Biodiversity of Mediterranean woodland ecosystems in a changing context: understanding for managing

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Introduction

The Mediterranean basin which is located at the crossroads of three continents is characterized by highly specific features including i) a dense human population (*ca* 460 million people), ii) contrasted climatic conditions, iii) an exceptional diversity of landscapes, and iv) an unique historic and cultural legacy. As a result of its geographical location and habitat diversity, this region is one of the 34 biodiversity hotspots so far identified around the world but it is also facing hot challenges in relation to environmental and developmental issues. In this unique and original eco-region, and in particular on its southern and eastern rim, local economy still depends to a large extent on natural resources. In a context of a marked demographic expansion, climatic uncertainty, energy crisis and other components of global change, the question of meeting needs of human populations is a crucial matter. How to provide sustainable basic needs such as water and food? How to preserve soil resources and fertility? More generally, how to provide the broad range of goods and services that ecosystems generate for the well-being of humans, which in turns raises the question of how to balance the needs between humans and ecosystems through integrated land-use planning and management?

Mediterranean woody ecosystems, forest, various types of matorrals and rangelands, are characterized by a high level of diversity from genes to landscapes. This diversity is a key driver of ecosystem evolution and resilience. Nowadays, nobody would claim that such a biological diversity should be kept in unchanged. This would be both impossible and undesirable. A crucial challenge is to better understand ecological and evolutionary processes, to use them and/or to enhance them for adapting woody ecosystems in the context of rapidly changing ecological conditions by making them more resistant and resilient. The aim of this paper is to address some relevant issues related to: i) the Mediterranean woodland ecosystems as biodiversity hot spots in a changing climatic context; ii) the spatio-temporal dynamics of woody ecological systems in response to climate and land-use changes; iii) the genetic diversity of woody plants as a background of evolutionary processes as a response to habitat and climatic heterogeneity, and iv) investigate some challenges and opportunities for improving woodland ecosystems and their diversity

1 Mediterranean woodlands ecosystems: biodiversity hotspots

The determinants and drivers of biodiversity in the Mediterranean region include the many processes of immigration, extinction, sorting processes, and regional differentiation that occurred in the region in the course of a long history which is rooted in a deep past of several million years. The main determinants biodiversity are related to the complex tectonic dynamics of the basin and orographic heterogeneity of a region which has been squeezed between the major continental land masses of Africa and Eurasia. In addition, climatic features, biogeographical issues, and anthropogenic drivers and factors contribute as well. The periodic oscillations of glacial and interglacial episodes during the whole Pleistocene played a key role in moulding and shaping present-day communities, species, and populations. Much of contemporary genetic diversity is primarily a legacy of the differentiation processes that occurred wherever and whenever biota were restricted and separated in isolated refugia, notably the large peninsulas of the northern shores of the basin, but also in many isolated localities where local microclimates allowed for the persistence of temperate biotas. This has resulted in the exceptionally high levels of endemism that characterize many groups of terrestrial plants and animals. The long-lasting processes that determined the diversity of plant and animals produced a biological legacy that has been deeply modified by humans through transformation of ecosystems, degradation of habitats, and persecution of animals. However, biological diversity remains exceptionally high with endemism rates at the scale of the whole basin amounting to 50% of the species in vascular plants (23 000 species), 63.5% for freshwater fishes (250 species), 48% for reptiles (355 species), 64% for amphibians (106 species), 25% for mammals (197 species), 17% for birds (366 species) and 46% for butterflies (321 species).

2. Spatio-temporal dynamics of woody species as a response to climate and land-use changes

Environmental changes always occurred in the Mediterranean basin but they are accelerating as a result of the combination of millennia land use practices and global change, especially climate warming. They will have profound consequences on species and communities. Population dynamics as well as upheavals of human societies have traditionally been a major driver of changes in the Mediterranean Basin. But the situation is becoming especially challenging because of the accelerated rate of urbanisation, mostly in coastal areas. In addition, forest contrasted rates of forest dynamics with *ca* 2% per year recover in the northern bank of the basin whereas forest loss still reaches 2% in the southern bank make the differences between the two sides of the basin particularly worrying. Due to their high exposure to human activities and sensitivity to climatic conditions, Mediterranean ecosystems appear to be especially susceptible to the impacts of global change.

Biological diversity is threatened by invasive alien species, which homogenizing effects on communities. Invading plants are not a real threat in most habitats, but there is currently a trend of alien plant species spreading rapidly in various ecosystems, especially along the coast. Predictions on climate change in the Mediterranean Basin lead to a series of expectations, which could make the Basin more severely hit by climate warming than other parts of the Palaearctic. Climate warming has already many measurable effects on populations and communities, including shifts in the distribution of species and changes in life history traits of many species.

3**. Genetic diversity of woody species, as background of evolutionary processes; its role for adaptation**

Organisms may respond in a variety of ways to global change, especially global warming. Responses include i) habitat tracking whereby populations will shift in altitude and/or latitude as their habitat move as a response to climate change, ii) phenotypic plasticity whenever the window of phenotypic plasticity is large enough for allowing individuals to cope with ecological change, iii) local adaptation if genetic responses to new selection regimes allow population to evolve. Several examples and simulation models show that tree species and assemblages of tree species do move as the thermal envelope and habitats to which they are adapted shift in latitude. Evidence that a plastic response to habitat change does occur is still scanty. Evolutionary adaptation to new selection regimes is expected in the future. However since the length of generation times of tree species is much longer that that of organisms with shorter generation times such as herbaceous plants or most animals, one may wonder whether most tree species will be able to adapt to new environmental conditions in context of rapid climate change. Prerequisites for adaptation to new local environmental conditions are that traits under selection are related to fitness and that they have some amount of heritability, which can be assessed from quantitative genetics approaches ($P = G+E+G.E$).

Examples will be provided showing that species for which data are available exhibit a large amount of genetic diversity. One of them is that of two vicariant pine species *Pinus* *halepensis* from the western part of the basin and *Pinus brutia* from the eastern part. These two closely related species have a fairly high genetic diversity and, globally the difference among them is clear. The within species genetic diversity (between populations) is even greater than the diversity among species:

Theory predicts that a cycle of genetic diversity results from feedbacks between fitness-related traits, demography and the genetic structure of populations. Local populations are assumed to be tightly adapted to their local environment which includes climatic and edaphic factors as well as biotic interactions. Actually, the current demographic structure of a population of trees is a component of the local environment so that demo-genetic models are already study models of responses to environmental change. Human action may have consequences on the dynamics of basic processes of genetic differentiation.

Whatever the adaptive (genetic) response of tree species to environmental change, the best option will certainly be to keep as much as possible the within- and between-population genetic diversity of populations because genetic diversity is presumably correlated to a wider range of phenotypic responses and a higher degree of adaptability to change. In any case, management options require to consider the dynamics of biodiversity in space and time.

4. Challenges and opportunities for managing Mediterranean woodland ecosystems and their diversity

Many management options of woodlands may be designed designed to maintain their diversity and sustainability in a context of environmental (and land use) changes. They are often site specific. However, the difficulty is that management decisions must be taken in a context of uncertainty regarding future changes and ecosystems evolution. Adaptive management, sound collective expertise, periodically revised management strategies and planning are key concepts to consider for adjusting to an inevitably moving target.

To keep within the limits of the format allocated to this presentation, we have chosen to highlight four major generic issues: i) organise spatial connectivity allowing communities and species to move and disperse; ii) set-up and implement observation/monitoring systems and networks at various scales; iii) change the paradigm of conservation in the context of climate change, by focusing more on evolutionary changes; iv) apply sound silvicultural principles for stands renewal.

4.1. Organise spatial connectivity allowing communities and species migration

A classical approach in nature conservation consists in setting up protected areas with the goal to protect and conserve habitat, species and populations. One example of this method is exemplified by the EU directive Natura 2000, resulting in a wide network of protected areas throughout Europe. However, such an approach assumes the long-term stability of environmental conditions, supposed in turn to guarantee the permanence of these habitats, species and populations. But things are more complex because of climate change and because natural processes are intrinsically dynamic. Therefore, the "sanctuary" approach of protected areas, albeit required in many cases, has to be complemented by a more straightforward strategy, consisting in a spatially explicit network connecting core protection areas with linear or landscape corridors, reducing landscape fragmentation and allowing communities and species to migrate in response to environmental changes. Designing such a network is rather complex, as the various communities have different requirements, so that priorities have to be fixed.

Such a strategy, developed at various scales, from local habitats to regions, has obviously major policy implications in terms of land use planning, and must be related to adjacent policies such as agriculture, rural development, transport, wildfires, etc.

4.2. Set-up and implement observation/monitoring systems and networks

Organising the biological connectivity of landscapes is one thing but it is not enough. A good knowledge of the actual evolution of woodland ecosystems in terms of dynamics, species composition changes, but also of fluxes of matter and energy between forest ecosystems and atmosphere is urgently needed. It would be a mistake to believe that this is an issue to be left only in researcher's hands. **Observation and monitoring of forest ecosystems are nowadays an integral part of management actions**.

Measures, observations and monitoring are addressed by a variety of methods applied at different scales. They include satellite imagery, aircraft borne sensors, instrumented forest research sites (eddy flux towers), dedicated experiments (rain exclusion), field observations on permanent plots, periodic inventories, etc. Data and parameters assessed are manifold. Just to mention a few examples we may cite the NVI (normalized difference vegetation index), a simple numerical indicator based on remote sensing measurements, reflecting whether or not the target being observed contains live green vegetation, atmospheric deposition, biogeochemical cycle and gas exchanges, plant composition, tree defoliation, etc.

These methods are implemented by various organisations operating internationally (trans-boundary), nationally, regionally or locally. Some countries have set up national systems for forest ecosystems monitoring. In France the network RENECOFOR consists in permanent plot covering several forest types, on which different variables are assessed with different levels of frequency and intensity. At an European scale, the International Co-operative Programme on Assessment and Monitoring of Air Pollution Effects on Forests (ICP Forests) operates under the UNECE Convention on Long-range Transboundary Air Pollution. One challenge is to make the different systems complementary, in order to make the best benefit of the data. This requires cooperation, concertation and integration in order to seek for maximal coherence between various systems. Concerning the southern and eastern Rim of the Mediterranean, this field offers large perspective for cooperation.

4.3. Change the paradigm of conservation in the context of climate change, by focusing more on evolutionary processes and changes

As evolution will take place anyhow, conserving the current ecosystems with their diversity is neither possible, nor desirable. It is crucial to realize that we have to change paradigm and move from a logic of preservation to a logic of dynamic evolution in which opportunities for management can be found by playing on evolutionary processes. It is of course a difficult matter, which requires good knowledge in evolution biology, but some basic management principles can be applied:

• maintain the current genetic diversity over the long term by using appropriate forestry practices.

• foster evolutionary processes to keep stands adapted to their changing environment as closely as possible. In this respect, it could be wise to speed up the generation cycle by decreasing the rotation time.

• act on or use the main drivers of evolutionary changes. These drivers may have a biological nature, for example the genetic content (the original one or after genetic enrichment by plantation) of the stand to be managed, or the dispersal of pollen and seed linked to stand density and structure (aerological properties). Other drivers depend on demographic factors such as, the size of the reproductive population, the mating systems, the generation overlap and the stocking (stand density). Lastly drivers related to environmental factors, biotic and abiotic, can be considered, such as selection intensity in the population of seedlings, positive

& negative biotic interactions (for example, seed predation).

• integrate multiple processes of the response to climate changes of various communities.

Some examples of application to silvicultural prescriptions are described in the section below.

4.4. Apply sound silvicultural principles in particular for stands renewal (regeneration)

A critical stage at which the forest manager can act, is the transition from one generation to the other, i.e. the regeneration, whatever it is: manual, artificial (plantation) or mixed.

Natural regeneration can provide positive features in terms of local adaptation, best local sampling, natural selection and local integration. But it may have also some negative consequences, in case the seed tree population has a small size or is genetically not diverse enough, or the number of seedlings too low, resulting in a new generation genetically too narrow to adapt to changes. Therefore, it is required to maximise the number of reproductive trees and the seedling density.

Plantation of local material can also provide local adaptation and selected material fairly integrated; but negative impacts might also be expected in case of poor sampling of trees on which seeds were collected, and of an initial low genetic diversity, resulting in a deficit of genetic diversity in the plantation for further adaptation. This can be counteracted by mixing the seeds coming from several stand within the region, and by using higher stocking (density plantation) to give room for natural selection in this constrained seedling population.

Plantation of non-local material may enhance the diversity and provide new adaptation, but there are also risks of mis-adaptation, demographic swamping and disturbances of the ecosystems. Using seed material from neighbouring regions, thus providing a broad genetic base can counteract these risks.

As a conclusion, a few additional recommendations related to woodland management, mainly based on common sense, can be suggested: i) do not put all your eggs in the same basket, keep the capacity for further adjustment of strategies; ii) use gradual adaptive response, and do not rely on miracle solutions; iii) record all movement of forestry reproductive material and keep on observing climatic impacts.