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Finally, although actions taken at the interface between science, policy and management are necessary, it is important to note that much needed scientific information is still lacking, particularly on the distribution, ecology and genetics of Mediterranean forest tree species, and new research initiatives in these areas are needed. These should be prioritized by, for example, focusing first on endangered tree species, choosing model species for various climatic situations or altitude ranges, or choosing model species to represent a number of genera. These options are not necessarily mutually exclusive, and science–policy–management interactions are needed for prioritization and to take action for adapting Mediterranean forests to the challenges posed by climate change.

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The future of Mediterranean forests and the sustainable delivery of their goods and ecosystem services are threatened by the rapid climatic changes that the region is experiencing (Palahi *et al.*, 2008; FAO, 2010a; see Chapter 1). These climatic changes have caused or contributed to tree mortality across the Mediterranean region (Bentouati, 2008; Chenchouni, Abdelkrim and Athmane, 2008; Semerci *et al.*, 2008) and are having negative impacts on the carbon and water balances of many Mediterranean forests (Martínez-Vilalta *et al.*, 2008; FAO, 2010a).

The already harsh climatic conditions for forest growth are projected to continue to deteriorate under all the Intergovernmental Panel on Climate Change (IPCC) greenhouse gas emissions scenarios. Such changes in climatic conditions have major implications for the future functioning and sustainability of Mediterranean forest ecosystems (Lindner *et al.*, 2010). Beyond vulnerability assessment, these changes require adaptation using appropriate existing practices and the development of innovative practices. Adaptive strategies are required to cope with multiple uncertainties about the impacts of increases in the frequency and intensity of extreme events; the capacity of current ecosystems to respond to changes; potential tipping points; the response of complex biotic interactions; and future responses to current adaptive measures. Therefore, adaptive strategies, including local-scale (*e.g.* silviculture and forest planning) and large-scale (*e.g.* land uses and regulations) activities, should be robust and flexible, and exit strategies might also be needed (*e.g.* to diversify rather than restrict the portfolio of forest reproductive material offered for use in plantations).

The importance of Mediterranean forests under climate change is threefold. First, projections of climate change in the region are particularly severe and the region's forests provide the main gene pool for future adaptation. Second, Mediterranean tree species that are threatened in their current ranges are potential resources for use elsewhere. Third, current Mediterranean forestry systems can provide know-how to other regions that could experience Mediterranean conditions in the future.

Water management

Most Mediterranean forests grow under water-limited conditions, with potential evapotranspiration higher than precipitation and actual evapotranspiration comprising up to 90 percent of annual precipitation. Trees are unable to reach their full potential level of transpiration, restricting the amount of carbon that can be fixed. Projected climatic changes will exacerbate these conditions.

Up to a certain point, forest management and planning can help to reduce tree water stress and increase the survival of forest stands. Management practices can also help to maintain or increase the biomass produced in a stand using less water (*i.e.* better water-use efficiency).

The volume of water used by trees by forest depends to a large extent on stand age (Farley, Jobbagy and Jackson, 2005; Jackson *et al.*, 2005) and density but depends mainly on variables such as leaf area index and canopy roughness. Both these are amenable to management control, and several proposals have been made (Vanclay, 2008).

Thinning may decrease the susceptibility of trees to drought stress (and enhance fire resilience) by increasing the availability of resources to the remaining trees (Gracia *et al.*, 1999; Gyenge *et al.*, 2011). Thinning may also improve plant water status and water-use efficiency (Ducrey and Huc, 1999).

Gas exchanges between trees and the atmosphere above the canopy depend to a certain extent on the structure of the canopy. The high degree of heterogeneity of tree height and shape in mixed forests creates wind turbulence that facilitates gas exchange in such forests. Planted mixed-species forest stands may have higher canopy roughness than even-aged pure stands, which may reduce transpiration (Forrester, 2007); thus, they can continue carbon fixation when atmospheric conditions become limiting for fully exposed crowns. Afforestation design can modify atmospheric coupling of forests by, for example, the use of mixed species or softening plantation edges through thinning and pruning.

Plantations of mixed species may have greater production efficiency (*i.e.* the transpiration: assimilation ratio) compared with pure stands. For example, Acacia mearnsii (N-fixing species) and Eucalyptus globulus doubled their production when planted together in mixed stands (Forrester, 2007). This is probably due to the heterogeneous structure of such stands (tree height and shape).

Integrated fire management

Integrated fire management is a concept for planning and operations that include social, economical, cultural and ecological evaluations with the objective of minimizing the damage and maximizing the benefits of fire. Integrated fire management combines prevention and suppression strategies and techniques and the use of prescribed and traditional burning (Rego *et al.*, 2010) (figure 4.4).

Rather than viewing fire as a disaster, integrated fire management tackles its full range of effects, both detrimental and beneficial. Fire has always been used for various purposes in the Mediterranean region, but the benefits of fire are in danger of being forgotten. These two aspects of fire – its detrimental and beneficial effects – represent the so-called paradox of fire2 (Fire is used in rangeland management and agriculture, as well as in forests, and the long fire history in the Mediterranean region has created ecosystems that need fire for their sustainability.

In integrated fire management, the objective is to minimize the inappropriate use of fire and to maximize its appropriate use. Appropriate use includes good practices in the traditional use of fire, prescribed burning, and suppression fire. Rural communities have traditionally used fire for land and resource management based on accumulated know-how. Prescribed burning is the application of a fire under specified environmental conditions that allow the fire to be confined to a predetermined area and to attain planned resource management objectives. Suppression fire is the application of a

2 Fire can be used both in the context of prevention in order to decrease the quantity of biomass (prescribed burning) and as a tool for suppression during the fire season.

Figure 4.4. Prescribed burning in Spain
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fire to accelerate or strengthen the suppression of a wildfire.

The concept of integrated fire management was developed outside Europe but was recently proposed for Europe under the project Fire Paradox and could be extended to the Mediterranean region (Silva *et al.*, 2010). Usually, integrated fire management involves community-based approaches, sometimes called community-based fire management, which integrate the activities and make use of the capabilities of rural people to meet the overall objectives of land management and forest protection. There is a need to regulate traditional fire use. On the other hand, in some regions, good practices in traditional burning have been maintained and should be consolidated. Community-based fire management requires a permanent dialogue between professionals and the rural population and an acknowledgement of the need for fire use. Recognition of the fact that fire exclusion isn't appropriate for many Mediterranean forest types is very recent. A move from a fire exclusion policy towards a "learning to live with fire" objective is needed, since fire won't be eliminated from the Mediterranean environment, with its human-dominated fire regime. This vision, including an intersectoral consideration of the multiple purposes of fire use, should drive approaches on public awareness and increase community fire preparedness and response capacity, especially at the wildland–urban interface.

Using and preserving forest genetic resources in forestry and habitat conservation

FGRs are an essential resource for forest adaptability in the face of an uncertain future (see "Biodiversity, forest genetic resources and climate change"). On the time scale foreseen for climate change – that is, a few generations of trees at least – the challenge is to combine two objectives: to accelerate the genetic adaptation of tree populations to new environments; and to preserve their adaptive capacity for further evolution. The value of FGRs is not limited to traits of interest today, such as drought resistance: given the multiple uncertainties about future biotic and abiotic environmental constraints (*e.g.* the emergence of new diseases), the full suite of diversity needs to be conserved. To ensure this, more may need to be done, in particular related to the following:

- Guidelines on seed movement across provenance regions may need to be re-examined to include the movement of FRMs to areas where they may better suit the future climate.
- Breeding programmes for Mediterranean trees should focus on traits related to increased drought resistance but should also consider overall resilience to stochastic changes. This will require a significant shift in the Mediterranean tree-breeding paradigm.
- As the climate changes, forest health will be increasingly affected by new pathogens and pests, and breeding and the identification of natural resistance are needed urgently.
- Seed collection practices should ensure representative sampling of the genetic diversity by collecting from more than 30 trees per collected stand.

Forest management can favour evolution through natural selection by encouraging the emergence of new genotype combinations by mating unrelated trees or by avoiding counter-selection of fitness-related traits. Further research is required on the fitness value of traits that are selected for in silviculture (*e.g.* the extent to which juvenile vigour is associated with drought resistance). Forest management can also help maintain the evolutionary potential in stands by varying stand structure and density, maintaining connectivity between forest patches and accelerating rotations.
At the same time, conservation strategies need to be strengthened and the identification of ecologically marginal populations that may serve as sources of valuable adaptations encouraged. Although ex situ conservation may be the only alternative for species and provenances under extreme threat of extinction, dynamic in situ conservation networks should be preferred, particularly in the context of climate change (Koskela *et al.*, 2012). Indeed, it is in situ where adaptation is challenged by new environmental conditions, and it is thus in situ where evolutionary novelty is created via natural selection. The Mediterranean region is still underrepresented in the coordinated pan-European FGR conservation network developed by EUFORGEN (Koskela *et al.*, 2012; Lefèvre *et al.*, 2012). The same criteria and standards could efficiently be used to extend the conservation effort on FGRs to the entire Mediterranean region. It is also crucial that conservation networks cover the full range of environmental heterogeneity (including marginal stands of low production value), as well as the establishment of experimental afforestation in new environments resembling those predicted in the near future by ecological models.
Where possible, habitat restoration using ecological engineering technologies should be promoted, especially in areas where human impact is highest, such as in the vicinity of large urban, industrial and agronomic centres. Such efforts should be strongly connected with gene conservation approaches to ensure that the adaptive value of the reproductive materials used is properly considered. Awareness-raising efforts should aim to ensure that the managers of habitat restoration projects understand the importance of selecting the most appropriate reproductive materials: a failure to use locally adapted and evolutionary resilient material will likely impair restoration projects. There might be a need for regulation, since many restoration projects do not currently fall within the reach of national forest laws and escape the need for FRM control.

Integration

In the rapidly evolving environmental, social and economic context, forest management objectives, decision-making tools and strategies need to be adapted to potential new conditions and new demands for forest goods and ecosystem services. For example, improving the water balance or creating appropriate stand structures that reduce the vulnerability of forests to climate-driven risks (*e.g.* fire and drought) might appear to be the most relevant management objectives in certain Mediterranean areas (FAO, 2010a). However, developing new management strategies adapted to climate change is not easy because of the underlying uncertainties in climate change projections, the incomplete understanding of tree responses to the changing climate, and the lack of knowledge and information on how forest management might affect the adaptation of forest ecosystems to the changing climate and related risks.

Adapting forest management to changing and uncertain conditions requires compromises between short-term and long-term objectives, for example between achieving mitigation today without increasing vulnerability and without counteracting selection for the future, and achieving selection today without eroding adaptive capacity in the future. Therefore, a major interdisciplinary research effort is needed to rethink current forest management objectives to address new demands (*e.g.* water versus biomass) and conditions (risks); optimize forest management strategies based on an understanding of the genetic and physiological mechanisms underlying the response of tree species to climate change; and explore the effects of climate change on optimal management strategies for various objectives (*e.g.* profitability, water and biomass production) (Birot *et al.*, 2011). To support these research fields, the most recent emerging methodologies (*e.g.* in modelling and statistics) and tools (*e.g.* in genetics) should be used and collaboratively shared by the scientific community working on Mediterranean forests.

To support the development of adaptive forest management, new forest management decision-support tools (Muys *et al.*, 2010) are needed to integrate the following: dynamic forest simulation models based on genetic and physiological processes controlled by climatic and edaphic factors; optimization techniques that can aid in finding the optimal combination of management variables (*e.g.* thinning intensity and periodicity, and rotation length); and user-friendly interfaces that facilitate the selection of, for example, climate scenarios, management objectives, site variables and economic parameters, and provide visual and summarized information on optimal forest management strategies for the selected variables. One of the few examples of an operational decision-support tool for Mediterranean forests is Gotilwa+, developed as part of the European MOTIVE project, which supports forest management design for the optimal delivery of multiple ecosystem services under climate change.

Legal aspects should also be addressed. In times of economic constraint, most managers operating in a market-based economy will seek the cheapest solution, even when it may be suboptimal in other respects. Legal instruments, based on ecologically and genetically sound scientific findings, should set minimum requirements for forest practice.

Conclusion

Adaptive management is not only urgent for the Mediterranean forests themselves but also for regions that might experience a shift in climate towards a typically Mediterranean one in the future and which could benefit from Mediterranean FGRs. Action is needed now towards adaptation and the development of new forest practices. It is challenging because of the uncertainty. The state of the environment in 50–100 years cannot be predicted with any certainty, but the direction of change is clear. Thus, over the long term, adaptive strategies can be thought of in terms of trajectory. Innovative forest practices are required, and the challenge is to combine immediate-term and long-term objectives.

Experimenting with innovative forest practice takes time, and it is needed. In the short term, however, knowledge can be gained from uncontrolled specific situations, such as exceptional climatic events. For this, there is an urgent need to improve the documentation of the current situation of Mediterranean forests regarding climate change, such as long-term climatic data, vegetation maps and records of past silviculture (including of the origins of planted material). The lack of such documentation frequently limits the capacity for analysis in specific situations. If accurate assessment data were available, modelling could help to deal with uncertainty.

New research lines have been identified. Networking and collaboration with and beyond the scientific community working on Mediterranean forests should be encouraged. Knowledge transfer, expertise and innovation can only be achieved by building and fostering close links between science, policy, management and society.

Forest fire prevention under new climatic conditions

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Forest fire regimes depend on many factors that change over time, such as weather, fuel load, type and condition, forest management practices, and socio-economic context. Changes to a forest fire regime can have significant impacts on natural resources and ecosystem stability, with consequent direct and indirect economic losses. On the other hand, active forest and fire management can help counteract the impacts of climate change.

Although most forest fires in the Mediterranean region are caused by human activity (*i.e.* have anthropogenic ignition sources) it has been shown that, for Mediterranean Europe, the total burnt area changes significantly from year to year, largely because of weather conditions (Camia and Amatulli, 2009). In many cases, extreme fire danger conditions in southeastern Europe leading to major wildfire events have been driven by an explosive mix of strong winds and extremely high temperatures, following prolonged periods of drought (San-Miguel-Ayanz, Moreno and Camia, 2012).

Climate is an important driver of wildfire potential over time (Flannigan, Stocks and Wotton, 2000), but recent studies (Pausas and Paula, 2012) have shown that, under Mediterranean climatic conditions, fuel structure (*i.e.* the amount and connectivity of burnable resources) is more important than the frequency of climatic conditions conducive to fire. Landscape features, such as vegetation and fuel characteristics, are also important in shaping current and future fire–climate relationships at a regional scale. Thus, future changes in fire regime might differ from what might be predicted by climate alone. Future modelling efforts should include landscape components in climate change scenarios to improve projections for the Mediterranean region.