

Plants and climate change: which future?

Chapter 3: Observing and predicting plant responses to climate change

Summary

Understanding the effects of climate change on plant species and communities is a fairly recent conservation concern, but requires long-term data sets. Some such data sets exist, such as long-term phenological records for a few plant species, but analysis can be hampered because data collection protocols and species selection generally were not set up to answer contemporary questions. Similarly, experimental approaches can be prohibitively expensive and lengthy, so research in this field relies heavily on modeling. Models can be used for predicting responses of single species, multi-species assemblages, global vegetation patterns, and climate or hardiness zones. Models are only as good as the data and assumptions on which they are built and are continually improving as we refine and test them using data from past climate changes. While it remains important to scrutinise climate change predictions adequately, the scientific debate must not divert us from taking timely and appropriate action on both mitigation and adaptation. The extent of global change is still IN OUR HANDS and scientific rigour should not replace action.



Key points of this chapter:

- Observations such as earlier bud burst and longer growing seasons confirm that the behaviour of plant species is changing in response to climate change.
- Observations also show changes in species distributions over the past 30 years.
- Predictions of future plant species ranges are critical for conservation planning, but can only be obtained through modeling.
- Models must be treated with caution as they (largely) do not take into account local situations, such as plant-to-plant interactions, dispersal ability or plant adaptability to changing environments.
- Lack of data on existing plant distributions is a further limitation to modeling approaches.
- Experimental approaches which assess the climatic tolerances of species can help to overcome some of the limitations of modeling.

Case studies from this chapter:

Case study 3.1 – Model complexity

The Lund–Potsdam–Jena Dynamic Global Vegetation Model (LPJ) is a prominent model that combines process-based, large-scale representations of terrestrial vegetation dynamics and land-atmosphere carbon and water exchanges. The model includes feedback through canopy conductance between photosynthesis and transpiration and interactive coupling between these processes and other ecosystem processes such as resource competition, tissue turnover, population dynamics, soil organic

matter and litter dynamics and fire disturbance. Since global vegetation models cannot stimulate all plant species, they are aggregated into plant functional types (PFTs). In the LPJ model ten PFTs are differentiated by physiological, morphological, phenological, bioclimatic and fire-response attributes. Resource competition and differential responses to fire between PFTs influence their relative fractional cover from year to year. Photosynthesis, evapotranspiration and soil water dynamics are modelled on a daily time step, while vegetation structure and PFT population densities are updated annually (Stich *et al.*, 2003). Although PFTs bridge the gap between plant physiology and community and ecosystem processes (Díaz & Cabido, 1997), a criticism of this approach is that most PFTs encompass the full spectrum of migration rates. Migration processes span scales of time and space far beyond what can be confidently stimulated in dynamic global vegetation models (Neilson *et al.*, 2005).

Case study 3.2 – PRECIS modeling in east Africa

East Africa has a complex regional climate, affected by, for example, the Indian Ocean circulation systems, the African rift and Ethiopian highlands and the existence of large lakes. It is also a region predicted to be particularly vulnerable to climate change and variability, namely flooding and drought. Of course, localised water resources, namely groundwater for potable water and rainfall for agriculture, are massively important to rural populations and will be impacted by climate change.

Taking these unique local considerations into account, a local PRECIS model coupled with soil moisture balance and groundwater recharge models, has provided critical information necessary for local climate change impact assessments (START Project, 2006).

Case study 3.3 – Single species modeling

Purshia subintegra, or Arizona cliffrose, is an endangered endemic shrub known from just four populations in the Sonoran desert in Arizona in the US. Models show that populations will be increasingly endangered under increasing aridity. The fine scale of the modeling illustrates where the highest extinction risk or potential refugia may occur, which can guide human conservation intervention (Maschinski *et al.*, 2006).

In South Africa, several Proteaceae species' ranges were modeled in order to inform protected area management. Species were classified according to the spatial scale of movement exhibited in the model. For example, 'stay-at-home' species (*Serruria glomerata*) have substantial overlap in current and future ranges. 'Neighbourhood movers' (*Serruria bolusii*) have ranges that may be accommodated within a single large protected area, and 'cross-country movers' experience range shifts on a large scale that would require land between protected areas ('corridors') to enable migration (*Serruria linearis*) (Hannah & Hansen, 2005). Other studies in the region show that fewer than half of species modeled showed overlap between current and projected ranges, therefore transport, and establishment in novel ranges and conservation landscape linkages are of critical importance (Midgely *et al.*, 2003; Bomhard *et al.*, 2005; Hannah *et al.*, 2005; Arújo, 2006;).

Fagus sylvatica, the European beech, is particularly sensitive to drought and flooding. In southern Germany, where it is an important forest species, hot and dry summers are predicted, alongside periods of heavy rain in spring and autumn causing flooding events. Models show the species exhibiting reduced growth and reduced competitive capability, especially at range extremes (Geßler *et al.*, 2007).

Even more starkly, *Virola sebifera*, a tree found in Central and South America, is used medicinally to treat skin conditions and fevers. It's entire current distribution is predicted to become climatically unsuitable by 2050 (Thomas *et al.*, 2004).

Case study 3.4 – Model testing

Climate change predictions derived from models are highly dependent on assumptions about feedbacks between the biosphere and atmosphere. Modeling plant responses to climate change is therefore problematic. However, models can be tested against past climates ('hindcast'), as well as compared against each other and tested against field observations.

In the 1990s, model research showed that climate models successfully stimulated the patterns of 20th century climate change only when anthropogenic effects were included, thus strengthening the evidence that it is humans who have caused recent climate perturbations. Models are also tested against proxy measurements, such as ice core or tree ring data, and have been shown to successfully reproduce climatic conditions from as long ago as 9,000 years (Scaife *et al.*, 2007).

Dynamic crop-growth models for *Triticum aestivum* (spring wheat) were tested in the field, using simulated scenarios of CO₂ concentration (Free Air Carbon Dioxide Enrichment (FACE)) and water availability. Models can be evaluated using measures of crop phenology, aboveground dry matter, grain yield and evapotranspiration. In this case, the model did not simulate the accelerated crop phenology, indicating the need to include stomatal effects in models (Tubiello *et al.*, 1999).

In China, Gao *et al.* (2004) compared the behaviour of two suites of models (biogeochemical and leaf photosynthesis models) against field data of 11 plant species in the semi-arid Loess Plateau of northern China, including trees, shrubs, grasses and crops (i.e. C3 and C4 species). The results suggest that the biogeochemical models explained on average 66% and 82% of variations in observed net photosynthesis rates for C3 and C4 plants respectively and the leaf photosynthesis models explained 72% and 76% of variations, suggesting that the models performed similarly to each other and simulated field results relatively successfully.

Case study 3.5 – Plant hardiness zones in Canada

In Canada, zones have been developed based on seven different climate variables including average winter minimum temperatures, rainfall in January, maximum wind gusts and also snow cover. The use of several variables is an attempt to better reflect the complexity of plant responses to more than just temperature. A recent update of the Canadian zones suggested zone increases in much of western Canada but relatively little change or even lowering of the zone values in parts of eastern Canada (McKenney *et al.*, 2007a; 2007b). This in fact is consistent with what is known about climate change in Canada; temperature increases are much more pronounced in the west than the east.

The complexity of mapping plant distributions and potential changes due to climate change has spurred on a North America-wide project called 'Going Beyond the Zones' (McKenney *et al.*, 2007a; 2007b). This work provides a web-based approach to better quantify the climatic tolerances and map the possible consequences of climate change on thousands of individual plant species across both the United States and Canada. Planting zones and/or species ranges are expected to shift northward hundreds of kilometres and in many cases species suitable habitats shrink by more than half. It is clear that there will be significant stresses on the climate habitat of many species over the course of this century if IPCC climate change scenarios are even roughly correct.