

Introducing the climate change effects on Mediterranean forest ecosystems: observation, experimentation, simulation, and management

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Current and projected climate change trends in the Mediterranean region

Although global temperature-change scenarios vary regionally, they show a clear trend towards a general warming. The temperature increment from 1850-1899 to 2001-2005 has been 0.76°C on a global scale; in some Mediterranean countries, however, the increment from 1971 to 2000 was 1.53°C, a much higher value than the 1.2°C predicted by the climate models. In addition, simulations of future climate scenarios (Fig. 1) tend to agree that higher greenhouse gases emission levels could produce a temperature increase higher than the global average value, further reduce precipitation (of up to 20%) and increase the interannual variability of both temperature and precipitation (floods, droughts and heat waves).

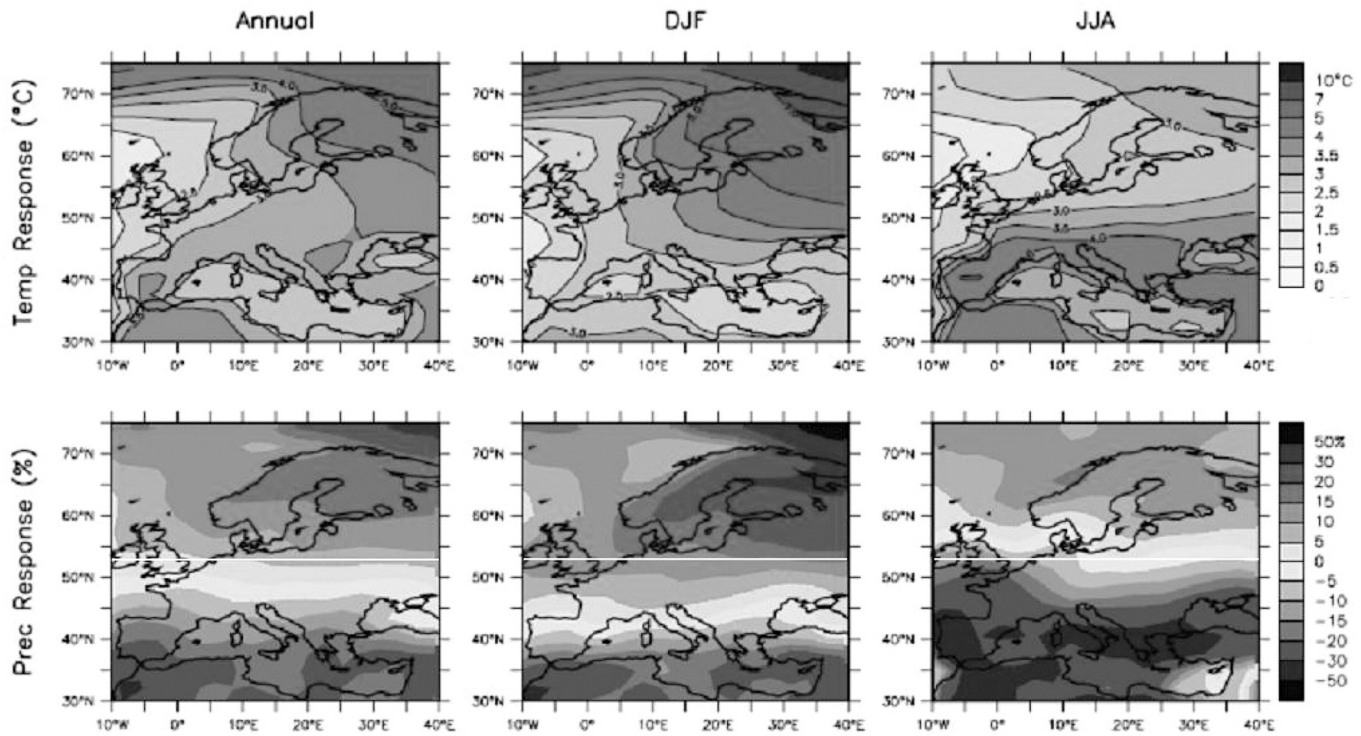


Fig. 1:
Simulated temperature and precipitation changes over Europe for the A1B scenario.

Top row:
temperature change between 1980 to 1999 and 2080 to 2099 averaged over 21 models; annual mean; winter (DJF); summer (JJA).

Bottom row:
same as top, but for fractional change in precipitation.

Source: IPCC 4th assessment report 2007

Biological impacts of climate change in the frame of global change

If the combination of climate change, associated disturbances (floods, droughts, forest fires...) and changes in other components of global change (particularly changes in land use, pollution and overexploitation of resources) continues as in current years and decades, it can overcome the resilience of many ecosystems (their ability to adapt naturally) (IPCC 2007). It alters their structure and operation, and alters the services they currently provide. The effect of climate change will be influenced by interactions with these other components of global change and by the way we manage these issues.

Climate change is global, but the ecological impacts vary locally. The effects of climate change will be different in different climatic areas, with major effects of global warming in cold areas limited by energy, and most important effects of drought in arid and warmer areas such our Mediterranean region limited by water availability.

While simulation models like GOTILWA+ predict a dramatic decrease of soil water content in Mediterranean areas, recent studies predict an enlargement of the length of the growth period by 2080 of 50 days for the Mediterranean region. The growing season has already been enlarged by many days in the last decades (Fig. 2). This situation leads and further will lead to an increased demand for water parallel to a decrease of the water resources available for forest ecosystems.

In addition, higher temperatures will induce an exponential increase in the respiration rates of living tissues of trees, while photosynthetic responses to temperature are not expected to increase so much. This may result in a depletion of the reserves of mobile carbohydrates which are used by Mediterranean trees to overcome the dry summer periods. Some of the dieback episodes observed in Mediterranean forests in recent years could be associated with the exhaustion of carbohydrates reserves which can be consumed in periods of three to four consecutive dry years, although it is still controversial whether there are other factors such as xylem cavitation that can play a more important role or not. Most pest attacks

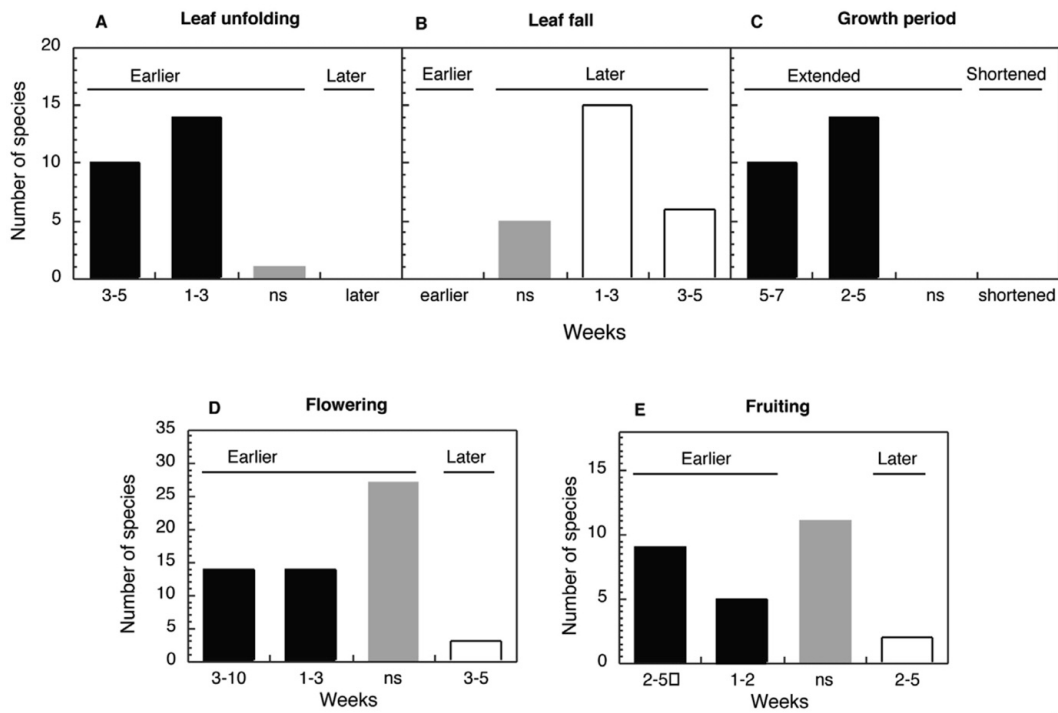


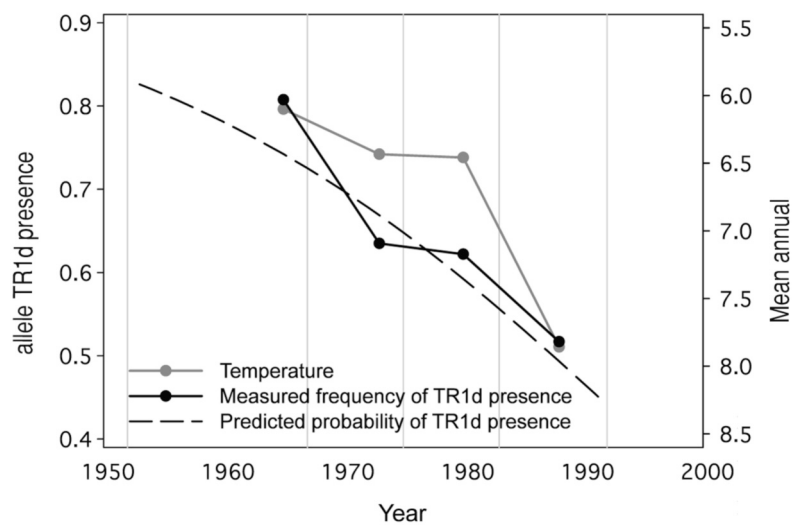
Fig. 2: Phenological changes in a western Mediterranean locality (Cardedeu, Catalonia, NE Spain) in the last five decades of 20th century. Source Peñuelas et al 2002

may be the consequence of this weakening of the trees and not always the origin of the dieback. It is also true that in many cases, although pests may not initiate dieback, they can be the main cause of death. Drought weakens the tree, pathogen load increases, and pathogens kill the tree, even though drought is ultimately responsible.

As each species responds specifically to climate change, their interactions with other organisms and the physicochemical environment also consequently change. All this generates a cascade of impacts throughout the ecosystem. These impacts include the spread of some species to new areas and the disappearance of others. In the Mediterranean region, there is already substantial observational and experimental evidence of the first biological effects of climate change. In recent decades, increased efficiency in water use by vegetation has been identified, and the genetic composition of populations has changed in response to rising temperatures (Fig. 3) but even so, the progressive drought in recent years has resulted in defoliation (Fig. 4) and slower growth of trees (JUMP et al. 2006) in many Mediterranean regions. As commented above, the spring has advanced several weeks relative to previous decades and winter comes later, so that the vegetative period has lasted about 4 days per decade during

the past fifty years (Fig. 2), with strong implications for living organisms and the environment. In addition, some species have moved to higher altitudes and latitudes as temperatures and drought impacts increase (PEÑUELAS and BOADA 2003, PEÑUELAS et al. 2007, JUMP et al. 2009). In the most extreme cases, decreased habitat suitability due to climate change acts in combination with land use change such that habitat fragmentation impedes migration and populations are threatened with extinction.

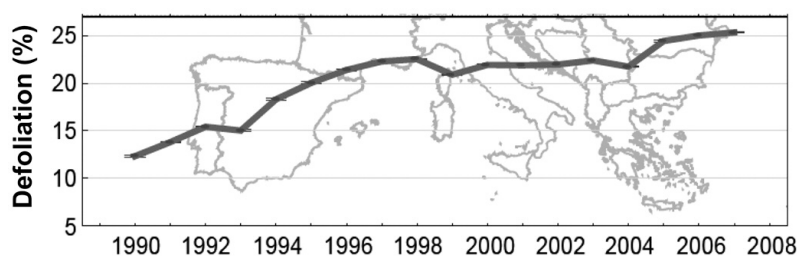
Fig. 3: Parallel changes of a temperature responsive locus of beech trees and temperature during recruitment in the Montseny Mountains and the Pyrenees (Catalonia, NE Spain). Source Jump et al 2006



The different responses of each species alter the competitive abilities and ultimately the community composition. For example, a decrease of species richness is observed in field experiments that simulate the heat and drought projected for the coming decades (Fig. 5). The post-Pliocene Mediterranean genera seem better suited to respond to an environment not easily predictable with a great seasonal and interannual variability and subject to frequent disturbances (PENUELAS *et al.* 2001). These experimental studies also show that the drought conditions predicted for the coming decades exert a negative impact on soil bacterial diversity, and that decomposition of organic material and their ability to respond to enhanced temperature will be controlled by drought-resistant functional groups, e.g. fungal community (YUSTE *et al.* 2010).

These changes on the species composition of plant, animal and microbial communities have been accompanied by numerous functional changes. There are decreases in the enzymatic activity of soil, the recycling nutrients, the phosphorus accumulated in the forests and the plant tissues absorption of CO₂ in response to droughts, increased losses of nutrients in leachates after the rains, and increases in the emissions of biogenic volatile organic compounds (BVOCs) in response to warming. And these changes generate other cascading changes, for example, these increases in BVOCs alter the communication between living organisms and also affect atmospheric chemistry and climate (PENUELAS and STAUDT 2010).

Fig. 4:
Increasing defoliation of Mediterranean forests in the last two decades.
From Carnicer *et al.* 2010



Feedbacks and ecosystem services

The biological changes generated by climate change, in turn, have significant effects on the climate change itself, both through biogeochemical processes and biophysical processes (PENUELAS *et al.* 2009; Fig. 6). Among the former, there is the altered carbon fixation, i.e. the altered sinks of atmospheric CO₂, and the emissions of volatile organic compounds with multiple effects on climate. As for the biophysical effects, the changes in activity and structure of vegetation caused by climate change seem especially important since they affect the albedo, the turbulence and the latent and sensible heat, all together warranting more detailed quantitative studies.

All these changes affect multiple productive (supply of renewable natural products such as wood, mushrooms, medicines, food...), environmental (biodiversity maintenance, regulation of atmospheric composition, the hydrological cycle and climate, soil protection against erosion, carbon...) and social (recreation, education and entertainment, traditional cultural values, tourism...) services provided by terrestrial ecosystems.

One of the services linked to climate change is the fixation of CO₂. Responses to climate change and other factors of global change will alter the carbon storage in terrestrial ecosystems, but the extent and direction of change are not clear. In any case, current droughts in both the northern and southern hemispheres are reducing the biosphere carbon uptake in the last two decades (PENUELAS *et al.* 2010, ZHAO and RUNNING 2010).

The multi-use strategies for the management and restoration of terrestrial ecosystems in front of climatic disturbances require a great effort of research, education, and government. In the coming years, policies and reforestation of abandoned agricultural areas management should take into account the changes occurring and the conditions predicted for the immediate future. Among these the declining availability of water both as a result of declining rainfall and / or increased potential evapotranspiration appears as the most crucial issue.

Acknowledgements

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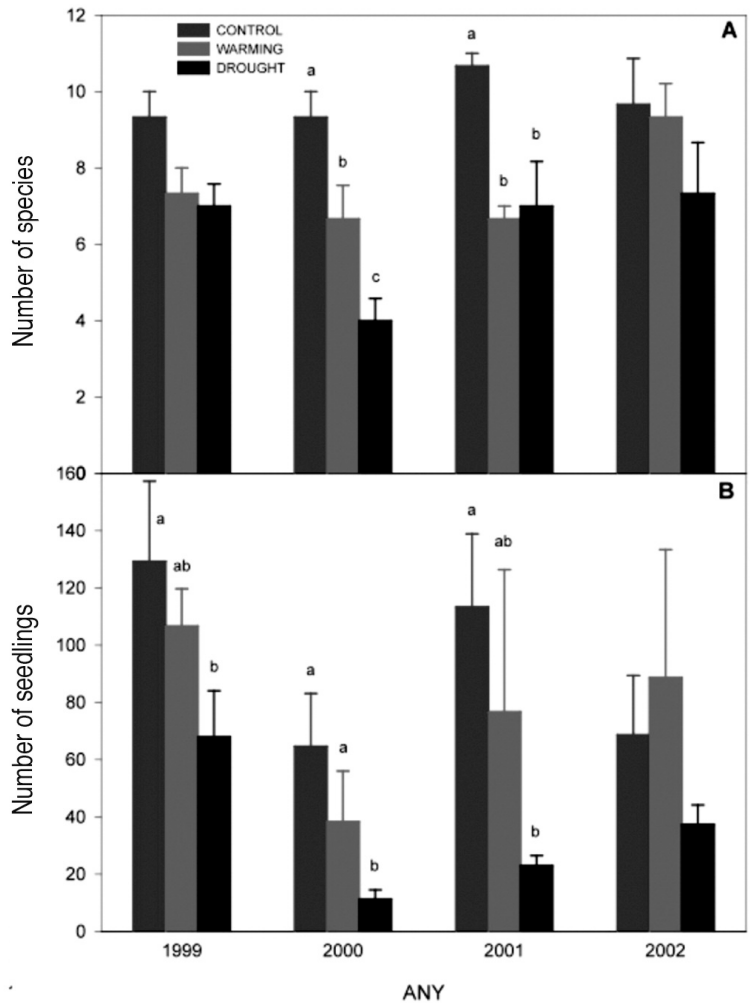


Fig. 5 (above): Decreased species richness (A) and individual number in seedlings (B) of a shrubland submitted to drought or warming projected for the next two decades in Garraf (central coast of Catalonia, NE Spain) From Lloret et al 2004

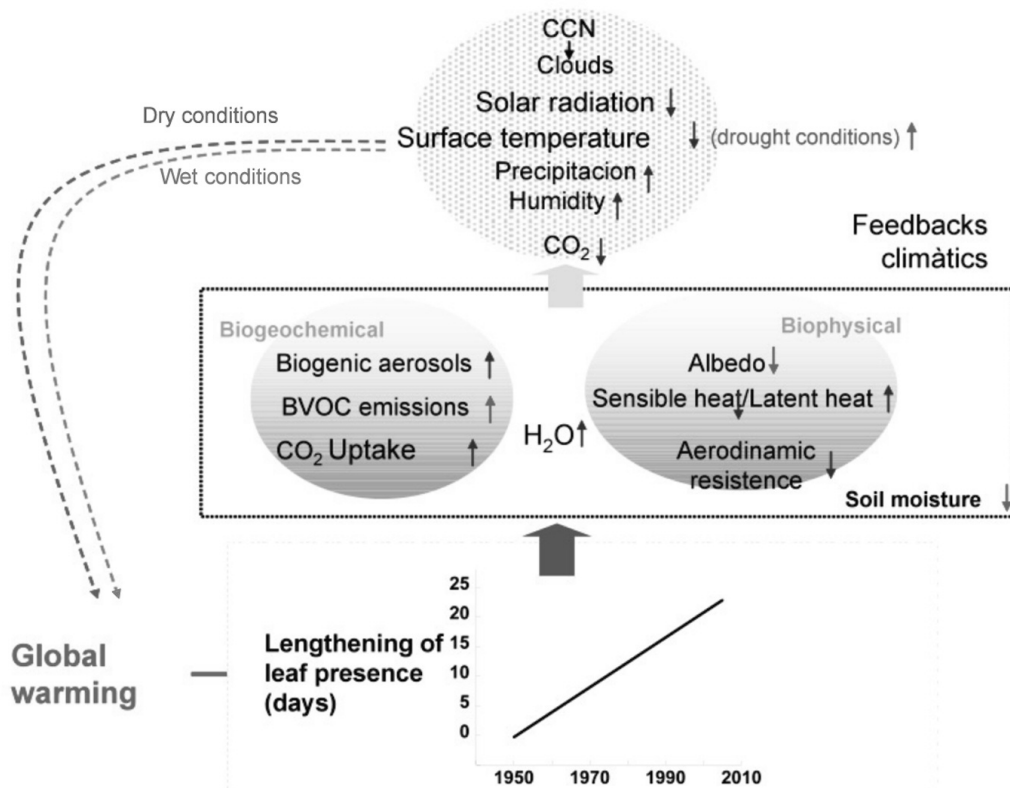


Fig. 6: Climatic feedbacks of vegetation phenological changes Based on Peñuelas et al 2009

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Summary

An increasing number of observational evidences on the biological effects of climate change is becoming available in the Mediterranean forests. Biological spring is arriving earlier and winter arrival has been delayed, so that the vegetative period has extended about 4-5 days per decade during the last forty years, and the Mediterranean vegetation seems to move northwards and upwards in our mountains. Many other changes have been observed in the last decades in response to this climatic change: more frequent and severe droughts, greater fire risks, greater biogenic volatile organic compounds emissions from our ecosystems... The warming increase and the precipitation decrease forecasted for the next decades, if they occur, will affect the physiology, phenology, growth, reproduction, establishment and, finally, the distribution of organisms, and therefore the structure and functioning of our forests. In fact, it has been already verified in experimental studies simulating warming and drought, where some species have been found to be more affected than others and to present altered competitive ability. As a result, the composition of the community has been found to be modified. It has been observed, for example, that the diversity of shrublands has decreased in warming and especially in drought conditions. In addition to these structural changes, functional changes have also been observed. One of them is the diminution of the CO₂ absorption caused by the drought episodes; another is the greater loss of nutrients by leaching after rains in response to the warming. These changes affect and will affect the multiple productive, environmental and social services provided by the terrestrial ecosystems. For example, the role of many of our terrestrial ecosystems as carbon sinks can be seriously compromised during the next decades. In the next years, the policies of "afforestation" of abandoned agricultural areas and of "reforestation" of disturbed areas would have to consider the conditions that are projected for the immediate future. Among them, it stands out the decreasing water availability as a consequence of both the diminution of precipitations and/or the increase of the potential evapotranspiration, and the greater demand of ecosystems that are more active because of the increase of CO₂ and the temperature. The management of the forested areas has to be dealt with at the landscape scale, in a planning that considers the combination of different spaces, as well as their multiple uses and the effect of the disturbances, like for example forest fires.