Forests of the Mediterranean region: gaps in knowledge and research needs

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Abstract

Mediterranean forests are characterised by a remarkable set of features that make them naturally and aesthetically attractive, on the one hand, but also quite fragile, on the other, therefore calling for careful strategies for their conservation and management. An exceptionally large variation of environmental conditions characterises the Mediterranean countries, where the environment can limit forest growth and succession but can also give rise, more often than it is supposed, to lush, mesic forest ecosystems, similar to those of central Europe. Moreover, Mediterranean forests contain an ample, plant and animal biological diversity, exemplified by the large number of tree species as compared to Nordic forests, and by their relatively high genetic variability due to the survival of many conifer and broadleaf species in southern European refuges, during the glacial periods. Another peculiar aspect of this region is the long-lasting manipulation of trees, forests and landscapes, since ancient times, with the diffusion all over the Mediterranean basin of such species as \textit{Pinus pinea}, \textit{Cupressus sempervirens}, \textit{Castanea sativa}, and \textit{Quercus suber}. The harsh and unpredictable climate, the difficult socio-economic conditions and the history of over-exploitation of the Mediterranean forests require that a scientifically sound conservation strategy and a locally-tailored sustainable management should be implemented. In particular, the need for identifying those silvicultural and management strategies appropriate for southern European forests should be stressed. Obviously, this consideration will have important effects on the definition of criteria for sustainability and eco-certification. Also, social issues should be considered key factors for effective forest conservation in the Mediterranean region, otherwise it will be impossible to control forest fires and landscape degradation.

Based on these considerations a number of research priorities are discussed, with special consideration to possible impacts that global change may have on Mediterranean forest ecosystems. © 2000 Elsevier Science B.V. All rights reserved.

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1. Introduction

The Mediterranean environment presents peculiar features that make it attractive not only from an ecological point of view but also for its human history.
and cultural aspects. The mild, winter-rainfall climate established along the shores of the Mediterranean basin in the post-glacial times and the rich diversity of terrestrial and marine life were determinant factors for the social and cultural evolution of humanity and for the development of so many civilisations. From archaeological sites, artefacts and written reports found in this region we can trace our development ‘from harvesters of the wild to managers of our environment’ (Hobbs et al., 1995). Through the ages, people of the Mediterranean region have tried, not always successfully, to find a balance between exploitation and conservation of natural resources. In the present time, despite some economic improvements, dramatic socio-economic, environmental and land-use problems have emerged; the Mediterranean environment, therefore, represents an enormous challenge to scientists and land managers because of its size, physical complexity, geological and anthropological history (Blondel and Aronson, 1995).

The objective of the paper is to review the main characteristics of Mediterranean forest ecosystems and forest management, while identifying a number of research priorities, with special consideration to possible impacts that global change may have on Mediterranean forest ecosystems; the need for devising silvicultural and management strategies appropriate for the forests of the region will also be stressed.

2. Features of the region

2.1. Climate, topography and vegetation

Typical characteristics of the Mediterranean region include (i) an unusual geographical and topographical variability related to the presence of a jagged coastline and of many, relatively young mountain ranges, often quite high in elevation; (ii) a pronounced, climatic bi-seasonality with dry and hot summers and moist and cool autumns and winters; also, occasional, violent precipitation events, a large year-to-year variability of total rainfall as well as frequent strong and dry winds that favour the spread of forest fires; (iii) a high diversity of plant and animal species, coupled with a rich variability of more or less natural vegetation types and land-use forms, giving rise to complex mosaics of patches; (iv) a long history of manipulation of trees, forests and landscapes, as documented by the continued presence of planted forests of Pinus pinea, Cupressus sempervirens and Castanea sativa in areas where these species were extended since the Greco-Roman age, and gradually have become characteristic elements of the landscape.

A few data suffice to exemplify the richness of plant and animal species accommodated by the large diversity of ecological conditions. The Mediterranean area harbours ca. 25,000 plant species whereas in central and northern Europe, a region four times greater, only 6000 flowering plants and ferns can be found. Fifty percent of the Mediterranean flora are endemic to the region and evolved over a long time interval, under highly variable and diverse climatic conditions. In fact, it is possible to differentiate a ‘Paleo-Mediterranean’ contingent, evolved in the pre-Pliocene period under tropical climatic conditions, from a ‘Neo-Mediterranean’ group, originated from immigration and speciation after the establishment in the region of what we know today as a Mediterranean-type climate.

Forest trees represent an important component of the Mediterranean flora; again, the number of tree species is quite large compared to the trees living in central Europe (100 vs. 30, respectively), with the genus Quercus alone presenting more than 20 species in the region. Besides, many of the Holarctic and Eurasian tree species survived during the glacial ages in Mediterranean refugia, from where they re-colonised the continent when temperatures rose again at the end of glaciations, ca. 15,000–10,000 years ago (Huntley and Birkes, 1989). In fact, intraspecific genetic variation in such species as Fagus sylvatica or Abies alba, in Mediterranean forests, is larger than in other European forests (Comps et al., 1991; Konnert and Bergmann, 1995; Leonardi and Menozzi, 1995; Bucci et al., 1999).

Vertebrate diversity is also very high but differs among groups because of historical and biological reasons. The number of mammal species, especially large animals, was greatly reduced during climatic changes of the Pleistocene; later, after massive immigrations from temperate Asia into southern Europe the number of animal species increased sharply. But then, again, because of strong human pressure, many extinctions occurred during the Neolithic age. Presently,

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1 Nomenclature follows: Pignatti, 1982.
there are ca. 200 species of terrestrial mammals, of which 25% are endemic. A larger number of species, 350, can be counted for the avifaunal communities, a figure that approximately corresponds to the breeding birds of North-Central Europe, occupying a much larger area. If we express this diversity as a ratio between species richness and area, the indices for the two regions are 11.3 vs. 4.2, respectively.

The natural vegetation of the Mediterranean region is closely related to the typical features of the Mediterranean climate but depends also on the altitudinal factor, a very decisive one in this area of the world, given the steep gradients that can be experienced from the sea shores up to the high mountains of the region. The truly Mediterranean vegetation zone is represented by the plains and the low-elevation valleys all along the sea coasts. It can be subdivided in the Thermo-Mediterranean and Meso-Mediterranean belts (Quézel, 1985) and corresponds approximately to the area where olive trees are cultivated. As the elevation increases along the low and high hills and then the mountains, we pass from the Supra-Mediterranean to the Montane-Mediterranean and Oro-Mediterranean vegetation zones (Quézel, 1985) with completely different forest types. Latitude and topographic exposure also affect this vegetational succession, raising the boundaries of the various belts as we move from North to South and from north-to south-facing slopes.

The Mediterranean vegetation is well adapted to difficult ecological conditions being characterised by mechanisms which counteract the deleterious effects of the environment (summer drought and wildfires) and to increase the ability of survivors to grow and reproduce. Mechanisms of response to environmental stresses include morphological, phenological and physiological adaptations. Relevant morphological characteristics are small leaf size, especially in evergreen sclerophyllous species, deep root system, thick bark and high sprouting ability. Phenological adaptations include an early and quick development of leaf area. Physiological adaptations include tolerance to tissue dehydration, early spring development of photosynthesis, plasticity of photosynthesis depending upon particular environmental conditions (winter photosynthesis in evergreen species) and ability for a complete recovery after a long summer stress period. Mechanisms of resistance to fire include high sprouting ability and thick bark in broadleaf species while conifers have early and large seed production, serotinous cones and high ecological plasticity.

The persistence over the ages of different forms of over-exploitation by man and his herds of domestic animals caused the virtual disappearance of most climax forest types from the Mediterranean region (Quézel, 1978). The remaining so-called natural forests are altered woods, more or less intensively managed by man, that often correspond to different stages of regressive succession of the original forest. In the typical Mediterranean zone, forests are composed of broad-leaves, particularly oaks, both evergreen and deciduous, as Quercus ilex, Q. suber, Q. coccifera, Q. pubescens, Q. cerris, Q. pyrenaica, Q. toza, Q. calliprinos, Q. ithaburensis and others, or conifers as Pinus halepensis, P. brutia, P. pinea, P. pinaster and Juniperus sp. The degradation of these forests has also produced a variety of low density, woody vegetation as the one with oleasters and Pistacia lentiscus shrubs like the ‘macchia’ and the ‘garrigue’. In the low plains and along the rivers, where no water limitation occurs, lush forests of Quercus robur, Q. petraea, Fraxinus spp., Populus alba and P. nigra can thrive. Another form of arboreal vegetation, typically found in the Iberian peninsula, is the ‘dehesa’ a type of pasture with scattered trees of evergreen and deciduous oaks, sometimes mixed with stone pine. In the Xero thermo-Mediterranean zone mainly shrubs communities can be found, made of Acacia, substituted on saline soils by Atriplex vegetation. As the elevation increases, other types of forests appear, partly made up of endemic Mediterranean trees but also with tree species that occur in other parts of the European continent; besides Castanea sativa and Fagus sylvatica we find Pinus laricio, other Austrian pine species, P. leucodermis, P. sylvestris, Abies alba and Mediterranean firs and Cedrus sp. Non-indigenous species have also been introduced over the course of the centuries in the forest lands, notably in the last century, such as hybrid poplars, eucalypts, radiata pine and various cypresses.

All in all, the Mediterranean region is characterised by a high proportion of broadleaf (≈60%) relative to coniferous forests, varying from Italy (76%) to Portugal (49%) (Dafis, 1997). In contrast, in central and northern Europe, conifers dominate the forest landscape, with the proportion of broadleaf forests ranging from 30% in Germany and Sweden to 12% in Finland.
2.2. Utilisation of forest resources and services

The once splendid Mediterranean forests of the Bronze Age cover presently ca. 100 Mha all around the Mediterranean basin (FAO, 1997; Lanly, 1997). The distribution of these forests is rather uneven, as 65% of the forest area is found on the northern rim of the basin, whereas the remaining area is almost equally divided between northern Africa and the Near-East. The proportion of forest cover relative to the total land area is also quite different among sub-regions; it varies from 20–30% in the northern Mediterranean countries to 1–8% and 5–10% in southern and eastern Mediterranean countries, respectively. In countries like Greece and Albania the forest cover is as high as 50%, although only one-third of the forests is utilised for wood and timber production, the remaining area being covered by under-stocked woodlands or by maquis-type vegetation mainly utilised for soil protection, as in many other Mediterranean countries; however, a standard definition of forest is critical for the correct assessment of the forest cover of the region. The type of forest ownership also has important implications on the use and conservation of the forests of the region: while in southern Europe forests are mainly community and privately owned, in the other subregions forests largely belong to the state.

The forest surface is not static but is changing in the Mediterranean basin; whereas in southern Europe forests are currently expanding, even if at a different pace from one country to the other, in the rest of the Mediterranean region they are still decreasing at an annual rate of 0.5–2%, because of the increasing human pressure on natural resources (FAO, 1997). Another index of sustainability of forest resources management is the average growing stock (FAO, 1997). It is relatively modest all around the Mediterranean, partly because a large percentage of forests are made of coppice stands, but it is also quite variable among the subregions; growing stock is >100 m$^3$/ha$^{-1}$ in European countries, 66 m$^3$/ha$^{-1}$ in south-eastern Mediterranean and only 35 m$^3$/ha$^{-1}$ in northern Africa. The largest forest growing stock is found in southern France (136 m$^3$/ha$^{-1}$) and the lowest in Lybia (27 m$^3$/ha$^{-1}$). In southern Europe it has increased steadily in the last 50 years, by $\approx 50\%$.

Keeping in mind the ecological constraints and present conditions of forest resources, productive capacity and functions of forests in the Mediterranean region are relatively limited. Volume increments in the northern part of the Mediterranean basin vary considerably according to climatic conditions, site fertility, forest tree species and forest management system (MIPA, 1985). Coniferous mountain forests of firs and pines have maximum mean annual increments (MMAI) of 3–12 m$^3$/ha$^{-1}$ per year; deciduous broad-leaf forests of beech and oaks have MMAI values of 2–10 m$^3$/ha$^{-1}$ per year, whereas those of evergreen forests of pines and broad-leaves in the Meso- and Thermo-Mediterranean belts range from 1 to 5 m$^3$/ha$^{-1}$ per year. By contrast, fast growing plantations of poplars, eucalypts and other species (radiata pine, etc.) can reach values of 25–50 m$^3$/ha$^{-1}$ per year. Such high productivity is possible due to the high solar radiation and the mild air temperatures throughout most of the year, provided there is adequate water supply in the soil.

Total amount of wood harvested in the Mediterranean region is ca. 120 Mm$^3$, with fuelwood still representing ca. 40% (FAO, 1997). But only two countries, Portugal and Yugoslavia, have a positive trade balance for wood and wood products. Overall, the balance of trade for the Mediterranean region is negative by ca. M$\$ 15,000, revealing a significant production deficit in the region (Boydak and Dogru, 1997). This situation is well symbolised by the case of Italy which has a strong industry of wood and paper products with an overall revenue of ca. M$\$ 30,000 and a positive balance of trade of the entire wood sector of ca. M$\$ 5000. This positive balance, however, rests on a very fragile base since wood and timber production covers only ca. 20% of the national need while the remaining portion has to be satisfied by imported roundwood and semi-finished products.

In many countries of the region, wood has always been, and still is, the basic source of energy. In many Mediterranean countries large areas of broadleaf forests continue to be managed as coppices in order to fulfil the local fuelwood needs. Even in industrialised countries fuelwood requirements have increased recently, partly because of developing social needs such as fuelwood for domestic fireplaces, restaurants and charcoal production. And in mountainous regions, the communal ownership of many forests still affords the local residents the right to a quota of the wood production for their energy requirements.
statistical data usually underestimate the real consumption levels since they ignore the amount of wood taken from the forests illegally (Boydak and Dogru, 1997).

During this century extensive reforestations have been conducted by national forest services all over the Mediterranean region. In northern Africa planted forests cover in total 1.2 Mha whereas in the Near-East forest plantations cover 300,000 ha (FAO, 1997). In Italy, recently planted forests amount to 500,000 ha and were installed mainly from the 1950s through the 1970s; also relatively small countries like Israel and Cyprus have very active national reforestation programs with a mean annual plantation rate of 500–1000 ha per year. While largely successful, reforestation has produced simplified pioneer ecosystems which need to be transformed to more durable and diverse forests in order to increase their ecological stability and to reduce the risk of catastrophic events such as fires and pests outbreaks. The primary objective of reforestation in the region is soil protection and runoff control; however, in the northern Mediterranean countries, the resulting forests are expected to provide also significant wood production. In contrast to reforestation for reclamation, a new role is seen in specialised tree plantations of fast growing species, mostly poplars and eucalypts but also native and exotic conifers, with high production rates. These tree crops, cultivated as intensive plantations, agroforestry systems or line plantations and windbreaks, are beginning to meet a significant portion of the needs of various Mediterranean countries, as in Turkey and Italy where, they now supply ca. 50% of the national production of industrial wood or as in Spain and Portugal where almost 2 Mha have been planted with eucalypts and radiata pine.

Traditionally, Mediterranean forests have provided a large variety of other products besides wood. They include food for humans and animals, gums and resins, dyes and medicines and cork and aromatic plants; revenues from such products sometimes exceed the value of wood. Food from forests, for example with chestnut (*Castanea sativa*) in southern Europe, has assured for centuries the survival of human populations living in hilly and mountainous areas. Of value today are a large variety of fruits, nuts and pine-nuts (*Pinus pinea*), mushrooms and truffles, that are in high demand for both fresh consumption and the food industry. At the same time, forests still provide large food supply for domestic animals as grass and shrubs, tree branches and oak acorns, not only in northern Africa and the Near-East but also in southern Europe. The production of cork by *Quercus suber* is a very significant source of income in the western part of the Mediterranean region; 50% of this production is provided by Portugal, 25% by Spain and the remaining 25% by Morocco, Algeria, France and Italy. Finally, the economic and social value of hunting can occasionally exceed the value of wood production (leasing of hunting rights, etc.) in some forests provided that a careful management of the wildlife population is applied in order to avoid possible damage to the forest ecosystem.

Ultimately, the value of Mediterranean forests is largely related to their environmental and social functions. The risk of erosion, landslides and floods being so high in the region, forests play a major role in protecting soil, stabilising slopes and reducing water runoff in the mountainous and hilly watersheds. In some Mediterranean countries most forests are under legal constraints for hydro-geological protection so that any conversion to another type of land-use is strictly forbidden. Nor can silvicultural operations be undertaken without permission of the forest authority. This has also led many Mediterranean countries during recent decades to adopt restrictive measures in the management of natural and man-made forests and woodland areas, all the way to the prohibition of wood harvesting particularly in the eastern and southern countries of the region. Also, major programs have been initiated in the afforestation of large areas for conservation purposes, the establishment of protected areas and the conservation of existing forests, greenbelts and recreation forests, windbreaks and plantations for the stabilisation of sand dunes (Boydak and Dogru, 1997).

The role of forests in improving and maintaining the beauty of the landscape has long been recognised and is nowadays even more emphasised in the forest laws of many countries. Landscape and microclimate amelioration by forests is especially important in the densely populated urban and suburban areas of the Mediterranean basin (Corona and Mariano, 1992), as well as in the many important historic sites. Proper planning, establishment and management of natural and planted forests for the recreation, amenity and
relaxation of local populations and tourists are some of the important challenges of the coming years, which require institutional strengthening supported by regional co-operation and exchange of experiences. This is closely connected with the growing attention to eco-tourism as an economic perspective in many countries (Boydak and Dogru, 1997)

2.3. Resulting problems of forest ecosystems

The history of forests in the Mediterranean area is an history of forest fragmentation, degradation and eventually deforestation, but also of temporary natural expansion of the forests. The strong, continual and long-lasting human pressure has even caused, according to di Castri (1981), co-evolution of trees and other plant species with man over perhaps a period of >100,000 years. The spread of agricultural practices and animal grazing, the need of wood for shipbuilding, constructions and heating, the devastation by wars, reduced the extent of the forest cover, resulting in progressively open and degraded woods and, finally, bare land with eroded slopes, especially in mountain areas (Thirgood, 1981). Already in ancient Greece, Plato recognised that as a consequence of deforestation ‘all the rich soil has melted away, leaving a country of skin and bone’. The history of land-use change has included periods of intense deforestation and, in part of the region, even desertification with the rise of powerful civilisations, as in the Greco-Roman time, the period of the Arabic conquest, or during the Renaissance and its exceptional economic development. The spread of agriculture and the construction of large military and commercial fleets imposed a heavy toll on Mediterranean forests. But, there were also periods of land abandonment, as in the early Middle Age in southern Europe, that reversed the deforestation trend and led to an increase of forest vegetation on less intensively used land.

More recently, wood use for energy has greatly increased when the industrial revolution spread to the northern Mediterranean, and with it the expansion of the railways network which in Italy, as an example, increased from 2100 km in 1870 to 16,000 km in 1900, utilising large amounts of wood both for sleepers and for energy. Also, new political developments in the 19th and the 20th centuries such as the waning feudalism, the privatisation of public land, and large land reclamations, contributed significantly to the destruction of forests and the spread of agricultural activities to areas previously covered by natural vegetation.

Forestry problems of the Mediterranean region can be better understood if seen in light of differences existing in socio-economic development and in the balance between town and countryside. It seems useful, therefore, to distinguish the northern sub-region, that is southern Europe, from the southern and eastern sub-regions composed of northern Africa and the Near-East. In the north, while urbanisation continues, abandoned agricultural lands become progressively covered by a woody vegetation of shrubs and young trees that eventually will give rise to natural reforestation as a result of secondary succession. This process, which proceeds at different rates according to local climate and soil fertility, is also favoured by the reduction of animal grazing in the forest, that previously inhibited the growth of the understory. Management of production forests, in turn, is lacking both manpower and profitability, whereas some of the non-woody products, such as forage, fruit, cork, gum and turpentine, have lost some of their importance and marketability. By contrast, the ecological, recreational and landscape functions of the forest have increased their relevance as never before. But, it is difficult to give monetary values to these functions, and they provide no revenues to their private or communal owners. As a negative feedback loop, this results in an even diminished interest of the forest owners in cultivating and maintaining their forests and increases the risk for natural disasters such as soil erosion, land slides and forest fires. There is an urgent need for devising silvicultural treatments that can assure stability and, particularly, natural regeneration to many forests of the region which currently are experiencing changes in species composition and stand structure because of shifting objectives in forest management.

A major problem in these areas are forest fires. The accumulation of fuel creates serious hazards, especially during the dry summer months, when combined with the negligence of tourists coming from the cities or with vandalistic acts. Despite better fire-fighting tools such as aeroplanes, helicopters and forest roads, the large deployment of human forces and the exponential growth of costs of the ‘wildfire battle’, forest fires are far from being effectively controlled and
remain a very serious menace in the northern Mediterranea
sub-region (Lanly, 1997). From 1985 to 1995 an average of ca. 1% (±0.5 Mha) of the forest area was destroyed annually by fire in this sub-region, but the percentage was >3% in Portugal, Spain and southern Italy. Even if wild fires can not be prevented, their extent can be limited through effective measures. Therefore, much emphasis has been put during the last decade, on new methods for risk assessment, fire danger rating, and the development of physical fire behaviour models as well as specific silvicultural treatments (regulation of stand density, spatial distribution, fire-breaks, etc.). Recently, prescribed burning has been legalised in France; it constitutes a cost-efficient silvicultural tool not only for fuel control but also for wildlife management and other silvicultural purposes (Delabraze et al., 1991; Rigolot, 1993) but it is doubtful whether this system can be applied throughout the whole region. Finally, a better understanding of the socio-economic causes underlying these recurrent natural disasters and the implementation of effective prevention initiatives are urgently needed.

Whereas forest and shrub vegetation is expanding in the northern Mediterranean countries in marginal and remote areas, natural forest vegetation in coastal zones, riparian belts and suburban spaces is increasingly jeopardised by land development for tourism or industry, by transportation infrastructures and by extensive degradation. The devastation and ‘anarchic’ transformation of a complex mosaic of naturally vegetated and cultivated land patches, forming a system in ‘quasi-equilibrium’, is a major problem for the region and with it the loss of biological diversity and erosion of genetic variability of forest tree species (Hobbs et al., 1995). Restoration of fragmented landscapes should be based on the recognition that ‘the different segments and land uses in a landscape are closely interlinked ecologically and that the management needs to be integrated across the whole landscape rather than related to isolated landscape segments’ (Hobbs and Saunders, 1993). This need is particularly evident in the Mediterranean basin where certain regions are almost completely devoid of forest vegetation or with completely isolated forest patches where their conservation, the management of wildlife and of biodiversity, and the adaptation of plants and animals to environmental changes are impaired.

The southern and eastern Mediterranean sub-regions, on the other hand, are characterised, by a continually increasing overexploitation by the local population and their livestock. Productive functions of forests are still important for the local economy but this negatively affects the protection capability of these ‘green mantles’ although the need to combat water and wind erosion is often dramatic. Furthermore, woodlands are still being eliminated to expand agricultural land and pastures, or may be subjected to an irreversible degradation of soil and vegetation; this is caused by overexploitation for wood and forage, often exceeding the resilience of these ecosystems. This reduces or inhibits the natural regeneration capabilities of the woodlots and contributes to the desertification process. Desertification is, however, a problem also in many areas of southern Europe (Spain, southern Italy, etc.), and is caused by both human abuse of the land and adverse climate conditions that are likely to worsen because of climate change (Bullock and Le Houérou, 1996). Forests are therefore confined to the most infertile and remote mountain areas where they represent the principal natural resource for the local communities. Fortunately, the presence of a large rural population and their herds actually reduces considerably the fuel load and with it the risk of wild fires.

2.4. Knowledge gaps and research needs

Ecologists are well aware of the risks when land is managed without a sound scientific understanding of the structure and functioning of ecosystems. Ecosystem function can be defined as the set of processes that maintain natural systems through the transfer of energy, matter and information (Keeley and Swift, 1995). These processes are regulated by species and biotic interactions that characterise the ecological system. However, still large gaps exist in our understanding of Mediterranean ecosystems functioning, impairing our capability for implementing a safe conservation strategy of the environment.

2.5. Biological and structural diversity

Mediterranean-type environments rival tropical regions for their biological richness, particularly in
plant species (Mooney, 1988). In contrast to other parts of the world, however, the Mediterranean basin has a long history of human disturbance that has affected structures and functions of most of the forests and, in general, plant communities of the region. Diversity of plant species has even increased in certain ecosystems as a result of ‘human-driven relatively rapid evolution under stress by drought, fire, grazing and cutting’ (Mooney, 1988). Therefore, the comparison of plant ecosystems among Mediterranean-type zones offers the opportunity to investigate the effects of human impact on biological diversity relative to various forms of natural disturbances. We are just beginning to elucidate the role of different types and patterns of disturbances, at the species, community and landscape levels, on stability and resilience of ecosystems (Bazzaz, 1983). This information is essential if we intend to manage and conserve the ecosystems and landscapes of the region, given that they generally correspond to ‘successional stages affected by either natural or artificial exploitation, and they should be conserved under the prevailing conditions of relative instability’ (Ruiz de la Torre, 1985). The appropriate choice of such conservation strategies will have important implications for the philosophy that underlies natural-park management and is deserving increased scientific research in this field. Just one of many examples is the ‘passive’ management of Mediterranean pines and black pine stands being adopted in many natural reserves of the region; these stands represent early successional communities that have long been maintained through the recurrent sequence of natural and man-made disturbances (i.e. fire, frequent harvestings, pasture). The prohibition of any type of silvicultural treatment inside parks, under this ‘passive’ management, combined with fire prevention, forces the conversion of these forests to late-successional communities of evergreen and deciduous broad-leaves. By comparing the results of an ‘active’ silviculture in some of these forests with those under natural dynamics, a wealth of scientific and technical information can be obtained that will be a guide for future management of these forests.

One important question concerns the effect of these contrasting management options on biodiversity at the stand and landscape level (Bengtsson et al., 2000). Silvicultural treatments and landscape management, in fact, have also profound effects on structure and richness of animal communities, as a function of the territorial requirements of the various animal species. Managed beech forests of central and southern Italy are almost as rich in bird species as much older and more fertile beech forests of central Europe, thanks to their mosaic-like, complex structures, largely created by human interventions (Masci et al., 1998). A better understanding of the relationships between forest management and wildlife diversity is needed, both for implementing appropriate forest management plans and for correct planning of eco-tourism in natural parks.

Genetic variability of forest trees is high in the Mediterranean basin, at the inter- and intra-specific levels; one of the reasons for this being the natural history of the region during the glacial and post-glacial periods (Huntley and Birkes, 1989). The presence of endemic species such as Pinus leucodermis (Albania, Greece and southern Italy) (Bucci et al., 1997), Abies nebrodensis (Sicily) (Vicario et al., 1995) and many others, as well as the larger gene pools, existing in southern Europe versus northern Europe, of the populations of such species as beech and silver fir exemplifies a situation that deserves a much more detailed knowledge of the genetic variation of Mediterranean forest trees (Bucci et al., 1998). Genetic markers and genetic maps will be useful to study population genetics and the evolutionary processes of trees and other forest organisms; immediate applications of such studies span from tree breeding to natural reserves planning and management and to the implementation of in situ and ex situ forest gene conservation. The need to conduct integrated studies on the genetic and eco-physiological diversity of these tree species and populations is justified by the presence of some interesting traits, such as growth and ecological adaptability, that could also be useful in the future in view of rapidly changing, environmental conditions.

Two research priorities can therefore be identified:

- to study structural and functional interactions between land cover management and biological diversity at the level of forest stands and of the land-use mosaic;
- to study and evaluate genetic variation of endemic tree species as well as of local ecotypes of Mediterranean forest trees.
2.6. Functions, resilience and adaptation of forest ecosystems

The problem of maintaining biological diversity and providing for renewable natural resources in a changing climate calls for the integration of basic and applied sciences. A better understanding of mechanisms that regulate the energy and matter fluxes among and within ecosystems will be essential for environmental preservation and, therefore, for our future. Forests are increasingly recognised as ecological systems of fundamental importance for environmental protection not only at the regional level but also on the global scale. Forests seem to play a key role in global bio-geochemical cycles as the carbon and water cycles, and regulating regional and global climates. Only recently, however, have fluxes between forests and atmosphere begun to be quantified and elucidated, partly due to new experimental techniques as the use of stable isotopes and the eddy covariance of gaseous fluxes above forest stands. This micro-meteorological technique allows to measure fluxes of carbon, water, and pollutants above forest ecosystems, their daily and seasonal variability, and their relationships with environmental factors. The quantification of carbon absorption potential by forests as well as its inter-annual variation, especially in the Mediterranean region, are becoming important scientific questions because of their relevance for the intergovernmental agreements on greenhouse gases as well as because of the large climatic unpredictability of the Mediterranean environment (Valentini et al., 1996); a European network was recently laid out to study carbon fluxes between forests and atmosphere, including some representative ecosystems of the Mediterranean region.

Preliminary observations on net ecosystem carbon exchanges of Montane-Mediterranean forests seem to point to the soil as a compartment with a larger carbon pool than in the forest ecosystems of northern Europe (T. Persson, personal communication). Possible explanations may relate to climatic conditions and to peculiar mineral soil properties; these hypotheses deserve much more study.

The forest environment, particularly in the Mediterranean region, is rapidly changing; but, how trees and other forest organisms will respond and adapt to these changes is largely unknown. It is therefore prudent to augment the basic knowledge on physiological and genetic mechanisms controlling growth and development of native forest species, their interrelations as well as their responses to environmental stresses, including pollution and probable environmental changes. New technologies based on DNA molecular markers offer new opportunities to analyse the genetic basis of a wide variety of processes such as biomass production and allocation, response to environmental stimuli and to the presence of pathogens and parasites.

The Mediterranean area is especially sensitive to any climate change because it represents a transition zone between arid and humid regions of the world. Although Mediterranean forest and shrub ecosystems represent a small fraction of the world’s forest cover, they have specific aspects that make this region an interesting model system in which to study effects of global change on terrestrial ecosystems. Aspects of global change impacts include high sensitivity of ecosystem productivity to water availability; elevated susceptibility of natural ecosystems of the region to nitrogen depletion because of slow nutrient cycling; high incidence of fire damages and intense soil erosion; increasing nitrogen deposition and elevated levels of ozone formation; very high biogenic carbon emissions; high risk of major land-use (i.e. forest fires) changes affecting surface albedo, carbon fluxes and energy balance (Moreno and Fellous, 1997). Despite the difficulty to synthesise in few points the research needs for Mediterranean forest ecosystems, it seems reasonable to identify the following key aspects: interactions of increasing concentration of atmospheric CO2 with nitrogen and water availability on plants and ecosystem physiology and community dynamics; predictions of possible changes of fire regimes in the future; interrelations of water cycle and water availability with ecosystem functions and land-use changes; changes in ecological diversity as affecting responses to global change, including carbon sequestration, fire resilience and soil erosion.

Acclimation and adaptation represent critical processes affecting how trees and forests will cope with environmental changes (Borghetti, 1998). Acclimation capability is an intrinsic property of living organisms, especially in trees, characterised by their large size and long life cycle. On the other hand, adaptation of forest trees and ecosystems to global change may occur over long time-intervals; yet, climate change
models tend to predict very rapid changes that natural evolution may not be able to handle. Genetic diversity in forests is supposed to be a favourable factor to face such rapid change as shown from pollution studies that demonstrated a better adaptation of intrinsically diverse forest tree populations than less diverse ones (Mueller-Starck, 1989). The importance of such processes underlines how urgent it is to maintain high levels of biological diversity in forest ecosystems and, at the same time, to restore a continuity of the forest-connecting structures in the landscape, a feature that is not common in the Mediterranean environment. However, acclimation and adaptation processes may be severely affected by competition among tree species and by interactions of plants and trees with parasitic organisms as insects and fungi (Führer, 2000); these phenomena are seldom investigated and taken into account when attempts are made to predict how future climate scenarios may affect forest ecosystems.

Two research priorities can therefore be identified:
- to study how climate change will affect Mediterranean forest ecosystems, their composition, productivity and carbon sequestration potential and how it will interact with biotic (insect and pathogen pests) and abiotic factors (drought, fires, etc.);
- to study how can human intervention mediate the adaptation of forests to environmental change and prevent ecosystem and landscape degradation.

2.7. Sustainability of forest management

Sustainable production is a concept often referred to natural resource management but, surprisingly, our understanding of the biology of biomass production is still limited. Yet, the harsh and unpredictable climate, the difficult socio-economic conditions and the history of over-exploitation of the Mediterranean forests require that scientifically sound conservation strategies and locally-tailored sustainable management rules be implemented. Obviously, this will influence the definition of criteria for sustainability and eco-certification.

In turn, sustainable management of forest ecosystems requires that primary production, carbon storage capacity and biological variation be preserved over time. Therefore, forest conservation can not be limited to maintaining forests as they presently are, making them almost untouchable. Most of the forests, in fact, are utilised by man or are influenced directly or indirectly by its presence. Thus, it is necessary to identify and experiment appropriate management procedures for an adequate conservation of ecological functions. Management procedures to be adopted require a better understanding of the biology of various populations living in a forest ecosystem, and how they respond to different silvicultural operations.

Fragile and unstable ecosystems, like the Mediterranean ones, are often unable to produce large quantities of woody biomass per unit area; consequently, intensive management is often incompatible with the other roles of forests such as soil conservation and landscape improvement. Pressure on these ecosystems can be partially reduced if the more fertile and stable Mediterranean ecosystems are managed in a more intensive, although durable, way. In the forestry sector, management intensity, that is the quantity and quality of factors provided as inputs to the productive system, may vary considerably, from natural forests to intensively managed plantations under short rotation. Plantation forestry for wood production represent <5% of the global forest surface and in some countries of the Mediterranean region, like Italy, only 2%; nevertheless, these woody crops can supply large quantities of woody biomass because their productivity rates are 5–10 times those of natural forests. They can greatly reduce human production demands from natural forests and protective ecosystems. Research and experimentation on plantation forestry and on agro-forestry should aim at production sustainability through the selection of plant material resilient to fluctuating environmental conditions.

Reforestation has been extensively conducted in the region mainly for soil conservation purposes; most of these planted forests, mainly composed of native but also exotic conifers, are now at an age of 40 up to more than 100 years. Thus, questions arise as to their regeneration or their transformation into more natural and stable forest ecosystems, with a richer species mixture. Spontaneous forest expansion is also occurring naturally in many areas on abandoned farmland; however, very little is known from scientific and operational points of view on how these stands and their high species richness should be managed.

Natural forests of conifers and also of some broadleaf forest tree species (beech, oaks, etc.,) growing on
better sites, are managed as high forests by clear-felling or shelterwood systems; many variants ranging from pure or mixed even-aged stands to pure or mixed uneven-aged forests, with or without a dense understory, can be found. Depending on tree species, site quality and functions and/or production goals, single tree selection or group selection systems are also used locally, but require intensive management. Although natural regeneration is generally adopted in almost all these forests, careful management schemes of stand structures and wildlife densities still need to be identified for many forest types. Furthermore, silvicultural strategies to improve ecosystem resilience by reducing the susceptibility to biotic and abiotic stresses, and also the selection of more appropriate silvicultural operations to reduce costs while maintaining the complexity and multiple functions of forests, are important needs for Mediterranean forest management.

One additional management system typical of the Mediterranean region, is the extensive area of coppice of evergreen and deciduous broad-leaved species, such as oaks, beech, chestnut and, more recently, eucalypts. These coppices, which provide firewood and fodder, play a major role in erosion control, especially after wildfires, because of their rapid vegetative regeneration capacity. Coppice should therefore be maintained on sites with high erosion and wildfire risk. Open questions for coppice management are the optimal rotation length or ecological rotation in order to prevent fertility loss (Lucci, 1985) and the desired level of genetic variation to aim for in these stands.

Another form of tree vegetation management is the ‘dehesa’; since cereals are often grown under the tree cover, the ‘dehesa’ can be considered as a specific agroforestry system. Other agro-forest systems include animal grazing in forests or in widely spaced cork oak stands, firebreak maintenance with sheep, and annual crops cultivation in combination with poplar plantations; however, a sound management of highly degraded forest ecosystems is sometimes incompatible, at least during the recovery stage, with any kind of agricultural use.

The following research priorities can be identified to foster sustainable management of Mediterranean forests:

- to study and conduct integrated research efforts in representative forest stands of the region, combining ecosystem functional observations with silvicultural management options in order to develop sustainability indices for Mediterranean forests;
- to study how can plantation and short rotation forestry contribute to the woody biomass needs of the region while effectively sequestering carbon and improving environmental conditions (biodiversity, erosion control, nitrates absorption and landscape amelioration).

2.8. Multifunctionality of forests and scaling aspects

In the Mediterranean region, historically man has profoundly modified the natural environment producing finely grained combinations of different types of vegetation, varying from intensively cultivated fields to almost natural forest tree and shrubs communities, generally referred to with the term of landscape (Naveh and Lieberman, 1993). The notion of landscape refers to the perception ability of man towards the beauty of nature; at the same time the landscape is a dimensionally convenient structural unit where to conduct studies on functions and behaviour of the territory. Landscape is also an appropriate management unit because it allows to take into account the interrelatedness of landscape segments. The creation of a spatial heterogeneity made of a mosaic of structurally different forest patches, the presence of different age classes, the implementation of contact or transition zones among contrasting ecosystems, are all conditions that favour environmental variability and, therefore, biological diversity. Many of these forest management aspects should be analysed and solved at the landscape level. It is necessary, therefore, to develop the theoretical bases of landscape ecology as there is an absolute need for analytical and forecasting tools such as GIS and simulation models.

The following research priorities can be identified:

- to study the effects of landscape structure on ecosystem functioning and resilience, in relation to natural and man-made disturbances; and linking these studies to the transfer of knowledge to landscape and forest management and to decision-makers as an important task that needs also the development of user-friendly decision-making tools (Dreyfus and Bonnet, 1995);
• to study the multiplicity of aspects dealing with man and forests interactions because the perception of forests and forest activities by human populations, especially those living in cities, has a prominent role in determining a sound utilisation or, on the contrary, an over-exploitation or the abandonment of forests and forest landscape.

3. Conclusions

The drought-prone environment, the difficult socio-economic conditions and the history of over-exploitation of the Mediterranean forests are indisputable weaknesses of Mediterranean forestry; however, some peculiar and relevant aspects, as the rich biological diversity, the attractiveness of the environment and the high production potential for specific products and environmental conditions, are clear strengths that should not be overlooked. It would be wise to take advantage of the renewed political and socio-economic interest that Europe is directing to the Mediterranean region and of the new European research policy, to study and experiment scientifically sound conservation strategies and a locally-tailored sustainable management of the regional forest and landscape resources. In particular, the need for identifying those silvicultural and management options appropriate for southern European forests should be stressed. Also, social issues should be considered key factors for effective forest conservation in the Mediterranean region, otherwise it will be impossible to control forest fire and landscape degradation.

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