

Plants and climate change: which future?

Chapter 2: The physiological responses of plants to climate change

Summary

The diversity and distribution of the world's terrestrial vegetation is the product of a complex suite of interactions between individual plants and a multitude of climatic and environmental variables. Plants are major regulators of the global climate, and their collective responses to increased atmospheric CO₂ concentrations have clearly played an important role in mitigating climate change to this point. The uptake of CO₂ by plants during photosynthesis is the major pathway by which carbon is stored.

In looking to the future, it is increasingly critical to understand how plants respond on a basic level to the changes imposed upon them by continued increases in atmospheric CO₂, as well as the cascade of climatic and environmental changes triggered by this increase. While plant responses to changes in single variables, such as CO₂ or temperature, are increasingly well-understood, we have only just begun to understand how the interaction of these changes impacts plants and their role in regulating the global climate. Recent discoveries reveal just how much remains to be learned while illustrating the many ways in which the world's plants can all-too-easily lose their ability to act as a global carbon sink, becoming instead yet another carbon source.



Key points of this chapter:

- Increased levels of CO₂ in the atmosphere can increase plant productivity, so long as no other factors (such as water) are limiting. However this is likely to be a temporary effect as plants acclimatise to the change.
- Increased levels of CO₂ may allow plants to become more water efficient (i.e. requiring less water for the same productivity). However, reduced water flow through the plant can reduce the cooling (air conditioning) effect of vegetation.
- Increased temperature can increase plant growth up to a limit, beyond which death occurs. Increased temperatures can also cause plant respiration rates to increase relative to photosynthesis, resulting in no net gain in biomass production and to plants even becoming a potential source of CO₂.
- Nitrogen availability limits plant growth and thus capacity to uptake carbon and benefit from increased CO₂.
- Nitrogen-fertilised soils emit nitrous oxide (N₂O), a greenhouse gas with more than 200 times the warming potential of CO₂.
- Individual species will react differently to changing environmental conditions, resulting in changes in species compositions and ecosystem structure.

Case studies from this chapter:

Case study 2.1 – Toxicity response of poison ivy (*Toxicodendron radicans*) to elevated CO₂

Toxicodendron radicans is widely distributed and abundant in North America and also occurs in Central America, parts of Asia, Bermuda and the Bahamas. It has been introduced in Europe, South Africa and Australia and New Zealand, where it has become invasive. In the USA, contact with poison ivy is one of the most widely reported ailments at poison centres – approximately 80% of humans develop dermatitis upon exposure to the active allergenic compound, urushiol.

A six-year study at Duke University in the USA showed that increased CO₂ in an intact forest ecosystem increases photosynthesis, water use efficiency, growth and population biomass of *Toxicodendron radicans* and that the CO₂ growth stimulation exceeds that of most other woody species (Mohan *et al.*, 2006). Additionally, under higher CO₂ the plants produced a more allergenic form of urushiol.



This study thus indicates that poison ivy will become both more abundant and more toxic in the future and adds to studies indicating that rising CO₂ may be responsible for the increased vine abundance that is inhibiting forest regeneration and increasing tree mortality around the world (see p.37), with implications for long term carbon storage in old growth forests (Philips *et al.*, 2002; Swaine & Grace, 2007).

Case study 2.2 – Early spring, late autumn

In Japan, cherry blossom festivals are hugely popular and culturally significant. Because of this, the flowering times of cherry blossom have been recorded for over a thousand years. From 1401 to the present time (a 605-year time span) there are records of the cherry blossom festivals for most years. The cumulative flowering record shows a six week range in flowering dates from as early as late March to as late as early May. Extreme flowering dates are scattered through this period. However, after approximately 1830 flowering times become progressively earlier. By the 1980s and early 1990s, average flowering times had become earlier than at any time previously during the entire flowering record of over one thousand years (Primack & Higuchi, 2007).



At Kew in the UK an advance in flower opening has been observed since the 1980s, a subset of plants are flowering on average 8 to 19 days early. For example, the first daffodils opened at Kew on 16 January 2008, a week earlier than 2007, and 11 days earlier than the average for this decade for that type of the flower. Crocuses also set a record, flowering on 24 January, 11 days ahead of the decade average (Dugan, 2008).

Intense late summer heat delays the frosts which trigger chlorophyll in leaves to degrade, thus changing the colour of leaves. In New England in the US the spectacular colours of autumn leaf change are projected to become duller. Some observations indicate that this is already happening.

Case study 2.3 – Blackcurrants (*Ribes nigrum*) and frosts

Blackcurrants need a heavy frost to ensure their buds break evenly to produce an even ripeness in the fruit. Increasingly mild winters in England have led to a steep decline in in blackcurrent harvests, fruit quality and juice yields. At least two traditional varieties are expected to die out within 10 years due to climate change.

Several new varieties of the fruit have been developed that are more resistant to changing climate, but it takes roughly 16 years to develop a new strain (SCRI, 2008) and it will take several years for the new varieties to bear fruit.



Case study 2.4 – Yellow birch (*Betula alleghaniensis*) and winter thaw

In eastern Canada, studies indicate that winter thaws and late spring frosts may partially explain the large scale decline of yellow birch. Winter thaws decrease the cold hardiness of the tree, thereby increasing vulnerability to frost.

Winter thaws have also been shown to affect the xylem of the tree, making it harder for water to pass from the roots to the branches (Cox & Arp, 2001).



Case study 2.5 – Effects of drought on growth of beech (*Fagus sylvatica*) trees

A study of *Fagus sylvatica* trees in Catalonia in Spain showed that populations of the species toward the southern limits of the species' distribution are increasingly limited by drought. Further, the region is expected to warm in the future.

The study looked at annual growth levels over the past 50 years and found a rapid recent decline of southern range-edge populations, starting in approximately 1975. By 2003, growth of mature trees had fallen by 49% when compared with predecline levels. The decline is not seen in populations at higher altitudes, therefore the effects of drought (less water, higher temperature) are impacting tree growth (Jump *et al.*, 2006).



Case study 2.6 – Consequences of species-specific nitrogen strategies

In the Netherlands, an increase in atmospheric nitrogen deposition led to the accelerated accumulation of soil organic matter and an initial increase of the grass *Molinia caerulea* at the cost of the dwarf shrub *Erica tetralix*.

Due to high litter production and decomposition, *Molinia* increased soil N-mineralisation two-fold, which triggered a positive feedback, resulting in monospecific stands of *Molinia* and an unexpected rapid disappearance of wet heathland communities, including endangered species such as *Gentiana pneumonanthe* and *Dactylorhiza maculata* (Berendse, 2005).



Case study 2.7- Melting permafrost in Siberia

Western Siberia has warmed faster than almost any other region on the planet, with an average increase of 3°C over the last 40 years. It is here, over an area covering a million square kilometres (the size of France and Germany combined) that frozen peatbog is melting and becoming a mass of shallow lakes, releasing CH₄ at a rate 5 times faster than expected. The western Siberian peatbog alone is estimated to contain some 70 billion tonnes of CH₄, a quarter of all the CH₄ stored on land surface worldwide (Walter *et al.*, 2006). Considering the warming potential of CH₄ this has frightening implications for the rate of global warming.



Case study 2.8 – Effects of elevated CO₂ plus unseasonal freezing on *Ginkgo biloba* (Maidenhair tree)

Elevated CO₂ has the capacity to influence the freezing temperatures of plant tissues. A study exposed *Ginkgo biloba* saplings to elevated CO₂ for five years. Leaf freezing temperatures and recovery times of photosynthetic apparatus were measured. Results showed that leaves of the Maidenhair tree, an ancient species which is now endangered in natural habitats, became more susceptible to freezing at higher temperatures under elevated CO₂ and that recovery was negligible, suggesting that an early season 'freezing injury' could persist into the growing season, limiting carbon fixation and tree survival (Terry *et al.*, 2000).

