%$ )

Resprouter shrub cover

High ( $>60\%$ )  
Medium ( $30 - 60\%$ )  
Low ( $0-30\%$ )

Resprouter herbaceous cover

High ( $>60\%$ )  
Medium ( $30 - 60\%$ )  
Low ( $0-30\%$ )

Resprouter total cover

High ( $>60\%$ )  
Medium ( $30 - 60\%$ )  
Low ( $0-30\%$ )

**FIRE SEVERITY**

Litter

Not affected  
Partially burned  
Consumed

White ash

Absent  
Punctual  
Generalised

Soil hydrophobicity

None or low  
Medium  
High

Trees

Stem partially affected.  $>80\%$  crown green  
 $80-50\%$  crown green  
 $>50\%$  brown crown  
Leaves consumed

Shrubs

Almost not affected  
Plants with some green leaves  
Small branches not consumed  
Only thick branches left ( $>6$  mm)

Herbs

Green leaves remaining  
Partially burned  
Consumed

**POST FIRE SOIL CONDITION**

Degree of soil crusting

Slight  
Moderate  
Severe

ASSESSMENT

Return

Help

Figure 8—Screen showing the variables and ranges considered for the assessment of short-term fire impacts and the need for emergency rehabilitation actions (POSTFIRE-DSS).

### Short- to Mid-term Planning (2-5 yrs.)

Short- to mid-term interventions aim to facilitate the natural regeneration of keystone species (trees and tall shrubs) and to reintroduce the key species that have been eradicated by fire or their abundance has been severely reduced. The application requests information about the presence and abundance of resprouter species, and on the density of natural regeneration of tree species. The criteria used in the assessment are shown in table 1.

### Long-term Planning ( $>5$ yrs.)

This is related to long-term ecosystem restoration, in accordance with the established management objectives (Vallejo et al., 2009). In general, long-term restoration actions are needed when the ecosystem's resilience capacity has been vastly altered and cannot be naturally recovered. In the MB, this is often caused by an unprecedented combination of fire regime and other disturbances. The long-term perspective should attempt to recover ecosystem integrity in accordance with ecological restoration concepts. In addition, as fire hazard is inherent in the

**Table 1—Criteria and recommendations used in the regeneration assessment**

Regeneration	Cover/Density	Assessment	Recommendation
Woody resprouters cover (shrubs and trees)	> 60%	Good plant cover regeneration expected	No vegetation reinforcement required for increasing fire resilience
	30-60%	Intermediate plant cover regeneration	Reinforcement with woody resprouter plantation
	< 30%	Poor plant cover regeneration	Containerized seedling plantation with resprouter species.
Tree density	> 3000 seedlings/ha	Overstocking: density control with selective thinning.	In pine forests, thinning to reduce fuel accumulation, to increase seed production and limit crown fire propagation. In broadleaved forest (coppices), cleaning stools to promote high forest structure
	1000-3000 trees/ha	Good tree species regeneration	Do nothing.
	200-1000 trees/ha	Poor tree species regeneration	Open woodland regeneration.
	< 200 seedlings/ha	Very poor tree regeneration	Containerized seedling plantation of tree species, often hardwoods and conifers combined.

Mediterranean, fire prevention principles should be incorporated into post-fire restoration strategies on ecosystem, and especially, on landscape scales. Landscape ecology principles should be considered when designing new plantations.

This long-term planning can have diverse objectives in accordance with the specific socio-economic and ecological conditions of the affected area. Depending on the situation, restoration may include type-conversion to other forest types, afforestation or reforestation and, in general, promoting ecosystem services in the socio-ecological systems context.

## Implementation

Wildlands in the Mediterranean have been negatively selected by humans for centuries because the most productive soils were devoted to agriculture and pasture. Soils in wildlands are usually shallow, stony and develop on steep slopes and crests (Vallejo et al., 1999). Only in recent times have abandoned terraced lands presented better, deeper soils, made available to recolonize natural vegetation and for restoration purposes.

The restoration of degraded lands should take into account poor soil productivity and the characteristic drought occurrence of the Mediterranean climate, which is expected to worsen in the near future (IPCC 2012). Therefore, when the reintroduction of keystone plant species is considered in restoration, containerized seedling plantation should be designed to overcome transplanting shock. This applies to both post-fire restoration and the restoration of degraded lands caused by other disturbances. Indeed, drought is the main cause of seedling mortality for plant recruitment and in plantations (Vallejo et al., 1999).

Technical options to reduce water stress in plantations include (Chirino et al. 2009; Vallejo et al. 2012b; Vallejo et al. 2012c): 1) Species and provenances

selection, including seed collection and conservation quality criteria; resprouting sclerophyllous tall shrubs and trees is preferred because of their high post-fire regeneration capacity, and also because of their low rate of risky fuel upload as compared to seeder shrubs. Species and provenances are selected by considering their water use efficiency. 2) Nursery cultivation techniques to produce high quality seedling acclimated to overcome transplanting shock. In our experience, the most successful techniques were drought preconditioning, the use of deep containers for species developing tap root (e.g., *Quercus* species), and the addition of hydrogel in the culture substrate to provide extra water supply immediately after plantation. 3) Soil preparation and amendment focus on improving water availability to seedling (Valdecantos et al., 2014). 4) Plantations using several native species, in contrast to traditional mono-specific pine plantations; 5) Tree-shelter for shade-tolerant seedlings. Tree shelters reduce transpiration demands, protect seedlings from small and domestic herbivores, and generate a shaded environment during the first years after outplanting. 6) Extant vegetation treatment: facilitation or competition? Frequently, extant shrubs have a nurse effect on introduced seedlings (for example, see Castro et al. 2002). However, this is not always the case and contrasting results may be obtained depending on site conditions (Maestre and Cortina 2004; Maestre et al. 2003). 7) Spatial configuration of plantations according to the spatial distribution of microsites, and also to landscape ecology and fire prevention principles; 8) Post-plantation care: in principle, it should be reduced to as much as possible to minimize costs.

## Concluding Remarks

The post-fire restoration assessment approach presented herein has proven applicable to representative fire prone ecosystems in the Mediterranean basin. It is still uncertain how applicable it might be to the other Mediterranean type ecosystems (MTE) in the world. In spite of the many common climate characteristics and plant adaptations in the various MTEs (Keeley et al. 2012), particularly between the MB and California, both of which share common Laurasia plant lineages, many differences appear in relation to land use history, the impact of disturbances affecting the fire regime and degradation processes (Vallejo et al. 2012b) and, hence, affect restoration needs and the associated technologies. For example, the long-term extensive land use history of the MB, and the recent widespread land abandonment in the European MB, are causing an unprecedented modification of ecosystems, fuels and the fire regime. Therefore, given the direct impacts on landscapes and ecosystems, and the indirect impacts on the fire regime, land use history can be considered the key driver to primarily shape MB landscapes. This is quite different in at least three of the other MTEs, but is no so different in Chile. Conversely, invasive exotic species are a major issue in most MTEs, but not so much in the MB, especially in relation to fire regime: MB fire-prone ecosystems are generally slightly invasive (so far) (Vallejo et al. 2012a). Finally, MB countries share a long-standing tradition of active and extensive afforestation to improve degraded lands, which could somehow be assimilated to the modern ecological restoration concept. This tradition is still probably influencing the proneness of MB policy makers and forest services to promote restoration projects, including plantations.

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