Plants and climate change: which future?

Chapter 6: Ecosystems at risk

Chapter summary

An ecosystem is an array of living things (plants, animals and microbes) and the physical and chemical environment in which they interact. Healthy ecosystems provide the conditions that sustain human life through the provision of a diverse range of ecosystem services. Plant diversity underpins terrestrial ecosystems and they are often described according to the major vegetation type they consist of. Many ecosystems will be highly vulnerable to projected rates and magnitudes of climate change and the services lost through the disappearance or fragmentation of ecosystems will be costly or impossible to replace. Forest ecosystems are particularly important, containing as much as two thirds of all know terrestrial species and storing about 80% of above-ground and 40% of below-ground carbon. Deforestation is a major source of greenhouse gas emissions and contributes to loss of species as well as changes in regional and global climate. Reducing deforestation is therefore one of the most effective ways of reducing greenhouse gas emissions. Ecosystem responses to climate change will be complex and varied. Climatic changes will essentially affect all ecosystem processes but at different rates, magnitudes and the directions. Responses will vary from the very short term response of leaf-level photosynthesis to the long-term changes in storage and turnover of soil carbon and nitrogen stocks.

Key points from this chapter:

- Healthy ecosystems provide services essential for human life, including clean air, water and food.
- In the past 50 years humans have altered the earth's ecosystems more than any other time in our history.
- Devastation caused by extreme weather events is often exacerbated by degraded ecosystems, with untold consequences for human livelihoods.
- Greater diversity is likely to provide ecosystems with greater resilience and ability to respond to climate change.
- Ecosystems are increasingly fragmented and this provides a major constraint to the movement of species under climate change scenarios.
- Conserving ecosystems is an important strategy for conserving plant species diversity.

Case studies from this chapter:

Box 6.1 – Defining the ecosystem

An ecosystem is; *"A functional unit consisting of all the living organisms (plants, animals and microbes) in a given area, and all the non-living physical and chemical factors of their environment, linked together through nutrient recycling and energy flow. An ecosystem can be of any size - alog, pond, field, forest,* *or the Earth's biosphere – but it always functions as a whole unit."* British Columbia Ministry of Forests and Range, 2008.

Case study 6.1 – Maximum plant biodiversity is best

There is a positive relationship between species richness of vascular plants and terrestrial vertebrates. A study in China looked at 186 nature reserves in China and found that plant richness was a significant predictor of richness patterns for terrestrial vertebrates. This suggests a causal relationship, dependent on trophic links (i.e. though food supply) and non-trophic links, such as the effects of plants on the resources that an invertebrate may require (Zhao *et al.*, 2006).

Case study 6.2 – The impacts of climate change on tropical forests

Tropical forests, found near the equator, are massively species rich; containing as much as 50% of all recorded terrestrial biodiversity and as many as 1,000 tree species in one sq km. The Amazon is the world's largest tropical forest, located in nine countries; Brazil, Columbia, Peru, Venezuela, Ecuador, Bolivia, Guyana, Suriname and French Guyana. It contains at least 40,000 plant species. At least 12% of all flowering plants are found within the Amazon (Hansen & Hiller, 2007) and there are probably thousands of plant species as yet undiscovered. At the country level, based on current knowledge, Brazil has the highest number of forest trees in the world, with 7,800 known species. As a comparison, Canada has approximately 180.

Though there are many different types of tropical forest they are all invariably epicentres of biodiversity and important modulators of climate change. These ecosystems are hugely threatened by logging, cattle ranching for the beef trade, clearance for agriculture and plantations of biodiesel crops. In Brazil and Indonesia alone, 4.9 million hectares of primary forests were lost between 2000 and 2005 (FAO, 2005a).

Cloud forests are montane forests in the humid tropics that are frequently covered in clouds or mist. They are widely recognised as being of exceptional conservation importance, being a centre of high diversity and endemicity for many different groups of organisms (Bubb *et al*., 2004). In Mexico, cloud forests cover less than 1% of the land surface of the country, but are thought to contain about 12% of the country's 30,000 plant species. Some 30% of these species are endemic to the country (Newton, 2007). It is anticipated that cloud forests may be amongst the first ecological casualties of climate change.

In general, the predicted increase in drought stress in the southern hemisphere is likely to have an important impact on tropical forests (Schröter *et al.,* 2003*)*. The Amazon basin is predicted to experience an increase of temperature of around 3°C and a decrease in precipitation by around 30% by the end of the century, thus increasing drought stress for Amazon plant species (Mayle *et al*., 2004). In 2005, the government of Brazil declared a state of emergency due to extreme drought conditions, possibly caused by the warming of the Atlantic sea near Africa altering the circulation patterns of air currents (WWF, 2005).

Under certain climate change scenarios, modeling has shown that Amazon rainforests could become a source of CO_2 as warming accelerates plant respiration, forest dieback and loss of soil carbon (Cox *et* *al.*, 2004). Other models of climate change in the Amazon predict that, as well as large-scale forest loss, evergreen forests will be succeeded by mixed forests. Increases in temperature and associated decreases in soil moisture are projected to lead to the expansion of savannah and grasslands, all accelerated by positive feedbacks. Western Amazonia is especially sensitive, with some 43% of plant species predicted to become non-viable by 2095 (Miles *et al.,* 2004). Though this is qualitatively understood, it is difficult to estimate the probability of this happening in a real Earth system. However, the science behind the predictions that global warming is increased by carbon cycle feedbacks is solid (Huntingford et al., 2008).

Further, many models do not take into account land use changes, such as deforestation, which make it unlikely that tropical forests will be able to migrate to climatically suitable habitats, even if they were able to move over hundreds of kilometres in a relatively short space of time (Hansen & Hiller, 2007).

Case study 6.3 – Climate change impacts on boreal forests

Boreal forests, or taiga, are found in northern latitudes throughout Alaska, Canada, Scandinavia and Russia, where temperatures are low.

Predictions of ecological change in boreal Alaska, Canada and Russia have suggested that warming will induce the northern and upslope migration of the treeline and an alteration in the current mosaic structure of boreal forests.

A recent study presents observations of the migration of keystone ecosystems in the upland and lowland treeline of mountainous regions across southern Siberia. Ecological models have also predicted a moisture-stress-related dieback in white spruce trees in Alaska, and current investigations show that as temperatures increase, white spruce tree growth is declining. Additionally, it was suggested that increases in infestation and wildfire disturbance would be catalysts that precipitate the alteration of the current mosaic forest composition. In Siberia, seven of the last nine years have resulted in extreme fire seasons (Hayasaka, 2003) and extreme fire years have also been more frequent in both Alaska and Canada.

Alaska has also experienced extreme and geographically expansive multi-year outbreaks of the spruce beetle, which had been previously limited by the cold, moist environment (Wolforth, 2002). There is thus substantial evidence throughout the circumboreal region to conclude that the biosphere within the boreal terrestrial environment has already responded to the transient effects of climate change.

Additionally, temperature increases and warming-induced change in these regions are progressing faster than had been predicted in some regions, suggesting a potential non-linear rapid response to changes in climate, as opposed to the predicted slow linear response to climate change (Soja *et al.,* 2007).

Ecosystem type sections in this chapter:

Section 6.2.1 Mountains

Because of their altitude, slope and orientation to the sun, mountain regions are highly sensitive to climatic changes and are therefore important indicators of climate change (Mountain Partnership, 2002).

As intact ecosystems they are also of critical importance globally, particularly in the provision of water. Montane endemics are particularly vulnerable to climate change because of exceeded temperature tolerances, the upward migration of pioneer species and regionally specific changes, such as reduced cloud water in the tropics.

Thuiller *et al*., (2005) point out that based on their predictive modeling for European plants, an excess of plant species loss is expected for mountain regions (mid-altitude Alps, mid-altitude Pyrenees, central Spain, French Cevennes, Balkans, Carpathians). They note that;

"Severe climatic conditions have occurred in mountains over evolutionary times, promoting highly specialised species with strong adaptation to the limited opportunities for growth and survival. The narrow habitat tolerances of the mountain flora, in conjunction with marginal habitats for many species, are likely to promote higher rates of species loss for a similar climate anomaly than in any other part of Europe."

Section 6.2.2 Tundra

The tundra is a treeless polar ecosystem supporting mostly scattered communities of sedges, heaths and dwarf shrubs including some rare, endemic plant species. They are enormously sensitive to changes in climatic variables, in addition to being threatened already by mining, heavy industry and tourism.

Climate change models predict a great reduction in Arctic tundra as forests move (Huntington *et al.*, 2000; Moore, 2004). Shifts of the treeline generate strong positive feedbacks to climate systems, via the effects of tree cover on albedo. It is thought that the change in feedback mechanisms will lead to a rapid shift to a new stable state in which the extent of the tundra is reduced (Huntley, 2003). Rising timberlines could trigger much change, and this is apparently already under way in some places.

Alaska for example is seeing changing vegetation patterns. Comparisons of photographs taken from 1948 to 1950 to those taken in 1999 to 2000 of the area between the Brooks Range and the Arctic coast show an increase in shrub abundance in tundra areas, and an increase in the extent and density of spruce forest along the treeline (Sturm *et al*., 2001). The increased vegetation growth is attributed to increasing air temperatures in Alaska, on average 1°C per decade over the last three decades (Alaska Regional Assessment Group, 1999).

In Russia, researchers have reported that in the Ural Mountains, temperatures have gone up as much as 4ºC during the 20th century and trees have moved 20-80m upslope, reducing alpine zones by 10% to 30% (Moiseev and Shiyatov, 2003). Similar trends have been widely observed globally, for example in Sweden (Moen *et al.,* 2004) and in Canada, where spruces have shifted upward by 50-60 metres since 1990 (Krajik, 2004).

Whilst treelines are expected to generally move northward this is also effected by other factors, such as topography, so advancement will vary in extent and intensity (Holtmeir & Broll, 2005) and may be hampered because of habitat fragmentation (Honnay *et al*., 2002). Further, some modelling, such as that done with N American tree species, assumes species are in equilibrium (Iverson & Prasad, 2001).

Section 6.2.3 Forests

Forests cover a third of the Earth's surface and are estimated to contain as much as two thirds of the all know terrestrial species. In the last 8,000 years, about 45% of the Earth's original forest cover has been cleared, mostly during the last century (CBD, 2007a). Living forests 'soak up' CO_2 and store it as biomass and in soils. They are estimated to contain about 80% of above-ground and 40% of below-ground carbon (See Fig. 2.1). Forests thus sequester more carbon than is stored in the atmosphere (Michalak, 2007). Forests are particularly vulnerable to climate change as they are composed of slow-growing, woody species with a limited ability to move in response to changing conditions. In general terms, climate change is likely to reduce the ability of trees to survive where they are and increase the occurrence of forest dieback.

Dead forests cannot soak up CO_2.

Moreover disturbed forests are more vulnerable to pests, invasive species and fire, and burning wood releases once stored CO_2. In non-fire-adapted ecosystems, burning can have a significant impact on the soil substrata, destroying soil seed banks and impeding subsequent recovery. Once burnt the forest becomes more vulnerable still, as a reduction in forest cover leads to an exponential decline in precipitation, increasing the likelihood of further fire (Mahli & Phillips, 2004), droughts and ultimately desertification (Mitchel *et al.,* 2007). Unstable, disturbed soils release yet more CO_2, equating to the release of billions of tonnes into the atmosphere.

The direct impacts of climate change on forests however are currently dwarfed by the human impacts of rampant deforestation and forest degradation. Today deforestation continues at a rate of around 13 million ha/yr (FAO, 2006) and accounts for up to 30% of total GHG emissions according to some calculations (Woodland Trust, 2005). The conservation of forests is therefore particularly important, offering important opportunities to conserve species diversity as well as slowing climate change. In terms of climate mitigation impacts, studies have shown that conservation efforts should particularly be focused on ancient old growth forests, as these store significantly more carbon than young stands (Broadmeadow & Matthews, 2003; Zhou *et al.,* 2006). Though young, fast growing forests soak up carbon quickly, old growth forests store substantially more carbon in soils and continue to 'inhale' carbon even when growth has slowed. Converting old growth forests to faster growing young plantations is not therefore an effective method of increasing NPP and CO_2 storage. In fact, carbon storage of young forests does not even approach old growth capacity for at least 200 years (Harmon *et al.*, 1990). With respect to their environmental responses, mature forests also have well established root systems and are less sensitive to moisture changes in the short term (Agrawal & Agrawal, 2000).

Section 6.2.4 Peatlands

Peatlands are a particular form of wetland characterised by the underlying accumulation of peat. Peat is undecomposed plant matter that has accumulated over thousands of years. The absence of oxygen in these water-saturated environments mean that decomposition is halted. Intact peatlands thus form vast carbon stores. In their natural state, peatlands are 85-95% water so they are also important because of their ability to store, filter and provide water. The biodiversity found in peatlands is unique and highly adapted.

Peatlands are found in various parts of the world. Examples are the permafrost areas of Russia and Canada and the highlands of the Andes and Himalaya. Other examples of areas endowed with extensive peatlands are the lowlands of humid tropical forests in China and southeast Asia. In these areas peat stores 30 times more carbon than that stored above ground in normal rainforests.

Peat has been commonly used as fuel. Currently for example, peat fuelled powers stations provide 10% of the total energy consumption in Northern Ireland. During the 1960s they accounted for 40% (Environment and Heritage Service, 2004). Other uses include bedding for livestock, filtration systems and as a growing medium and soil improver for the horticultural industry. In 2001, the United Kingdom used 5.4 million cu. m. of (mostly imported) growing media and soil improver; 63% of this was peat.

Image courtesy of larsomat

Peatlands are highly sensitive ecosystems, especially vulnerable to climate changes such as an increase or decrease in rainfall. Human pressures of peat cutting, burning, land use change and overgrazing are very real threats to these ecosystems. On all continents, peatlands are exploited in an unsustainable manner.

The marshy areas of southeast Asia for example used to be covered with millions of hectares of dense lowland rainforest where plant material decomposed very slowly in the soaking wet soil. Over thousands of years, a thick layer of peat was formed, storing carbon equivalent to 100 years of current global fossil fuel use. Of these forests, only small patches now remain intact and virtually none are unaffected. The global demand for hardwood, paper pulp and palm oil are the driving forces behind the destruction. Areas are drained to enable logging of the swampy rainforest. After clearance, the drainage is intensified to enable commercial production such as for palm oil. Normally, peat is wet and will not burn. Through drainage, the peat dries and starts decomposing and emitting CO_2. In the tropics this process takes place very rapidly and is often accelerated by fires. In Indonesia these fires cover millions of hectares and can last for weeks, sometimes months, burning thick layers of peat over large areas and contributing large amounts of CO_2 to the atmosphere (Wetlands International, 2007).

Section 6.2.5 Coasts and Seas

Our seas cover 70% of the planet. Thirteen of the world's 20 largest cities are on a coast. In fact, the majority of the world's population lives within 60km of a coastline, a figure that is steadily increasing since they are among the most productive ecosystems on Earth.

Coastal ecosystems include coral reefs, beaches, mangroves, islands and estuaries. They are home to diverse plant and animal communities and provide critical ecosystem services, such as coastal protection, water purification, CO_2 absorption and food security.

However, intact coastal habitats are disappearing rapidly, with rates of loss reportedly four to ten times that of tropical rainforests (Duarte, 2007). Coastal development brings pollution, agricultural runoff and the over exploitation of fisheries. Climate change brings sea level rise and the submergence of low-level areas, as well as an increase in the frequency and intensity of storms, storm surges and coastal erosion. Decreases in sea ice cover and changes in salinity, wave conditions, ocean circulation and nutrient upswelling can rapidly alter habitats to which species have long been expertly adapted.

In mangroves, plants have developed diverse physiological adaptations to high salinity and tidal inundation. Mangrove ecosystems and thus the species they contain are currently particularly threatened by clearance for logging and by intensive shrimp farming. In terms of climate change, they are increasingly trapped between rising sea levels and a proliferation of man-made barriers, such as dykes and sea defences, designed to stop coastal erosion. Perversely, where mangroves have been destroyed, coastlines are fatally vulnerable to storms and tsunamis, as was the case with the Indian Ocean tsunami in 2004, where sea was able to penetrate far inland. Areas with intact mangroves and dense vegetation were markedly less damaged than areas without (Danielson *et al.*, 2006, Dahduh-Guebas, 2005, Environmental Justice Foundation, 2006).

Similarly, seagrass ecosystems have suffered severe shrinkages in the past 40 years. Seagrasses are underwater flowering plants that often occur in vast meadows and provide nurseries, shelter, and food for a variety of commercially and ecologically important species. Additionally, seagrasses filter estuary and coastal waters of nutrients, contaminants, and sediments and are closely linked to other community types; in the tropics to coral reef systems and mangrove forests, and in temperate waters to salt marshes, kelp forests, and oyster reefs. Seagrasses are threatened by numerous anthropogenic impacts, such as nutrient loading, as well as global climate change (Short *et al*., 2004). Conservative reports of losses since 1980 of an area equivalent to two football fields every hour. Importantly, these figures are based on only 9% of seagrass meadows that have been studied.

Section 6.2.6 Drylands

Drylands constitute over 40% of the world's surface and are home to one third of the world's population. They constitute ecosystem types such as true desert, savannah and tropical dry forest.

Drylands harbour extremely specialised communities of plants with diverse survival strategies; from trees that can store water in vast, bottle-shaped trunks (*Adansonia* spp., *Commiphora* spp.) to shrubs with small, resin covered leaves (*Laurea* spp.) to CAM plants that accumulate water in the central bud of their fleshy leaves (*Agave* spp.). Since water is a vital and limiting factor, many life forms also exist in ephemeral life stages, dormant for years until suddenly bursting into fruit and reproducing in vast numbers in response to pulses of rain.

Changes in rainfall patterns thus have the potential to impact drylands massively. The Dashti Kbir desert in Iran has seen a 16% decrese in rainfall per decade from 1976 to 2000; the Atacama desert in Chile an 8% reduction. Conversely, the Gobi desert in China is expected to receive more rain. Drylands fed by melting snow or ice, such as those in the Andean foothills, are also particularly vulnerable to climate change impacts.

As well as climate change impacts, many of these dryland areas face additional severe land degradation, in which marginal areas are turned into wastelands and natural ecosystems are altered through the destruction of surface vegetation, poor management of water resources, inappropriate land use practices, overuse of fertilisers and the disposal of industrial and military waste. But deserts are not barren wastelands, and because of their slow rates of biological activity they take many decades to recover from even slight damage. For example, overall, about 97% of the remaining area of tropical dry forest is at risk from the above threats (Miles *et al*., 2006).

As a result of the vulnerability of these ecosystems, populations of humans in drylands on average lag far behind the rest of the world on well-being and development indicators (MA, 2005). The maintenance of the services delivered by dryland ecosystems (firewood, food, medicine) is therefore critical to half the number of people living in poverty globally and to help to achieve the Millennium Development Goals (MDGs).

There is a wealth of traditional knowledge in dryland, particularly desert, ecosystems, associated with soil and water conservation in exteme conditions. These have proved useful in modern water conservation techniques in Morocco and Tunisia. Drylands are also important centres of origin for agricultural crops, both now and for an increasingly arid future.

Finally, dryland ecosystems, particularly deserts, are linked to other ecosystems in suprising ways. For example, about 40 million tons of dust are transported annually from the Sahara to the Amazon basin, making Saharan dust one of the main mineral source that fertilises the Amazon basin. Research has shown that about half of the annual dust supply to the Amazon basin is emitted from a single source: the Bodélé depression located northeast of Lake Chad in Africa, approximately 0.5% of the size of the Amazon or 0.2% of the Sahara. Placed in a narrow path between two mountain chains that direct and accelerate the surface winds over the depression, the Bodélé emits on average more than 0.7 million tons of dust per day (Koren *et al*., 2006).

Section 6.2.7. Grasslands and prairies

Grassland ecosystems exist on every continent and provide a wide range of goods and services for human kind. They are home to many food grains, such as wheat, maize, rice, millet, and sorghum and remain the primary source of genetic resources for improving these and other important crops. They also supply forage for domestic livestock, rangelands for wild herbivores and provide habitat for breeding, migrating, and wintering birds. Grasslands also help to build and stabilise soil and serve as large storehouses for carbon. However today many grasslands are better characterized as ‘fragments’ rather than as ‘vast expanses’. Increasingly, roads interrupt grasslands, breaking large tracts into pieces, and invasive species and human-induced fires change grassland composition and extent (White *et al*., 2000).

Conversion to agricultural land has caused the greatest loss of the world's grasslands. The effects of this conversion can be dramatic as native vegetation is removed and replaced with farm crops, soil is exposed and becomes vulnerable to wind and water erosion and the use of fertilisers and pesticides changes soil composition and water-holding capacity, reducing the moisture available for plants and animals.

The major impact of climate change on grasslands is likely to be the loss of species diversity, diminishing the ability of the grasslands to support grazing animals and other wildlife. This effect has been proven in experimental trials carried out in the USA where a multiyear experiment was carried out to demonstrate how grassland ecosystems would respond to predicted increases in temperature and precipitation caused by global warming. Researchers found that exposing open grasslands to increased levels of CO_2 for three years caused a nearly 20% reduction in wildflower species and an 8% decline in plant diversity overall. The addition of excess nitrogen and other predicted climate changes caused diversity to plunge even further. The study also revealed that wildflowers were much more sensitive to the treatments than grasses, regardless of the combination of treatments applied (Zavaleta *et al*., 2003).