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## Mediterranean forests, unique ecosystems?

A Mediterranean forest is defined as a forest growing under a Mediterranean climate characterized by a marked rainfall deficit in summer that causes the vegetation stress (Gauquelin 2011). Forests in the Mediterranean basin cover more than 48.2 million ha of which 35 million are located in southern Europe, 8.8 million ha in the Middle East and 4.4 million ha in North Africa (adapted from Quézel and Médail 2003; Fady and Médail 2004). The seasonality of air temperature and precipitation, which is the most distinctive feature of Mediterranean-type climates, has major implications for vegetation functioning, as it limits the active growing season to the humid period between fall and spring (Blondel and Aronson 1999). This period ranges from 5 to 10 months according to distinct climatic subtypes.

### Structure and biodiversity

As reported by EEA (European Environment Agency, 2006), evergreen and sclerophyllous plants, usually but not exclusively represented by deciduous forests, are particularly common in humid and perhumid bioclimates, underlining the complexity of forests in the Mediterranean basin (Quézel and Médail 2003). In the Mediterranean region, the term “forest” does not always refer to high, dense stands of trees with a closed canopy, and three main forest types (forest *sensu stricto*, pre-forestal structure and pre-steppic structure) can be distinguished (Quézel and Médail 2003) according to tree density and height.

The Mediterranean basin (*sensu lato*: 2% of the Earth’s surface) is one of 34 identified biodiversity hot-spots (Médail and Quézel 1997; Benabid 2000). Mediterranean forests include 290 woody species versus only 135 for non-Mediterranean Europe, including a large number of endemic species (e.g. *Tetraclinis articulata*, *Argania spinosa*, *Juniperus thurifera*, *Quercus suber* and fir species such as *Abies pinsapo*, *Abies marocana*, *Abies nebrodensis*; Blondel et al. 2010) and high genetic diversity (see Fady 2005 for conifer species) with high levels of genetic originality in refugia (Médail and Diadema 2009).

### Functioning

The specificity of Mediterranean forest ecosystem functioning (phenology, primary and secondary plant metabolism, carbon storage, productivity, water cycle, redistribution of nutrients and microorganisms activity) is linked to the

long period of drought, with highly discontinuous functioning linked to alternating dry and wet periods. In these conditions, phanerophyte evergreen and sclerophyllous species dominate, but are not the only type, and deciduous forests, mainly oak forests, are also well represented, particularly in humid and per-humid bioclimates, underlining the complexity of Mediterranean forests (Quezel and Medail, 2003)

Mediterranean plant species produce numerous plant secondary metabolites (PSMs), most of which are terpenoids (volatiles) and phenolics (non-volatiles). PSMs, together with morphological traits (sclerophylly), allow these species to cope with climatic stress (Chaves and Escudero 1999). Plant investment in PSMs affects numerous ecosystem function processes and biodiversity (Fernandez et al. 2013, 2016; Chomel et al. 2014).

Decomposition of organic matter, a key process for forest functioning, is also determined by the period of drought. Controlled by biotic factors such as decomposers (bacteria, fungi, invertebrates), and by the biochemical composition of the plant litter (i.e. plant diversity; Santonja et al. 2015a), this process is linked to the environmental conditions, particularly soil water content under a Mediterranean climate. Marked dry summer periods result in a discontinuous decomposition process that is closely linked to water availability (Chomel et al. 2014). The diversity of mycorrhizal fungi present in these ecosystems is crucial, as these symbiotic fungi are belowground linkers between plants that facilitate their host plant's access to soil nutrients (Barto et al. 2012) and to the soil water compartment.

Widely spaced trees, mainly in pre-forestal and pre-steppic stands, have a major impact on forest functioning (Joffre and Rambal, 1988; Gauquelin et al. 1992), leading to the very marked spatial heterogeneity. In man-made ecosystems characterized by a savannah-like physiognomy, e.g. the *dehesas* and *montados* of the Iberian Peninsula, scattered trees lead to high spatial heterogeneity in ecosystem functioning.

## Dynamics

Ecosystem dynamics on the southern and northern shores of the Mediterranean basin are quite different (Gauquelin 2011). The northern shore is characterized by coastal urbanization and the abandonment of agricultural and pastoral land, leading to spectacular forest re-colonization; for example, in the French Mediterranean area, between 1980 and 2011, forest covering more than 1.4 million ha increased by between 0.5% and 2% a year (IF 2013; FAO 2013), which corresponds to approximately 16.000 ha a year. On the southern shore, degradation is still intense and is causing the fragmentation or disappearance of different habitats including forest, with for example, an annual decrease of 0.5% in Algerian forest between 1990 and 2010 (FAO 2013).

## Mediterranean forests: a long history of agro-sylvo-pastoral management by rural populations and interactions between local societies

Most forests in the Mediterranean region are the result of a long history of agro-sylvo-pastoral management by rural populations and of interactions between local societies (Blondel 2006, Aubert 2013). In spite of the strong influence of local management practices and socio-political relationships on the *production* of Mediterranean forests, most studies insist on the *negative impact* that local societies have had on “natural forests” and on their biodiversity (deforestation, forest degradation and desertification). In contrast, Michon et al. (2007) analyzed the *co-evolution* between forest ecosystems and their related human populations in terms of *domestication* (of trees, ecosystems and landscapes), and considered the resulting forests (*domestic forests*, or *rural forests*; Genin et al. 2013) as biocultural, or socio-ecological products for agroforestry systems like those found on the Iberian Peninsula (Joffre et al. 1987, 1999).

Mediterranean forests have been, and in certain regions, still are, intensively used for rural livelihoods. They provide a wide range of resources including human food, medicines, ritual material, firewood, construction wood and forage for livestock. These forests are characterized by different levels of formal and informal appropriation by rural communities and are shaped by specific, refined knowledge and practices.

## Mediterranean forests and climate change

Climate models predict increases in both temperature and drought conditions in the Mediterranean (Schleussner et al. 2016). These changes are expected to increase the frequency, intensity and duration of drought, especially in summer (IPCC, 2014; Polade et al. 2014). The response of Mediterranean forests to such extreme climatic events is poorly understood, because conducting controlled field experiments to mimic such conditions is costly and difficult at a large scale without introducing environmental modifications. Different *in natura* platforms have been implemented in different types of forest in France, with rain exclusion devices that make it possible to apply a precipitation scenario close to the projections made by models for the end of the 21<sup>st</sup> century. Holm oak at Puechabon (Limousin et al. 2008, 2009, 2012), Aleppo pine at Font Blanche (Gea-Izquierdo et al. 2015) and downy oak at O<sub>3</sub>HP (Santonja et al. 2015b)

have been the subject of such experiments. Results showed that changing rainfall patterns will (i) directly affect the production and decomposition of litter (Santonja et al. 2015b), and (ii) the emissions of volatile organic compounds (Staudt et al. 2002, 2003; Genard et al. 2015). There is a plan to set up a network of experimental stations around the Mediterranean basin with simpler and less expensive devices to monitor the effects of climate change on other important forest ecosystems and under other bioclimates.

Recent studies in northwestern Africa reported recurrent drought events from the second half of the 20<sup>th</sup> century on (Touchan et al. 2010; Linares et al. 2011; Kherchouche et al. 2012, 2013; Slimani 2014). Touchan et al. (2008) showed that the 1999-2002 drought was the worst in northwestern Africa since the middle of the 15<sup>th</sup> century. This suggests climate conditions are limiting for tree growth and affect the geographical distribution of drought-sensitive species, especially those at the edge of their range. The 1999-2002 drought event triggered substantial mortality in *Cedrus atlantica* forests where, in some areas, stands disappeared completely (Zine El Abidine 2003; Linares et al. 2011; Kherchouche et al. 2012, 2013; Slimani et al. 2014), and even in other tree species reputed for their drought hardiness, including *Pinus halepensis*, *Quercus ilex*, *Quercus suber*, and *Juniperus thurifera* (Allen et al. 2010).

Extreme climatic events could cause major disruption of Mediterranean forest functioning, increasing soil erosion, the frequency and intensity of forest fires, and pest outbreaks (Moriondo et al. 2006; Lindner et al. 2010). These disturbances will put a number of important ecosystems services at risk (Schröter et al. 2005). In this context, new ways of increasing the resistance and resilience of Mediterranean forests need to be developed, including those that harness the full potential of Mediterranean forest genetic resources (Lefèvre et al. 2014). Favoring mixed pine-hardwood species stands is increasingly proposed as a strategy to enhance forest resilience (Pausas et al. 2004). But it is also important to prepare the future of managed stands by careful selection of species in their optimum site conditions favoring more resilient species to future climate and making them less vulnerable. Partial thinning of some stands to limit competition is a solution to be recommended in some cases potentially linked with the wood energy sector, as well as protection against fire in the case of degraded stands at risk of desertification.

## Conclusion: reconciling particular ecological functioning, biocultural heritage and threats

Linking different elements allows us to propose an integrative and original outlook for Mediterranean forests:

– Linking basic and applied research: exploiting all scientific results should enable the identification of a successful strategy for the preservation and development of Mediterranean forests. Knowledge of the different levels of biodiversity could help preserve Mediterranean forests. At the species level, genetic diversity studies and the adaptive potential of a given species could help understand its reactions to environmental change. At the community level, understanding interactions between different species could lead to dramatic changes in reforestation practices. For instance, identifying the mycorrhizal community of some trees used in reforestation programs and the nurse effect of some shrub species on these trees could optimize large scale reforestation programs that take climate change into account, reduce the cost of watering and increase the success rate of these plantations. On the other hand, climate modelling applied to species distribution and genetic exploration of marginal populations can help predict shifts in species range and reduce the conservation actions required.

– Linking hard sciences, humanities and social sciences: understanding Mediterranean forest ecosystems and their future must first integrate 1) the secular human-forest interactions that have shaped functional cultural landscapes, and 2) the ecosystem services provided by these forests to secure both overall diverse ecosystems and livelihoods.

– Linking forestry, agricultural and social approaches and objectives: forests and the human populations living in and from these forests have to be protected in a global, comprehensive approach that takes both biological and cultural diversity into account. This requires truly participatory methods (i.e. not forcing local populations to participate in projects designed by foresters or biologists that aim at preserving forests *per se*, but conducting negotiations in which all stakeholders have a say).

– Linking the northern and southern Mediterranean: the forest structure, dynamics and threats are very different on the two shores of the Mediterranean and comparing the different situations is indispensable to understand the overall evolution of Mediterranean forests in the context of climate change.

– Linking “nature” and productive systems: particularly in the Mediterranean basin. This link refers to the continuum between “wild” and highly anthropized ecosystems that needs to be better understood to detect forms of uses able to guarantee the sustainability of these sensitive forest ecosystems and that of local livelihoods.

Mentioning the need for these links may sound like “praying for a miracle” since it has little to do with what is happening today. It is also difficult to report true “success stories” in developing productive “biocultural” approaches, i.e. combining ecological and cultural approaches for a better understanding and management of Mediterranean forests, as these two approaches are generally barely connected. Foresters, biologists, local populations and social scientists need to join forces to define a desirable “state of conservation” for Mediterranean forests, one that takes flora, fauna, and ecological services as well as local

knowledge, practices, and production, into account. Practical measures to achieve, monitor and maintain this state will have to be invented, mobilizing scientific as well as local indicators of “degradation”, regeneration practices, protection measures, for example combining the protective enclosure methods of foresters or *agdal* (a traditional forest management system in the Moroccan High Atlas practices of local populations). This can only be done if local populations are included in the definition of conservation management objectives from the very beginning. The same global model can be mentioned for cork oak forest, formerly a “cultural forest” in the northern part of the Mediterranean basin that was “naturalized” after local cork oak management practices were abandoned, and that is currently severely affected by forest fires. Conservation of the cork-oak forest may reactivate local farmers’ interest in ecosystem management that combines cork, pastoral and agricultural production. Such management models still exist in Spain and in the southern Mediterranean basin and could inspire the rehabilitation of abandoned cork oak forests in the North.

The aim of this brief synthesis was to highlight both the risks faced by Mediterranean forest ecosystems, and the opportunities they represent for sustainable development including for humans and human activities. The idea is to consider 2100 not only from the point of view of projected climate change but also possible changes in land use and socio-economic aspects, and to make proposals in this direction.

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# The Mediterranean Region under Climate Change

A Scientific Update

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# The Mediterranean Region under Climate Change

A Scientific Update

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