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AN OUTLINE OF THE IMPACTS OF CLIMATE CHANGE ON ENDANGERED SPECIES IN THE MEDITERRANEAN REGION

SUMMARY

The Mediterranean has a unique climate and an extremely rich and diverse flora. The flora and vegetation of the region are the most vulnerable in Europe to climate change because of their sensitivity to drought and rising temperatures and the fact that they are already under stress. The role of the Mediterranean sea as a barrier to plant migration from the southern shores and the absence of a hinterland are major factors in determining the flora and vegetation that will develop in the southern and Mediterranean Europe as a result of climate change over the coming 100 years. Novel no analogue assemblages of species may be expected and an increase in the number of invasive species. High mountain and coastal species will be especially at risk from the effects of climate change.

RIASSUNTO

Un profilo degli impatti del cambiamento climatico sulle specie minacciate nella regione mediterranea. Il Mediterraneo ha un clima unico ed una flora estremamente ricca e varia. La flora e la vegetazione della regione sono le più vulnerabili in Europa al cambiamento climatico a causa della loro sensibilità alla siccità e alle crescenti temperature e del fatto che si trovano già sotto stress. Il ruolo del mar Mediterraneo come barriera alla migrazione delle piante dalle rive meridionali e l'assenza di un "hinterland" sono fattori importanti nel determinare la flora e la vegetazione che si svilupperà nell'Europa meridionale e mediterranea come risultato del cambiamento climatico nei prossimi cento anni. Si può prevedere la formazione di nuove "inedite" comunità di specie e un incremento nel numero delle specie invasive. Le specie delle alte montagne e delle coste saranno particolarmente a rischio degli effetti del cambiamento climatico.

INTRODUCTION: THE MEDITERRANEAN REGION AS A MAJOR CENTRE FOR PLANT DIVERSITY

The Mediterranean is one of the major centres of plant diversity (DAVIS *et al.*, 1994; HEYWOOD, 1998), housing some 9-10% of the world's higher plant species, in only 1.6% of the earth's surface (MÉDAIL & QUÉZEL, 1999). About half of the 25-30,000 plant species found there are endemic to the region and there most of the major concentrations of endemism are found in high mountain regions such as the the Appennini, Alpi Apuane, le Madonie of Italy, the Pyrenees of Spain and France, the Sistema Central, Sierra Nevada and the Baetic and Subbaetic sierras of Spain, the Rif mountains, Middle Atlas and High Atlas in Morocco, Lefka Auri (White Mountains) of Crete, Greece, Óros Ólimbos and the mountains of south and central Greece, the Troodos mountains of Cyprus, the Taurus and Amanus ranges of Turkey and the Lebanon and Anti-Lebanon mountain ranges.

It is not known precisely how many of the Mediterranean's endemic plant species are threatened although based on the more or less detailed information available on a national basis through Red Books for several countries such as France, Greece, Spain and Italy, a figure of around 3-4,000 can be estimated.

THE PROJECTED EFFECTS OF CLIMATE CHANGE ON THE MEDITERRANEAN REGION

The Mediterranean is one of the regions that has been identified as most vulnerable to the impacts of climate change. The IPCC Synthesis Report (2007: 50) concluded that: "In Southern Europe, climate change is projected to worsen conditions (high temperatures and drought) in a region already vulnerable to climate variability, and to reduce water availability, hydropower potential, summer tourism and, in general, crop productivity. Climate change is also projected to increase the health risks due to heat waves and the frequency of wildfires." According to the EC (CEC 2007) the most vulnerable areas in Europe to climate change include southern Europe and the entire Mediterranean Basin due to the combined effect of high temperature increases and reduced precipitation in areas already coping with water scarcity.

The Mediterranean region has attracted a great deal of attention because of its unique climatic characteristics: its semi-enclosed sea, elongated shape, large topographic contrasts and climate gradient from mid-latitude to subtropical and its great sensitivity to climate change (LIONELLO *et al.,* 2008). Added to this are the impacts the region has suffered from anthropogenic change over thousands of years, notably the expansion of agriculture, introduction of new crops, urbanization and industrial development, and tourism which have depleted both terrestrial and marine resources and led to major alterations to the landscapes. This environmental degradation has important implications for the security of the region, especially in the Middle East and North Africa (CHETERIAN *et al.*, 2009).

A review of climate change projections over the Mediterranean region by GIORGI & LIONELLO (2008) based on the latest and most advanced sets of global and regional climate model simulations give 'a collective picture of a substantial drying and warming of the Mediterranean region, especially in the warm season (precipitation decrease exceeding – 25-30% and warming exceeding 4-5 °C). The only exception to this picture is an increase of precipitation during the winter over some areas of the northern Mediterranean basin, most noticeably the Alps. Inter-annual variability is projected to generally increase as is the occurrence of extreme heat and drought events'. Temperature scenarios for the Mediterranean have been estimated by HERTIG & JACOBEIT (2008) whose assessment indicated that even with a high level of uncertainty regarding the regional distribution of climate change in the region, 'substantial changes of partly more than 4° C by the end of the century have to be anticipated under enhanced greenhouse warming conditions'. This will have a serious impact on the evaporation rates and water budget and availability in the region which is likely to be at increased risk of water shortages, forest fires and loss of agricultural land. GAO & GIORGI (2008) used three measures of aridity to estimate the possible effects of late 21st century climate change on the Mediterranean area and their analyses suggest that the region might experience a substantial increase in the northwards extension of dry and arid lands, especially in central and southern parts of the Iberian, Italian, Hellenic and Turkish peninsulas and in areas of southeast Europe, the Middle East, north Africa and the islands of Corsica, Sardinia and Sicily. They identified the southern Mediterranean region as especially vulnerable to water stress and desertification as a result of these climate changes.

As noted in a report to the Council of Europe on the impacts of climate change on European plants (HEYWOOD, 2010), 'The Mediterranean region plays a unique role in the context of climate change and its effects on biodiversity as it acts as a barrier to migration of many plants from south to north within the time-scale of concern. Because of the lack of a comparable Saharan hinterland that characterises the corresponding North African climatic belt, a novel climate will develop in southern/Mediterranean Europe as a result of climate change and it is difficult to envisage the kind of vegetation that will occupy this in the absence of large-scale migration of species from North Africa although long-distance dispersal will allow some species to migrate. It will be vulnerable to weedy or invasive species: existing ones will be expected to persist or expand their distributions and new ones take hold'.

While large scale migrations from North Africa to the northern Mediterranean are known to have taken place in the past, the issue here is which and how many species will be able to migrate there successfully in the short time scale of concern. Because of the different rates of migration of individual species, new combinations of species will develop in parts of the Mediterranean region. The loss of some species will create niches that will be occupied by aggressive or invasive species, thus adding to the admixture. As LUGO (2009) notes, 'What distinguishes a novel ecosystem from a native one is its species composition, which includes introduced species and combinations of native and introduced species not seen before. The interactions between the species in these novel or 'no analogue' communities[1] (WILLIAMS & JACKSON, 2007) cannot be predicted and may lead to greater rates of local extinction if the species cannot adapt quickly to the new conditions (STRALBERG *et al.*, 2009). The conservation, management and use of such communities will pose new problems for land use managers and conservationists .

THE IMPACTS OF ACCELERATED CLIMATE CHANGE ON THE ENDANGERED FLORA OF THE MEDITERRANEAN

It is widely agreed that the flora and vegetation of the Mediterranean region are the most vulnerable in Europe to climate change because of their sensitivity to drought and rising temperatures and the fact that they are already under stress (EEA 2005; SCHRÖTER *et al.*, 2005; BERRY *et al.*, 2007a,b; GIANNAKOPOULOS *et al.*, 2005). On the other hand, it has been suggested that because the Mediterranean region has already been subjected to a major extinction event in an earlier period, it is more resistant now to further climate change (GREUTER, 1995).

Modelling suggests that species are likely to be at serious risk in some coastal regions and in high mountains in the Mediterranean zone as a result of climatic and other elements of global change.

Many Mediterranean species are of restricted distribution and confined to mountains or islands or both. It is estimated that alpine species that occur in Europe's high mountains account for some 20-25% of Europe's total plant diversity (GRABHERR *et al.*, 2007; NAGY & GRABHERR, 2009) and as noted

[1] No-analogue communities are defined by WILLIAMS & JACKSON (2007) as consisting of 'species that are extant today, but in combinations not found at present'. They are also known as 'novel' or 'emerging' (MILTON, 2003; HOBBS *et al.*, 2006).

above there are major concentrations of plant diversity, including many endemic species, in mountain chains across the Mediterranean region, including not just rupicolous mountain plants but those that grow in mountain pastures. For example, in the high summit pastures of Crete, 20-30% of the plants are endemic, while the rate is 10-20% in the Taurus Mountains of Turkey (Regato & Salman, 2010).

A considerable percentage of species listed by the Bern Convention occur in the Mediterranean parts of Europe, many of them, as discussed below, mountain species occurring in small populations in specialized habitats and many of them of threatened status. The prospects for the survival of a significant number of these species in a period of accelerated climate change are not favourable because of lack of suitable habitat into which to migrate, even assuming that successful migration is possible.

Nogués-Bravo *et al.* (2008) consider that Mediterranean mountain ecosystems will likely experience significant climatic change during the 21st century and will be subjected to an intensive transformation in terms of structure, functions, and services, even assuming the most conservative estimates.

Evidence of recent change attributed to climatic factors

Considerable evidence has been accumulated on recent changes in the distribution of species and ecosystems that can be attributed to the effects of climate change. Shifts in phenological features such as changes in time of budburst, flowering, fruiting, leaf coloration and leaf-fall are how species commonly respond to climate change (Cleland *et al.*, 2007). Phenological networks have been established in Europe since the middle of the 18^{th} century and extensive sets of phenological data, some of them long-term, have been gathered in several countries (Menzel, 2003). An important resource is the network of International Phenological Gardens (IPG) founded in 1957 and now based at the Institute of Crop Sciences at Humboldt University in Berlin (Menzel & Fabian, 1999; Menzel, 2000, 2003; Chmielewski & Rötzer, 2001). Its basic goal is to obtain comparable phenological data for plants across Europe by studying cloned material of trees and shrubs at various botanic gardens and other locations, the idea of using cloned material being to avoid the influences of genetic variation on the phenological observations. Since 2000, the observation programme includes 21 plant species (the core programme) and as at 2010 the network ranges across 28 latitudes from Scandinavia to Macedonia and across 37 longitudes from Ireland to Finland in the north and from Portugal to Macedonia in the south. It consists of 89 gardens in 19 European countries. Unfortunately few Mediterranean sites are included, and these are mostly in Italy. An analysis of observational data held by the IPG for the period 1959-1996, shows that spring events, such as leaf unfolding, have advanced on average by 6.3 days (-0.21 day/year), whereas autumn events, such as leaf colouring, have been delayed on average by 4.5 days (+0.15 day/year). The average annual growing season has thus lengthened on average by 10.8 days since the early 1960s**.**

The most extensive set of data on plant phenology in the Mediterranean region is that maintained by the Spanish Meteorological Agency (AEMET). Detailed analyses were made by GORDO & SANZ (2009, 2010) of c. 204,000 records gathered and digitized from the archives of the Agency for the period 1943-2003 for 29 of trees and shrubs. The results showed that great majority of species showed a shift in leaf unfolding, flowering and fruiting in recent decades. The main conclusion of their present study is that plant phenology is strongly controlled by climate and as consequence phenological temporal changes observed during last decades can be attributed to the recent climate change, thus confirming other published studies showing that plants are a reliable bioindicator of climate change. In addition, a comparison of sensitivity coefficients to temperature reported in literature for the same species in other parts of Europe suggests a higher sensitivity of plant populations in the Mediterranean (GORDO & SANZ, 2010).

Another effect of climate change that has been recorded in recent years is altitudinal range shifts. For example, LENOIR *et al.* (2008) compared the distribution of 71 forest plant species between 1905-1985 and 1986-2005 along the whole altitudinal range (0-2600m) in western Europe (Western Alps, northern Pyrenees, the Massif Central, Jura mountains, the Vosges, and the Corsican chain). They showed that climate change resulted in an appreciable movement of species above their climatic optimum by on average 29 m per decade. In the Rhaetian Alps, N Italy, PAROLO & ROSSI (2007) compared historical records for 1954-1958 with recent surveys (2003-2005) and found that climate change is forcing plants to move to higher altitudes: 52 plant species have moved 430 m higher than their previously recorded limits in response to a 1.5°C rise in temperature. If one accepts the general modeled temperature rise of 2°C expected in Europe between now and 2050, plants will have to achieve a vertical displacement of 75m per decade to remain in the same climate zone and the figure for the Mediterranean may be even higher given the grater temperature rise that some forecasts indicate.

PREDICTING THE IMPACTS OF CLIMATE CHANGE

The tool that is most frequently used in attempting to simulate species-climate change impacts is bioclimatic modelling to highlight at-risk species (for a review see ELITH & LEATHWICK, 2009). Bioclimatic models (bioclimatic envelope models) are a special case of ecological niche or distribution models. Most current predictions of the future migration of plants use the 'climate envelope' or bioclimatic modelling techniques (GUISAN & THUILLER, 2005) in which projected future distributions are based on the current climate in the species' native range. But it should be noted that models are simplifications of reality and primarily important aids to research as THUILLER *et al.* (2008) point out. These techniques aim at defining the climate 'envelope' that best describes the limits to its spatial range for any chosen species by correlating the current species distributions with selected climate variables. Although commonly referred to as predictions, their proper role is in providing part of the information base on which predictions of future change are made.

While climate envelope modelling is a valuable tool in our efforts understand the interaction between species distributions and climate and to work out the likely impacts of climate change on biodiversity, current models have severe limitations and are unable to take into account factors such as dispersal capacity, migration processes, biotic interactions, the capacity of species to adapt to climate change and the range of genetic variation in species populations (HEIKKINEN *et al.*, 2006; BROOKER *et al.*, 2007; THUILLER *et al.*, 2008; BUISSON *et al.*, 2010). Moreover, the quality of the niche models depend on the quality and sufficiency of underlying data and in many cases lack of detailed data on distribution of species is a limiting factor for resolution, coverage or both.

Bioclimatic models have also been criticized by WILLIS & BHAGWAT (2009) and ACKERLY *et al.* (2010) for their coarse spatial scale so that they fail to take into account microtopography and their use may therefore exaggerate the scale of loss of species. The latter suggest that 'Fine-scale spatial heterogeneity may provide a critical buffer at a landscape and reserve scale, enhancing genetic and species diversity and reducing gene and organismal dispersal distances required to offset climate change, at least in the short run'. On the other hand, in the case of many Mediterranean mountain/alpine species with highly specialized habitat requirements, their limited dispersal capacity and the non-availability of suitable niches are likely to be limiting factors in their survival, no matter how fine the scale of modelling applied.

Models must be interpreted on the basis of our knowledge of the biology of the organisms being modelled although for many species such knowledge is often quite limited and it is clear that we need to undertake much more research into the biological characteristics, dispersal capacity and adaptive range of species that are likely to be at risk.

KEY ROLE OF MIGRATION CAPACITY OF SPECIES

It is of course important for us to try and ascertain which species will be able to migrate and how quickly, in the face of climate change and other factors. The effective migration of species is a complex process and depends not only on climatic factors but, for example, on

– availability of suitable habitat
– availability of suitable migrants
– seedling recruitment (COPETE *et al.*, 2008; GÓMEZ-APARICIO, 2008)
– dispersal capacity (VITTOZ & ENGLER, 2008)
– colonization potential (IBÁÑEZ *et al.,* 2008)
– 'permeability' of the new habitats to incoming species, and capacity to grow, establish and compete with the 'resident' species and then disperse.

As pointed out by HEYWOOD (2010), 'What we cannot do with existing modelling approaches is to predict what the new vegetation cover will be nor the overall environmental conditions, in areas impacted by climate change. This applies both to the move-out areas and the move-in areas, a distinction that is not often made but which may be critical in some parts of Europe such as the Mediterranean zone … Since the likelihood of survival and multiplication of migrant species will depend on the environmental context into which they move, not to mention stochastic factors which may intervene, we have to accept that our present understanding of the consequences of climate change is severely limited and sometimes dependent on little more than intelligent speculation'. It is, however, very probable as mentioned above that in parts of the Mediterranean region, we can expect novel assemblages of species to develop.

MEDITERRANEAN ISLANDS

The Mediterranean region encloses some 5,000 islands, ranging from islets of a few square metres to large islands such as Sicily with 25,700 km^2. The larger islands in particular house a great richness of Mediterranean endemic plants, many of them already endangered before taking into account the probable impacts of climate change, with an average rate of endemism of 10%. While the smaller islands are less rich, they frequently share endemics with other islands (DELANOË *et al.*, 1996). High mountain species are most at risk as they may not have niches to migrate to or simply the mountain may not have sufficient altitude to allow further upward migration of certain species in response to climate change.

RISK FROM INVASIVE SPECIES

Until recently, alien invasive species (IAVs) have so far not been considered to pose as serious a threat to native biodiversity in the Mediterranean region as in some other parts of the world but this is likely to change with rising temperatures and alterations to disturbance regimes and parts of the region will see a substantial increase in weedy, alien invasive and pioneer species. Mediterranean islands, in particular, are highly vulnerable to invasions in comparison with adjacent mainland areas (HULME, 2004; GIMENO *et al.*, 2006; HULME *et al.*, 2008) and more than 400 introduced plant species were recorded by LLORET *et al.* (2004) from Lesbos, Rhodes, Crete, Malta, Corsica, Majorca and Menorca. A study (GRITTI *et al.,* 2006) on the vulnerability of ecosystems in five of the main islands of the Mediterranean basin (Mallorca, Corsica, Sardinia, Crete and Lesvos) to climate change and invasion by exotic plants showed that while the effects of climate change alone are likely to be negligible, the main factors promoting invasions is habitat disturbance. Their simulations predict that in the longer term almost all the ecosystems will be dominated by invasive aliens. While this may be true at lower altitudes, it is unlikely to be the major threat to the specialized rupicolous flora of these islands. Experimental work undertaken by VILÀ *et al.* (2008) on the invasibility of ecosystems at the establishment phase, using *Ailanthus altissima*, *Carpobrotus* spp. and *Oxalis pes-caprae* as exemplars, at more than 200 locations in Crete, Lesbos, Sardinia, Porquerolles, Mallorca and Menorca, showed that with the exception of *Oxalis*, they showed widespread resistance to invader establishment. Their results are, however, only preliminary and other factors may be involved as the authors indicate.

CONCLUSIONS

Evidence is growing to suggest that climate change, notably higher temperatures and increasing aridity, will have severe impacts on the Mediterranean region and its biodiversity during the present century. While it is possible to forecast the fate of individual species, using bioclimatic modelling, it is difficult to envisage what kinds of ecosystem will develop because of the barrier to inward migration that the Mediterranean area presents and it seems likely that novel or non-analogue assemblages may occur in which weedy and invasive species will play a substantial role. High mountain species, many of them already endangered, will face increased risks of extinction through lack of suitable habitat or lack of migratory capacity within the short time-scale of concern.

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