Chapter 14

Adapting to Global Change

> *A profound transformation of Earth's environment is now apparent, owing not to the great forces of nature or to extraterrestrial sources but to the numbers and activities of people – the phenomenon of global change* (Steffen et al, 2004).
>
> *The implications of climate change for the environment and society will depend not only on the response of the Earth system to changes in radiative forcings, but also on how humankind responds through changes in technology, economies, lifestyle and policy* (Moss et al, 2010).

Until recently, the conservation of biodiversity has been undertaken based on the assumption that we live in a dynamic but slowly changing world. Such an assumption must be reconsidered in light of the rapid rate of change to which our planet is being subjected. The main components of this change are summarized in Box 14.1 and are collectively referred to as global change. Today, climate change is attracting a great deal of both scientific and public interest because of its implications for food security, health, global and national economies and our ways of life. It is important, however, to recognize that other components of global change, such as population growth, habitat change, deforestation and degradation, will also have major effects on the world and will interact with climate change as well. This chapter will first consider the impacts of climate change on biodiversity and, in particular, CWR and then the effects of the other aspects of global change.

Climate change and biodiversity conservation

In the last few years, accelerated climate change has attracted a great deal of attention, publicity and concern. This has been fuelled by a series of documents such as *The Economics of Climate Change* (Stern, 2007), the IPCC Reports (IPCC, 2007)

Box 14.1 The main components of global change

Population change

- human population movement/migrations;
- demographic growth;
- changes in population pattern.

Changes in land use and disturbance regimes

- deforestation;
- degradation, simplification or loss of habitats;
- loss of biodiversity.

Climate change – as defined by the Intergovernmental Panel on Climate Change (IPCC)

- temperature change;
- atmospheric change (greenhouse gases: carbon dioxide, methane, ozone and nitrous oxide).

Other climate-related factors

- distribution of nitrogen deposition;
- global dust deposition (including brown dust and yellow dust);
- ocean acidification;
- air pollution in mega-cities.

and *Confronting Climate Change: Avoiding the Unmanageable and Managing the Unavoidable* (Bierbaum et al, 2007) which, together with many other findings in the literature, present a picture of large, serious and damaging climatic impacts on our way of life and on biodiversity in the short, medium and long term. Current and predicted patterns of global climate change are a major cause of concern in many areas of biodiversity and agrobiodiversity, conservation planning, socioeconomics, ecology and politics.

Although the evidence for climate change is overwhelming, there are still major uncertainties that need to be resolved and gaps in our knowledge (Schiermeier, 2010). While the general trends revealed by the use of general circulation models (GCMs) are evident, they are accurate only to a resolution of one to three degrees in latitude and longitude, and details are far from clear at the regional and local scale. There are also problems with the use of bioclimatic models for estimation of likely migrations of species as discussed below. This makes planning adaptation or mitigation strategies difficult. We need estimates of changes in biodiversity that are sufficiently accurate to allow us to make the necessary adjustments to population management and conservation. In response to these issues, a set of next-generation scenarios for climate change research and assessment has been developed by Moss et al (2010).

Another serious problem is that we do not know with any confidence how far we can allow global change to continue before reaching a tipping point; or as a recent study has termed it, transgressing planetary boundaries with unacceptable environmental change (Rockström et al, 2009a, 2009b).

We already have good evidence of recent phenological change – time of bud burst, flowering, fruiting, etc. – attributable to climate change (Cleland et al, 2007) and of shifts in altitudinal range of species and communities (e.g. Parolo and Rossi, 2007; Lenoir et al, 2008). If such trends continue or increase, the impacts on biodiversity will be significant.

Already countless studies of the impacts of global – and more specifically climate – change have been published at global, regional and national levels. The impacts on plant life have been particularly well studied in parts of Europe (e.g. Thuiller et al, 2005; MACIS, 2008; EEA/JRC/WHO, 2008; Berry, 2008; Araújo, 2009; Heywood, 2009) where it has been estimated that up to half of plant species may be at risk because of climate change. As noted below, very few studies have been carried out on the possible fate of CWR.

Changes in both temperature and precipitation regimes over the coming decades are likely to affect many biological processes, including the distribution of species. Observational and empirical data attest to recent shifts in the distributions and altitudinal range of species and changes in phenology and disturbance regimes that can be attributed to climate change. These are predicted to continue or intensify over the coming decades and will require us to adapt our current biodiversity conservation strategies or adopt new ones. With regard to CWR, the impacts of climate (and other aspects of global) change on protected areas and on the distribution of species will be critical.

As regards the CWR Project countries, the expected consequences of climate change in Armenia are summarized in Box 14.2 while the projected climatic changes and responses for Madagascar are outlined by Hannah et al (2008). Strategies for maintaining biodiversity under global change in Madagascar are proposed by Virah-Sawmy (2009).

Climate change and protected areas

In situ conservation of CWR will mostly take place in some form of protected area, so the effects of global change on such areas are of major concern. It is clear that the projected impacts on protected areas in many parts of the world will force us to rethink their role in biodiversity conservation. The political boundaries of protected areas are fixed, but the biological landscape is not (Lovejoy, 2006). It is clearly difficult for a fixed system of protected areas to respond to global change and considerable rethinking in the design of such areas will be needed if they are to survive and remain effective. Climate change, therefore, has major implications not only for protected areas but for protected area management and managers (Schliep et al, 2008). Generally, protected area managers have tended to adopt minimum intervention procedures, but climate change will force them to reassess management objectives, paying attention to the maintenance of ecosystem health and the conservation needs of target species. They will need to be prepared for

Box 14.2 Consequences of climate change in Armenia

According to Armenia's draft Second National Communication to the United Nations Framework Convention on Climate Change (UNFCCC) in 2009, climate change models predict that annual temperatures in the country will increase by 1°C by 2030, 2°C by 2070 and 4°C by 2100. Precipitation is projected to decrease by 3 per cent, 6 per cent and 9 per cent, respectively. These consequences can essentially affect the climate-dependent branches of economy. Global climate change and internal micro-climatic changes on the territory of Armenia might have the following consequences:

- The modelling of the vulnerability of mountain ecosystems of Armenia with regard to the climate change for the next 100 years foresees a shift of the landscape-zone borders up the mountain for 100–150m. It is expected that the desert to semi-desert zone area will expand by 33 per cent. The steppe belt will be expanded by 4 per cent and shifted upwards by 150–200m, which will cause transformation of steppe vegetation communities. The lower border of the forest belt will move upward by 100–200m. The area of subalpine belt will be reduced by 21 per cent and that of the alpine belt by 22 per cent on average.
- An increase of climate aridity and intensification of desertification processes can be expected under the projected increase of temperature and precipitation reduction.
- In the case of the accepted scenario of climate change, reduction of annual river flow by 15 per cent and an increase in evaporation from the surface of Lake Sevan by 13–14 per cent is expected.
- Under the projected change of climatic characteristics, the efficiency of plant cultivation in Armenia will be reduced by 8–14 per cent. The productivity of cereals will be reduced on average by 9–13 per cent, vegetable cultures by 7–14 per cent, potatoes by 8–10 per cent and fruits by 5–8 per cent. The productivity of more heat-resistant grapes may grow by 8–10 per cent.

Source: Climate Change Information Centre of Armenia; http://www.nature-ic.am/ClimateChange/Env_NGO/EnvNGO.htm/

more frequent and sometimes intensive management interventions (Hagerman and Chan, 2009). A comprehensive strategy should include (Ervin et al, 2010):

- *Improved linkages between protected areas:* by creating biological corridors that allow species to move and genes to flow, from one protected or conserved area to another;
- *Improved protected area management:* by better managing existing protected areas to ensure species survival within these areas and other intact habitats and species persistence within intact habitats;
- *Improved protected area design:* by ensuring that the design, layout and configuration enhances species survival and enhances connectivity with the surrounding landscape;

- *Improved management of the surrounding matrix:* by encouraging natural resource sectors to adopt practices that either positively impact (or at least do not negatively impact) biodiversity conservation and connectivity;
- *Improved connectivity to allow species to migrate in the face of climate change:* by ensuring species have a wider range of options for movement and adaptation in the face of climate change.

> *Protected areas that were set up to safeguard biodiversity and ecological processes are likely to be affected by climate change in a number of ways. Climate change is expected to cause species to migrate to areas with more favourable temperature and precipitation. There is a high probability that competing, sometimes invasive species, more adapted to a new climate, will move in. Such movements could leave some protected areas with a different habitat and species assemblage than they were initially designed to protect* (Mansourian et al, 2009).

Various papers suggest that many protected areas will suffer moderate to substantial species loss and some may experience catastrophic species loss and cease to be functional. However, the evidence is still equivocal and is likely to remain so while there continues to be uncertainty as to the scale and extent of climatic and other change. For example, an assessment was undertaken by Araújo et al (2004) of the ability of existing reserve-selection methods to secure species in a climate-change context. It used the European distributions of 1200 plant species, considering two extreme scenarios of response to climate change: no dispersal and universal dispersal. The results indicated that 6–11 per cent of species modelled would potentially be lost from selected reserves in a 50-year period. A study by Hannah and Salm (2003) on protected area needs in a changing climate concluded that such areas can be an important conservation strategy under a moderate climate change scenario, and that early action may be both more effective and less costly than not taking or delaying action. In the three areas observed (Mexico, Cape Floristic Region of South Africa and Western Europe) the study showed that protected areas remain effective in the early stages of climate change, while adding new protected areas or expanding current ones would maintain species protection in future decades and centuries.

A report by the Secretariat of the CBD (2009) notes that 'an assessment of the ecological regions that are most at risk due to current and projected climate change trends might suggest that the conservation of 10 per cent of ecological regions could be too small a threshold to prevent further extinctions'.

The likely responses of species to climate change

A great deal of effort has gone into developing tools that will help us predict the impacts of climate change on the future distribution of plants. Among the questions we need to answer are (Heywood, 2009):

- Which species will be able to track their climate envelopes as they move?
- Which will not be able to migrate and why (lack of dispersal capacity or reproductive capacity, lack of suitable niches, etc.)?
- What will the physical (climate–soil) conditions in these new climate envelopes be?
- What are sources of potential immigrants (both native and non-native) for many regions, i.e. where will the species that occupy the new habitats come from?
- What will the biotic diversity be like, i.e. what combinations or assemblages of species (plants, animals, micro-organisms, pollinators etc.) will grow there?
- Will the novel (emerging) assemblages be able to provide similar values of ecosystem services (including pollinators) to those that they replace?

In response to climate change, plants have three possibilities: adapt, migrate or become extinct.

Bioclimatic modelling

The tool that is most frequently used in attempting to predict the impacts of climate change is *bioclimatic modelling*. Bioclimatic models (bioclimatic envelope models) are a special case of ecological niche or distribution models. Currently, most current predictions of the future migration of plants use the 'climate envelope' or bioclimatic modelling techniques (Nix, 1986; Guisan and 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. Bioclimatic modelling techniques combine computer-based models of the current climate with information on the current distribution of species to establish a bioclimatic (also known as edaphic, fundamental, environmental or Grinellian) niche model. This model of optimal environmental parameters is then fitted to a range of future climate scenarios to establish likely shifts in environmental optima for species. 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.

Bioclimatic modelling has been applied extensively in Europe and is also being applied in other parts of the world. There is no single standard approach and techniques are constantly being developed.

> *While we can use various types of model to predict the possible migrations of species into 'new' climatic envelopes, 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, as mentioned above. 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. If we add to this the level of uncertainty that still surrounds the details of the extent of climate change and their impact at a local level, much of our planning has to be broadly based rather than site-specific, such as modifying or enhancing our protected area systems, or precautionary such as employing* ex situ *complementarity* (Heywood, 2009).

In an agrobiodiversity context, it would obviously be of great importance to be able to predict the effects of climate change on the future distribution and survival of target species of economic importance such as wild relatives or crops. One of the few studies so far published (Lane and Jarvis, 2007; Jarvis et al, 2008) used current and projected future climate data for ~2055, and a climate envelope species' distribution model to predict the impact of climate change on the wild relatives of three of the world's major food crops: peanut (*Arachis*), potato (*Solanum*) and cowpea (*Vigna*). They considered three migrational scenarios for modelling the range shifts (unlimited, limited and no migration) and found that climate change strongly affected all taxa, with an estimated 16–22 per cent of these species predicted to become extinct and most species losing over 50 per cent of their range size.

Climate envelope modelling has been used to indicate possible shifts in the distribution of *Pinus kesiya* and *P. merkusii* in Southeast Asia, and their possible implications for the conservation and use of their genetic resources (van Zonneveld et al, 2009a). This showed that in the case of *P. kesiya*, in addition to the areas where natural populations of the species have been recorded, it could potentially occur in several other locations in Myanmar, north-eastern and southern Thailand, the Lao People's Democratic Republic and south-western Cambodia, where it now occurs naturally. In addition, the Indonesian provinces of Java and Nusa Tenggara, which are outside its recorded natural distribution range, appear to have a suitable climate for the species. In the case of *P. merkusii*, its climate envelope coincides with the observed distribution of the species in mainland Southeast Asia and in Sumatra, while suggesting that the climate in several parts of the Malay Archipelago and in northern Australia is suitable for *P. merkusii* outside its natural distributional range.

Another study by van Zonneveld et al (2009b) of climate change impact predictions on populations of two important forest plantation species, *Pinus patula* and *Pinus tecunumanii*, in Mexico and Central America, using climate envelope modelling (CEM) found that climate change significantly impacts on the natural species distribution of the two pine species. However, assessment of the adaptive ability of the these species based on the evaluation of provenance trials, undertaken to validate the CEM impact assessment studies, showed that they performed well in a wide range of climates, including conditions that were recorded by CEM as unsuitable for natural pine occurrence. They interpret these

Box 14.3 CWR and bioclimatic modelling in Mexico

Using bioclimatic modelling, two possible scenarios of climatic change in Mexico were used to analyse the distribution patterns of eight wild Cucurbitaceae closely related to cultivated plants, *Cucurbita argyrosperma* subsp. *sororia*, *C. lundelliana*, *C. pepo* subsp. *fraterna*, *C. okeechobeensis* subsp. *martinezii*, *Sechium chinantlense*, *S. compositum*, *S. edule* subsp. *sylvestre* and *S. hintonii*. Most of these taxa have restricted distributions. Many of them also show proven resistance to various diseases, which could be crucial for the improvement of their related cultivars. The possible role that the Mexican system of protected areas might have in the conservation of these taxa was also assessed. The results showed a marked contraction of the distributions of all eight taxa under both scenarios. It was also found that, under a drastic climatic change scenario, the eight taxa will be maintained in just 29 out of the 69 natural protected areas where they currently occur. Accordingly, it seems that most of the eight wild taxa will not have many opportunities to survive under climate change. However, the ability of these plants to maintain low-density isolated populations for long periods, as well as the low resolution of the bioclimatic models, are discussed as possible mitigators of these rather grim predictions.

Source: Lira et al, 2009

findings as suggesting that the pine species in their natural habitat are better adapted to climate change than is predicted from CEM and recommend caution in interpreting CEM climate change impact predictions.

Bioclimate envelope modelling analysed the distribution patterns of eight Cucurbit wild relatives and their survival prospects under climate change (Lira et al, 2009) (Box 14.3).

A recent study modelling the shifts in species' ranges in Madagascar in response to forthcoming climatic change predicts that the littoral forest will disappear (Hannah et al, 2008), although Virah-Sawmy (2009) notes that palaeoecological reconstructions show the littoral forest remaining stable throughout several pronounced arid intervals, lasting hundreds of years each, during the last 6500 years, as well as during past sea-level rises of 1–3m. Temperature rises were not accounted for in this timeframe.

Non-modelling approaches

Although bioclimatic modelling is the most common method of suggesting the likely response of species to climate change, other approaches can be used to assess species' vulnerability on the basis of their biological and ecological characteristics, and other factors, that determine their sensitivity, adaptive capacity and exposure to climate change (Gran Canaria Group, 2006; CBD/AHTEG, 2009) (see Box 14.4).

Box 14.4 Criteria for identifying taxa vulnerable to climate change

- taxa with nowhere to go, such as mountain tops, low-lying islands, high latitudes and edges of continents;
- plants with restricted ranges such as rare and endemic species;
- taxa with poor dispersal capacity and/or long generation times;
- species susceptible to extreme conditions such as flood or drought;
- plants with extreme habitat/niche specialization such as narrow tolerance to climate-sensitive variables;
- taxa with co-evolved or synchronous relationships with other species;
- species with inflexible physiological responses to climate variables;
- keystone taxa important in primary production or ecosystem processes and function;
- taxa with direct value for humans or with potential for future use.

Source: Gran Canaria Group, 2006

Indigenous peoples and climate change

> *Sustainable agricultural growth in developing countries is challenged as never before – by climate change, increasingly volatile food and energy markets, natural resource exploitation, and a growing population with aspirations for a better standard of living* (Mark Rosegrant, Director of Environment and Production Technology at the International Food Policy Research Institute (IFPRI), 2010).

Indigenous peoples relying on traditional agriculture will be among the most severely affected by climate change although their reliance on a diversity of local crops and traditional varieties may provide some insurance against major losses. Their possible role in adaptation to and mitigation of the effects of climate change are discussed in Box 14.5. Examples of the use of indigenous knowledge for climate change mitigation and adaptation strategies by tree planting, conservation measures, management of natural resources, better land-use practices in Kenya, South Africa, Botswana, Ghana and Nigeria are given in a report by the Bureau of Environmental Analysis (BEA) International (Karani et al, 2010). The conservation of CWR *in situ* as part of such measures would be a win–win situation.

REDD (Reducing Emissions from Deforestation and Forest Degradation)

Given that forest clearing and degradation is responsible for about 17 per cent of global greenhouse emissions, according to estimates by the IPCC, efforts to reduce such emissions are an essential component of climate change adaptation strategies. The United Nations Collaborative Programme on Reducing Emissions

Box 14.5 Indigenous people and addressing the climate change agenda

Indigenous peoples have played a key role in climate change mitigation and adaptation. The territories of indigenous groups who have been given the rights to their lands have been better conserved than the adjacent lands (i.e. Brazil, Colombia, Nicaragua, etc.). Preserving large extensions of forests would not only support the climate change objectives, but it would respect the rights of indigenous peoples and conserve biodiversity as well. A climate change agenda fully involving indigenous peoples has many more benefits than if only government and/or the private sector are involved. Indigenous peoples are some of the most vulnerable to the negative effects of climate change. Also, they are a source of knowledge to the many solutions needed to avoid or ameliorate those effects. For example, ancestral territories often provide excellent examples of a landscape design that can resist the negative effects of climate change. Over the millennia, indigenous peoples have developed adaptation models to climate change. They have also developed genetic varieties of medicinal and useful plants and animal breeds with a wider natural range of resistance to climatic and ecological variability.

Source: Sobrevila, 2008

from Deforestation and Forest Degradation in Developing Countries (UN-REDD) is a mechanism that creates incentives for developing forested countries to protect, and better manage their forest resources, thus contributing to the global fight against climate change. REDD+ goes beyond reducing deforestation and forest degradation solely for the purpose of emissions reductions, and its strategies include the role of conservation, sustainable management of forests and enhancement of forest carbon stocks. The aim is to make standing forest more valuable than the timber obtained from felling it by giving a financial value to the carbon stored in the standing trees (Katerere, 2010).

It has been suggested that indigenous lands protected areas (ILPAs) should form part of government REDD strategies (Ricketts et al, 2010). They suggest that the steps that national governments could take to include ILPAs effectively in their REDD strategies could consist of:

- identifying where establishing or strengthening ILPAs would most effectively reduce emissions;
- as a matter of urgency, the establishment of national monitoring schemes to measure deforestation rates and quantify carbon emissions reductions (cf. Brazil's system of remotely sensed monitoring); and
- establishing insurance mechanisms, pooling the risk that illegal logging or fires reverse gains in individual ILPAs.

Of course, as they point out, it is also essential to ensure that governments provide indigenous groups and local communities with the information and capacities they need to participate and that payments are distributed transparently to reward those responsible for reducing emissions.

Global change, agriculture and food security

> *Although considered by many to be a success story, the benefits of productivity increases in world agriculture are unevenly spread. Often the poorest of the poor have gained little or nothing; and 850 million people are still hungry or malnourished with an additional 4 million more joining their ranks annually. We are putting food that appears cheap on our tables; but it is food that is not always healthy and that costs us dearly in terms of water, soil and the biological diversity on which all our futures depend* (Watson, 2008).

It is obvious that substantial improvements are needed in current crops to achieve higher yields and sustainable farming and this should be done without a major expansion of agricultural land and in such a way that it does not exacerbate climate change. In achieving these aims, all possible means and techniques will be needed to streamline breeding programmes, including the more extensive use of the genetic diversity found in CWR. As the *World Development Report 2010: Development and Climate Change*[1] notes, the weedy and wild relatives of today's crops retain higher genetic diversity and may be a useful base for enhancing crops' plasticity and their adaptability to changing conditions – some weeds, for example, thrive in conditions of higher CO_2 and warmer temperature. One of the main reasons for conserving CWR is so that genetic variation will be available for plant breeders so as to be able to breed new cultivars for crops in response to the conditions under climate change. Material of traditional landraces will also be an important source of genes for breeding new cultivars adapted to the conditions of abiotic environmental stress that may be expected as a result of climate change. As Semenov and Halford (2009) note: 'Breeders select new cultivars of agricultural crops that are better suited to a specific environment utilizing available resources in the most optimal way. However, cultivars that are recommended for use at present might not be suitable if the climate changes. Breeding for a new cultivar usually takes 10–12 years, if the target traits are known and the environment in which to test new lines is available. Faced with the prospect of a rapidly changing climate, breeders do not have access to the climatic conditions of even the near future in which to carry out field trials, and they do not know which … traits might be important in 15–25 years time.'

> *We know that the main sources of agricultural growth in the 20th century are drying up. Theoretically the global agricultural area could still be expanded by 80% but most spare land is little suited for productive agriculture. Only Africa and Latin America have significant reserves of suitable land. In several grain belts, especially in Asia, freshwater supply for irrigation is running dry. And yield potentials of major food crops*

> *have stagnated, even though there might still be some room for lifting potential yields along conventional pathways'* (Koning and van Ittersum, 2009).

Climate change and forestry genetic resources

The effects of climate change on forestry species and their CWR are likely to be significant, given that many of them are already impacted by non-climatic factors such as habitat loss or fragmentation with a consequent loss of genetic diversity in their populations (Bawa and Dayanandan, 1998). These effects will include rising temperatures, changes in precipitation patterns, extreme weather events, prolonged droughts leading to more frequent incidence of forest fires and changes in the physiology and reproductive success of tree species (Rimbawanto, 2010).

Strategic responses and new conservation strategies

As we have seen, conventional approaches to biodiversity conservation may not be a broad enough strategy to combat the effects of climate change and a number of novel approaches are being considered. These include the controversial approach known as *human-aided translocation of species*. Human-aided translocation of species' populations as a means of countering biodiversity loss from global change is a very recent approach and is being proposed for situations where the rate of change, the existence of obstacles or barriers or the lack of continuous suitable habitat is considered likely to prevent natural migration. Known as *assisted migration* (McLachlan et al, 2007) or *assisted colonization*[2] (Hunter, 2007; Hoegh-Guldberg et al, 2008), it is a complex and potentially costly venture and needs to be subject to careful cost–benefit analysis and perhaps used only in exceptional circumstances. Moving species into new environments is, as McLachlan et al (2007) say, a contentious issue and may involve considerable risks. It is a complex process involving not just scientific, technical and economic but also sociological and ethical considerations.

Seddon et al (2009), for example, state that 'calls to take proactive conservation measures need to consider that there are currently huge uncertainties involved, not only in climate change predictions and consequent species responses … but also in our understanding of the habitat requirements of species … and the effects of translocations on ecosystem function'. Ricciardi and Simberloff (2009) argue against assisted colonization as a viable conservation strategy on the grounds that: (1) species translocations can erode biodiversity and disrupt ecosystems; (2) planned introductions carry high risks; (3) risk assessments and decision frameworks are unreliable; and (4) the lack of power in predicting species invasiveness suggests that assisted colonization is ecological gambling and should be avoided as the precautionary principle.

On the other hand, human-assisted migration also has strong supporters: Richardson et al (2009), for example, believe that its importance as a conservation strategy will increase as global change takes hold and that it should not be considered *a priori* as a last resort approach but as one of a portfolio of options. It is evident that assisted migration requires a sound and well-thought-out policy framework before being widely undertaken as a management response to global change. It may be worth considering for CWR of particular importance but is unlikely to become a major component of CWR conservation strategies.

Other components of global change

Although the emphasis in recent years has been very much on the predicted impacts of climate change, it is important to recognize that the world is experiencing the effects of global change which, as Steffen et al (2004) observe, 'is much more than climate change. It is real, it is happening now and it is accelerating.'

Population change

Population change refers to both changes in the *pattern of distribution* of human populations and to *demographic growth.* Large-scale migrations of human populations can be caused by social, economic, political and health factors. The effects of war and civil conflict can leave large areas of land devastated or unusable and cause large human migrations, thus affecting the natural and agro-ecosystems involved and their biodiversity. In 2008, more than about half of the world's population (an estimated 3.3 billion people) lived in urban areas, and every day about 160,000 people move from rural areas to cities (United Nations, 2006; UNFPA, 2007). In comparison, the world's rural population is expected to *decrease* by some 28 million between 2005 and 2030, so that at the global level, *all* future population growth will thus be in towns and cities. Urbanization levels are rising, especially in less developed countries: in 2000, approximately 40 per cent of people living in less developed countries were in urban areas, but this proportion is anticipated to rise to 54 per cent by 2025.

Changes in land use and disturbance regimes

During the course of the past hundred years, changes in land cover and land use have accelerated largely in line with human demographic growth, as a result of industrialization, agricultural intensification, abandonment of traditional agricultural practices, population movements away from the land and many other factors.

Sometimes, land-use practices alter the natural disturbance regimes that generate the complex patterns of habitats that native plants and animals need for survival. If land-use practices change the frequency, size and intensity of natural disturbances, such as floods, fires, droughts and other extreme climatic events, then ecosystem functioning will be affected and communities with quite a different composition may develop. Deforestation and other forms of habitat destruction or degradation remain the major cause of biodiversity loss.

Tourism

Annual tourism is another form, albeit temporary, of population migration. The increase of tourism has led to massive urban and touristic development with accompanying infrastructural effects. It is estimated that carbon dioxide emissions from the tourism sector account for 4–6 per cent of total emissions and changing climate patterns might alter major tourism flows where climate is of paramount importance, such as southern Europe, the Mediterranean and the Caribbean. This will leave coastal and mountain-based destinations in least developed countries and small island developing states particularly vulnerable to direct and indirect impacts of climate change (such as storms and extreme climatic events, coastal erosion, physical damage to infrastructure, sea-level rise, flooding, water shortages and water contamination), given that most infrastructure is located within a short distance of the shoreline (UNWTO, 2008).

The number of environmental refugees – 'people who can no longer gain a secure livelihood in their homelands because of drought, soil erosion, desertification, deforestation and other environmental problems' (Myers, 1997) – is expected to increase by 200 million by the middle of this century. Their effects on biodiversity could be serious in that they will move into territories not able to support or feed them without large-scale disruption. Displaced people have to rely heavily on the surrounding environment for food and fuelwood, leading to forest and other vegetation degradation or loss.

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Notes

1. WDR (2010), 'Chapter 3: Managing land and water to feed nine billion people and protect natural systems'.
2. Hunter uses the term *assisted colonization* in contrast to *assisted migration* 'because many animal ecologists reserve the word *migration* for the seasonal, round-trip movements of animals … and because the real goal of translocation goes beyond assisting dispersal to assuring successful colonization, a step that will often require extended husbandry'.

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