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Does global warming pose a true threat to Mediterranean biodiversity?

Abstract

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Global change is frequently considered a major conservation threat. The Earth's climate has already warmed by 0.5 °C over the past century and Global Climate Models (GCM) have suggested a general pattern of global warming over the next century or two. Some features of this warming include a maximum warming in high latitudes, a displacement of the subtropical belt, in each hemisphere, a greater temporal and spatial variability in both temperature and precipitation, with stronger and more frequent violent storms and a reduced predictability of weather patterns. Recent studies show that it is possible to detect the effects of a changing climate on ecological systems. Most of approaches are based on models but experimental also exists. In order to know the vulnerability of species, climatic and biological boundaries are critical data. For instance, plants in the Mediterranean region are mainly limited by moisture, so it is expected that a increase in atmospheric CO_2 has a high effect on biodiversity in those biomes. Respect to vegetation types if their main structural elements have wide tolerance limits, they may be in the least danger of breakup. Vulnerability may also be reduced by greater diversity in main structural elements of a community. Models have shown that *Quercus ilex s.l.* community seems to be one of the most vulnerable vegetation types under a warming scenario. However the lack of knowledge concerning boundaries, i.e. the upper temperature limits of species and communities, may be important under global warming conditions. Finally, loss of biodiversity in Mediterranean scenarios along the present century will be due not only to atmospheric changes in CO_2, but also to other scenarios such us land use (habitat fragmentation) or easily establishment of invasive species, coming from warmer climates, due to the largely isolation of mediterranean floras and extensive convergent evolution they suffered.

Introduction

Mankind is carrying out an experiment with the global climate. Not intentionally, but each year billions of tonnes of CO_2 are released into the atmosphere from man's exploitation of the world's natural resources, as fossil fuels (coals, oil and gas). In addition other gases as methane (CH_4), chlorofluorocarbons (CFCs) and nitrous oxide (N_2O) are also being released as a result of human activities. As a consequence, the atmospheric concentration of these gases have been increased, with large implication for the world's climate. This is what has become known as the greenhouse effect (Warrick & al. 1990).

CO_2 is one of the most important greenhouse gas. Its main sources are deforestation and the burning of fossil fuels (coal, oil, and gas) for energy. Methane (CH_4) comes from digestive processes of ruminants (cattle) and anaerobic decomposition of organic matter associated with rice paddy cultivation. Both have enlarged over the last 200 years. A third source and, probably the most important are combustion and extraction of fossil fuels. The concentration of N_2O in the atmosphere is not very high, but it is important its long permanence in it. Its increase has occurred principally since the middle of the 20th century. CFCs are an artificial addition to the atmosphere. Warning about their danger was confirmed with the discovery of the Ozone Hole, but its releasing to the atmosphere has decreased during last decade. Atmospheric water vapour, which is expected to increase as the worlds warms, is also a very important greenhouse gas, however it coexists with the solid and liquid phases of water, releasing heating in the pass from one phase to another. Its main radiative effects are taken into account in climate model experiments as a "positive feedback" internal to the climate system rather than as an external "forcing" agent (Linés 2000).

The release of greenhouse gases is producing a cooling effect in the stratosphere (16-40 km) and a warming effect on the troposphere (8-16 km) with changes in temperature, precipitation and other climatic events. If climate is changing, then What is expected to happen? Some features of this warming following GCM's models include a maximum warming in high latitudes, a greater temporal and spatial variability in both temperature and precipitation, with stronger and more frequent violent storms, a reduced predictability of weather patterns and a displacement of the subtropical belt, in each hemisphere. The last is important in the western part of the Mediterranean Basin, affected in summer by the Azores' anticyclone. If this pressure belt shifts changes can affect to biodiversity.

Tendencies observed in Mediterranean climate

Although many climatic studies have been focused on annual variables, seasonality is very important in mediterranean territories due to the highly variation of climatic events that affect many biological processes. Those processes could be affected if seasonal and annual patterns of climatic variables change.

Seasonal temperature and precipitation

Scenario of climate change for temperature (Fig. 1) predicts a warming greater than the global mean, for winter, in most of the north of the Mediterranean Sea. Over land, the changes are smallest in the areas immediately adjacent to the Mediterranean Sea. Changes in spring will be smaller, with most of the west and south of the region having values less than the global change. However, in much of the north and east, in a belt stretching from France around the northern Mediterranean to Jordan, changes are indicated to be greater than the global level of warming, particularly away from the coastal margin. Summer warming is greatest in the east and northeast, with a more limited area of warming over northwestern Africa and southern Spain and Portugal. In autumn the greatest warming is seen in the west over northwest Africa, Spain and southwest France, and in the east over eastern Turkey (Palutikof & al. 1996).

Scenario of climate change for precipitation (Fig. 2) predicts an increase in the north-

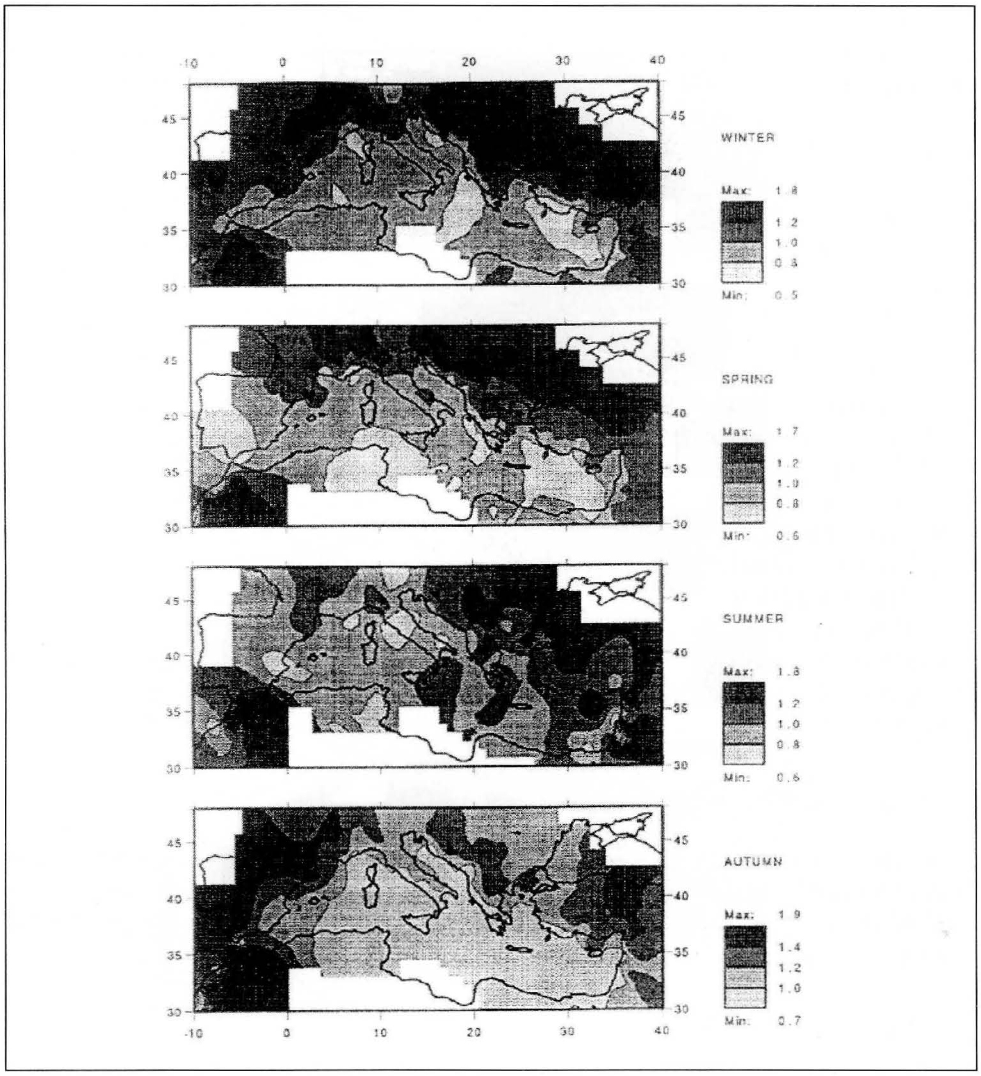

Fig. 1. Seasonal temperature changes in the Mediterranean Basin for a warming scenario of 1 °C. From Palutikof & al. (1996).

ern areas of the Mediterranean Basin in winter, together with an area extending from Italy and Sardinia, south into Tunisia and parts of Algeria. Lower precipitation over land areas is indicated mainly over the Middle East and North Africa. In spring the dividing line between higher and lower rainfall runs along the north coast of the Mediterranean sea, with only three spatially restricted areas of higher precipitation over Africa. In summer the patterns are not spatially coherent because of low correlation arising from very low rainfall in this season (Palutikof & al. 1996). However, some scenarios of climate change have predicted more decreasing in some areas of the Iberian Peninsula (IPCC '95). The scenario

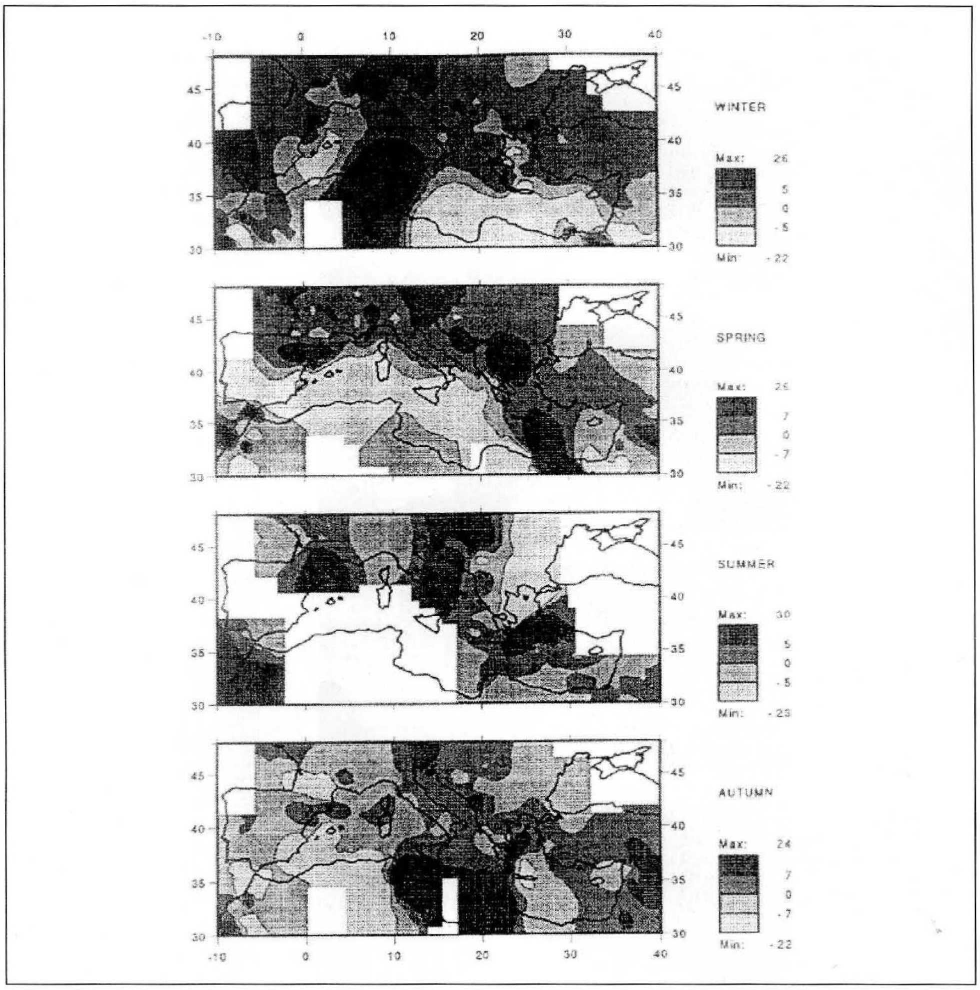

Fig. 2. Seasonal precipitation changes in the Mediterranean Basin for a warming scenario of 1 °C. From Palutikof & al. (1996).

for autumn precipitation suggests a decline over the western Mediterranean and an increase over much of the central and eastern Mediterranean (Palutikof & al. 1996).

Potential evapotranspiration (PET)

It is an interesting measure for studies about diversity. Current PET shows a north-south gradient in potential evapotranspiration across the Mediterranean Basin in all seasons. Under a global warming of 1 °C (Fig. 3), PET experiences less changes in winter than in the rest of seasons. In summer, the largest change is found, being absent the north-south trend: lowest values are found in the central region of the Mediterranean Basin, over Corsica, Sardinia, Sicily and southern Greece being the predicted lower than 1.5 mm/day.

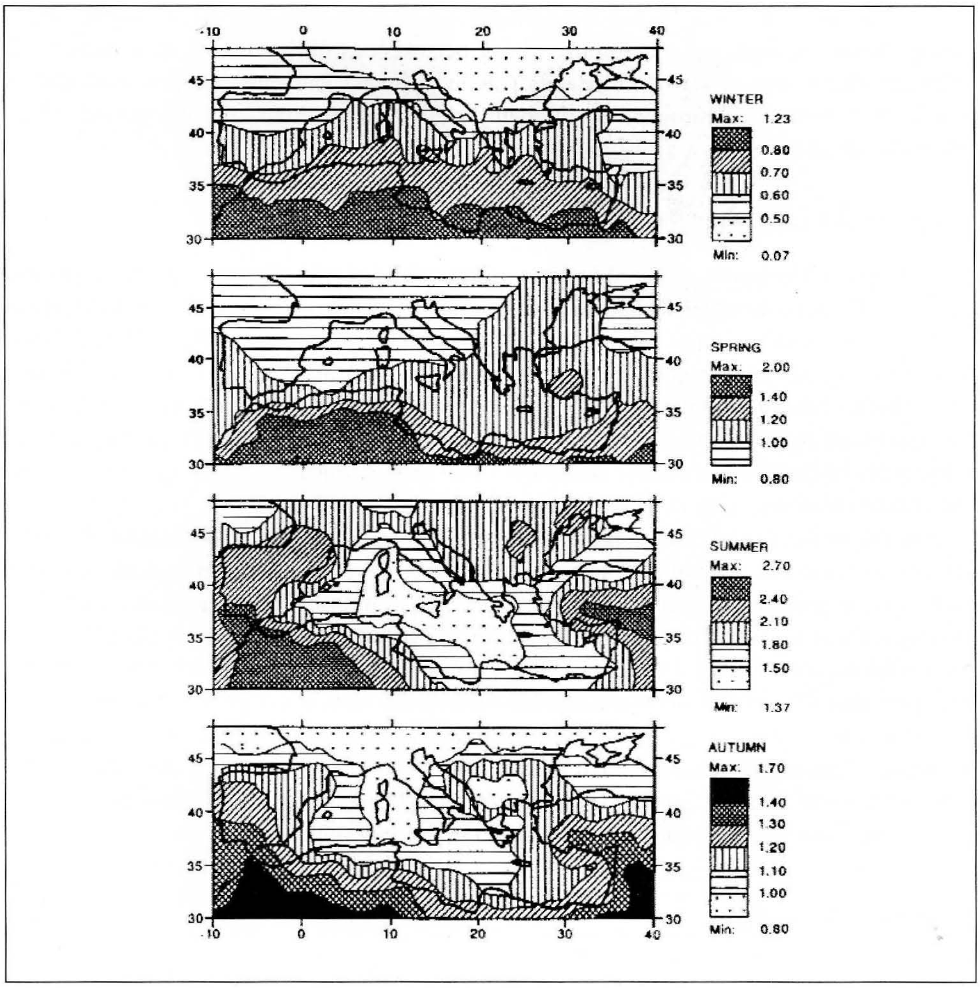

Fig. 3. Seasonal potential evapotranspiration (PET) changes in the Mediterranean Basin for a warming scenario of 1 °C. From Palutikof & al. (1996).

The change in PET increases towards the edges of the map, particularly towards North Africa and southern Spain in the west, and towards southern Turkey in the east, where the predicted change is greater than 2.4 mm/day. Spring and autumn follow the same pattern as summer with changes between 0.8 and 2.00 mm/day (Palutikof & al. 1996).

Extreme events

Also extreme events have been studied in the Mediterranean Basin. Due to the increase of anticyclonic weather events called as "heat waves" related to a particular high pressure patterns consisting of bringing of warm air from northern Africa, that provokes an increase in temperature. However, other extreme events such as the called "meteorological bombs", or very intense depression, lasting almost a day, accompanied by very strong winds, heavy precipitation and high sea conditions, whose occurrences during 65-92 have decreased, probably due to the effect of more anticyclone weather. The same happen with strong winds, like Mistral or Sirocco, all of them with negative trends for the period 50-90 (Piervitali & al 1998).

The particular case of the Iberian Peninsula

The Iberian Peninsula, situated in the western part of the Mediterranean Basin, participates of all above mentioned. Particularly, climatological studies have shown an increase of 1,6 ºC in annual average temperature. The warmest years were 1989, 1995 and 1997. The warming has been higher in summer (close to 2 ºC) than winter (1,4 ºC), although local studies have detected a higher increase on the minimum mean temperature than on the maximum mean temperature in central Spain (Gavilán & al. in press). However, as in other parts of the Mediterranean Basin a cooling have been detected in the seventies for the annual mean temperature (Palutikof & al. 1996).

Rainfall in the Iberian Peninsula has increased during the most humid season, the winter; the increase has been about the 15% during the 20th century. Other regional or local studies have pointed out that rainfall in winter and autumn have increased at expense of spring, without no significant change in the annual precipitation (Hulme & Sheard 1999). Nevertheless, some severe droughts have been observed in 1988/89, 1991/92 and 1992/93, probably due to a higher influence of the subtropical belt, together with a decrease in cloudiness (Piervitali & al. 1998). Other authors (Merino & al. 1995) have predicted a decrease of around 60 mm of annual rain, for the 2100, that could cause the local extinction of the most sensitive species, resulting in a net loss of diversity. Summarizing, there is agreement on predicted future temperature but not on precipitation.

Changes in biodiversity

Changes in animal behavior

Short-term climate variations can affect the metabolism and breeding of small birds. This is the case of the blue-tits (*Parus caeruleus*) whose populations were studied in France and Corsica. Three populations of birds were compared. One of Corsica, nesting in evergreen oak, two in the continent, one nesting in evergreen oak and a second one nesting in deciduous oak. In Corsica birds breed in June when new oak leaves stimulate a population of caterpillars, the birds' favorite food. On the continent, the birds breed 3 weeks earlier, coinciding with the greening of the deciduous oaks and, again, an abundance of caterpillars. The population nesting in evergreen oaks in the continent was in disadvantage, since the caterpillars have not emerge so early than in deciduous oaks. Then, the Montpellier birds were using almost twice as much energy as the birds in Corsica to rear their young. Breeding too early has a fitness cost. This could be an example of what can happen under climate change conditions (Thomas & al. 2001).

Plant-animal interactions

They are related to pollinators and the species they pollinate. In this kind of interactions it is important the phenology of plants that is related to three environmental factors: photoperiod, temperature and moisture. Photoperiodic control is common in herbaceous, short-lived plants; temperature is more common on woody species, generally cumulative heat sums above some threshold level. The abundance of flowers has been related to rainfall in the preceding rainy season in some mediterranean species (Keeley 1987). Thus, under climatic change timing of flowering might shift to early spring in woody species, more affected by changes in temperature, whereas herbaceous species may show little change. The quantity of flowers produced could be sensitive to shifts in precipitation amount and seasonality. The final result of all these changes it that the number of individuals that flower or set fruits may also change (Bond 1996).

Respect to the activity of pollinators, temperature has been considered a dominant factor controlling insect development and survival, while moisture play a second role. Thus, climate change will influence insect distribution and abundance and they can influence foraging patterns that are also dependent on climate. Global warming could allow the release of insects to areas where before a constraint of low temperature existed for them. As an example of how obligate mutualism can be affected by climatic change we can mention the case of the common fig (*Ficus carica*). The fig can be grown from seed north of the 46^{th} parallel in France but can not reproduce due to the absence of its pollinator, a wasp that lives south of the 46th parallel in France. Under climatic warming such pollinator may reach northern areas allowing the fig to spread northwards (Kjellberg & Valdeyron 1990).

Finally, we could make us the following question: can asynchrony between plant and pollinators appear under climatic change? Pollen viability and seed set can be influence by climate change, but also the activity of insect pollinator could be disrupted. Climatic changes in time can happen since seasonal phenology of flowering and insect development are sensitive to them. However, not only changes in time can occur, also in space since the distribution of pollinator assemblages may also change altitudinally.

Some studies have been conducted to see the synchrony between pollinators and plant species that could show us how weak is the equilibrium between them, as in *Banksia spinulosa*, a *Proteaceae* of western Australia. The effect of flowering season on pollinator visits and seed set was studied (Table 1). Birds and honeybees visits changed through the flowering season, with fewest bird visits, most honey visits and lowest seed set, presum-

Table 1. Seasonal Variation in Pollinator Activity on *Banksia spinulosa* (*Proteaceae*), from Vaughton 1992.

	Early	Mid	Late
No. visits/inflor.			
Birds	23.1	16.0	7.2
Honeybees	0.0	0.0	8.1
Flowers pollinated (%)	22.0	27.0	64.0
Fruit set (% inflor.)	61.9	58.5	29.2

Early: May-June; Mid: July-August; Late: September.

ably because bees are less effective pollinators towards the end of the season. Pollinator visits also changed from year to year, with three times more visits in themed-flowering period in one year than the following. This difference was correlated with difference in follicle set (Vaughton 1992).

Changes in flora

As a response of species distribution to changes in climate, migration could be a mechanism for plants when troubles in water availability appeared. Species could migrate northwards until they reached areas having temperature and evapotranspiration in equilibrium with their physiological characteristics. It is clear not all species belonging to the flora of a territory will react similarly, so vagile or primocolonizer plants will migrate quickly than others. In Spain we have detected some changes in the geographical distribution of taxa (Sobrino & al. 2001). It is the case of *Sonchus tenerrimus* and *Dittrichia viscosa*, two termophilous species that after the 70's have reached areas inland or at higher altitudes (Figs 4 and 5).

Simulation of how species can react to possible changes in precipitation was done in the north of Spain. Navarra, situated south the Pyrenees, has a strong N-S rainfall gradient that produces changes in flora, from the Eurosiberian Region to the Mediterranean. Changes along this boundary was studied for different rainfall scenarios. In the Eurosiberian territories some species, such as *Brachypodium pinnatum* (Fig. 6) or *Genista anglica* can almost extinct, while in the Mediterranean part species can shift northern but also can

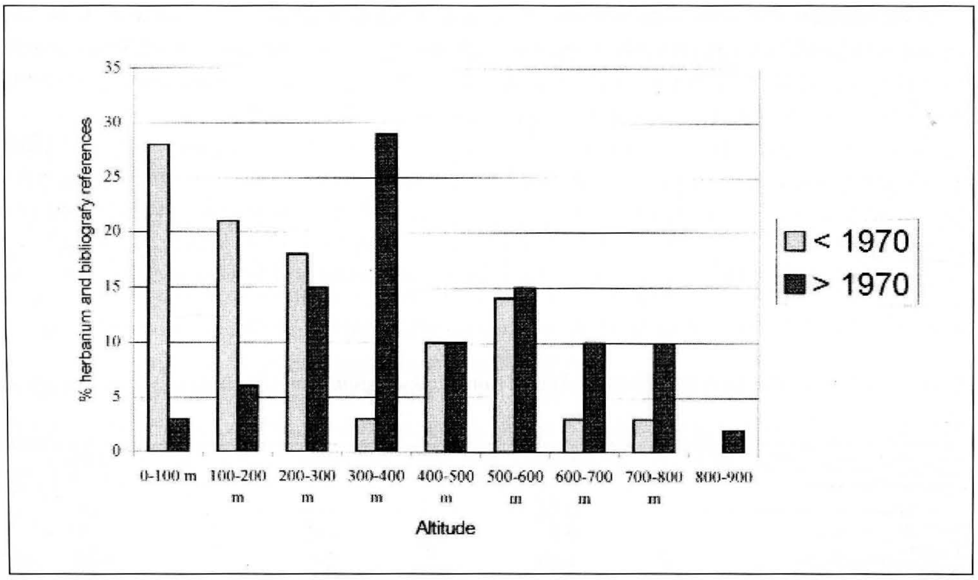

Fig. 4. Distribution percentage of *Dittrichia viscosa* citations bibliography by altitude intervals (gray before 1970, dark-dotted after 1970). From Sobrino & al. (2001).

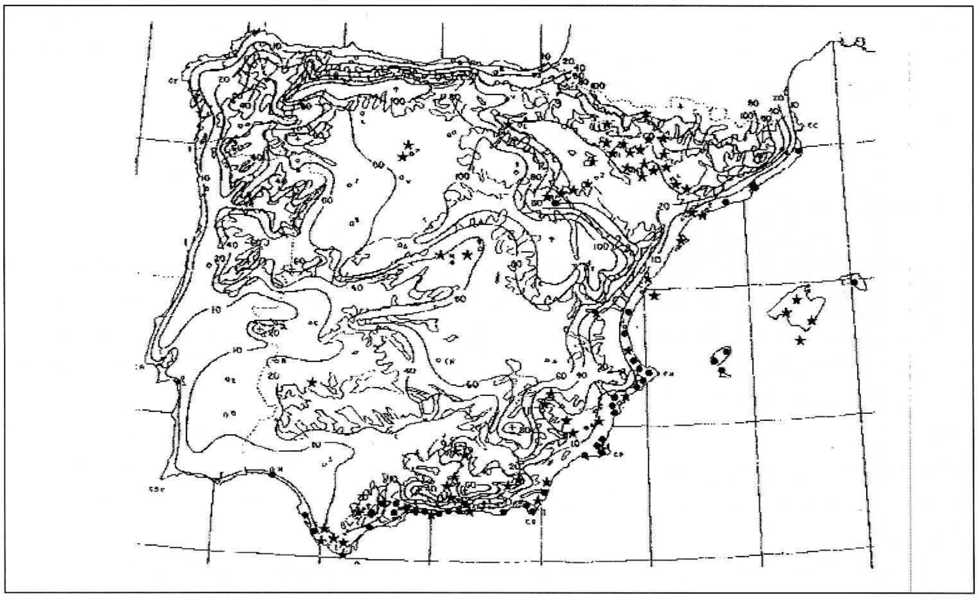

Fig. 5. Distribution of *Sonchus tenerrimus* in the Iberian Peninsula (• before 1970, * after 1970). From Sobrino & al. (2001).

increase their presence in Mediterranean territories where now they are not very abundant, as in the case of *Rosmarinus officinalis* (Fig. 7; Olano & Peralta 2000).

A consequence of the different behavior of species to migrate can be the invasion of exotic species. They are coming from other territories whose climatic conditions are also changing and find new territories to colonize. Usually, they have competitive mechanisms not present in natural flora. It has been pointed out the problems of chemical allelopathy, mechanism by which invasive plant species eliminate natives. These competitive mechanisms are not present in natural communities that they invade and they disrupt coevolved interactions among long-associated native species (Callaway & Aschehoug 2001). For that reason the invasion of exotic species could be one of the greatest problems for the Mediterranean flora since they have long been isolated and exhibit extensive convergent evolution that can be disrupted by the invasive mechanisms. Some authors show it as the

Table 2. Main threats that can affect biodiversity of World biomes. Medit.: Mediterranean biome; N temp: Northern Temperate biome; S temp: Southern Temperate biome. From Sala & al. (2000).

	Alpine	**Medit.**	Desert	N temp	S temp	Tropic
Land use	1.0	**3.0**	2.0	1.0	4.0	5.0
Climate	3.0	**2.0**	2.0	2.0	2.0	1.0
Nitrogen deposition	3.0	**3.0**	2.0	5.0	1.0	2.0
Biotic exchange	1.0	**5.0**	3.0	3.0	2.0	2.0
Atmospheric CO_2	2.5	**2.5**	2.5	2.5	2.5	2.5

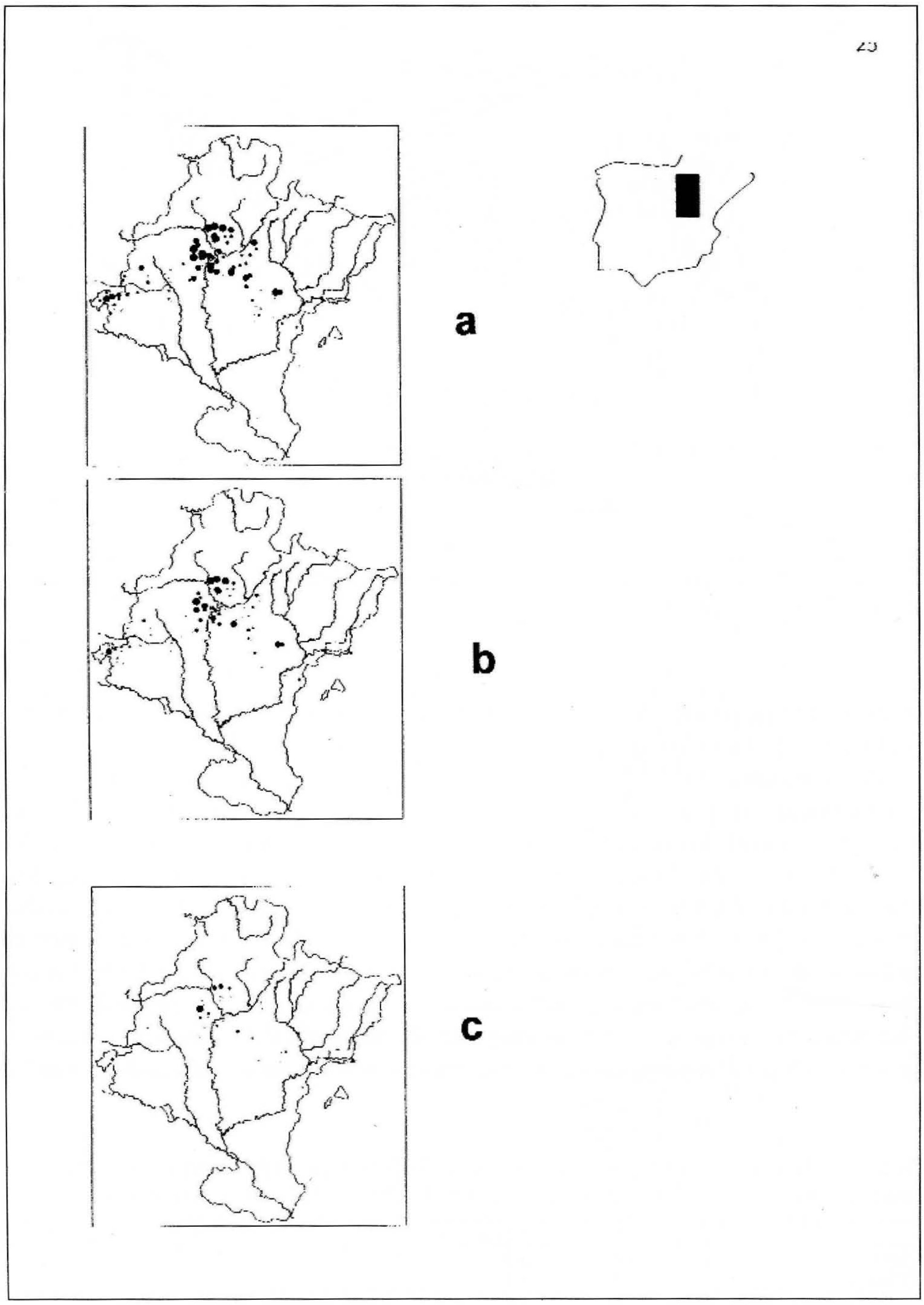

Fig. 6. Probability of *Brachypodium pinnatum* occurrence at present rainfall (a); at 90% of rainfall (b); at 70% of rainfall (c). From Olano & Peralta (2000).

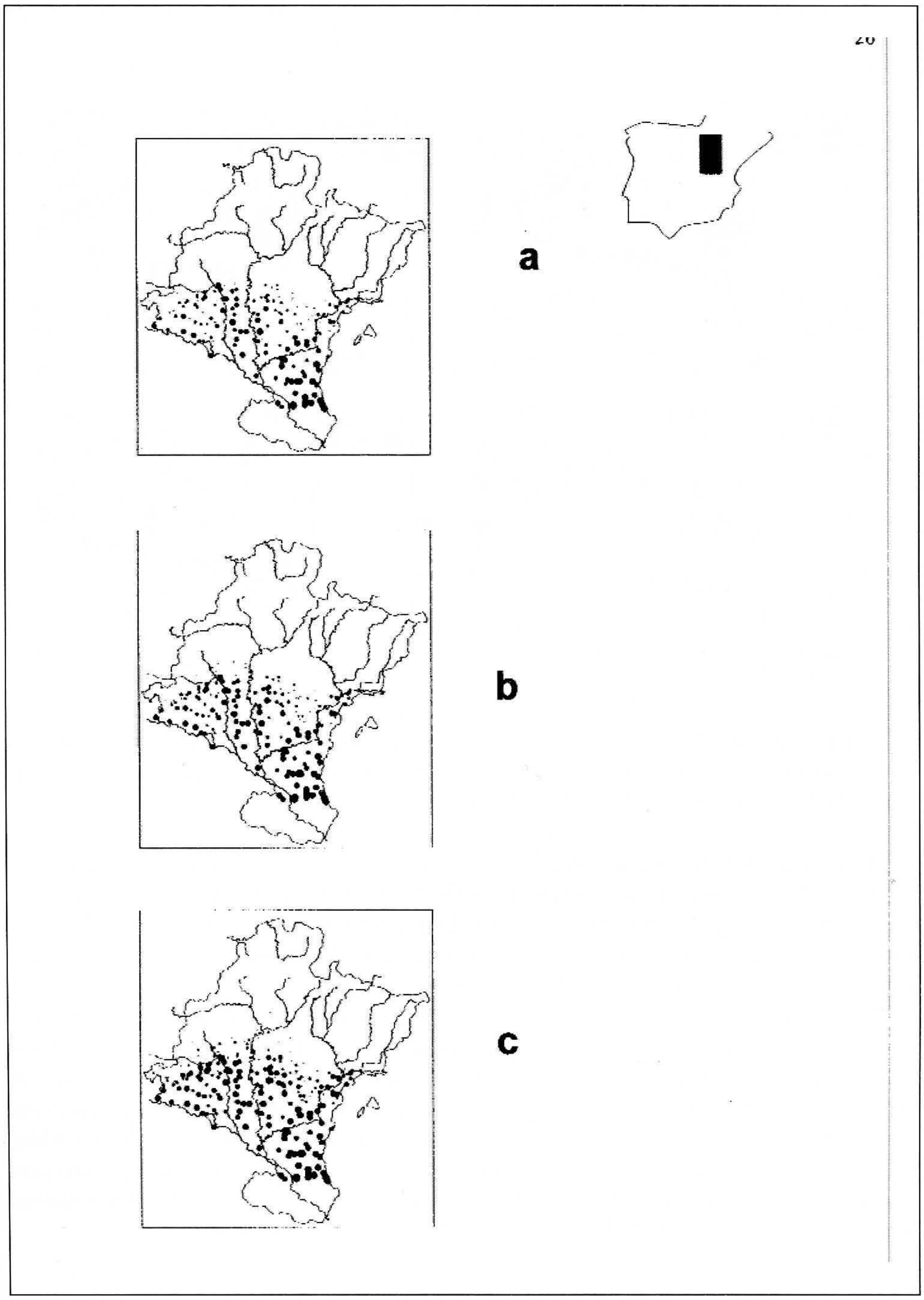

Fig.7. Probability of *Rosmarinus officinalis* occurrence at present rainfall (a); at 90% of rainfall (b); at 70% of rainfall (c). From Olano & Peralta (2000).

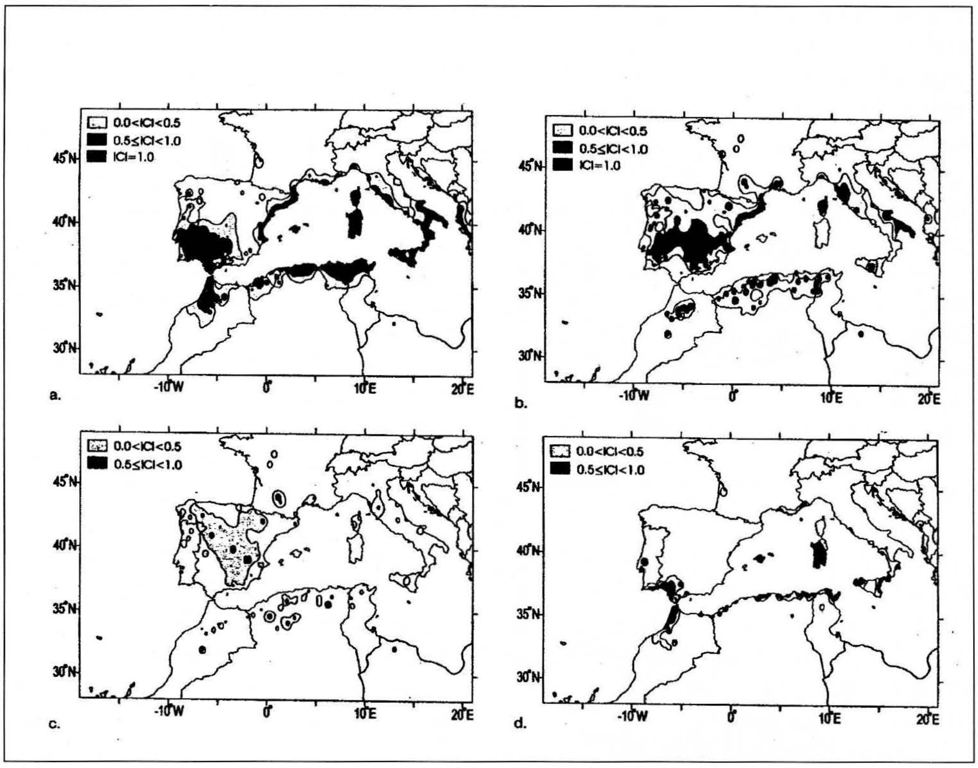

Fig. 8. Estimated integrity of *Quercus ilex* s.l. forest in the western Mediterranean Region, at present (a) and under a 2° C warming scenario (b); c and d are areas gained and lost, respectively, by the community under tha warming scenario. From Box & Choi (2000).

most dangerous for the Mediterranean ecosystems (Sala & al. 2000, Table 2). In the Iberian Peninsula some exotic species coming from the Cape or the Neotropical Kingdoms, such as *Arctotheca calendula, Araujia sericifera, Tropaeolum majus* and *Ageratina adenophora* have extended their range along the last three decades being a real threat for some endemic plant communities (Sobrino & al. 2001).

Finally, an additional problem to migration is the fragmentation of habitats and the troubles of plants to disperse and/or to migrate. In spite of the fragmentation of the habitats could make no possible this migration since it depends in many cases of the integrity of the ecosystems that influence the capacity of dispersion. This is the case of *Juniperus turbinata* a small tree of dunes whose fruits are dispersed by a bird, a spotless starling (*Sturnus unicolor*) and by the red fox (*Vulpes vulpes*). If the habitat is fragmented and these two animals not appear in areas suitable to the juniper for establishing, then it has serious troubles to disperse properly (Merino & al. 1995).

Changes in ecosystems and communities

Related to the different reaction of different species to changes in climate, vegetation, or plant communities, will not shift as discrete units, but will change in composition. They will become more unstable and probably much weedier, as vagile secondary species respond quicker, colonizing new habitats and competing more efficiently than characteristic species. There is a clear potential for breakup of present-day communities and landscapes over large areas, being time scale for biotic response and restabilization not predictable. If changes are more rapid than expected, then changes will affect extremely at ecotones, the boundaries between ecosystems, particularly those in semiarid landscapes (Allen & Breshears 1998).

An integrity index (ICI) has been built to relate the fidelity of species to a plant community and to some particular environmental factor, such us climate, being particularly useful under warming scenarios (Box 2000). The ICI involves use of climatic envelopes and the fitness of species to plant communities and ranges from 0 to 1, increasing as the main defining elements of a community become further from environmental limits (Box & Choi 2000). The results for *Quercus ilex s.l.* forests in Western Mediterranean under a 2 ºC of warming scenarios are shown in figure 8, comparing to present predictions. Current integrity (Fig. 8a) is estimated to be greatest over large areas in southwestern Iberia, southern Italy, the western Mediterranean islands, in Greece, and across northwestern Africa. Lower values of integrity appear in central Iberia or northern coastal areas of Italy and France, being absent from northern Portugal and Galicia due to the lower summer temperatures as well as greater wetness. Under the warming scenario (Figs 8b-d) the distribution of the community expanded into central Iberia, southern France and northern Africa, disappearing in coastal southern Iberia, southern Italy, northwestern Africa and some Mediterranean islands.

Other models studying the functional aspects of vegetation have indicated a potential for vegetation to exert a feedback on climate (Woodward & al. 1998). Small changes in temperature are therefore expected to cause significant changes in the distribution of different vegetation types. Not only will these changes in climate influence vegetation, the changes in vegetation functioning as evapotranspiration, net primary and ecosystem productivity, nutrient cycling and structure (vegetation height, albedo, distribution) will also exert a feedback on climate itself. The degree, the sign (negative or positive) and the geographical distribution of vegetation feedback on climate will all play a role in determining the final distribution and functioning of vegetation. These models have shown a CO_2 fertilization effects on vegetation that will produce a reduction on atmospheric CO_2 concentration in the order of 12% by the year 2100. In addition, the reduction in atmospheric CO_2, through increases in soil and vegetation biomass, also leads to a slight cooling effect of -0,7 ºC on a total global warming of 3,9 ºC. However, they also predicted a negative feedback that will produce a reduction in Net Primary Production (NPP), greater in the forested regions of middle latitudes like those of the Mediterranean Basin (Woodward & al. 1998).

Other studies have been carried out on seeing how elevated concentrations of CO_2 could affect in several parts of nutrient cycle of the ecosystems (Fig. 9). Thus, Mediterranean ecosystems can be divided in those with poor litter quality, having high organic polymer and low mineral content and nutrient rich ecosytems with efficient mechanisms of decomposition. Supposing an increase of the Net Primary Production (NPP) due to the increase of CO_2 (positive feedback), then there will be an increase of litter inputs. In some Mediterranean ecosystems where litter quality is poor and mineralization in many cases

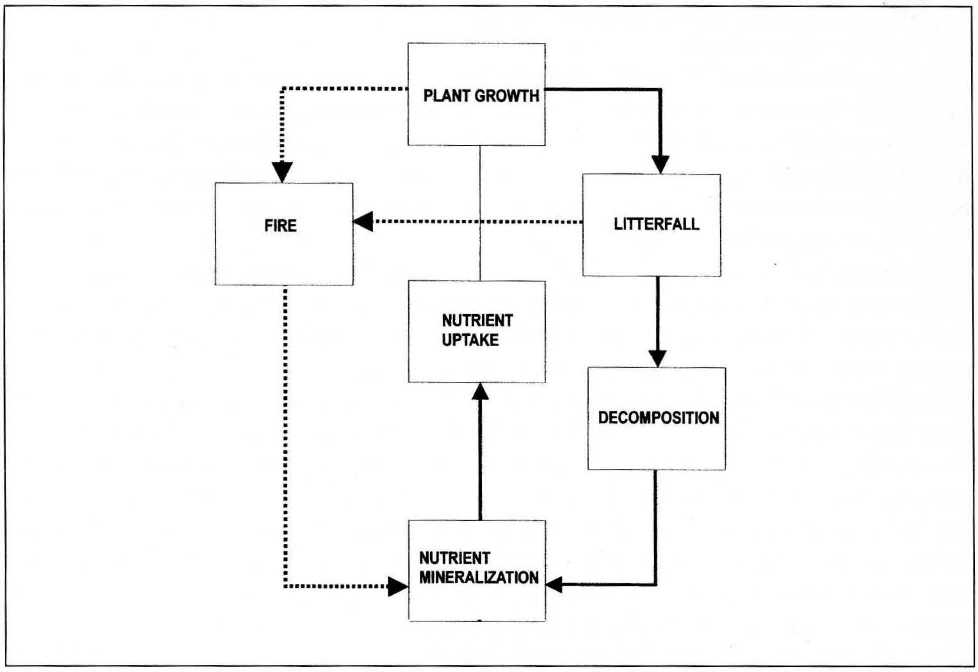

Fig. 9. Representation of nutrient cycle processes that can be affected by the increasing of atmospheric CO_2 levels in Mediterranean ecosystems (Stock & Midgley 1996).

depends on fire, those can increase. In more nutrient-rich ecosystems with decomposition processes of mineralization, the quality of litter becomes critical. Elevated CO_2 involves changes in C:N and C:P ratios and allocation of other compounds: phenolics and lignin. Changes in nutrients as N or P could be crucial for the decomposition of litter and the nutrient cycle of a ecosystem (Peñuelas & Matamala 1990). If the response of plants under elevated CO_2 is to accumulate non-structural carbohydrates, then patterns of decomposition should be less affected than if plants increase lignin, tannin or other polymer concentrations.

The problem of the coasts

The Mediterranean basin has a long coastal area. Some territories are refuge of many birds and other animals. Changes in the sea level could affect to many species. For instance the national park of Doñana in Spain has an altitude between 0 and 40 m.a.s.l. The sea level has increased during last century about 20 cm. If climate continues changing, then future elevations could produce seawater floods, destroying some habitats. Some scenarios of climate change calculated suggest an elevation between 30 cm and 110cm for the end of the present century. The loss of some species of birds can affect to the Iberian lynx (*Lynx pardinus*) that is one of the most threatened animals due not only to the fragmentation of habitats but loss of some of its preferred food, such as rabbits and ducks (Hulme & Sheard 1999).

The problem of fire in Mediterranean ecosystems

It is being a tendency to increase the number of fires in parts of the Mediterranean. The occurrence of natural fires is very low, since they are related to human activities, the global changes has contributed in some degree. The two main climatic factors that could be pointed out as responsible are the increase of the daily temperature and the diminish of the relative humidity (Hulme & Sheard 1999). Analysis of the wildfire data base showed that both the number of fires and the area burned increased between 1968 and 1994 in the coast of Spain, despite an increased fire suppression effort in later years, whereas rural activities have decreased. Moreover the 1994 summer has been described as one of the worst since 1968 in the coasts of Catalonia since 1968 without any reference to wildfires in the 20th century administrative records (Piñol & al. 1998).

Together with change in climate, man is also responsible of fires. In Spain only around a 10% of the fires are lighting-caused, but they have also the opposite influence, through fires suppression. Land use change in Spain has included the abandonment of crop lands that have been replaced in many cases by open forests or woodlands with a dense understory and the abandonment of previously exploited forest, usually not very productive. Clearly, these changes confound the relationship between meteorological fires hazard and fire activity (Piñol & al. 1998).

Conclusions

If climate change rapidly migration of species had to cope with dispersal barriers such us rivers, lakes, mountain ranges or desert basins. If additionally there is other kind of barriers created by human activities, then migration will result more and more difficult.

Although wide habitat corridors and artificial translocations of populations northward and upslope may help some species in some areas, these solutions will not suffice for whole communities, especially if climate change is as rapid as predicted.

Vegetation will not shift as discrete units, but rather will change in composition, as consequence of plant migration and will become more unstable and probably much weedier. It is being to take into account that different species will respond differently, so there is a clear potential for breakup of familiar present-day communities and landscapes over large areas.

In Mediterranean ecosystems some studies conclude that habitat fragmentation could be a major problem than climate change since it will affect to many species like rare species, species with limited power of dispersal, species with low reproductive potential or short life cycles or dependent of resources that are unpredictable in time or space, ground-nesting birds. All of them will extinct if we sum the effects of fragmentation and climate change.

Time scale for biotic response and restabilization is not yet predictable.

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