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ECOLOGICAL SOUNDING

Mediterranean terrestrial ecosystems: research priorities on global change effects

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Abstract. Ecosystems of the Mediterranean Basin are suggested as model regions for global change research, particularly in relation to the importance of land use changes. The large body of preexisting ecological knowledge should facilitate progress on complex issues relating to interactions among multiple drivers of global change, including climate, atmospheric, land use and socio-economic changes. Four research areas appear as priorities in relation to pressing needs for prediction: (1) fire regimes and effects; (2) feedbacks from the land to the atmosphere; (3) water availability and quality; and (4) changes in ecological diversity. We summarize current knowledge and present future directions for research in these areas. While a number of the topics outlined as priorities are presently addressed by ongoing studies, some of the future challenges will lie in appropriate coordination and synthesis of that research. We suggest that this structuring effort could serve as an example to be applied in other MTEs and across MTEs.

Key words. Mediterranean ecosystems, land use change, fire, feedbacks to the atmosphere, water availability, biodiversity.

INTRODUCTION: THE MAIN GLOBAL CHANGE ISSUES IN THE MEDITERRANEAN BASIN

The ecology of mediterranean-type ecosystems (MTEs henceforth) has been among the best studied of the world for two main reasons. First, mediterranean ecosystems are known for their outstanding biodiversity (Cowling *et al.*, 1996), next only to the tropics. Second, the convergences and divergences among different mediterranean regions have attracted the interest of researchers from areas ranging from evolutionary biology to ecosystem physiology (e.g. Di Castri & Mooney, 1973; Arroyo, Zedler & Fox, 1995). More recently, the issue of global change has stimulated a new development of research in MTEs. Mediterranean regions are transitional climate regions where it has been hypothesized that climatic changes may have the greatest effects. Mediterranean regions are also predicted to have particularly intense feedbacks from the land to the atmosphere (Seufert *et al.*, 1995). The Mediterranean Basin itself has been shaped by human activities for millennia and is for that reason seen as a model to examine the interactions between abiotic and anthropogenic forcings. Finally, the substantial scientific background mentioned above makes MTEs favoured candidates as model ecosystems to study impacts of different components of global change.

The main questions on the effects of global change in MTEs were synthesized during a workshop held in Valencia in September 1992 (Table 1, Moreno & Oechel, 1995). Four years later, many of those issues remain important but major attention is now devoted to understanding the interactions among multiple drivers of global change, including climate, atmospheric and land use changes.

A first example of interaction is that of the combination between increases in atmospheric CO_2 concentration and water limitation, which is expected to either amplify or limit the effects of increased CO_2. Indeed, temperature and precipitation changes will have strongly interactive effects in terms of water availability to plants and evapotranspiration, and their

Table 1. Research needs in MTEs for different categories of global change drivers (from Moreno & Oechel, 1995).

Driver	Effects	Specific research needs
(1) Atmospheric change		
CO_2 (+1.5 ppm/yr)	Photosynthesis acclimation	Functional groups
	Competition	Sclerophylls
	Ecosystem physiology	C fluxes and pools Evapotranspiration Fuel accumulation Forage quality, plant-herbivore interaction
	Biogeochemistry	Water yield
	Soils	Roots, rhizosphere, organic matter
N deposition ($\leq$25 kg/ha/yr)	Ecosystem productivity Biogeochemistry	Water quality
Ozone formation (+2.4%/yr)	Ecosystem physiology	Interaction with water availability Competition
dust	Biogeochemistry Hydrology	
(2) Climate change		
Temperature × rainfall regime	Plant and community phenology	Crops Natural ecosystems
	Community dynamics	Competition Mutualisms and symbiosis
	Biogeography	Migration, invasions, extinction Conservation reserves
	Biogeochemistry and hydrology	Water yield and quality
(3) Land use change		
Land abandonment	Landscape pattern Increased connectivity	Fluxes (e.g. water) Species migration and invasions Fire spread
	Invasions	Ecological engineering Ecosystem function
Fragmentation Overexploitation (grazing, logging)	Species extinction Ecotone position Fluxes: water, erosion	Ecosystem functioning Desertification Restoration

effects need to be considered jointly. While predictions for average annual temperature change in the Mediterranean Basin agree on a 2–3°C increase by 2050 (Cubash *et al.*, 1996), the direction and magnitude of precipitation change remain more uncertain. Recent regional climate modelling has shown that, while the total annual rainfall would decrease more or less in different regions of the Mediterranean Basin, decrease in summer rainfall would be a common feature (Cubash *et al.*, 1996). This prediction agrees with data from recent years (Rambal & Hoeff, 1998). From the ecosystem perspective, changes in the mean value of annual precipitation will have as much importance as changes in the seasonal distribution. Therefore, a range of climate change scenarios will need to be investigated. These scenarios should combine changes in both the mean and the interannual variance of precipitation (Rambal & Debussche, 1995), as well as in the occurrence of extreme events (droughts and intense rainfall episodes).

Any atmospheric and climatic changes also need to be considered in terms of their interactions with land use change. Land use changes are recognized as a priority issue in the Mediterranean Basin because it is thought that their effects in the short term may override climatic and atmospheric effects. The range of socio-economic conditions within the region, overlying the north–south climatic (temperate to arid) gradient, will also represent a diversity of situations applicable to various other parts of the world.

Thus, four research areas appear as priorities in relation to pressing needs for prediction: (1) fire regimes and effects; (2) feedbacks from the land to the atmosphere; (3) water availability and quality; and (4) changes in ecological diversity. As they all have multifactorial controls relating to the three main types of global change drivers, research needs to focus on analysing net effects of their interactions. Below, we detail how research could be structured into priority areas to address those four issues in the Mediterranean Basin. It is suggested that such a structuring effort could usefully be applied to other MTEs.

PRIORITY 1. FUTURE FIRE REGIMES AND EFFECTS

In the Northern Mediterranean Basin, ecosystems have evolved in the presence of fire. Recent land abandonment is thought to modify fire regimes, leading to an increase in fire extent (Vázquez & Moreno, 1995). In addition, because fire incidence and spread is largely dependent on weather conditions, climate changes are likely to lead to changes in fire frequency and intensity within fire-prone regions (Malanson & Westman, 1991; Torn & Fried, 1992; Gardner *et al.*, 1996; Piñol, Terradas & Lloret, 1998). Changes in climate would also be expected to affect species recruitment and hence the regeneration of communities after fire. Finally, changes in atmospheric composition (in particular increased CO_2) may lead to changes in fuel loading and species composition that will determine vegetation flammability, fire spread and post-fire regeneration. Future fire regimes and their impacts will thus be the result of complex interactions among land use, climate and atmospheric composition. Three priority areas are identified to explore these interactions.

Priority 1.1. Prediction of future fire regimes

(i) *Fire regimes and land use.* Fire regimes under which present ecosystems have evolved, and their changes through human history can be reconstructed using palaeoecological records of fire activity. Paleoanthracology, the analysis of fossil charcoals, has been used to track the joint dynamics of vegetation and fire activity linked with land use (Thinon, 1992). The analysis of present fire regimes and their recent changes needs to determine (1) how land use changes have altered landscape pattern, (2) how much of that change has been caused by fire, and (3) whether such changes can have positive feedbacks on fire incidence through decreases in landscape heterogeneity.

(ii) *Fire regimes and climate.* While fire frequency and size were shown to be related to weather patterns in a study of Californian chaparral (Davis & Michaelsen, 1995), the relationship between the period of fire occurrence and meteorological variables has been shown to be very poor in Spain (Vázquez & Moreno, 1995). This lack of correlation was in particular linked with human fire ignitions which tend to be spread throughout the year and are unpredictable. It is, however, established that in warmer years fire activity is higher (Vázquez & Moreno, 1993), apparently as a consequence of increased regional aridity (Piñol *et al.*, 1997). On the other hand, modelling studies have indicated that the frequency of natural ignitions and the potential for fire spread are highly sensitive to climate variables both directly (Gardner *et al.*, 1996), as well as in their interaction with stand production (Malanson & Westman, 1991; Davis & Michaelsen, 1995). Developing a better understanding of the role of weather conditions in fire spread in the Mediterranean Basin is seen as a major priority. This will involve the analysis of larger data sets of fire records and the development of specific models for different vegetation types.

(iii) *Fire regimes and changes in atmospheric composition.* Increased atmospheric CO_2 concentrations are expected to have indirect effects on fire regimes resulting from their direct effects on biomass productivity and possibly community composition. Greater biomass productivity under elevated CO_2 would increase flammability and fire frequency (Oechel *et al.*, 1995). Further shifts in community composition could also affect fire regimes (Davis & Michaelsen, 1995). For example, a shift towards species with more volatile flammable components or finer fuels (e.g. graminoids) would feed back to increased fire frequency. This area remains the least explored component determining future fire regimes. Because of the complexity of the issue, it is recommended as a first step that efforts be concentrated in understanding the effects of potential changes in stand productivity.

Priority 1.2. Fire impacts

(i) *Effects on landscape pattern.* Fires are heterogeneous (Turner *et al.*, 1994) and the recolonization of burned areas is likely to depend on fire size, shape and the spatial patterns of intensity. Remote sensing is a useful tool to monitor changes in landscape features after fire and relate changes in landscape complexity with records of fire conditions.

(ii) *Impacts on vegetation composition and biological diversity.* As a next step, research needs to establish the role of burned patch size on postfire recovery. Population dynamics and seed rain should be monitored in burned patches of different sizes to assess species changes, including relative responses of seeding *v.* resprouting species and colonization by species previously absent from the community. The effects on recolonization of past land use history and surrounding landscape pattern will also be of particular interest. The results of these investigations on post-fire recolonization should be synthesized in the form of a comprehensive simulation model of community dynamics in landscapes submitted to different fire regimes.

(iii) *Interactions with climate change.* Post-fire regeneration depends strongly on climatic conditions. Bond (1995) concluded that dominant shrub and herb species of the Mediterranean Basin are unlikely to suffer complete reproductive failures because common and dominant species tend to be resprouters, have generalized and abundant pollinators, and are not seed limited. Two questions remain: (1) whether future climates, combined with increased CO_2, are likely to limit or enhance species ability to resprout vigorously, (2) how much increased temperatures associated with lower and more unpredictable and variable rainfall might compromise recruitment from seeds. Oechel *et al.* (1995) hypothesized that under increased CO_2 and evapotranspiration, resprouting species might be more vigorous while soil surface drying would decrease germination and seedling survival.

(iv) *Feed backs on ecosystem processes.* As they modify vegetation cover and composition, as well as landscape heterogeneity, fires will also have feed backs on ecosystem processes such as gas emissions and water fluxes. These issues are dealt with in the following two sections.

Priority 1.3. Fire control and mitigation

As the Mediterranean Basin is densely populated and used by humans, fire can represent a risk to populations and have large economic impacts (e.g. on forest plantations). Mitigation will then be a necessity and procedures will have to be developed both for prevention and restoration of large, heavily burned areas.

(i) *Fire prevention.* Studies of the relationship between fire spread and landscape pattern should provide quantitative arguments to aid the design of landscape barriers to fire spread. Models coupling vegetation dynamics and fire spread developed under 1.2 need to be applied to assess the efficiency of different landscape configurations and barriers in preventing large scale fires. They will also be useful to identify sensitive landscape positions where fire prevention and suppression should be targeted. However, Rambal & Hoeff (1998) showed that fires in the Mediterranean region are controlled by climate rather than fuel loading, so that they will be difficult, if not impossible to suppress under predicted climate changes. The results of the studies under 1.2 (i) and (ii) should also help concentrate protection on sensitive landscape positions and areas with sensitive vegetation or species types. Further work should also focus on the effects of fire control regimes on vegetation composition, species diversity and landscape diversity (Moreno & Oechel, 1994).

(ii) *Restoration of burned areas.* Recolonization after large severe fires is a concern because (1) internal recovery potential (seed banks and resprouting individuals) is largely destroyed and (2) propagule influx to the centre of the burned area is limited. That concern also relates to risks of soil erosion and nutrient leaching resulting from an increased frequency of heavy rains, especially in rugged terrain. Earlier strategies based on the establishment of fast-growing pines or eucalypts in dense monospecific plantations have proved unsatisfactory because they generate positive feedbacks on fire and create systems with high sensitivity to global change factors. Rather, research should focus on the reconstitution of multi-layered communities and on the designing of species assemblages with high resilience to disturbance and drought (Naveh, 1995).

PRIORITY 2. EFFECTS OF LAND USE ON BIOSPHERE-ATMOSPHERE INTERACTIONS

We know that anthropogenic emissions affect global climate through atmospheric accumulation of greenhouse gases (CO_2, CH_4). However, less is known about the feedbacks that changes in the land cover and ecosystem physiology may have on the atmospheric composition and the physical climate.

Several characteristics justify the use of the Mediterranean Basin as a model to study regional responses to a variety of global change drivers and feedbacks to climate. (1) The region has a climate with highly specific rainfall patterns, so that changes in land cover and ecosystem physiology can potentially have a detectable impact in the regional physical climate. (2) Mediterranean ecosystems are especially sensitive to climate change because of the transitional nature of this biome, which falls in between temperate forests and deserts. A small decrease in the annual precipitation, for instance, can easily shift Mediterranean communities towards low-cover desert shrublands with associated consequences for water and carbon fluxes. (3) Of all the changes expected to occur within the next century, increased atmospheric CO_2 is probably the most reliably predicted in trend and magnitude. Water-limited ecosystems, including MTEs, are among the most responsive to elevated CO_2 because of increased water availability due to reduced stomatal conductance (Owensby *et al.*, 1996; Field *et al.*, 1996). (4) Mediterranean ecosystems feature the world's highest production of biogenic emissions per unit area (e.g. monoterpenes, isoprenes), with 49% of the plant species growing in MTEs producing aromatic volatile oils (Ross & Sombrero, 1991); (5) The Mediterranean Basin is unique in the intensity and pattern of land use change, which may drive a great deal of the regional biogeochemical cycles, in particular in the time frame of decades. The prominence of land use change as a driver of the dynamics of Mediterranean ecosystems is a primary criterion for the prioritization of issues for future research on biosphere-atmosphere feedbacks detailed below.

Priority 2.1. Feedbacks of land use changes on the climate system

Modelling studies have shown that the conversion of forest to grassland can have climatic consequences similar in magnitude to those associated with changes in the radiative forces alone (Nobre, Sellers & Shukla, 1991). The water and energy balances need to be quantified for the main land cover types (e.g. evergreen forest, shrubland, croplands). These data can then be coupled to regional climatic models to test the climatic implications of different land use change scenarios.

Priority 2.2. Ecosystem physiology feedbacks on the climate system

(i) *Effects of increased CO_2 on temperature.* Coupled biosphere-atmosphere models such as SiB2-GCM, indicate that the physiological responses of ecosystems to elevated atmospheric CO_2 can result in temperature increases similar to those due to changes in radiation and energy balance (Sellers *et al.*, 1996). Effects of increased atmospheric CO_2 on canopy conductance, as well as their implications for the overall water and energy balance, need to be studied for the main land cover types.

(ii) *Effects of increasing temperature on biogenic emissions.* The high emission rates of carbon compounds to the atmosphere may increase the coupling among biosphere and atmosphere processes as biogenic emissions are expected to change with altered atmospheric composition and climate (Seufert *et al.*, 1995).

For both these research areas, two approaches are needed.

(1) A network of monitoring sites. Eddy correlation techniques are currently the best available tools which can monitor continuously water, CO_2, and volatile organics. The European network of Eddy correlation tower sites (Euroflux) is currently being extended to cover Mediterranean countries. Some process-level understanding can be derived from comparing flux measurements at sites from different ecosystems ranging across environmental conditions.

(2) The best mechanistic understanding will be achieved by manipulative experimentation where temperature and other climatic and atmospheric factors can be changed. There are several techniques to increase temperature that have been successfully used such

as infrared heating, electric resistance heating, field greenhouses, and temperature-controlled field chambers. Warming experiments should always deal with other climatic and atmospheric factors likely to change, such as CO_2, N deposition, and precipitation. Experiments using multi-factorial arrangements are the appropriate way to understand the interactive nature of global change. Species-level measurements are important because climate and atmospheric changes are predicted to alter species' contributions to overall fluxes, for example of water and carbon.

Priority 2.3. Contribution of fire related emissions of carbon, nitrous oxides and other trace gases to the atmosphere and their potential effects on climate

More frequent fires are expected to contribute to the emissions of carbon (CO_2, CO), nitrous oxides, and various other trace gases to the atmosphere. Smoke plumes should be analysed for carbon emissions and nitrous oxides. These fluxes need to be analysed in relation to changes in fire frequency and intensity. Data would need to be fed back to climate models that account for the greenhouse effects of these gases.

Priority 2.4. Coupled biosphere-atmosphere models for the Mediterranean Basin

The empirical results from 2.1 through 2.3 need to be integrated into coupled biosphere-atmosphere models that can be run under different land use change scenarios.

PRIORITY 3. LANDSCAPE EFFECTS ON WATER AVAILABILITY AND QUALITY

MTEs are transition zones for the control of biomass production. For low precipitation areas (<600 mm) and areas with low soil water availability (karstic regions), biomass production is controlled by water availability instead of being under the control of light and nutrients (Piñol *et al.*, 1995). Therefore, MTEs are extremely sensitive to changes in water availability. Water availability is expected to be altered by increased atmospheric CO_2, increased temperature, and changes in the annual total and seasonal distribution patterns of precipitation, including rare drought events. Nitrogen deposition is also likely to have interactive effects with atmospheric CO_2 because it will ameliorate nitrogen limitation on NPP. Its effects on water quality will also be highly important.

Disturbances increase flows out of ecosystems. Experimental and modelling studies in several mediterranean regions have shown that fires, and indeed any large disturbance which reduces vegetation cover and leaf area, lead to a transient increase in water yield at the landscape scale, possibly followed by a decrease during the phase of regrowth (Rambal, 1994). In arid ecosystems, increase in landscape grain (decreased heterogeneity) resulting from changes in pastoral practices, often leads to an increase in flows of water, nutrient, and soil particles, promoting further soil degradation and landscape homogenization (Tongway & Ludwig, 1995). Understanding the relationship between the magnitude of flows and changes in landscape patterns brought on by fires, overgrazing or reduced human disturbances is a priority.

While a wealth of intensive work has been targeted at local scales, work at the landscape scale is needed to address the interactions between different global change drivers. We propose approaches at both the patch and landscape scales.

Priority 3.1. Research at the patch scale

Using five different scenarios of climate change and vegetation response in terms of leaf area index (LAI) and stomatal conductance, simulations calculating rate of transpiration, deep drainage and water yield emphasized the effects of new equilibrium LAIs brought on by increased CO_2 and decreased rainfall (Rambal, 1994). To understand these processes and their consequences for MTEs, research at the patch scale should cover the following topics.

(i) *Effects of small changes in LAI on hydrological response.* In low LAI shrublands, widespread in MTEs, limited changes of transpiring surface induced by climate change or disturbance have the potential to yield contrasting hydrological responses. To understand such changes, research should focus on rapid changes that occur in hydrologic properties and in ecosystem attributes for some key stages such as regrowth after clear cutting or fire. For example, using patches burned at different intensities, it would be possible to correlate soil physico-chemical parameters and hydrological properties with the dynamics of plant recovery.

(ii) *Testing the hydrological equilibrium hypothesis in MTEs*. This hypothesis, based on abundant literature, is a useful tool to relate ecosystem characteristics such as LAI and vegetation cover to both climate and soil moisture availability (Eagleson, 1982). Applied to landscapes for which soil data are limited or unavailable, it yields estimates of soil properties. Particular attention could be directed to reforested areas in which the hydrological equilibrium hypothesis can not be applied. These areas are likely to be highly sensitive ones, where changes in rainfall regime and amounts can induce drastic changes in water budget, resulting in water stress in turn inducing major dieback and subsequent wildfires.

(iii) *Temporal variability of water fluxes*. The temporal variability of water fluxes is an important parameter for the stability of ecosystems as well as an important concern from a socio-economic point of view. Two temporal scales will be of particular interest. First, the sensitivity of water-related ecosystem parameters to unusually long droughts and to rare events will need to be monitored. Second, seasonal fluctuations in water availability need to be related to seasonal changes of ecosystem attributes such as LAI. Accurate measurements of the fluctuations of ecosystem attributes, and particularly of LAI, will improve models simulating plant and soil water status and fluxes. They will also add to our understanding of the control of transpiring leaf surface to both maximize carbon budget and minimize water use and stress.

(iv) *Dynamic functional simulation models*. These should integrate the knowledge accumulated in (i) to (iii).

Priority 3.2. Research at the landscape scale

(i) *Structural* v. *functional mapping*. Remote sensing offers efficient possibilities of characterizing the structure of terrestrial ecosystems and can yield correlative assessments of functional features. Surface temperature mapping improves the definition of homogenous landscape units based on heat fluxes and hence functional patterns. However, the acquisition time of TM data (the only high resolution thermal IR sensor available) is not convenient for thermal contrasts and specific spatial structures are not easy to identify in this channel.

(ii) *Studying scales and emergent properties in Mediterranean landscapes*. The assumption of overlap between structural and functional units is not true at all scales. Geostatistical analysis will help in formulating hypotheses on how nested environmental variables influence spatial mosaics. These hypotheses are needed for the quantitative comparison of landscapes with different composition (types of vegetation communities), grain and heterogeneity.

(iii) *Effects of landscape change on hydrological properties*. Intensive studies should target catchments with different levels of patchiness (e.g. varying forest cover). In addition, it would be useful to identify watersheds with pre-existing long-term data sets (at least stream gauges), but recent changes in land use. These data would make it possible to analyse the consequences and time lags involved in the effects of land use change on water yield (and possibly quality). Burned landscapes will also be useful sources of data. Relating measurements of post-fire flows of soil, water and nutrients from a burned watershed to the spatial pattern of factors of potential influence identified in (iii) (soil quality, LAI recovery, etc.) will make it possible to understand how changes in landscape heterogeneity affect these flows.

(iv) *Landscape scale hydrological simulation models*. Models that synthesize the knowledge acquired through (i) to (iii) should be the final product that make it possible to predict future water availability in MTEs.

PRIORITY 4. CHANGES IN ECOLOGICAL DIVERSITY

Ecological diversity encompasses genetic diversity, species diversity, functional type diversity, trophic diversity, and landscape diversity. The Mediterranean Basin has outstanding levels of diversity at several of these levels (e.g. Cowling *et al.*, 1996). In addition, the large amount of knowledge already available makes it a key area to investigate the relationship between diversity and ecological functioning (Richardson & Cowling, 1993; Hobbs, Richardson & Davis, 1995). More specifically, research should investigate the effects

Table 2. Hypothesized areas of effects of different levels of diversity on processes in interaction with global change.

Level of diversity	Effects
Genetic	Productivity
	Resilience
Species	C emissions
	Interspecific interactions (competition, mutualism)
	Fire resilience
Functional type	C fluxes and pools
	Water availability
	Fuel accumulation
Trophic	C fluxes and pools
	Predation, symbiosis
Landscape	Water yield
	Soil erosion
	Extinctions and invasions
	Fire spread

of ecological diversity on responses to global change, including ecosystem services such as C sequestration, fire resilience, soil erosion and water yield. Topics presented in Table 2 necessarily overlap with those addressed in relation to fire and ecosystem processes (feedbacks to the atmosphere and water availability) presented above. Below we detail aspects of ecological diversity of particular relevance to global change effects in the Mediterranean Basin.

Priority 4.1. Genetic diversity

The role of genetic diversity in ecosystem function remains little studied. As genetic diversity can be quite high in many Mediterranean species, the importance of that diversity for ecosystem response to climate change needs to be investigated. For example, the existence of ecotypes related to different altitudes might improve the persistence of species under climate change. Experiments are needed to determine whether genetically diverse populations perform basic ecosystem functions (carbon fixation, water use, nutrient cycling) more efficiently than a clone or a genetically impoverished population of the same species.

Priority 4.2. Species and functional diversity

Field experiments need to be set up to tease out the relative roles of species diversity *per se* (species number) and functional diversity (number of functional groups) in the functioning of ecosystems and their resilience to environmental changes and disturbance. These include the construction of synthetic communities, manipulative experiments where species or functional groups are added or deleted, and the use of natural diversity gradients. Part of that approach needs to be applied to the identification of bioindicator species or species groups, identified for their particular sensitivity to environmental and disturbance changes. Similar experiments would also be used to investigate the effects of trophic diversity. In particular, soil trophic diversity is likely to be of key importance for the response of ecosystems to climatic and atmospheric changes. This aspect could be investigated through manipulative experiments with selective deletions of soil trophic groups.

Priority 4.3. Landscape diversity

The Mediterranean Basin offers unique opportunities to investigate the effects of landscape diversity on the regional response to global change drivers. Particular aspects relating to changes in landscape pattern resulting from land use change and climatic change were developed above. At the landscape scale, manipulative experiments are unlikely. On the other hand, a careful inventory of existing 'natural' experiments would make it possible to sample a range of landscapes representing gradients of diversity and to tease out effects of the number of types of landscape elements (e.g. plant communities) from effects of the spatial pattern *per se*.

The landscape scale will also be the one at which the conservation of biological diversity will be addressed. Designing conservation strategies which take into account the effects of landscape heterogeneity on species persistence, coupled with potential shifts in the vegetation remains a challenge (Holdgate, 1994). Conservation strategies will also need to be devised to accommodate for contrasting changes from the long history of disturbance, ranging from land abandonment in the North to increasing agricultural pressure in the South (Naveh, 1995).

CONCLUSION

The Mediterranean Basin is proposed as a model region for the study of global change impacts because it offers scope to investigate the complexities of the interactions among climatic, atmospheric and land use changes. Future studies need to be based on cross-cutting themes such as those proposed in this paper. In addition to its general ecological interest, the Mediterranean Basin offers the opportunity to focus specifically on the effects of land use and how it may interact with atmospheric and climatic changes. This region also offers prime systems where interactions with ecological diversity can be integrated into studies of global change. A number of the topics outlined as priorities in this paper are being addressed by current activity in the area of global change research. Some of the future challenges will lie in appropriate coordination and synthesis of that research. Similar efforts to identify priorities for global change research in other MTEs individually, and across MTEs, need to be encouraged, both scientifically and politically, in order to take advantage of their unique characteristics, and make them example regions for the study of interactions among global change drivers.

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