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Wildlife in a changing climate

Cover images, clockwise from left:
The Lemuroid ringtail possum (*Hemibelideus lemuroides*), particularly the white form, may be at the verge of extinction (photo: Mike Trenerry); the population of the ‘i‘iwi (*Vestiaria coccinea*) is declining (photo: John Kormendy); and the golden toad (*Bufo periglenes*) is considered extinct (photo: Charles H. Smith). All have been affected by climate change.

Wildlife in a changing climate

FAO FORESTRY PAPER

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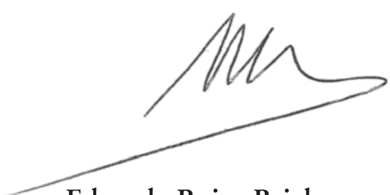
Foreword

For the past twenty years climate change has been high on the international agenda. Together with desertification, soil degradation and biodiversity loss, it is widely recognized as the major environmental threat the world is facing. Evidence is increasing that warming and other climate-related changes are happening more quickly than anticipated, and prognoses are becoming worse.

This publication analyses and presents how climate change affects or will likely affect wild animals and their habitats. Although climate change has already been observed and monitored over several decades, there are not many long-term studies on how the phenomenon is affecting wildlife. There is growing evidence, however, that climate change significantly exacerbates other major human-induced pressures such as encroachment, deforestation, forest degradation, land-use change, pollution and overexploitation of wildlife resources. Case studies are presented in this book that describe some of the body of evidence, in some instances, and provide projections of likely scenarios, in others.

An emphasis of this paper is on tropical terrestrial ecosystems. Subtropical, temperate and boreal regions, as well as coastal areas and inland waters, are covered to a lesser degree. These climatic zones and ecosystems are interconnected in many ways, and in particular for animals, there are no strict boundaries between them.

The publication not only highlights climate-induced changes and their likely consequences, but it also provides useful and up-to-date information on how these could be addressed by skilful measures of adaptive management. The findings and suggested measures explore current knowledge and propose a way forward. As climate change is ongoing, there is a need for more concerted research to inform policy and improved monitoring of its implementation. The increased knowledge would allow to better address this urgent issue and further improve climate policy.



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Wildlife in a changing climate

1. Summary

The world already faces a biodiversity extinction crisis, and it is likely to be made worse by climate change. This paper examines the likely ecosystem and landscape changes that will occur in forests, mountains, wetlands, coastal areas, savannahs, grasslands and steppes. Impacts include changes in physical conditions, weather patterns and ecosystem functioning. As a consequence, terrestrial, freshwater and marine wildlife will be severely affected unless we manage to cope with climate changes through decisive planning and action. The main focus is on tropical terrestrial wildlife and its habitats, but other fauna, ecosystems and geographical regions are covered as well.

The impacts of climate change will include permanent changes in physical conditions, such as snow cover, permafrost and sea level along with increases in both the irregularity and severity of extreme weather events like droughts, floods and storms, which will lead to changes in ecosystems and ecosystem functioning. Degraded ecosystems are expected to be less resistant to climate change than intact ones.

This paper explores several main consequences for wildlife, including:

- *Ecosystem changes*: These include geographical and altitudinal shifts, changes in seasonality and rates of disturbance, changes in species composition and a rapid increase in invasive species.
- *Species interactions*: Impacts on wildlife species include changes in species distribution, abundance and interactions, for example through shifting phenology and mistiming.
- *Human–wildlife conflicts*: These are likely to increase as humans and wild species compete for the same dwindling resources.
- *Wildland fires*: Increased drought, the drying out of previously wet forests as well as human interference and pressure are leading to more frequent and disastrous fires in ecosystems that are poorly adapted to such events.
- *Health and diseases*: Wildlife, humans and livestock will be affected by the emergence and increased spread of pathogens, geographically and across species boundaries, due to climate, landscape and ecosystem changes.

Also considered are a number of responses to climate change:

- *Maintaining current ecosystems*: This is crucial, particularly where ecosystems are reasonably intact and therefore likely to withstand climate change. A strong and effective network of protected areas is a critical element in this strategy.
- *Adaptive management*: Protection alone will not be enough, however, as ecosystems change around us. Wildlife biologists are now considering new approaches and more radical steps, including the relocation of protected

areas, perhaps on a temporary basis, to allow migration to suitable conditions; translocation of species that have lost optimal ecological conditions; artificial feeding of wildlife in times of emergency; and modification of habitats. All of these approaches are accompanied by risks and costs and will require that strong safeguards are in place to be successful.

- *Restoring ecosystems*: Restoration will also be needed, particularly in ecosystems that are important for climate change resilience but are already badly degraded. These include mangroves, inland waters, forests, savannahs and grasslands.
- *Landscape approaches*: Actions taken in isolation are likely to fail, making integrated approaches vital. Examples of fire, invasive species and disease and pest management are included in the paper to allow consideration of how such integration might be applied in practice.

Addressing wildlife management among the multiple other concerns resulting from climate change will be challenging. Developing and communicating information on the value of wild species and ecosystems to humanity will be an important strategy in building political momentum for conservation, alongside ethical considerations. Developing, managing and retaining an effective system of protected areas is critical for success. The concept of "mainstreaming" biodiversity conservation needs to be applied consistently and carefully. Finally, as we embark on a period of great uncertainty, further research and careful monitoring are needed to ensure that adaptive management and other new approaches can succeed in responding to existing and newly emerging climate pressures.

2. Introduction

The world is undergoing an extinction crisis – the most rapid loss of biodiversity in the planet's history – and this loss is likely to accelerate as the climate changes. The impact of climate change on wildlife is already notable at local, regional and global levels. The direct impact on species that humans make use of or with which we compete, affects human communities in a very immediate way: the loss of biodiversity is our loss as well. Arguably, we also have an ethical responsibility to address the rapid increase in the rate of global species extinction that has been caused by our own actions.

Climate change is expected to become one of the major drivers of extinction in this century as a result of changes in the breeding times of species and shifts in distributions caused by the variation in temperatures and precipitation regimes. It has been estimated that 20–30 percent of plant and animal species will be at higher risk of extinction due to global warming and that a significant proportion of endemic species may become extinct by 2050 as a consequence. Some taxa are more susceptible than others. For example, 566 of 799 warm-water reef-forming coral species are at risk of becoming endangered because of the increasing climate change, as are about 35 percent of birds and 52 percent of amphibians. Moreover, the impact will likely be more severe on species that are already at risk of extinction: 70–80 percent of red-listed birds, amphibians and corals are considered susceptible to the effects of climate change (Vié, Hilton-Taylor and Stuart, 2008).

When climate change disrupts ecosystems that provide global services, the implications are even more serious. With regard to rainfall generation, the potential impact on food security is huge because weather systems that water crops in the temperate world can be traced back to evapotranspiration in the three main tropical forest blocks (as demonstrated by precipitation simulations showing rainfall patterns over the course of a year). Average annual temperatures have risen steadily over recent decades and an even higher increase is predicted for the years ahead. This is most pronounced in Africa where current climate models project a mean temperature rise of 3–4 °C across the continent by the end of this century, approximately 1.5 times the global average increase (Kleine, Buck and Eastaugh, 2010; Seppälä, Buck and Katila, 2009).

All global ecosystems are likely to be affected by climate change to a greater or lesser extent. Forests cover approximately one-third of the global land surface. They provide essential services that support human livelihoods and well-being, support the majority of terrestrial biodiversity and store about half of the total carbon contained in land ecosystems, including in the peat of some tropical forest soils. Tropical and subtropical forests contain many biodiversity hotspots. There are still major gaps in knowledge about the impacts of climate change on forests, associated wildlife and people and how adaptation measures can best be tailored to local conditions. The productivity of tropical forests is projected to increase where water is available in sufficient quantity. In drier tropical areas, however, forests are projected to decline (Seppäla, Buck and Katila, 2009). Major impacts are also predicted elsewhere, particularly in polar ecosystems, inland waters, grasslands and in the oceans, where climate-driven acidification is perhaps the most extreme threat of all (Parry *et al.*, 2007).

Even moderate climate change, as projected in both unavoidable and stable scenarios, would put some wildlife at considerable risk; worst-case scenarios would see catastrophic losses. Thomas *et al.* (2004) conclude that "for scenarios of maximum expected climate change, 33 percent (with dispersal) and 58 percent (without dispersal) of species are expected to become extinct. For mid-range climate change scenarios, 19 percent or 45 percent (with or without dispersal) of species are expected to become extinct, and for minimum expected climate change 11 percent or 34 percent of species (again, with or without dispersal) are projected to become extinct." According to the Intergovernmental Panel on Climate Change (IPCC; Parry *et al.*, 2007), roughly 20–30 percent of vascular plants and higher animals on the globe are estimated to be at an increasingly high risk of extinction as temperatures increase by 2–3 °C above pre-industrial levels. The estimates for tropical forests exceed these global averages. It is very likely that even modest losses in biodiversity would cause consequential changes in ecosystem services (Parry *et al.*, 2007; Seppäla, Buck and Katila, 2009).

As average global temperatures rise, the impacts on habitats and species will depend on many factors, including local topography, changes in ocean currents, wind and rainfall patterns and changing albedo. In addition to variations in the rate and extent of temperature increases at different latitudes, there may be changes in the length and severity of seasons, including decreases in temperature in some areas. Rainfall patterns may likewise be affected in terms of overall annual quantity, seasonal distribution of precipitation and year-by-year regularity. Extreme weather events, such as droughts and floods, are expected to occur more often. In particular, droughts are projected to become more frequent and intense in subtropical and southern temperate forests; this will increase the prevalence of fire and predisposition to pests and pathogens (Seppälä, Buck and Katila, 2009).

Natural ecosystems are not only threatened by climate change. Loss and degradation due to human encroachment, agricultural expansion for crop and rangelands, invasive species, over-harvesting and trade in natural resources (including wildlife), epidemic diseases, fires, and pollution still exceed the current impacts of climate change. It is widely recognized that measures to limit such non-climatic human-induced pressures can help reduce the overall vulnerability of ecosystems to climate change.

Non-timber forest resources, such as fuelwood, charcoal, non-wood forest products and wildlife sustain the livelihoods of hundreds of millions of people in forest-dependent communities. Most rural and many urban populations in developing countries rely on woody biomass as their main energy source and depend on wild plant medicines for their healthcare. In many developing countries, bushmeat is an important source of protein, while for coastal communities or those living near freshwater, fish can be a major source of protein. In Central Africa, there is a very large and well-established trade in bushmeat products, which is driven mainly by consumer demand in major cities. Up to 5 million tonnes of bushmeat are believed to be consumed every year in the Congo Basin (Fa *et al.*, 2002; Kleine, Buck and Eastaugh, 2010; Seppäla, Buck and Katila, 2009) in a trade that is recognized as unsustainable and often illegal. Despite their importance to local communities, about 13 million hectares (ha) of the world's forests are lost due to deforestation each year (FAO, 2010a) and further large areas are also degraded.

3. Major climate-induced changes

Ecosystems are exposed to the effects of changing climates in different measures. Although the impacts of climate change may be difficult to detect since they are often combined with the effects of other activities, such as land use changes, the most recent Global Biodiversity Outlook report (Secretariat of the Convention on Biological Diversity, 2010) identifies climate change as one of the main factors responsible for the current loss of biodiversity. Some aspects of biodiversity loss through, for example, deforestation and the draining of wetlands, will themselves exacerbate climate change by releasing centuries' worth of stored carbon.

Climate change affects different ecosystems in different ways, depending on the complexity and original characteristics of the system, geographical location and on the presence of factors that may regulate the extent of the changes. Degraded ecosystems are generally believed to be less resilient to climate change than intact and healthy ecosystems. The recorded increase in mean annual temperature is already affecting many ecosystems and scientific studies predict that future changes will be of much greater amplitude. The highest rates of warming have been observed at high latitudes – around the Antarctic Peninsula and in the Arctic – with the recorded reduction of the extent, age and thickness of ice occurring at unprecedented speed and even exceeding recent scientific predictions (Secretariat of the Convention on Biological Diversity, 2010).

Increased temperatures affect physical systems, as ice melts and snow cover is reduced, as well as affecting biological systems through a series of direct and indirect pressures. Physical systems include deep snow, glaciers and permafrost. Increases in temperature can lead to a drastic unbalancing of the physical system, causing irreversible losses. The water cycle and hydrological systems are affected by changing temperatures, often indicated by dry riverbeds or floods due to increased runoff. In semi-desert areas, the decreased availability of water is already placing additional pressures on wildlife, which aggregate around limited water points and compete with domestic livestock (de Leew *et al.*, 2001). Reduced plant production as a consequence of reduced precipitation increases the probability of soil degradation due to overgrazing by wildlife and domestic animals. Many freshwater species are under serious threat of extinction as a result of rising temperatures and the disappearance of ponds and coastal lagoons (Willets, Guadagno and Ikkala, 2010).

Snow and ice melts in mountainous areas have been recorded as occurring at alarming rates. Such processes severely affect mountain ecosystems, which are particularly susceptible to increasing temperatures. The extent of snow cover in the Northern Hemisphere has decreased by about 10 percent since the late 1960s and 1970s (Parry *et al.*, 2007) and mountain vegetation zones are recorded to have shifted upwards.

Biological systems are also being affected by increasing temperatures, which introduce changes in biophysical conditions that influence their development and maintenance. Changes in water availability affect the flowering and survival of aquatic plant species, as well as the abundance of wildlife species in affected areas. Shifting seasonal changes, which are already being recorded in most temperate regions, affect the timing of animal migrations and the flowering of plants, and thus destabilize the equilibrium of ecosystems that are far apart. One large potential ecological impact of such changes is mistiming, where, for instance, migrating animals arrive at times when their necessary food plants or animals are not available (Vissier and Both, 2005).

Rising sea levels are affecting coastal areas through shoreline erosion, the loss of coastal wetlands and modification of coastal vegetation. Marine and coastal ecosystems are also disrupted by storms that damage corals directly through wave action and indirectly through light attenuation by suspended sediment and abrasion by sediment and broken corals. Higher temperatures also cause the expulsion of zooxanthellae (single-celled plants living in the cells of coral polyps), which leads to coral bleaching and has caused the loss of 16 percent of the world's corals (Wilkinson, 2004). Up to a third of corals are considered to be threatened with extinction due to climate change (Carpenter *et al.*, 2008). In a chain reaction, the death of corals causes the loss of habitat for many species of tropical fish. Many studies report changes in fish populations, recruitment success, trophic interactions and migratory patterns related to regional environmental changes due to changing climatic conditions (e.g. Edwards and Richardson, 2004; Hays, Richardson & Robinson, 2005).

Variations in climate not only lead to the modification of ecosystems. They are also associated with a higher frequency of extreme weather events that have the potential to cause vast property destruction and loss of life. Weather events particularly associated with sudden natural disasters include extreme river floods, intense tropical and extra-tropical cyclone windstorms and their associated coastal storm-surges and very severe thunderstorms. The IPCC notes that "increased precipitation intensity and variability are projected to increase the risks of flooding and drought in many areas" (Bates *et al.,* 2008). The IPCC reports that future tropical cyclones will probably become more intense, with larger peak wind speeds and heavier precipitation (Parry *et al.,* 2007). Extreme weather events are usually rare, with return periods of between 10 and 20 years. The relationship between extreme weather events and climate change is not easy to establish, given that the record of significant temperature increase has been reported only since the 1970s. Thus, the number of events may not yet statistically support a correlation. Nevertheless, the links are now widely accepted by specialists (e.g. Helmer and Hilhorst, 2006).

Changing environmental conditions facilitate the establishment of introduced species, which may become invasive and out-compete native species, leading to the modification of entire ecosystems (Chown *et al.*, 2007; McGeoch *et al.*, 2010). For example, invasive species have been measured as growing faster than native species due to changing climatic conditions in the Mojave Desert, the United States of America (Smith *et al.*, 2000). Globalization of markets and the increased movement of people and merchandise have increased the translocation of species on local, regional and continental scales. Some species have expanded their range as temperatures have become warmer. Warmer temperatures have created opportunities for pathogens, vectors and hosts to expand their range, thereby enabling pathogens to be present in new geographical locations and, potentially, to infect new naïve hosts, which in some cases can result in morbidity or mortality of wildlife, livestock or humans. Diseases that were kept at low infection levels because of temperature restrictions are now reported to have become fatal and endemic.

The following sections analyse the major impacts of climate change on ecosystems and wildlife, providing details from scientific studies.

3.1 DISTURBANCE AND EXTREME WEATHER EVENTS

The frequency and severity of extreme weather events is widely reported to be on the rise, making it more difficult to plan for such events. Past records have previously been used to predict the likelihood of future droughts, floods, hurricanes and storm surges, but this approach is becoming less reliable as precipitation patterns change on local, regional and global scales. In addition, land shortages are forcing human communities to live in less stable areas, further increasing the risk that earthquakes or extreme weather events will develop into natural disasters. Today, half the world's human population is exposed to hazards that could develop into disasters (Dilley *et al.*, 2005).

ADRIANA CÁCERES CALLEJA

A Thomson's gazelle (Eudorcas thomsonnii) *faces a duststorm in Amboseli National Park.*

This unpredictability makes planning for climate change extremely challenging. It is clear that extreme weather events not only impact wildlife and human communities directly, they also hamper people's very capacity to survive, let alone to protect threatened and endangered species and habitats. As the interval between extreme events shortens, there is less time to allow a return to normal conditions before the next event hits.

The Amazon Basin, for example, has historically been subjected to severe droughts once or twice in a century. In 2010, the region experienced the third drought in only 12 years (Sundt, 2010; University College London, 2011). The 2010 drought was reported to be more widespread and severe than the previous drought in 2005, which itself was identified as a once-in-a-century event (Lewis *et al.*, 2011). The worst hit areas, such as the Brazilian state of Mato Grosso, received only 25 percent of the normal precipitation during July to September 2010, and most of Amazonia saw a significant reduction in rainfall. River levels reached record lows, impacting all river users, from shipping vessels to pink river dolphins (*Inia geoffrensis*). In August, the Bolivian Government declared a state of emergency because forest fires were burning out of control. Overall, this has led to concerns that the Amazon forest might have reached, or be close to reaching, a "tipping point" from which it will be unable to recover.

Although the popular perception of climate change is of global warming, the phenomenon might be more accurately termed "global water problems". Managing water for human activities frequently impacts wildlife and natural habitats, whether by flooding dammed river valleys or lowering river levels and water tables when water is extracted to supply cities or to irrigate large-scale agriculture. Extreme weather events can exacerbate these problems and bring about new ones. "When world leaders speak about climate, they invariably speak of water – of floods, droughts and failed harvests – and express their alarm. They are right to do so: because climate change is primarily about water." This was the message delivered by the Global Water Partnership (GWP; 2010) to the 16th Conference of the Parties to the United Nations Framework Convention on Climate Change in Cancun, Mexico. The GWP called on the 193 parties to make sustainable water resources management and disaster risk management an integral part of the global response to climate change.

Reduced precipitation not only places animals and plants under stress, but increases the risk of forest fires. Globally, more than 350 million ha are estimated to be affected by vegetation fires each year, of which some 150 to 250 million ha are tropical forests (Appiah, 2007; UNEP, FAO and UNFF, 2009). Much of this arises from deliberate use of fire for clearing scrub or improving pasture, but extremes of dry weather increase the likelihood of such fires getting out of control. The FAO recommends two approaches in fire management. The first aims to establish balanced policies dedicated to fire suppression as well as to fire prevention, preparedness, restoration, etc. The second is a participatory and community-based approach involving all stakeholders, including at the field level (FAO and FireFight South East Asia, 2002). It has been recognized that these approaches should be integrated into a broader landscape or natural resources management framework. Drought also dramatically increases rates of breakdown in arid land and desert vegetation, leading to further desertification, soil erosion, dust storms and impacts on wildlife that live in these ecosystems (Omar and Roy, 2010).

Similarly, extreme precipitation events also affect wildlife. As well as the widely reported human suffering caused by recent flooding in Queensland, Australia, hundreds of orphaned bats were rescued by local carers. Serious losses of small macropods, especially wallabies, bandicoots and native rats and mice are also expected.

BOX 1

Cyclones threaten survival of the cassowary

The rainforests of Mission Beach in Queensland, Australia were seriously devastated by Cyclones Larry and Yasi in March 2006 and February 2011, respectively. By destroying their habitat and main food supply, the cyclones greatly affected the remaining populations of the already endangered Southern cassowary (*Casuarius casuarius*), a flightless bird – the third largest bird species after the ostrich and emu – and an important seed disperser of the rainforest's trees. The seeds are often so large that only the cassowary can swallow and thereby disperse them. Furthermore, many fruit plants will not germinate unless their seeds go through this digestive process. It is estimated that only 1 000 to 2 000 cassowaries remain in Northern Queensland, with about 200 concentrated in the Mission Beach hinterlands (Rainforest Rescue, 2011; Maynard, 2011). Under normal circumstances, habitat loss and fragmentation are considered the primary cause for their decline (Kofron and Chapman, 2006).

The strong cyclone winds stripped the forests of fruit – the cassowary's principal diet – and much of it was left to rot on the forest floor. Once any remaining fruit had been consumed, the cassowaries began to leave their usual habitat in search of food, particularly young cassowaries, which were unable to compete with the adults. This brought them to suburban areas and tourist resorts, where they suffered an increase in mortality from starvation, traffic accidents and encounters with dogs. As a consequence of the 2006 cyclone, the cassowary population was reduced by a third. (Rainforest Rescue, 2011; Maynard, 2011)

After Cyclone Yasi, Rainforest Rescue, a local non-governmental organization (NGO) working with Queensland Parks and Wildlife Service, provided food for cassowary populations in many remote feeding stations, enabling them to survive until the forest recovered and produced a new crop of fruit. An increase in humans feeding cassowaries has also been observed, but conservationists discourage this as it leads to changes in the habits of these wild birds, possibly making them aggressive and even dangerous to humans. (Rainforest Rescue, 2011; Maynard, 2011)

BOX 2

Elephants supplied with water during drought

There are about 350 elephants (*Loxodonta africana*) left in the Sahel of Gourma, Mali, down from 550 in less than 40 years (Bouché *et al*., 2009). Their range has shrunk considerably due mainly to climate change and the degradation of their habitat by livestock.

Not only are these the most northerly elephants in Africa, they are also the most peripatetic, migrating along a unique circular route in search of water. During the dry season, the elephants congregate at seasonal lakes in the north, especially Lake Banzena. These seasonal lakes have been decreasing in size due to wind and water erosion accentuated by deforestation, and access to them is impeded by plantations and livestock. (Bouché *et al*., 2009; Barnes, Héma and Doumbia, 2006)

Over the past 27 years, the region has suffered from four serious droughts that threatened the survival of the elephants. Each time, the Government, together with NGOs, took action to supply the elephants with water. The drought of 1983 completely dried up Lake Banzena and the Government sent in tankers of water to help save the elephant population. The partial drought of 2000 led to the construction of two deep boreholes equipped with pumps to draw water for elephants. (Wall, 2009)

In 2009, the worst drought since 1983 again dried Lake Banzena, leaving behind only 30 cm of sediment-filled muddy water. With their main water reservoir gone, the elephants began to suffer severely. Six died from drought-related causes (heat stress, starvation and polluted water), while three calves died after being trapped in a well. Bulls were found kneeling on the edge of small wells, drinking at full trunk-length; juveniles, with shorter trunks, could not reach into these remaining wells and suffered more from the drought. (Douglas-Hamilton and Wall, 2009; Loose, 2009a)

The two existing boreholes were used to capacity by herdsmen and livestock and crowded out the elephants, which could only get to the water at night. With the challenge of providing water to both livestock and the elephants, a concrete reservoir was built by the non-profit organization Save the Elephants and placed under Government administration (Douglas-Hamilton and Wall, 2009). Designed in such a way that the water cannot be churned into mud, the reservoir holds enough water for 100 elephants to drink each day (Wall, 2009) and can be used perennially during the dry season (Loose, 2009b).

The following year brought another drought, once again putting the remaining desert elephant population under severe pressure. Twenty-one elephants died over a two-week period. With 50 000 heads of cattle concentrated around Lake Banzena, competition for water was strong. The droughts are a consequence of climate change causing the desiccation of the Sahel (Barnes, Héma and Doumbia, 2006). In response, plans are in place to create water points along the elephants' migration routes and shared water points in conservation areas, as well as to deepen existing ponds and establish boreholes with solar-powered pumps. Moreover, Lake Banzena is now reserved exclusively for elephants. (The World Bank, 2010)

JAKE WALL

Elephants (Loxodonta africana) *waiting for access to wellwater during a drought.*

3.2 ECOSYSTEM AND LANDSCAPE CHANGES

Changes in temperature and precipitation will affect individuals, species, ecosystems and whole regions. Individual variation and topographic differences will mean that, within any species, an individual plant or animal may be genetically predisposed to survive the stresses of dehydration, high winds or inundation for longer than another. Thus, at the micro-habitat level, each tiny location may see changes in species composition; these changes will have ramifications up and down the trophic levels and throughout the food-web, ultimately changing ecological communities at the landscape level. Predicting the consequences for humans and other species is essential if measures are to be taken in time, either to prevent these changes or adapt to them.

3.2.1 Coasts

Coastal wetlands are among the most productive of all natural ecosystems (Day *et al.*, 1989) and so the impacts of climate change will be extremely important in coastal regions and have ramifications far beyond them. In addition to the effects of rising temperatures and changes in rainfall, animals and plants in coastal habitats face another threat from climate change: rising sea level. This is due to a combination of melting polar ice caps, ice sheets and montane glaciers coupled with thermal expansion, wherein warm water occupies a greater volume than cold water. The IPCC predicts that in the next century, average sea level will rise by 0.18–0.59 m compared to the 1980–1999 levels (Parry *et al.*, 2007). Other climate models go even further, with estimates of 0.5–1.4 m – a rise that would inundate many low-lying areas. Human population and development pressure is in many cases likely to prevent coastal habitats from moving inland, thus leading to net habitat loss.

Such changes will have immediate impacts on many wildlife species (e.g. Michener *et al.*, 1997). Sea turtle populations are likely to be hit as their nesting beaches are inundated. It is predicted that a rise in sea level of 0.5 m will result in the loss of 32 percent of sea turtle nesting grounds (Fischlin *et al.,* 2007). Tidal mudflats, low-lying coastal and intertidal areas may cease to be exposed, affecting the feeding grounds of many species of birds, such as ducks, geese, swans and waders. If their feeding success is reduced, migratory birds may be prevented from building up sufficient stores of energy to allow their annual migration to breeding grounds (Galbraith *et al.*, 2002). Low-lying coastal forests and wetlands will suffer increasing salination as high tides and storm surges bring saltwater inland, causing the death of plants that cannot tolerate brackish water and, subsequently, of the animals that depend on those plants. This salination will affect not only coastal biodiversity, but also ecological processes and primary and secondary productivity – with adverse impacts likely for local communities, whether dependent on agriculture or fishing.

Location specific coastal inundation models have been developed and found to match known flooding patterns, but these have been primarily motivated by the desire to minimize the loss of life in coastal communities (e.g. Dube *et al.*, 2000 for the Andhra and Orissa coasts of India). There is a need for more detailed research on the likely effects of flooding on natural systems and measures to mitigate ensuing changes.

Mangrove forests would seem to be preadapted to inundation, as they thrive in coastal locations below the high tide where their stilt roots are submerged in saline water on a daily basis. They cannot, however, survive permanent submersion due to rising sea levels, and mangrove die-off has been reported from several locations (e.g. Ellison, 1993). FAO estimates that there are 15.2 million ha of mangrove worldwide, mainly in the tropics, but also in a few warm temperate locations (FAO, 2007). Yet mangroves have been badly affected by unsustainable development activities, particularly aquaculture, and have already declined to less than half their original area (Valiela, Bowen and York, 2001). Their distribution is likely to move further into the temperate zones as global average temperatures rise and further inland as sea levels rise. There is geological and contemporary evidence that mangroves have expanded and contracted quite rapidly in the past and they are likely to be early indicators of the effects of climate change (Field, 1995).

BOX 3

Climate change drives an increase in tiger attacks in the Sundarbans

The Sundarbans in the Ganges delta, a United Nations Educational, Scientific and Cultural Organization (UNESCO) World Heritage Site at the border between India and Bangladesh, is one of the largest remaining areas of mangrove habitat in the world. The area hosts the most substantial population of Bengal tiger (*Panthera tigris tigris*), estimated at more than 500 tigers in the 1960s. The population decreased to about 350 in the whole Greater Mekong region at the beginning of the 21st century and is currently estimated at some 150–200 tigers in the area, with their decline mainly due to poaching and habitat loss. (New Scientist, 2008)

The Sundarbans is the largest natural low-lying mangrove ecosystem in the world, distributed over 10 000 square kilometres. The sea level rise recorded over the past 40 years is responsible for the loss of 28 percent of the mangrove ecosystem. Modelling suggests that up to 96 percent of suitable tiger habitat in the Sundarbans could be lost in the next 50–90 years (Loucks *et al.*, 2010). Mangroves are also a critical factor in reducing the impact of sea surges, which are already amongst the highest in the world in Bangladesh (Nicholls, 2006).

The decreasing size of the mangrove habitat has caused wildlife, particularly small and medium sized mammals, which the tigers prey upon, to move to other areas. The wildlife populations inhabiting the mangrove ecosystem have thus decreased dramatically. Tigers have followed the move of the most mobile species and are approaching villages more frequently, causing conflicts – often fatal – with inhabitants. At the same time, the loss of wildlife leaves the local fishing communities short of a primary source of income. The local people, who live off fisheries and non-wood forest products, such as honey, need to enter restricted areas more often, thus increasing dangerous contact with tigers. (New Scientist, 2008)

Records of tigers from the Sundarbans attacking humans date back to the sixteenth century with the arrival of the first Jesuit missionaries in Bengal. Today, fatal accidents for humans are reported continuously but no regular database of such information exists. The Sundarban area is protected and human access to many islands is restricted. Cases of humans killed by tigers are often associated with unlawful behaviour – for example, people entering the restricted area – and thus the fatal event is not reported to the authorities. Between 2003 and 2005, it was estimated that only 10% of tiger attacks resulting in injury or death were reported, with 90% of the victims having entered illegally into the Sundarbans of Bangladesh. For the same period an annual average of 168 total victims has been extrapolated (Neumann-Denzau and Denzau, 2010).

The number of humans killed by tigers is on the rise as the area of natural habitat of tigers decreases. As a result, tigers are exposed not only to higher pressure from poachers, but also to being killed in retaliation for the threat they pose to human life. Thus, the population of Sundabrans tigers is predicted to continue to decrease steadily in the future. (Neumann-Denzau and Denzau, 2010)

3.2.2 Mountains

Mountain ecosystems cover close to 24 percent of the earth's land surface and, with their steep and varied topography and distinct altitudinal zones, they support a high variety of species and habitats and a high degree of endemism. Mountains also provide essential resources to human communities, both at the local level and beyond. They are, however, particularly sensitive to changes in temperature and precipitation because of their geographical and orographic nature. Climate change is exposing alpine and subalpine areas to increasing temperatures, with the projected result of a slow migration of ecosystems towards higher elevations. This is, however, not always the case: on Mount Kilimanjaro the opposite has been observed, with climate-induced fires causing a downward shift of the upper treeline and a consequent reduction in important cloud-forest habitat (Hemp, 2009).

Alpine plants, which are usually long-lived and slow growing, may have particular problems in adapting to a rapidly changing climatic environment and alpine vegetation will likely reflect this lack of capacity to adapt. Many plants will respond to the changes in climate with a considerable time lag (Pauli, Gottfried and Grabherr, 2003), thus monitoring such changes must be planned as a long-term objective. The expected migrations will cause a disintegration of current vegetation patterns, seriously impacting the stability of alpine ecosystems by, for example, creating unstable transition zones with largely unpredictable behaviour (Gottfried *et al.*, 1999).

ADRIANA CÁCERES CALLEJA

Shrinking glaciers of Mount Kilimanjaro feed less water into surrounding savannahs.

Mountain ecosystems are often located in small and isolated areas, surrounded by environments with warmer temperature regimes and often with fertile soils that can be used for agricultural purposes. As a result, species will be forced to try to adapt to changing conditions within the ecosystem. Migrating upwards, plants and animals will be faced with reduced areas of habitat and, in some cases, no suitable habitat will remain. Cold-adapted alpine species are stressed by climate warming and must compete with species from lower elevations extending their ranges upward. Extinctions are predicted to occur at higher rates in mountainous areas than in other ecosystems. Among the species reported to be at highest risk are the mountain pygmy possum (*Burramys parvus*) in Australia, the ptarmigan (*Lagopus muta*) and snow bunting (*Plectrophenax nivalis*) in the United Kingdom of Great Britain and Northern Ireland, the marmot (*Marmota* spp.) and pika (*Ochotona* spp.) in the United States of America, the gelada baboon (*Theropithecus gelada*) in Ethiopia (see Box 4) and the monarch butterfly (*Danaus plexippus*) in Mexico (Malcolm and Markham, 2000).

Higher temperatures will mean more rain than snow, raising the risk of flooding for mountains and down-stream lowland ecosystems. Changes in permafrost and hydrology are being widely recorded, for example in Alaska, the United States of America (Hinzman *et al.*, 2005), while snowpacks are declining throughout western North America, melting 1–4 weeks earlier than they did 50 years ago (Mote *et al.*, 2005; Westerling *et al.*, 2006). Warmer temperatures will also have an impact on the depth of mountain snowpacks and glaciers, changing their seasonal melts and affecting large downhill areas that rely on them as a freshwater supply (see Box 10). Glacial lake outburst flooding can have immediate and dramatic impacts on local ecosystems (Bajracharya, Mool and Shrestha, 2007). Shifts in seasons will affect the timing of ice and snow melts and consequent water runoff, in turn affecting the timing of processes and activities that depend on water, including agriculture. Changes in stream and river flow will affect the microfauna living in aquatic ecosystems, thus having an impact on fish and waterfowl species.

BOX 4

Climate change affects gelada baboons in mountain highlands

Gelada baboons (*Theropithecus gelada*) are medium-sized African primates found only in the Ethiopian highlands, with anatomical adaptations to a highly terrestrial life. They have an almost totally grass-dependent (graminivorous) diet, feeding on grains produced by high mountain grasses that have a particularly high nutrient content. As a result, the current distribution range of gelada is restricted to areas with bioclimatic characteristics that allow the development of specific montane grassland habitat. Under current conditions, gelada are restricted to an altitudinal range between 1 700 and 4 200 m. (Dunbar, 2008)

Continues

Box 4 continued

Previous studies aimed at understanding the causes of extinction of sister species during the Pleistocene suggest that the main restrictive factor facing the fossil species was the move upwards of grass species required for their diet following a rise in temperature, suggesting that the same could happen to current gelada populations (Dunbar, 2008).

Increases in local temperature are likely to push gelada upwards in search of suitable conditions, resulting in their occupying increasingly limited and fragmented habitats. Further fragmentation may arise from expanding agricultural areas, made possible at higher altitudes due to warmer temperatures, unsuitable habitat and gorges, which may confine the gelada to isolated patches (Dunbar, 1998).

A behavioural study of gelada in the Ethiopian highlands (Dunbar, 1988) evaluated the potential effects of climate change on the species. According to the study, the gelada's ecology is unusually sensitive to ambient temperature due to its effect on the nutrient content of the grasses on which the gelada depend: these grasses only reach high nutritional values at specific temperatures.

Gelada behaviour is also susceptible to changes in climate. For the gelada to survive in suitable habitats, its activities must include social behaviour patterns that allow it to create bonds with groups of conspecifics, to feed and rest. Resting includes time needed for thermoregulation when temperatures are high, in order to avoid heat overload. In primates, there is a relationship between group size and the time needed for social bonding, which limits group size. As an increase in ambient temperature requires more time spent on thermoregulating resting, the time available for socialization will be significantly reduced, leading to weaker bonds in the group. (Dunbar, 1998).

DAVE WATTS

Climate change may affect social bonding of gelada baboons (Theropithecus gelada).

BOX 5

Mountain gorillas in the Virunga mountains face new threats as their habitat changes

The Virunga Volcanoes Conservation Area of Central Africa contains the habitat for the largest population of mountain gorillas (*Gorilla beringei beringei*) as well as many other endemic species of animals and plants. Made famous by the work of the late Dr Dian Fossey, these "gorillas in the mist" of the Democratic Republic of the Congo, Rwanda and Uganda have benefited from an exemplary conservation effort involving governments, NGOs, local communities and the private sector. The long-standing threats of poaching and habitat degradation have mostly been contained, despite being exacerbated by decades of civil war, genocide and refugee crises in the region. Thanks to an extraordinary cross-sectoral and transboundary collaboration, the 2010 Virunga gorilla census shows a steady if fragile recovery. From a low of 242 in 1981 (Harcourt *et al.*, 1983), the population of mountain gorillas has now doubled to 480 and, for the past seven years, has been rising at 3.7 percent per annum (International Gorilla Conservation Programme, 2010).

This is good news for the thousands of people employed in gorilla tourism. The survival of gorilla habitat is also good news for the millions of subsistence farmers in the region, whose crops are watered by the rainfall coming off the mountains. Rwanda's Volcanoes National Park, for example, occupies only 0.5 percent of the country's area but receives about 10 percent of the rainfall (Weber, 1979), which supports some of the most productive and densely populated agricultural land in Africa. The forest also acts as a carbon sink, both above ground in the *Hagenia-Hypericum* woodland and below ground in soils and the extensive peat bogs in the saddles between volcanoes and above the tree line. This could result in carbon finance adding to the economics of conserving this World Heritage Site while enabling its surrounding communities to develop and prosper.

All this is threatened by climate change. If the predicted changes in temperature and precipitation occur in Central Africa, the Virunga endemics will face new threats. An increase in average temperatures would cause the vegetation zones to move upwards, reducing their extent and changing the distribution of many species. But the Afro-Alpine endemics on the summits would literally have nowhere to go. The volcanoes form an archipelago of ecological islands and are just as vulnerable to climate change as species on oceanic islands that are facing rising sea levels. If they are unable to adapt to warmer conditions, they will become extinct unless translocated by human intervention.

Paradoxically, the upward movement of vegetation zones could benefit mountain gorillas by slightly increasing the distribution of their major food plants. The bitterly cold weather at high altitudes limits the time that gorillas spend there. Unfortunately, any gains from a temperature increase are likely to be countered by the likely decrease in precipitation and in the extent of relevant vegetation zones. If the montane forest dries out, it remains to be seen whether sufficient food plants can survive, and whether the gorillas will be able to adapt. The drier forest will be more susceptible to fire, which, along with the risk of the peat bogs drying out, would make the Virunga Volcanoes a significant carbon source rather than a sink. Agricultural productivity would decline with less rain and this would likely increase pressure on resources in the Virunga conservation area.

IAN REDMOND

Climate change poses an additional threat to mountain gorillas and the thriving ecotourism dependent on them.

BOX 6

Ecosystems changing on the Himalayan plateau

The Greater Himalayan region is known as the "water tower of Asia", as it is the source of ten of the largest Asian rivers (including the Yellow River, Irrawaddy, Ganges, Mekong and Brahmaputra). These basins provide water for about 1.3 billion people, who use it for agricultural and industrial purposes. The rivers are fed by melting glaciers, ice and snow, which cover 17 percent of the Greater Himalayan region. Many of these glaciers are now receding more rapidly than the world average and the rate of retreat has increased in recent years. If current warming continues, glaciers located on the Tibetan Plateau are likely to shrink from 500 000 km^2 (the 1995 baseline) to 100 000 km^2 or less by the year 2035. This melting will increase water runoff in rivers with subsequent flooding events. (Cruz *et al*., 2007; Kulkarni *et al*., 2007; Ye *et al*., 2008)

As president of the Union of Asian Alpine Associations, Ang Tsering Sherpa, observed in the regional climate change conference, Kathmandu to Copenhagen, in 1960 Nepal had more than 3 000 glaciers and no high-altitude lakes. Today, he contrasts, "almost every glacier is melting, and we have between 2 000 and 3 000 lakes. As the water from melting glaciers builds up, these lakes can burst from their rock or ice barriers and cause

Continues

Box 6 continued

rapid flash floods, known as 'glacial lake outburst floods', that inundate surrounding areas with water, boulders, and sediment" (da Costa, 2009).

Temperatures in the region are increasing at a rate of 0.9 °C annually, which is considerably higher than the global average of 0.7 °C per decade. Changes in the Himalayan ecosystem due to temperature increase have already been recorded. For example, mosquito nets are now needed in Lhasa, the administrative capital of the Tibet Autonomous Region of China. Residents of the city, located 3 490 meters above sea level, have reported seeing mosquitoes for the first time ever. There are similar reports of flies at Mount Everest base camp in Nepal. The presence of these insects suggests the possible spread of vector-borne diseases, such as malaria and dengue fever, to areas where cooler temperatures previously protected people from these threats. Climate change has also been implicated in the emergence of new plant diseases and pests, such as a rice blast fungus (*Magnaporthe grisea*; Thinlay *et al.*, 2000). In the Mandakini Valley of northern India, scientists report that the oak forests have been invaded by pine trees (between 1 000 and 1 600 m), particularly on south-facing slopes. This phenomenon can also be observed in many other valleys of the region. Many sources of water, such as springs, have dried up because of the disappearing oak trees and invading pines.

3.2.3 Forests

The impact of climate change on forests will vary from region to region according to the extent of change in local conditions. Among the effects already being reported, increased atmospheric carbon dioxide (CO_2) levels are thought to be stimulating growth and increasing the sequestration rate of forest carbon in areas with sufficient rainfall (DeLucia *et al.*, 1999). However, any potential growth increases are being countered by the negative effects of rising temperatures, higher evaporation rates and lower rainfall, with longer and more frequent droughts. This is leading to higher tree mortality, greater risk of forest fires, increases in insect attacks and a change in species composition (Eliasch, 2008). Unfortunately, these negative impacts on forests are likely to outweigh any positive effects and will create a negative feedback loop where burning or decaying vegetation make forests a source of CO_2 rather than a sink, thereby increasing greenhouse gas levels and exacerbating climate change and its effects (e.g. Phillips *et al.*, 2009). Initially, this will be most apparent in drier forests. Tropical moist forests consist predominantly of evergreen trees and form under conditions of constant high temperature (a yearly average of 18 °C or higher) and high rainfall (more than 2 m per year; Peel, Finlayson and McMahon, 2007; WWF, 2011) where there are no prolonged dry spells (Whitmore, 1990). Tropical dry forests receive less rainfall and shelter a very different suite of species, including many deciduous species that can shed leaves during dry periods. The two forest types have very different distributions. Thus a reduction in rainfall will not simply turn a tropical moist forest into a tropical dry forest.

Drastic changes in forest ecosystem structure and functioning will likewise have major impacts on associated wildlife, with specialized species likely to become extinct as the conditions for particular ecosystems disappear or shift to geographically distant places. The predicted effects of climate change on primates, for example, are highly negative. This is in addition to other anthropogenic threats that have put 48 percent of primate taxa on the International Union for Conservation of Nature and Natural Resources (IUCN)'s Red List of Threatened Species (IUCN/SSC Primate Specialist Group, 2008). Endemic species with strict ecological constraints are likely to be most affected.

Lehmann, Korstjens and Dunbar's (2010) study of the potential impacts of climate change on African apes reached conclusions consistent with those drawn for the gelada baboon (see Box 4). Gorillas (*Gorilla* spp.) and chimpanzees (*Pan* spp.) have temporal activity patterns that include time needed for maintaining social cohesion within groups of a given size. They also require resting time for thermoregulation to avoid heat overload or hyperthermia and/or to allow digestive processing.

Under the effects of a warming climate, suitable forest habitat for apes will further decrease, become more fragmented, and undergo changes in species composition. As a consequence, the apes' diet is expected to shift towards a higher percentage of foliage-based food, which requires longer resting time for processing. This might restrict the time available for social bonding, increasing the vulnerability of these species. The predicted effects of rising temperatures are a decrease in the community size of chimpanzees of up to 30 percent. Chimpanzees usually live in large fission-fusion communities and will likely be able to adjust to smaller group sizes. On the other hand, gorillas should be able to shift to a more frugivorous diet, but, given that they already live in smaller groups, they may be more vulnerable to local extinction given the inability to create effective social bonds and limited availability of suitable habitat. Ultimately, this will decrease the survival of individual animals and endangers the future for the species as a whole. (Dunbar, 1998; Lehmann, Korstjens and Dunbar, 2010)

Herbivores and frugivores already suffering from water shortage will face declines in the availability of food plants. Carnivores and scavengers may benefit from a short-term bonanza of weakened and dead prey animals, but, in the longer term, they will face a decline in prey populations. In montane cloud forests, one of the forest ecosystems most susceptible to even minor changes in climate, biodiversity losses are already associated with climate change (e.g. Pounds, 1997).

The impacts of climate change will add to other anthropogenic pressures on tropical forests and often exacerbate them, but the extent to which this occurs will vary from region to region. Analysing new deforestation data and climate change projections, Asner, Loarie and Heyder (2010) concluded, "In the Amazon, a combination of climate change and land use renders up to 81 percent of the region susceptible to rapid vegetation change. In the Congo, logging and climate change could negatively affect the biodiversity in 35–74 percent of the basin. Climate-driven changes may play a smaller role in Asia–Oceania compared to that of Latin America or Africa, but land use renders 60–77 percent of Asia–Oceania susceptible to major biodiversity changes. By 2100, only 18–45 percent of the biome will remain intact."

It is not just in the tropics that forests face dramatic changes. If current climate projections hold true, the forests of the western United States of America, for example, face more severe – and more frequent – forest fires, higher tree deaths, more insect infestation and weaker trees (Westerling *et al.*, 2006). This will add to the negative feedback, as burning and decomposing trees return their carbon to the atmosphere, thereby increasing the greenhouse effect of rising CO_2 levels.

BOX 7

Amazon forests' carbon cycle out of balance due to drought and higher temperatures

The Amazon rainforest is of global significance. It is the habitat of millions of species, most of them endemic and many not yet described by science. With an area equivalent to that of the United States of America, forests cover 40 percent of South America. They hold about 20 percent of the planet's freshwater and release about 20 percent of the world's oxygen. Normally this oxygen is released during photosynthesis as a result of assimilating carbon dioxide – two billion tonnes each year – and storing carbon in plant matter, especially wood. This makes the Amazon forest the largest carbon sink on earth. In 2005, a massive mortality of trees due to drought led to the release of an estimated 3 billion tonnes of greenhouse gases (Phillips *et al.*, 2009).

Clearly, Amazon forests are a key component of the global carbon cycle but they remain poorly understood. Relatively small changes in the forests' dynamics could result in macroscopic changes in the carbon cycle and the CO_2 concentration in the atmosphere. The Amazon forest is characterized by heavy rainfall, constant cloud cover and transpiration, which create intense local humidity. Degradation of the Amazon through logging and agriculture has been affecting the ecosystem for the past 50 years, though a decrease in the rate of deforestation was detected in 2010. The Global Forest Resources Assessment (FAO, 2010a) showed that tropical deforestation in the first decade of the 2000s was down 18 percent from the level of the 1990s. Nevertheless, rising temperatures and droughts pose increasing threats to the Amazon. In 2005, the Amazon suffered an unusual drought – not caused by the El Niño as is often the case for Amazonia, but by elevated tropical North Atlantic sea surface temperatures, which affected the southern two-thirds of Amazonia and especially the southwest through reduced precipitation and higher than average temperatures (Phillips *et al.*, 2010).

A long-term study that monitored forest plots across the river basin reported the effects of this unusual drought on forest growth (Phillips *et al.*, 2009). The drought affected the net biomass increase in the monitored plots. Before the 2005 drought, 76 percent of the plots gained biomass, but during the 2005 interval only 51 percent did so. Plots with more intense moisture deficits showed clear net biomass losses. Among the plots with longer and more severe water deficits than normal, the rate of

Continues

Box 7 continued

above ground woody biomass accumulation declined by 2.39 tonnes/ha/year, while in 15 plots that were not affected by drought, the biomass gain continued. Large trees suffered a greater relative increase in mortality.

The authors also recorded the type of trees most affected by biomass loss and found that fast-growing, light-wooded trees are especially vulnerable to cavitation and carbon starvation. This vulnerability has resulted in a change in tree species composition, most probably leading to significant consequences for the biodiversity of the region. Studies are ongoing to assess the impacts of the drought on key wildlife species. In the Pacaya Samiria National Reserve, Peru, for example, pink river dolphins (*Inia geoffrensis*) decreased by 47 percent and grey river dolphins (*Sotalia fluviatilis*) by 49 percent. Dr Richard Bodmer of DICE and WCS reported that "the dolphins have been forced to leave their habitats in the Samiria River and find refuge in the larger channels of the Amazon" (Earthwatch Institute, 2010). The decline in river dolphins is directly related to fish population sizes, which were severely affected by low water levels in the rivers of the Amazon.

Efforts to reduce the rate of deforestation have been successful in recent years, especially in Brazil, but the emissions from drought and resulting forest fires may create a negative feedback loop. By analysing 16 different models predicting climate change over the next century, Asner, Loarie and Heyder (2010) concluded that 37 percent of the Amazon could be affected by higher temperatures and shifts in rainfall, forcing animals and plants to adapt, move or die. If human development activities such as logging and the conversion of forest to agricultural land are factored in, the proportion of plants and animals affected could reach 81 percent.

Scientific analysis of the 2005 drought indicates that it significantly reduced net primary production (a measure of how much atmospheric carbon is removed from the atmosphere by photosynthesis), which may in turn be responsible for the exceptional rise in levels of CO_2 recorded during that year. A major study (Lewis *et al.*, 2011) predicted that the Amazon forest would not absorb its usual 1.5 billion tonnes of carbon dioxide from the atmosphere in both 2010 and 2011. Moreover, the resulting dead and dying trees would release enormous additional amounts of CO_2 into the atmosphere.

3.2.4 Savannahs, grasslands and steppes

Grasslands cover huge areas of the temperate, tropical and sub-tropical zones. Due to their high productivity, many have been converted to croplands over the centuries or used as pasture for domestic livestock. Many apparently natural grasslands have been altered more subtly through the use of fire or selective hunting. Grasslands are amongst the least protected ecosystems on the planet. They have changed so profoundly over time that in many cases scientists remain unsure about their ecological histories.

Savannahs and steppes are mainly grassland ecosystems found in semi-arid climates. They are usually transition zones between other types of ecosystems, and, if they were to receive less rain than they do currently, they would change into deserts. With increased precipitation, they would develop into tall grass prairies, shrubland or forests. Savannahs and steppes are generally rich in grazing and browsing ungulates and other fauna (small mammals, reptiles, birds and insects), and are usually controlled by fire and grazing regimes. Steppes and grasslands store most of their carbon in soils, while turnover regimes are relatively long (100–10 000 years) and therefore changes occur slowly and are of long duration (Parton *et al.*, 1995).

Savannahs, grasslands and steppes are characterized by seasonal variations of precipitation, with steppes further characterized by strong winds and temperature extremes. Steppes are usually more arid than grasslands and are dominated by short grasses. Steppe plants and ecosystems have developed effective strategies to survive under stressful conditions, such as water scarcity, very hot or cold temperatures, prolonged droughts and sporadic rainfall. They are usually resilient to extreme weather events, often creating microhabitats that are essential sources of nutrients for wildlife species (FAO, 2010b).

As global average temperatures rise, savannah, grassland and steppe habitats are predicted to shift their distribution polewards, where forest areas may be transformed into grassland- and steppe-like environments, potentially because more frequent and hotter fires may suppress tree growth (Briggs, Knapp and Brock, 2002). Elsewhere, grasslands are predicted to undergo significant scrub invasion (van Auken, 2000). An ecosystem can remain grassland rather than developing into forest or shrub, owing to peculiarities of temperature, rainfall, fire frequency and grazing pressure, although many grasslands are maintained in a treeless state through human intervention. Some of their management regimes have been in place long enough for wild species to adapt to them. Thus, in grasslands the impacts of climate change and human management are difficult to separate and their fate over the next few decades will be heavily influenced by development and agricultural pressures.

The seasonal characteristics of savannahs, grasslands and steppes regulate the occurrence of fire and the presence of herds of migrating herbivores. Fire naturally controls the production of grass in steppes and savannahs; humans often use fires as a management practice for maintaining ecosystem productivity. Rainfall is an important factor in determining the dynamics of migratory species, such as in African savannahs, where the reproduction, survival and movements of ungulates strongly respond to rainfall fluctuations (Ogutu *et al.*, 2008). Droughts thus have an important effect on herbivores in these savannahs: the species residing in the Mara-Serengeti ecosystem have declined by 58 percent in the last 20 years due to drought-related effects on vegetation (Ottichilo *et al.*, 2000) and the 2009 drought in the Amboseli ecosystem reduced the wildebeest (*Connochaetes taurinus*) and zebra (*Equus quagga*) populations by 70–95 percent (Kenya Wildlife Service *et al.*, 2010; see Box 24). The large mammals that inhabit such environments are adapted to the seasonality of the grassland resources and often undertake long-distance migrations. Most famous is the wildebeest migration in the Mara-Serengeti ecosystem. In many cases these journeys cross national boundaries, implying that conservation activities should be coordinated by international agreements like those under the United Nations Environment Programme (UNEP) Convention on Migratory Species.

Grasslands contain in excess of 10 percent of the carbon stored in the biosphere, mainly in soils (Nosberger, Blum and Fuhrer, 2000). The degradation of grasslands can result in the rapid release of this carbon, as has been measured recently in China (Xie *et al.*, 2007). Rising CO_2 levels can lead to negative feedback, further degrading grassland ecosystems and leading to even greater emissions, according to research done in the UK (Bellamy *et al.*, 2005). Temperate grasslands are considered to be the most altered terrestrial ecosystem on the planet and are recognized as highly endangered on most continents; with only 4 percent of grasslands located in protected areas, they have the least protection of any of the world's 14 biomes. The restoration of temperate grasslands is now a major conservation focus (Henwood, 2010).

The net carbon balance of many grasslands depends on their condition. Research on eight North American rangelands found that while almost any site could be either a sink or source for carbon, depending on yearly weather patterns, five of the eight native rangelands were typically sinks for atmospheric CO_2. There can be complicating factors, some of which are linked to climate change. Droughts, for example, tend to limit carbon uptake and, under such conditions, even the most productive sites can become carbon sources (Svejcar *et al.*, 2008). The main determining factors appear to be either the duration of daylight and precipitation.

ADRIANA CÁCERES CALLEJA

Increase in drought severity and frequency causes mass mortality in herbivores.

Climate change affects the productivity of vegetation and the composition of grassland species (Weddell, 1996). Droughts, in particular, cause a shift to less productive, more drought-tolerant plant species (Grime *et al.*, 2008). This change, in turn, affects the presence and behaviour of species that feed on such vegetation, often leading to population collapses within wildlife species, as recorded in Gonarezhou National Park, Zimbabwe, where 1 500 African elephants (*Loxodonta africana*) died after severe drought in 1991–1992 (Gandiwa and Zisadza, 2010). Changes recorded in grassland ecosystems include higher temperatures and less rain in summer, increased rates of evaporation, decreased soil moisture and an increase in the frequency and severity of droughts. Reduced rainfall also has an impact on fire regimes (i.e. the pattern, frequency and intensity of fires), which affect the survival of seeds in the soil, thereby regulating grass productivity (Gandiwa and Kativu, 2009). Drought also kills many tree and succulent species as well as affecting variation in the life cycles of remaining species, which leads to declines in bird populations and other wildlife that rely on such plants (Gandiwa and Zisadza, 2010). Changes in temperature and/or precipitation have already led to considerable shifts within short periods (1–2 years) in the distribution of grassland bird species; these species are expected to decline as a consequence of climate change. Changing climate will therefore accelerate the trends of already decreasing bird populations (North American Bird Conservation Initiative and US Committee, 2010).

BOX 8

Mediterranean cork oak savannah and its rich biodiversity under increasing stress

The Mediterranean region, one of the world's biodiversity hotspots, is home to cork oak savannahs. Endemic to the western Mediterranean, these savannahs range across Algeria, France, Italy, Morocco, Portugal, Spain and Tunisia. They are a good example of the development of the environmental, social and economic functions of the region's forests.

The rich biodiversity present in the cork oak savannahs includes many rare and threatened endemic faunal species. This has led to their classification under Annex I of the European Union Habitats Directive. Human management has favoured habitat heterogeneity, leading to a mosaic-like structure and high biodiversity. The open tree structure and the shrubland–grassland matrix of managed open cork oak savannahs, as occurs on the Iberian Peninsula, for example, support several species of concern to conservationists, such as the near-threatened Eurasian black vulture (*Aegypus monachus*), the vulnerable Spanish imperial eagle (*Aquila adalberti*) and the critically endangered Iberian lynx (*Lynx pardinus*) (BirdLife International 2008, 2009; von Arx and Breitenmoser-Wursten, 2008). The near-threatened Barbary deer (*Cervus elaphus barbarus*) is only found in the cork oak forests on the border between Algeria and

Continues

Box 8 continued

Tunisia (UNEP-WCMC, 2005). Mediterranean oak savannahs are also important for bird populations: acorns are an important diet for over 70 000 common cranes (*Grus grus*) overwintering in the Iberian Peninsula (Díaz *et al*., 1997) and the Maamora savannah of Morocco is home to at least 160 bird species (Thévenot, Vernon, and Bergier, 2003).

Until recently, Mediterranean forests – including cork oak woodlands – have been known for their remarkable resilience and adaptation to disturbances. Drought resistant and resilient, cork oaks, like other Mediterranean species, are adapted to a climate that can vary substantially over the course of the year (Pereira, Correia and Joffre, 2009). Climate modelling for the Mediterranean suggests that mean temperatures will rise by 2 to 4.5 °C above the current average and total precipitation may decrease by up to 10 percent in winter and by as much as 20 percent in summer (IPCC, 2007). Intensified summer drought periods and increasing average temperatures will create stressful conditions for many animal and plant species. In addition, the lack of forest management resulting from land abandonment in the north (together with the decline of the cork stoppers market) and the overexploitation of resources in the south, mainly from overgrazing, will reduce the resilience of the cork oak savannahs to natural disturbances, such as periods of intense drought. These conditions will result in the dieback of trees and an increased risk of wildfires.

4. Consequences of climate change

4.1 ALTERED ECOSYSTEMS AND LANDSCAPES

The IPCC has predicted that, as a result of changes in rainfall patterns and average global temperatures, "during the course of this century, the resilience of many ecosystems (their ability to adapt naturally) is likely to be exceeded by an unprecedented combination of change in climate and in other global change drivers (especially land use change and overexploitation), if greenhouse gas emissions and other changes continue at or above current rates. By 2100, ecosystems will be exposed to atmospheric CO_2 levels substantially higher than in the past 650 000 years, and global temperatures at least among the highest as those experienced in the past 740 000 years. This will alter the structure, reduce biodiversity and perturb functioning of most ecosystems, and compromise the services they currently provide" (Parry *et al.*, 2007).

Four broad ecological responses can be identified:

1. Major geographical changes (expansion of boreal forest onto tundra, shrubland expansion onto some grasslands, etc.).
2. Major compositional changes caused by broad climatic shifts (wet to dry forest, arid grassland to desert, changing pH levels in the sea).
3. Major changes in disturbance patterns (more fires, more droughts and more floods).
4. Species losses due to mistiming, competition from new species within an ecosystem and direct stress.

Some of the implications of these changes are discussed in the following sections. In general, the most threatened habitats and species are those without anywhere to go. These include mountaintop communities, species living in isolated habitat fragments, island species and those caught by rising sea levels without space to migrate inland.

Changes in the distribution and abundance of plant communities and habitat types have been widely observed. There is a growing body of evidence from all over the world that species and ecosystems are already changing due to climate change (Walther *et al.,* 2002). Many such changes are cyclical and so are more noticeable in temperate latitudes where the timing of the onset of seasons can be easily monitored. Changes in migration patterns have been observed in many countries (Parmesan, 2006). In the tropics, some changes are more noticeable in montane regions, where vegetation zones may be shifting upwards as temperatures rise. In Costa Rica, for example, changes in precipitation attributed to climate change have been linked, along with an epidemic fungal disease, to catastrophic declines in the populations of amphibian and anoline lizards (*Norops* species; Pounds, Fogden and Campbell, 1999).

In addition to the direct effects of changing temperature or precipitation on ecosystems, the human response to climate change is also having an impact. The intention to reduce our dependence on fossil fuels, for example, is increasing the demand for biofuels. Some fear that this will lead to competition for land used to grow food, with a corresponding risk to food security, especially of the poor (see Box 9). Crop failures due to changing weather patterns will encourage additional clearing of natural or semi-natural land to substitute. Warmer conditions are allowing cultivation on mountain slopes or at higher latitudes.

Islands are most at risk from these changes in land use whether they are surrounded by sea or by a different terrestrial habitat, with no alternative locations for species to move to. Human activities have greatly increased this risk through reduction and fragmentation of habitats to create ecological islands surrounded by human-dominated landscapes such as agriculture or intensive forest plantations. For many species and, indeed, for whole ecological communities, these human-made barriers (physical, chemical and ecological) will prevent the natural movement of individual animals in the short term and prevent the gradual shift of populations of plants and small territorial animals in the medium term.

Coastal inundation and salination is another landscape-level effect of climate change as sea levels steadily rise. Low-lying terrestrial ecosystems in the tropics will be increasingly exposed to storm surges as coral reefs decline. The deterioration of coral reefs is a result of ocean acidification and bleaching (due to dissolved CO_2 in the water) as well as rising temperatures of surface waters (Hays, Richardson and Robinson, 2005).

BOX 9

Growing biofuel demand leads to mass forest conversion

The global demand for certain crops has been boosted in recent years by government targets to replace a percentage of the fossil fuel used each year with biofuels. Globally, CO_2 levels are rising because our burning of coal, gas and oil is transferring carbon – laid down by plants millions of years ago – into the atmosphere. In theory, power stations fuelled by biomass and vehicles fuelled with bioethanol produced from corn (*Zea mays*) or sugar cane (*Saccharum* spp.) and biodiesel from palm (*Elaeis guineensis*) oil and rapeseed (*Brassica napus*) oil are considered to be less damaging to the environment because, although they, too, produce CO_2, they are made from plants that are a part of today's carbon cycle (i.e. their carbon has only recently been taken out of the atmosphere by photosynthesis). Carbon accounting must, however, include all emissions resulting from the production of biofuels – a task accomplished through the Life-Cycle Assessment. Where natural forests have been destroyed to create plantations for biofuel crops, it is estimated that the resulting emissions in the medium term are many times greater than what would arise from burning fossil fuels. The replacement time (the time taken to replace the carbon lost during plantation establishment) is

Continues

Box 9 continued

critical (UNEP, 2009a). For some ecosystems, a replacement time of 420 years has been calculated before biofuels "repay" the carbon debt incurred by establishing them (Fargione *et al.*, 2008). The displacement of food to produce biofuels can further intensify pressure on natural ecosystems and lead to food scarcity.

In the future, it seems likely that timber will become an increasingly important feedstock for biofuels. If the forests being converted to plantations are located in peat swamps, as with orang-utan habitat in parts of Indonesia, the resulting greenhouse gas emissions are even more dramatic. Not only is most of the standing carbon in the forest released, but as the peat is drained it decomposes thereby releasing thousands of years of stored carbon into the atmosphere (Page *et al.*, 2011). Emissions from these sources are largely responsible for Indonesia being the third largest emitter of greenhouse gases after the United States of America and China, despite having relatively little industry. The UNEP concluded that "the production and use of biodiesel from palm oil on deforested peatlands in the tropics…can lead to significant increases in greenhouse gas emissions – up to 2 000 percent or more when compared with fossil fuels. This is mainly as a result of carbon releases from the soils and land. However, a positive contribution to greenhouse gas emissions can arise if the palm oil or soya beans are instead grown on abandoned or degraded land" (UNEP, 2009a).

The economic pressure to increase the production of biofuels continues to lead to forest conversion. In Sarawak, Malaysia, the Government is planning to double its oil palm plantations to 2 million ha by 2020, with almost 1 million ha of tropical forest already developed (Wong, 2010). The Malaysian State Land Development Minister, Datuk Seri James Masing, states that the plantation land will come mainly from native customary rights land, which covers an estimated 1.5 million ha, but has been a point of conflict between industrial developers and traditional forest users like the Penan. According to this report, the Government has already approved more than 720 000 ha of native customary rights land for joint-venture development. But a new economic study (Wich *et al.*, 2011) concludes that the carbon value per hectare of orangutan habitat is up to three times that of oil palm plantations.

BOX 10

East African high mountains – not only losing their glacier caps

East Africa's mountains play a critical role in providing fresh, clean water, but several are now compromised by climate change.

The upper catchment area of Mount Kenya comprises the afro-alpine zone, which is protected by the Mount Kenya National Park (about 70 000 ha) and the Mount Kenya National Forest Reserve (about 200 000 ha). This vast zone is one of Kenya's five crucial sources of freshwater and is home to biodiversity of national and global importance. Six rare or threatened species of large mammals occur here: the African elephant (*Loxodontia africana*), the country's largest remaining forest population; the black rhinoceros (*Diceros bicornis*) – only a few individuals survive; the leopard (*Panthera pardus*); the giant forest hog (*Hylochoerus meinertzhageni*); the mountain bongo

Continues

Box 10 continued

(*Tragelaphus euryceros isaaci*), a critically endangered African antelope; and the black fronted duiker (*Cephalophus nigrifrons hooki*). There are many ungulates, primates, carnivores and small mammals, along with 53 out of Kenya's 67 African highland biome bird species, including the threatened and little-known Abott's Starling (*Cinnyricinclus femoralis*; Kenya Wildlife Service, 2010; Bird Life International, 2011).

The protected areas of the upper catchment are separated from the middle catchment by multiple-use "buffer" and "transition" zones along the outer perimeter of the National Reserve. The integrity of the whole ecosystem has direct benefits for the agricultural use of surrounding areas by protecting them against land degradation and erosion with their severe negative impacts: siltation, landslides and loss of soil fertility. Studies have calculated that the presence of the Mount Kenya forest (Category II, 58 800 ha and Biosphere Reserve, 71 759 ha) alone has saved Kenya's economy more than US$20 million by protecting the catchment for two of the country's main river systems, the Tana and the Ewaso Ngiro (Emerton, 2001).

Climate change now affects the water catchment area of Mount Kenya, which is witnessing the diminishment of ice caps and a reduction in rainfall. Mount Kenya glaciers have lost 92 percent of their mass in the last century and their volume and extent have shown a drastic decrease in recent years. In the recent past, melting snow contributed to the rivers and kept the catchment humid, while moderating the dry seasons. Presently, early and shortened snow-melt periods have implications for rivers and springs: dry-season flows progressively decline and the land becomes drier and less productive. The forest is affected because of more frequent fires and slower regeneration of vegetation. Local farmers report that this process is exacerbating human–wildlife conflict, due to the close proximity of human settlements to the protected areas. (UNEP, 2009b)

A lack of melt-water and degradation of the vegetation were reported to cause wildlife to migrate downstream in search of water and food, placing wildlife conflict at the top of the concerns expressed by the members of the Mount Kenya East Environmental Conservation Forest Association living in the Meru South District. (IFAD, 2009).

To respond to this situation, the International Fund for Agricultural Development Mount Kenya East Pilot Project for Natural Resource Management and an associated project financed by the Global Environment Facility (GEF) are promoting diverse mechanisms for reducing human–wildlife conflict over resources and limiting damages to agricultural crops. These measures include for the development of a long-term strategy on wildlife migration corridors, the establishment of wildlife barriers, for example using solar-powered electric fences, together with building the capacity of communities to maintain them. Measures to rehabilitate certain indigenous and plantation forest areas, accompanied by training Kenya Wildlife Service staff to address conflicts, will further help ensure the peaceful interaction between wildlife and the communities surrounding the protected area. (IFAD, 2009; Global Environment Facility, 2004; Republic of Kenya, 2002)

In the neighbouring United Republic of Tanzania, the mountain forests of Kilimanjaro are dominated by evergreen cloud forest vegetation, which through fog

Continues

Box 10 continued

interception and percolation into groundwater and/or streams plays a determining role in providing water for downhill ecosystems. Over the past 70 years, Kilimanjaro has lost more than one-third of its forest cover, mainly due to clearing in the lower parts and burning in the upper parts of the mountain and fires due to climate change led to the loss of nearly 150 km^2 of forest over the past three decades. (Hemp, 2009)

A study of vegetation changes on the slopes of Kilimanjaro over the past 30 years used the observation of fixed vegetation plots and analyses of satellite images to reveal changing fire regimes. Fire alters the species composition and structure of the forests and is affecting the Kilimanjaro ecosystem to a far greater extent than the well-known melting of glaciers. In fact, under natural conditions the forests of Kilimanjaro above 1 300 m receive nearly 1 600 million m^3 of water annually: 95 percent from rainfall and 5 percent from fog interception. As a result, about 500 million m^3 of water (31 percent) percolates into the groundwater or into streams. The changes in vegetation composition and precipitation regimes have reduced fog precipitation to close to zero. The loss of 150 km^2 of forest since 1976 to fire corresponds to an estimated loss of 20 million m^3 of fog water deposition per year. This is equivalent to the annual water demand of the 1.3 million people inhabiting the Kilimanjaro region (13,209 km^2) in 2002 (Hemp, 2009; National Bureau of Statistics, 2006).

Long-term meteorological data suggest that mean annual precipitation in the area decreased by up to 39 percent over the past 70 years and mean daily maximum temperatures increased at a rate of more than 2 °C per decade. Together with the enhanced solar radiation resulting from diminished cloud cover, these factors are responsible for intensified fire activity. (Hemp, 2009)

Fire not only transforms land cover, it also maintains the newly established land types, completely changing the composition of vegetal species and the role that they play in the ecosystem. Caused by a decline in precipitation above the major cloud zone, fire causes a natural sharp discontinuity in the composition and structure of 20–30 m tall subalpine forests at 2 800–3 000 m. Non-native species (e.g. *Erica excelsa*) become dominant, forming dense monospecific stands about 10 m in height. It is clear that this decline in precipitation has significant implications for the native wildlife, although it has not been well studied yet. Most fires occur through the carelessness of humans (e.g. honey collectors or poachers), but they would not be so devastating had the climate not become drier. (Hemp, 2009)

BOX 11

European and North American birds show similar northward shifts

In the United Kingdom of Great Britain and Northern Ireland, Thomas and Lennon (1999) compared bird distributions between 1968–1972 and 1988–1991. They discovered that southerly species had moved their ranges northwards by an average of 18.9 km over this twenty-year period (i.e. 0.945 km/year). This shift was only true for southerly species that increased in numbers: populations that decreased shifted their northern margins southwards. For northerly species, there was no systematic shift either way.

Continues

Box 11 continued

Using the same method, Brommer (2004) compared bird distributions in Finland between 1974–1979 and 1986–1989. He found that range margins of southerly birds shifted polewards about the same distance (18.8 km) as in the United Kingdom of Great Britain and Northern Ireland in about half the time (12 years, i.e. a rate of 1.567 km/year). This different shift rate may indicate that northern, high-latitude species – such as those in Finland – are more sensitive to climate changes than those in Central Europe. As with the Thomas and Lennon study, northerly species showed no significant range margin shifts.

A similar shift pattern can be seen in North America. Hitch and Leberg (2007) compared bird distributions between 1967–1971 and 1998–2002. Here again, southerly species were found to have significant northward shifts of 2.35 km/year. The bigger margin shifts in North America may be because recent warming has been greatest within continents. As with the British and Finnish studies, northerly species showed no general trends in distributional changes.

A comparative study of the distribution of bird species in New York State, the United States of America (Zuckerberg, Woods and Porter, 2009), between 1967–1971 and 1998–2002 is unique in that it is the only study that also found significant shifts in northerly species. Of the 44 northerly species in the study, 22 shifted their southern range boundaries polewards by an average of 11.4 km. These species include the pine siskin (*Carduelis pinus*), the boblink (*Dolichonyx oryzivorus*) and the Nashville warbler (*Vermivora ruficapilla*), the boundaries of which moved 57.5 km, 39.0 km, and 15.0 km, respectively.

In general, these studies document northward shifts in the distribution of southerly bird species from distinct geographical regions. The shifts seem to be a common phenomenon, regardless of habitat, migratory behaviour and feeding strategies. Given that temperature influences the timing and success of breeding, migration and species distribution, it is very likely that climate change is the driving factor behind these shifts. (Brommer, 2004; Thomas and Lennon, 1999).

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The pine siskin (Carduelis pinus) *has shifted its range northward by almost 58 km.*

4.2 CHANGES IN SPECIES DISTRIBUTION, COMPOSITION AND INTERACTIONS

Species distribution is determined by temperature, rainfall, geographical barriers and other ecological factors – such as underlying geological formations – that will be largely unaffected by climate change. Thus, where temperature and rainfall are the main limiting factors to a species' distribution, we can anticipate distribution maps to change accordingly. As each season's isotherms move north in the northern hemisphere and south in the southern hemisphere, so too will animal and plant populations as they follow their optimum conditions, assuming there is space to move to and the species is capable of doing so (see Box 11). Individuals of motile animal species may themselves migrate as their optimum ecological conditions move. Although sessile animals and plants are unable to migrate, the distribution of those with relatively short life-cycles will also advance along a front as natural selection favours those along the leading edge of changing conditions and reduces the survival rates of those living at the sub-optimal edge of their moving habitat. Clearly, protected area boundaries that have been designated with a particular species range or habitat in mind will need to be reconsidered under these circumstances (e.g. Hannah *et al.,* 2007 for habitats in Mexico and South Africa).

Tree species with very slow maturation times and a narrow optimum temperature range might be unable to survive if the speed of climate and associated ecological changes is faster than the length of their life-cycle. Seedlings at the leading edge might grow but not reach reproductive age before rising temperatures bring sub-optimal conditions to bear.

Vegetation zones around mountains are likely to move up the mountain in response to rising temperatures, assuming rainfall is not greatly affected (see Box 4, Box 5). This may lead to the extinction of endemic species that are adapted to conditions on isolated mountaintops and are unable to move.

Natural and human-made barriers to movement are likely to be problematic for many species as they try to move in response to changing conditions. Most terrestrial species on islands will be unable to move, except birds, bats and insects that can fly in search of new habitats, if these are not too distant.

The temperature increase due to climate change is responsible for the poleward and upward range expansion of several insect species and for changes in the seasonal phenology, leading to faster development and higher feeding rates. Two-thirds of 35 butterfly species assessed in Europe shifted their ranges northwards by 35–240 km (Parmesan *et al.*, 1999). In the Mediterranean region this shift has led to outbreaks of insect pests, such as the pine processionary moth (*Thaumetopoea pityocampa*; see Box 17), in previously unaffected areas (Battisti, 2008). The insects show high performance and low mortality due to the absence of their main natural enemies in their new distribution areas and the presence of many usual or potential host species. In the Atlas Mountains, large attacks by pine processionary caterpillars were observed in cedar forest stands. The case deserves special attention for the implications it may have for the management of European forests and plantations, as well as for ornamental trees.

The changing food supply of wildlife species will also change species distributions, stimulating some populations while depressing others. A decline in caribou and reindeer (*Rangifer tarandus*) in parts of the boreal region of the north is consistent with predicted climate change impacts on their food supplies (Vors and Boyce, 2009; see Box 25).

4.3 CONFLICTS AT THE HUMAN–WILDLIFE–LIVESTOCK INTERFACE

The resolution of conflicts between wildlife and humans sharing the same areas is a key issue in the management of wildlife and natural resources. Increasing human population densities and the encroachment of human settlements and activities into wildlife habitats have made conflict situations more frequent in the last few decades (FAO, 2004; Lamarque *et al.*, 2009). Local economies and land uses are traditionally the main factors that cause conflicts over the land, particularly for communities that live in rural areas and rely on subsistence economies. Where large-scale commercial plantations are developed, most species are extirpated, but human–wildlife conflict often still continues along the edge of any surviving natural habitat.

Conflicts are common in all areas where wildlife and human populations coexist and share limited resources. Climate changes affect the intensity and frequency of such conflicts indirectly, by modifying environments and their productivity, favouring some species that cause problems for humans. Together with increased human population densities, this is exacerbating existing conflict situations around the world (see Box 2, Box 3, Box 10).

Conflicts become more intense where livestock and agriculture are important to rural livelihoods. In rural communities of developing countries, competition with wild animals over natural resources is intense and the people are vulnerable to high economic losses. Severe droughts cause a decrease in natural resource productivity and are associated with a considerable increase in human–wildlife conflicts (Lamarque *et al.*, 2009). Considering current human population growth rates, climate change trends, increasing demand for resources and the growing demand for access to land, it is clear that human–wildlife conflicts will continue in the near future.

In Africa, most traditional dispersal and migration areas for wildlife are now occupied by humans as populations have increased exponentially. Under changing climatic conditions, wild animals move to these areas and human–wildlife conflict escalates. The consequence is that the animals are usually killed. Humans also invade wildlife reserves in search of natural resources – often fodder for their livestock – increasing the conflicts between wild and domestic animals.

One critical impact of these changes is the threat to connectivity between wildlife populations. For example, Nairobi National Park survives in the shadow of Kenya's capital city, with a healthy population of large mammals, but only because it is connected to other suitable habitats, such as the Kitengela Conservation Area and Athi-Kapiti plains. Now, increasing farming pressure risks isolating the site and careful negotiations are in place to ensure that wildlife corridors remain open. Such pressures are increasing all the time.

Mitigating conflicts between humans and animals requires interventions at different levels, from institutional to local and personal. Domestic animals cannot be left alone and need to be protected by fences and other efficient measures. In times of increasing pressure on limited resources, the capacity of local rural communities to coexist with wildlife can decrease substantially (Dickman, 2008). Losses from attacks by carnivores are usually lower than losses caused by other factors, including the natural mortality of domestic animals. Nevertheless, the perception of damage is usually greater than the loss itself – particularly when people are under stress from other factors as their environments change (Dickman, 2008).

Warmer temperatures reduce plant and vegetation productivity in semi-arid environments, and wildlife in those areas usually enter into competition with domestic livestock for both food and water. In northern Kenya, longer and more frequent droughts have ravaged pastoralist populations in recent decades, increasing the pressure on the limited resources available, which have to be shared with wildlife (Conservation Development Centre, International Institute for Sustainable Development and Safeworld, 2009). This situation has led to lower tolerance for damages caused by wildlife and higher rates of retaliation towards predators.

BOX 12

Flooding aggravates conflict between farmers and crocodiles

The southern regions of Malawi have been increasingly affected by floods that have washed away rural settlements and crops. In January and February 2010, the Department of Disaster Management Affairs reported that as many as 14 districts in the country were affected by heavy rains and storms at the beginning of the year (SADC and FEWSNET, 2006).

The Shire River, Lake Malawi's only outlet, is the most convenient water source for people living on its banks, but it is also home to a conspicuous population of Nile crocodiles (*Crocodylus niloticus*). Heavy rains enabled crocodiles to move into flooded areas, close to inhabited villages. Floods from the Shire River inundated small villages, turning them into swamps that became homes for crocodiles, making it impossible for local people to go back and recover what was left in their flooded homes. (Kalowekamo, 2000)

The crocodile presence in southern Malawi has long been a threat to humans. In the past, Malawi authorities permitted culling about 800 crocodiles per year. After becoming a signatory to the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES), the culls have been restricted to 200 per year. As a consequence, locals consider that the Government authorities are not taking sufficient action to resolve this human–wildlife conflict. Now, following CITES' Resolution Conf. 11.16 on the ranching and trade in ranched specimens of species transferred to its Appendix II and the successful experience of crocodile farms in the northern part of the country, Government authorities have encouraged the

Continues

Box 12 continued

establishment of new crocodile farms in southern Malawi. This could turn the threat of crocodiles into an opportunity for local entrepreneurs. Two of four established crocodile farms in Malawi – one in the Thyolo district, the other in the Chikwawa district – expect to start exports in 2011. (CITES 2000; CITES, 2010; Semu-Banda, 2007; Tenthani, 2001)

4.4 WILDLAND FIRES

Climate change will also be responsible for the increased frequency and severity of wildfires. Temperature, in particular, as well as atmospheric moisture, wind, drought and lightning, all have a strong influence on the occurrence of wildfires (BC Ministry of Forests and Range Wildfire Management Branch, 2009; Williamson, *et al.*, 2009). These will occur especially in areas where they are already a major threat: southern Africa, the Americas, Australia and parts of Europe (France, Italy, Portugal and Spain) (Bosomworth and Handmer, 2007; Miller, 2007). Specifically, climate change will increase wildfire seasons, the number and severity of fires and the amount of area burned (BC Ministry of Forests and Range Wildfire Management Branch, 2009; Williamson *et al.*, 2009; Wotton and Stocks, 2006). It has been estimated, for example, that the burned area in Canada will increase by 74–118 percent (Williamson *et al.*, 2009) per year and the fire season by about 30 days (Wotton and Stocks, 2006).

Not only are fires becoming more intensive and more frequent, they are also likely to spread into ecosystems that have not traditionally caught fire. Not being

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A mule deer (Odocoileus hermionus) *trying to escape a wildfire.*

adapted to fire, these ecosystems will suffer greater and longer-lasting damage. Annually, fires consume millions of hectares of the world's forests, causing the loss of biodiversity and human and animal lives (FAO, 2005a). While some forest and grassland ecosystems have evolved positively in response to frequent fires due to natural and human causes, maintaining their dynamic equilibrium and high biodiversity, others are negatively affected, resulting in the destruction of the forests or long-term site degradation (Goldhammer, 1998, 1999; FAO, 2005a; Myers, 2006).

From 1960–2000, wildfires burned an average of 380 million ha/year (range 270–570 million ha/year) globally (Schultz *et al*., 2008). This includes fires from natural ignition sources, such as lightning, and human ignition sources, including burning to clear fields for agriculture and accidentally escaped fires. Wildfires can also result in regional climate change. In tropical evergreen forests, for example, a large percentage of the canopy is often destroyed by low intensity fires (Barlow *et al.*, 2003; Cochrane and Schulze, 1999). Since water from transpiration makes up most, if not all, of the normally high humidity in these tropical forest systems (Makihara *et al.*, 2000), significant tree mortality reduces the amount of transpired water and increases the rate of drying in these forests (Holdsworth and Uhl, 1997) predisposing them to even more fires. As much as 50 percent of the rainfall in the Amazon Basin can be recycled from evapotranspired moisture (Salati and Vose, 1984). Fire-induced vegetation mortality, therefore, may make regional weather drier. Smoke-borne aerosols also interfere with normal precipitation and reduce rainfall (Ackerman *et al.*, 2000, Andreae *et al.*, 2004; Rosenfeld, 1999), exacerbating this effect.

Some climatologists believe that El Niño-Southern Oscillation (ENSO) anomalies will become more frequent as long as greenhouse gases continue to accumulate in the atmosphere (Timmermann *et al.*, 1999; Trenberth and Hoar, 1997; Hansen *et al.*, 2006). Warm ENSO events cause wet years, increasing herbaceous plant growth, which, in turn, causes large fires during dry La Niña years (Miller, 2007). These anomalies caused the 1998 drought and subsequent fires throughout Indonesia and similar large fire events in the Amazon (Alencar, Nepstad and Vera Diaz, 2006; Cochrane *et al.*, 1999; Cochrane and Laurance, 2002). Forest understory fires are likely to play an even more important role in the future in fire-sensitive ecosystems, as more degraded forests interact with more extreme climate events (Balch *et al.*, 2008). These fires will also affect the hydrologic cycle, the pollutant load in the atmosphere and the dynamics of atmospheric circulation (FAO, 2005a). Little is known about the vulnerability of tropical and sub-tropical ecosystems to anthropogenic changes in the climate and the atmospheres. A future with more intensive and frequent severe droughts can create conditions for fire spread and shorten the return interval of fire in these ecosystems, possibly leading to even greater regional forest degradation.

The effects of wildfires on local wildlife can be severe. Slow-moving animals are at the highest risk of mortality from flames and smoke. Escaping the fires is only the first step to survival. If habitat changes mean that displaced animals can no longer find food, compete for territory or access shelter, they will die of starvation or predation (Cochrane, 2002). For example, in savannah fires, ants suffer little direct impact from the fires due to their colonial structure and subterranean nests, but they are highly sensitive to post-fire changes in habitat and microclimate (Anderson *et al.*, 2003). However, these fires and other disturbances act as selective forces at the level of the individual organism, either directly, by affecting its ability to continue vital life cycle processes, or indirectly, by altering its habitat conditions (Gill, 1975, 1981; Noble and Slatyer 1980, 1981; Rowe, 1983; Ryan 2002). Wildfire can be beneficial, detrimental or neutral to the individual. At the community level, wildfire effects may be uniform in some ecosystem types or over small regions. In many cases, however, the patchiness of fuels will create heterogeneity in fire behaviour. This patchiness, in turn, results in spatially variable fire survival, yielding heterogeneous post-fire recruitment, reinforcing the original patterns of fuel patchiness (Bond and van Wilgen, 1996).

As a result, wildfire is one of several key drivers of ecosystems. If we are to truly understand climate change, wildlife management, biodiversity conservation and human health and safety, we need to improve and integrate our knowledge of fire regimes, herbivory, climate and land use/resource economics. Gaining such understanding for different ecosystems and geographical regions remains a challenge. Failure to confront the wildfire–climate change adaptation challenge in the near term may simply increase the threat to society and nature in years to come.

BOX 13

Disastrous fires in 2009 fuelled by climate change

In February 2009, following an unprecedented drought, Australia experienced the most disastrous wildfire in the nation's recorded history. The deadly combination of scorching temperatures and dry northwesterly winds from central Australia's desert regions resulted in fires that spread over 400 000 ha. More than 2 000 homes were destroyed and 173 people were killed in the conflagration. Up to a million wild animals are thought to have perished as a result of the fires, along with an estimated 13 000 commercial farm animals, including sheep, beef and dairy cattle, goats, poultry and pigs. Many companion animals also lost their lives. While the full extent of the impacts of bushfires on animals is not known, it is clear that these large, intense fires have probably devastated the populations of some of Victoria's most endangered animals and plants, raising major concerns for their future survival. In addition to conservation concerns, the fires raise serious welfare issues because countless animals were severely injured. Many animals were burned, mostly on the front and back feet but large numbers had more extensive burns. These animals were generally euthanized unless the burns were minor and the animal could be rehabilitated quickly and released. There were also thousands of starving wild animals and orphaned young. Other injuries included smoke inhalation, broken bones, eye damage, shock and dehydration. (Kameniev, 2010; Voxy News Engine, 2009)

Continues

Box 13 continued

Wildfires are common in Australia and are a factor that regulates the natural ecosystems. The International Plant Protection Convention pointed out in 2007 that fires in Australia were "virtually certain to increase in intensity and frequency" because of steadily warming temperatures over the next several decades. The Australian Government published a study indicating that an increase of up to 65 percent more "extreme" fire-danger days would be likely by 2020, as compared to 1990. Reduced rainfall in southeastern, southwestern and central Australia, changes in wind speeds, continued warming and decreased humidity are conditions that are very likely to be recorded in the near future. These conditions will probably increase the fire danger indices and shorten the intervals between fires – especially in southern Australia. In particular, the sclerophyllous vegetation and its associated biodiversity in southeastern and southwestern Australia appear to be at higher risk than vegetation in the savannah woodlands of northern Australia. (Steffen *et al.*, 2009; Walsh, 2009; The Wilderness Society Victoria, 2009)

A committee was established to investigate the causes of devastating wildfires. The resulting report highlighted the need to update Australia's national bushfire policy, including improving fire detection systems and suppression techniques as well as monitoring, early warning, prevention and preparedness (2009 Victorian Bushfires Royal Commission, 2010). With regard to wildlife in southwestern Australia, one of the report's contributors concluded, "Changes in fire regimes and lower rainfall may threaten particular species and functional types, especially non-sprouting serotinous plant species…narrow range endemics in the diverse kwongan plant communities." He added, "Synergies among threats are likely to reinforce current declines in biodiversity and lead to tipping points much sooner than hitherto realized" (Yates, 2009).

MARK PARDEW/AP

A firefighter providing water to a koala (Phascolarctos cinereus) *after disastrous wildfires in Australia.*

4.5 WILDLIFE HEALTH AND DISEASES

Emerging infectious diseases (EIDs) are defined as infections that have recently appeared in a population or have existed previously but are rapidly increasing in incidence or geographic range (Morens, Kolkers and Fauci, 2004). Since the 1940s, the occurrence of EIDs has risen significantly and more than 300 infectious human diseases have emerged (Jones *et al.,* 2008), most of which are viruses (Taylor, Latham and Woolhouse, 2001). More than 60 percent of EIDs are of zoonotic origin (Jones *et al*., 2008), and in the last decade of the twentieth century zoonotic EIDs constituted 52 percent of all EID events (Taylor, Latham and Woolhouse, 2001). Among the zoonotic EIDs to emerge since the 1940s, the majority of EID events have originated in wildlife (71.8 percent) and their incidence has continued to increase (Jones *et al*., 2008). West Nile virus, SARS, and highly pathogenic avian influenza are noteworthy diseases originating from wildlife and recently attracting media attention due to their transboundary nature and the risks they pose to public health. It is predicted that climate change will result in the even more rapid evolution of diseases among both humans and other animal and plant species.

Disease plays a vital role in ecological communities, serving as a valuable population regulator in many ecosystems. In return, pathogen biodiversity in a wildlife community acts to buffer the potential impacts of a single pathogen on a given species in that community. Pathogens and animals have co-evolved over centuries and diseases are often cyclical with increasing host population size, the outcome being a finely tuned equilibrium between host and pathogen. The optimal strategy for an infectious organism is not to kill its host, but to survive by using a host to replicate and spread its progeny. When this equilibrium is disturbed by changes in an ecological system, pathogens can negatively impact their hosts or move into new non-typical species and environments.

The concept of ecological health is often restricted to vegetation health, for example in the establishment of criteria and indicators for forest management. However, the concept should comprise the health of the entire ecosystem, and, in addition, cover that of the wildlife and people that depend on the natural resources. This approach is consistent, for instance, with the rapidly increasing evidence for the close connections between human health and forests (e.g. Colfer 2008; Colfer, Sheil and Kishi, 2006) and the recognition that these connections could be affected by climate change (Menne, Kunzli and Bertollini, 2002). There is considerable evidence, for example, that bat-borne viral zoonoses may be affected by climate change, and it has been hypothesized that the SARS coronavirus, Ebola fever and Nipah encephalitis are all in some way related to direct or indirect changes in the relationships between people and forest-dwelling bats (Gonzalez *et al.*, 2008; Leroy *et al*., 2009).

Multiple factors contribute to increased pathogen emergence, including rapid population growth of both people and livestock, the intensification of agriculture, encroachment into wildlife areas, increased exploitation of wildlife and natural resources, modification of landscapes and ecosystems and globalization. These factors undoubtedly contribute to pathogens increasing in virulence, jumping to new species or spreading to new environmental niches. Climate change can also play a more or less direct role in the changing dynamics and ecology of diseases in natural systems.

Both pathogens and their vectors depend on climatic factors, including temperature and humidity, for reproduction and survival. Most pathogenic organisms and ectothermic vectors, such as insects, do not develop or survive in extreme temperature and have limited temperature and humidity ranges for optimal reproduction. There is a wide variety of temperature tolerance for pathogenic organisms; some, like influenzas, "prefer" cold and wet seasons and others warm tropical environments. Changes in temperatures, seasonality and precipitation patterns may have a significant impact, especially on vector-borne diseases at the pathogen and vector levels: abiotic parameters regulate insect bionomic, lifecycles and home ranges (Harvell *et al*., 2002). Warmer temperatures could increase the incidence of disease both by increasing the vector population size and distribution and by increasing the duration of the season in which infectious vector species are present in the environment.

Temperate and higher altitude zones often have cold winters, preventing the survival of many pathogens and insect species throughout the year (Reiter, 2001). Many newly emerging infectious diseases arise from tropical regions where temperatures are warm and more suitable to the lifecycle of both pathogen and vector. If global temperatures and/or rains or humidity rise, as is predicted by climate change models, pathogens and vectors that are normally restricted to warmer and lower altitude zones will be able to expand their range to previously inhospitable latitudes and altitudes leading to the exposure of naive host populations.

Climate-driven change of ecotypes and the alteration of climate-dependent resources, such as vegetation cover, may also force animals to adjust their movements or migration patterns into new ecosystems where they may encounter or introduce novel pathogens (Altizer, Bartel and Han, 2011).

Climate change will increase the frequency of extreme climatic events that impact disease cycles and this could emerge as more important than the changes in average climatic conditions (de La Rocque, Rioux and Slingenbergh, 2008). As recently as 2010, in Africa, outbreaks of Rift Valley fever, a mosquito-borne disease, have correlated with higher than average seasonal rainfall and have even occurred with shorter heavy rainfall. Many insect vectors have population booms associated with large amounts of rain, particularly after long periods of drought. The flooding that accompanies heavy rainfall can increase the spread of waterborne pathogens, exposing more animals to potential infections. Conversely, decreased rainfall and drought can result in animals congregating around limited food and water resources, thus increasing population densities and often resulting in increased transmission of pathogens and parasites.

Climate change may also impact the immune status of host animals due to heat or nutritional stress (Kelly, 1980). If increased temperatures or extreme weather events limit the availability or abundance of food (e.g. a drought that reduces the amount of grass available to grazers), animals may become more susceptible to heavy parasite loads and increased exposure and susceptibility to pathogens. Heavier than normal pathogen loads or co-infections with multiple organisms can also cause a normally resistant host species to succumb to clinical disease, as observed in Serengeti lions (*Panthera leo nubica*; see Box 14).

Many wild animal species exist in isolated small pockets or in restricted ranges, where opportunistic pathogens can spread rapidly, causing large-scale losses and even the local extinction of populations. This has occurred in many regions of the world, including the amphibian extinctions from chytridiomycosis in the tropics of the Americas (Pounds *et al.*, 2006) and extinction of indigenous birds from avian malaria (*Plasmodium relictum*; see Box 15) in Hawaii, the United States of America. Diseases such as rabies and canine distemper are also thought to have played a role in the extinction of African wild dogs (*Lycaon pictus*) from the Mara-Serengeti ecosystem in East Africa (Ginsberg, Mace and Albon, 1995; IUCN/SSC Canid Specialist Group, 1997).

One recent example is the pasteurellosis outbreak of 2010 in the saiga (*Saiga tatarica*) population of Kazakhstan. Over the course of one week, nearly 12 000 saiga (mostly females and calves) died in the Ural region; this represented a loss of more than half of the local population and about 15 percent of the whole Kazakhstan population (Telegraph Media Group Limited, 2010). Mortality recurred in 2011 in the same region during the calving season, killing 441 saiga, although no diagnosis could be determined. Pasteurellosis outbreaks may also have been implicated in the saiga population declines of 1981, 1984 and 1988 (Lundervold, 2001). The bacterium *Pasteurella haemolytica* occurs naturally in healthy saigas (Lundervold, 2001) and it is not clear if unusual weather conditions such as the "extremely cold winter, followed by an unusually hot spring" of 2010–2011 (Telegraph Media Group Limited, 2010) could have played a role in this most recent mortality event. Toxicosis and environmental contaminants were also considered as possible explanations for the large-scale die-off but neither cause has been confirmed (Lillis, 2011).

By changing the conditions that affect the lifecycle, range and ecology of pathogens, vectors and host species, climate change has the potential to significantly alter the susceptibility of animal and plant populations to opportunistic infectious agents. Climate change is undoubtedly an important co-factor influencing the emergence of pathogens around the globe and it may play an even greater role if changes in temperatures, weather and ecosystems reach projected levels.

BOX 14

African lions decimated by climate-influenced pathogens

African lions (*Panthera leo*) are now legally protected throughout their range, having been subjected to uncontrolled hunting in the past. Their ecology is well studied and it is known that some populations thrive in certain protected areas of Africa. Lion numbers are, however, reported to be in decline in many areas, primarily due to the expansion of agriculture, ensuing control of problem animals, and, in some areas, poorly regulated sport hunting. Climate change brings new threats and exacerbates existing ones.

In 1994, an epidemic of canine distemper virus (CDV) decimated the lion population in the Serengeti, causing the death of one-third of the resident

Continues

Box 14 continued

population. This unusual die-off was followed by another event in 2001 in the nearby Ngorongoro Crater, the United Republic of Tanzania. A retrospective study was undertaken to understand these exceptional events, as CDV is an endemic disease in resident lion populations, but rarely causes mortality. In 1994 and 2001, analyses of blood samples of Serengeti lions detected unusually high levels of the tick-borne blood parasite *Babesia leo*. This parasite, among others, is usually detected at low levels in lion samples and ordinarily does not affect the health of the animal. The prevalence of this parasite was found to be at a very high level in prides suffering the highest mortality, while it was moderate in prides suffering no increase in mortality. This suggests that a co-infection with *Babesia* and the resulting lower immune status most likely was contributing to deaths caused by other pathogens among lion populations. (Dybas, 2009; Munson *et al.*, 2008)

Both of these CDV mortality events were linked to environmental conditions in 1994 and 2001, which were particularly dry and favoured the propagation of ticks in the Serengeti ecosystem. Tick (*Ixodida* spp.) levels on herbivores in the Serengeti were unusually high during these years, as extended droughts had weakened the animals. Lions feeding on this easily captured prey were very prone to high levels of infection by *Babesia,* due to the unusually large concentration of ticks present on the herbivores. Infection with *Babesia* triggered an immunosuppression, making lions more susceptible to the normally nonfatal CDV. Droughts and the resulting ecological conditions that led to these outbreaks are becoming more common in the Serengeti ecosystem. Munson *et al.* (2008) conclude that if extreme weather events become more frequent owing to climate change, mortality events caused by disruption of the ecological balance between hosts and pathogens are likely to become more common and to have devastating impacts on lion populations. (Dybas, 2009; Munson *et al.*, 2008)

BOX 15

Avian malaria and climate change in the Hawaiian Islands

Avian malaria (*Plasmodium relictum*) arrived in what is now Hawaii, the United States of America, in the early 1900s with the introduction of non-resident game and exotic birds. This pathogen translocation was followed by a precipitous drop in native bird species populations. Endemic Hawaiian birds were immunologically naïve and, once exposed, rapidly became infected and died. In 1968, Warner noted large populations of endemic Hawaiian birds in the Hawaiian mountains above 600 m, where no mosquitoes existed, and observed only a few native Hawaiian species below this altitude. The mosquito vector for malaria, *Culex quinquefasciatus*, has a range limited to the lower altitudes on the islands since it cannot reproduce effectively at temperatures below 13 °C. Further studies have shown that the range of *Culex* can extend to higher altitudes, but mosquitoes tend to concentrate in the more hospitable lower altitudes and around water, where there are ample larval production sites. The highest levels of avian malaria infection have been reported to

Continues

Box 15 continued

occur at mid-level altitude forests (1 500 m) where the mosquito vector and the range of susceptible native bird species intersect (Atkinson and Utzurrum, 2010; van Riper *et al.*, 1986; Warner *et al*., 1986).

Following the introduction of avian malaria, many native species adapted their ranges and foraging habits, with those species in higher altitude regions having better survival rates. The species that continued to feed in lower altitude ranges adjusted their feeding behaviour to account for the mosquito vector, feeding in the morning and returning to higher altitudes in the evening when mosquitoes become active. This adaptive behaviour has saved some endemic species from complete extinction, although population sizes are still greatly reduced and limited to restricted mountain ranges (Atkinson and Utzurrum, 2010; Benning *et al.*, 2002; van Riper *et al.*, 1986; Warner *et al*., 1968).

Over the past decade, surveys have shown a dramatic increase in the prevalence of avian malaria at all elevations across Hawaii. This can be attributed, in part, to increased human activity creating more breeding grounds for larval development, but climate change also likely plays a role. It has been predicted that a 2 °C rise in temperature would cause radical losses in these protective high altitude areas for endemic bird species. With an elevation in temperatures, *Culex* mosquitoes could reproduce and survive in higher altitude regions, and, again, birds will either need to adapt their behaviour to avoid mosquitoes or they will increasingly succumb to malaria. With the combination of the removal of forest habitat for agriculture and the rise in temperature, some islands are projected to lose up to 85 percent of the avian malaria low-risk forest habitat, which will undoubtedly result in the extinction of some native bird populations, especially those with limited population sizes due to other anthropogenically derived pressures (Atkinson and Utzurrum, 2010; Benning *et al*, 2002; van Riper *et al.*, 1986; Warner *et al*., 1968).

BOX 16

Climate change affects migration routes and disease risk

Every year, billions of animals, ranging from butterflies, dragonflies and bees to bats, birds, antelope and whales migrate across the globe. Flying species can cross continents or oceans, terrestrial species cross mountains and rivers, while aquatic species can travel upstream or move almost halfway across the world underwater. The movements of migratory animals typically correspond with seasonal changes and the underlying objective of migration is usually to find abundant food and an appropriate habitat to accommodate life cycle needs, such as breeding, moulting or overwintering. (Newman, 2011)

For migratory birds, the timing of arrival in breeding territories and overwintering grounds determines reproductive success, survivorship and fitness (Arzel, Elmberg and Guillemain, 2006; Cotton, 2003; Ely *et al*., 2007; Laaksonen *et al*., 2006). Migratory species time their spring arrival at breeding grounds and the chick-rearing period to coincide with peaks in food abundance (Arzel *et al*., 2009). Changing climate patterns

Continues

Box 16 continued

can result in mistimed migrations that lower breeding success and decrease population size (Both *et al*., 2006). Global climate fluctuations have been demonstrated to affect adult survival and fecundity (Boyd and Fox 2008; Sillett, Holmes and Sherry, 2000), and there is growing evidence that the timing of avian migration is affected by climate change (Ahola *et al*., 2004; Both and te Marvelde, 2007; Macmynowski *et al*., 2007; Parmesan, 2007; Saino and Ambrosini, 2008; van Buskirk, Mulvihill and Leberman, 2009). It is still too early to say in most cases what the long-term implications of these effects will be for the survival of migratory species.

Animal migration and the risk of infectious disease

Animal		Locations and distance traveled	Major infectious diseases	Major threats to migration
	**Chinook salmon** (*Oncorhynchus tshawytscha*)	3- to 4-year-old adults migrate up to 1500 km from the Pacific Ocean upriver to freshwater spawning sites in the Pacific Northwestern U.S.	Sea lice (*Lepeophtheirus* sp.); Myxozoan (*Henneguya* sp.)	Dam construction; Human-modified water flow; Deforestation; Fish hatcheries
	**Green sea turtle** (*Chelonia mydas*)	Adults migrate over 2300 km to nesting locations in tropical to subtropical areas of the Atlantic Ocean, Gulf of Mexico, Mediterranean Sea, and the Indo-Pacific	Tumor-forming herpesvirus (fibropapillomatosis); Spirorchid cardiovascular flukes	Hunting and egg poaching; Bycatch; Nesting and foraging habitat destruction
	**Western toad** (*Anaxyrus boreas*)	Annual breeding migration up to 6 km from hibernating sites (likely underground) to breeding ponds in high-elevation habitats in the Western U.S.	Chytrid fungus (*Batrachochytrium* sp.); Parasitic trematode (*Ribeiroia* sp.); Oomycete (*Saprolegnia* sp.)	Building of roads; Loss of breeding habitat through deforestation
	**Ruddy turnstone** (*Arenaria interpres*)	Annual migration up to 27,000 km from Arctic nesting grounds to overwintering sites along the coastlines of all continents except Antarctica	Avian influenza virus; West Nile virus; Multiple endoparasitic worms	Habitat loss (due to dams, freshwater extraction); Overharvesting of food resources at stopover sites
	**Flying foxes** (*Pteropus spp.*)	Unknown maximum migratory distances for many species; can range between 50-1000 km across Southeast Asia and Australia	Paramyxoviruses such as Nipah virus and Hendra virus	Loss of feeding grounds through deforestation; Habitat loss through land conversion
	**Green darner** (*Anax junius*)	Exact distances unknown, but adults travel 700 km or more annually from southern Canada and northern U.S. to Central America	Eugregarine protozoan (*Geneiorhynchus* sp.)	Unknown; possibly destruction of freshwater breeding habitats
	**Wildebeest** (*Connochaaetes taurinus*)	In the Serengeti, animals move between wet and dry seasons across an area of 30,000 km^2	Rinderpest (*Morbillivirus* sp.); Brucellolsis (*Brucella*); Foot-and-mouth disease (*Aphtae epizooticae*)	Landcover change (reduction in tree cover); Fire frequency; Exposure to infected domestic livestock
	**Swainson's thrush** (*Catharus ustulatus*)	Migrate up to 10,000 km annually between breeding grounds in Canada/northern U.S. to overwintering sites in Central and South America	West Nile virus; Lyme disease; Blood parasites (*Haemoproteus* and *Plasmodium*)	Habitat loss on breeding and wintering grounds; Building strikes during migration
	**Gray whale** (*Eschrichtius robustus*)	Annual migrations of over 18,000 km from feeding sites in the Bering Sea to winter breeding grounds along the coast of Baja California	Whale lice (cyamid amphipods, *Cyamus* spp.); Barnacles (*Crytolepas*); Multiple endoparasitic worms	Industrial activity near calving lagoons; Oil exploration along migration routes; Vessel harassment

From Altizer, S., Bartel, R. & Han, B.A. 2011. Animal migration and infectious disease risk. *Science,* 331(6015): 296–302. Reprinted with permission from AAAS. Photographs: Chinook salmon: FISHBIO; green sea turtle: M. Zinkova; Western toad: J. Kiesecker; Ruddy turnstone: N. Bacheler; flying fox: J. Epstein; green darner: E. Zelenko; wildebeest: J. Rushmoore; Swainson's thrush: D. Margeson; gray whale: SeaWorld San Diego.

Continues

Box 16 continued

More precise characteristics of migration, such as connectivity among subpopulations, will influence the ability of migratory species to adapt to changing environmental conditions due to climate change (Webster *et al*., 2002). If, for example, connectivity among the bar-headed goose (*Anser indicus*) subpopulations is strong, then individuals within each subpopulation have been subjected to similar selective pressures in both wintering and breeding locations. This selective pressure may have resulted in local adaptation that could limit the impact of large-scale climate change (Takekawa *et al.*, 2009; Webster *et al*., 2002). Studies conducted by FAO, United States of America Geological Survey and other partners demonstrate that the alteration of habitats in China, including the warming effects of climate change on glaciers increasing runoff to Qinghai-Tibetan Plateau wetlands, may be changing goose migration patterns and timing. With the exception of one individual, all geese from Qinghai Lake, China, wintered in the southern Qinghai-Tibetan Plateau near Lhasa, and their increasing numbers in that region may be related to the effects of climate change and agricultural development (Takekawa *et al*., 2009). From a disease risk transmission perspective, if geese are not making full-distance flights to capitalize on broader expanses of overwintering wetlands habitat in India at places such as Keoladeo and Chitwan National Parks, the increased concentration of wild birds on the northern side of the Himalaya will lend itself to higher transmission rates of avian viruses such as the highly pathogenic H5N1.

While migration ensures species survival, it must be recognized that when animals move across large spatial expanses, they carry commensal organisms (bacteria, viruses, fungi or prions), which do not cause illness in their hosts, but have the potential to be introduced into naïve hosts or other species. Changes in habitat use and migration patterns associated with climate change, land use development or the expansion of farming systems can lead to translocated pathogens (and vectors) contacting new potential hosts (including humans), where the implications can be significant (Newman, 2011).

In the Arctic, where scientists believe that climate change is causing temperatures to rise faster than in any other place on earth, there has been an invasion of southern species, such as the grizzly bear (*Ursus arctos horribilis*), red fox (*Vulpes vulpes*), white-tailed deer (*Odocoileus virginianus*), Pacific salmon (*Oncorhynchus* spp.) and killer whale (*Orcinus orca*). These new arrivals are all showing up in areas traditionally occupied by the polar bear (*Ursus maritimus*), Arctic fox (*Vulpes lagopus*), caribou and reindeer (*Rangifer tarandus*), Arctic char (*Salvelinus alpines*) and beluga whale (*Delphinapterus leucas*). In addition to causing Arctic species hybridization as a result of mating between related northern and southern species, and the associated losses of genetic diversity, invasive species from the south bring diseases for which Arctic mammals have no immunity. Pathogens such as the parasitic roundworm trichinella (*Trichinella* spp.), have invaded polar bears, Arctic fox and people. Brucellosis, a bacterial disease sometimes found in cattle, dogs, wild animals and humans, has attacked baleen whales (*Mysticeti* spp.). The threat that phocine distemper virus could be introduced into immunologically naive narwhal (*Monodon monoceros*) and beluga whales looms large: the migration of a single pilot whale (*Globicephala* spp.), harbour seal (*Phoca vitulina*) or dolphin (*Delphinus* spp.) could serve as the source of virus introduction. (Struzik, 2011)

Note: After a worldwide campaign to obliterate the disease and with the last confirmed case diagnosed in 2001, the United Nations declared rinderpest eradicated on 8 August 2011 (FAO, 2011a).

4.6 INVASIVE SPECIES AND PESTS

Global warming and biological invasions are two major agents of the global changes affecting our planet; these human-induced phenomena often work in synergy to contribute to the ongoing decline of biological diversity (see Box 26).

Invasive alien species affect many native species and habitats through predation, competition or foraging. The magnitude of these impacts is apparent when one considers that, over recent centuries, biological invasions have been the primary cause of species extinction; invasive species have been identified as a key factor in 54 percent of all known extinctions and the sole factor in 20 percent of the cases (Clavero and García-Berthou, 2005). Overall, the human-mediated movement of species outside their natural range has been shown to result in a deep impoverishment of species diversity, thus altering the functionality of ecosystems and habitats.

Due to their effects on ecosystems, invasions not only threaten biological diversity, but also affect human livelihoods in many ways. They can disrupt ecosystems, damaging the services they provide to humans, limiting access to food and water for local communities (Vilà *et al.*, 2010). Many of the most harmful agricultural pests are of alien origin, as well as many of the parasites and pathogens that affect forestry and fisheries and cause huge social impacts. The Great Famine that affected Ireland at the end of the 19th century was due to the introduced late blight oomycete (*Phytophthora infestans*), which caused an 80 percent loss in potato crops.

As a consequence, biological invasions cause huge economic losses, not only due to their direct impact on the production of goods, but also because of the resources required to manage the most invasive species. In Europe alone, these costs have recently been estimated to be more than €12 billion per year. On a global scale, the estimated damage from species invasions exceeds US$1.4 trillion per year (Kettunen *et al.*, 2009; Pimentel, 2002).

Not only is the magnitude of the current impacts of invasive species causing great alarm to the global community, biological invasions are constantly on the increase due to globalization and the growth in tourism, trade and transport. The number of alien species in Europe, for example, has increased by 76 percent over the period 1970–2007, with no sign of any saturation effect. Similar trends have been found in all regions of the world and in all environments, from marine, to terrestrial to freshwater ecosystems (Butchart *et al.*, 2010). Cultural preferences and affluence leading to the trade (both legal and illegal) of wild animals and animal products should be considered a factor as well, since the movements of these species coincide with the translocation and spread of any pathogens they may harbour.

The potential combined effects of species invasions and climate change are a matter of great concern that will likely amplify the present impacts of these two drivers of change in terrestrial, freshwater and marine habitats. There are many links between the increase in temperature, the change in precipitation regimes, the timing and distribution of vegetation growth, the rise of sea levels, and the patterns of introduction and spread of organisms outside their natural ranges.

One example is the water hyacinth (*Eichhornia crasspies*), which has long been an invasive species in tropical areas of Africa and Asia and has now also invaded the rivers of Italy and Spain. It is expected to expand over a much larger area of Europe in the future as a consequence of the increase in temperature, which is making many new areas suitable for this tropical plant. Many alien marine organisms have entered the Mediterranean through the Suez Canal and are now expanding through the basin because of the warming of the sea water. On land, the displacement of human communities as a result of climate change is expected to cause the movement of many more people and species, exacerbating the impacts of invasions (Burgiel and Mui, 2010). For example, there are predictions that an increase in invasive species due to climate change could fuel hot, cactus-killing fires in the Sonoran Desert in the United States of America (Karl, Melillo and Peterson, 2009).

Addressing biological invasions and climate change, as well as the combined effects of these impacts, poses a great challenge to the global community.

JOHN H. GHENT / USDA FOREST SERVICE / BUGWOOOD.ORG

Climate change faciliates the spread of pine processionary moths (Thaumetopoea pityocampa) *all over the Mediterranean.*

BOX 17

The pine processionary moth conquers Europe

The pine processionary moth (*Thaumetopoea pityocampa*) is a noxious insect pest found throughout the Mediterranean Basin and southern Europe (Battisti *et al*., 2006). The late-stage larvae pose a public health concern because they release urticating hairs, which cause severe allergic skin reactions (Battisti *et al.*, 2006). The larvae feed on pine trees (*Pinus* spp.), often resulting in severe defoliation and reduced growth, making this species an economically disastrous forest pest (Stastny *et al*., 2006). Its primary host is the Austrian black pine (*Pinus nigra*), although it is increasingly found on new hosts such as the Scots pine (*P. sylvestris*) and mountain pine (*Pinus mugo*) (Stastny *et al.*, 2006). The availability of actual or potential host plants does not appear to limit the spread of this species (Battisti, 2004; Robinet *et al.*, 2007).

Over the past three decades, the pine processionary moth has substantially expanded its range both altitudinally and latitudinally, a change which is attributed to climate (Battisti *et al*., 2006). Outbreaks in southern Europe have become more frequent (Robinet *et al.*, 2007). An unprecedented altitudinal shift of 110–230 m to higher elevation pine stands in the Italian Alps during the record hot summer of 2003 constituted more than one-third of the monitored expansion over the past thirty years (Battisti *et al*., 2006).

In France, the range of the pine processionary moth has expanded upwards to the higher elevations of the Massif Central (southcentral France) and the French Alps, shifting at an average rate of 27.1 km/decade between 1997 and 2004 and accelerating to 55.6 km/decade during the last ten years. The moth has also expanded northwards to the Paris Basin (northcentral France) and an isolated colony has even been discovered in eastern Paris in 2003, confirming that it is capable of surviving far beyond its current area of colonization. Modelling suggests that, in coming decades, a large part of northwestern France could have favourable climate conditions for the expansion of the species (Robinet *et al.*, 2007).

Temperature strongly affects both the survival and dispersal of the moth. The larvae develop during winter in communal nests and can only feed if nest temperature is above 9 °C and the air temperature at night stays above 0 °C (Robinet *et al.*, 2007). Larvae will only survive the winter if the mean minimum air temperature is above –6 °C and the absolute minimum stays above –16 °C (Pimental, Calvão and Ayres, 2011). During the summer, warmer nocturnal temperatures enhance flight activity, both in terms of the number of adult moths dispersing and the actual distance they can cover (Battisti *et al.*, 2006).

With temperature such an important limiting factor in the species' population dynamics, temperature surges resulting from climate change will greatly increase moth survival and propagate the expansion of its range (Battisti *et al*., 2006). In particular, warmer winters will increase the survival rate of founder populations in expansion areas (Robinet *et al.*, 2007). If an unfavourable year kills off colonies through lethal temperatures or starvation, the population may still persist in the area

Continues

Box 17 continued

and thus successfully extend its range because pine processionary moth pupae can enter prolonged diapauses of up to 7 years (Battisti *et al*., 2006)

Most authors focus on the effects of long-term, slow climatic changes when forecasting the expansion of the range of this species. In view of the extensive and consistent expansion of the pine processionary moth up the Italian Alps in the summer of 2003, however, Battisti *et al*. (2006) argue that short-term climatic fluctuations must also be taken into account when predicting the moth's response to climate change.

BOX 18

Invasive species and human health

One effect of invasions that has so far received scarce attention is the impact they can have on human health. There are many kinds of mechanisms by which alien species can affect human health. Many arthropods, for example, bite and can transmit diseases, including West Nile fever, Lyme disease and encephalmyelopathies; over 50 percent of the 47 alien nematodes introduced into Europe are endoparasites of humans or cause zoonoses in cattle and game animals. (Vilà *et al.*, 2010)

Some alien plants can also affect human health directly. For example, the common ragweed (*Ambrosia artemisifolia*), a North American weed introduced in many areas of Europe, produces large quantities of pollen that has a high allergenic potential. The pollen induces hay fever and asthmatic reactions in an extremely high proportion of the human population: 10 percent of people are sensitive to *Ambrosia* pollen and 25 percent may develop asthmatic reactions. The effects on the health systems in areas of Europe where the ragweed has established are immense; costs in Germany alone have exceeded €30 million in recent years. (Reinhardt *et al.*, 2003; Vilà *et al.*, 2010)

The giant hogweed (*Heracleum mantegazzianum*) is another alien plant that directly affects human health. This plant, native to the Caucasus and Central Asia, has been introduced in many countries for ornamental purposes and has become established in the wild in large areas of western Europe and North America. The giant hogweed produces a phototoxic sap that causes severe phytophotodermatitis (hypersensitivity of the skin to UV radiation). Tens of thousands of people are affected every year, and, in the worst cases, the skin burning can even be fatal. (Vilà *et al.*, 2010)

The effects of alien species on human health can also be indirect. The Asian tiger mosquito (*Aedes albopictus*), introduced in many areas of the world, is a vector for at least 22 arboviruses, including the dengue virus, chikungunya virus, West Nile virus, Japanese encephalitis and the eastern equine encephalitis virus. The spread of the species in northern Italy has caused several outbreaks of chikungunya and dengue fever. The dengue haemorrhagic fever complication is "a leading cause of serious illness and death among children in some Asian countries" (World Health Organization, 2011). Sometimes the effect of invasions can be subtler, such as through the spread in East Africa of invasive shrubs, which provide shelter to the tsetse fly. (Vilà *et al.*, 2010)

Continues

Box 18 continued

Similarly, the common water hyacinth (*Eichhornia crassipes*), which has invaded many areas of Africa and Asia, is favouring the spread of schistosomiasis and malaria, because the vectors for both these diseases (snail species, such as *Biomphalaria sudanica*, and the *Anopheles* mosquito) find an optimal habitat in the rivers invaded by the plant (Vilà *et al.*, 2010).

5. Measures for adaptation to climate change

This chapter draws on the conclusions of the previous chapters, considering what might be feasible solutions. How can wildlife management and land use planning adapt to changing conditions, with an aim of achieving sustainability? Possible tools could be revised laws, regulations, policies and management plans, long-term monitoring and reporting schemes for indicator species (plants and animals), adaptive management, transboundary cooperation, the involvement of local people, the enforcement of international agreements, etc. The adoption of such tools and approaches is particularly important where severe negative implications of climate change for human well-being and livelihoods are to be expected. But they must be used within the context of a realistic strategy about what can be achieved and when.

Prevention is, of course, better than cure in the case of climate change; urgent steps to reduce climate change are generally recognized as essential but continue to prove difficult to achieve. Climate change is already occurring, and as global average temperatures continue to rise, it will be important to develop strategies to conserve the species and habitats that are unable to adapt to change.

The response to wildlife challenges due to climate change fall into four main categories:

1. Maintaining current ecosystems wherever possible.
2. Adapting management to address climate change.
3. Restoring damaged or changing ecosystems.
4. Adopting landscape/seascape approaches.

5.1 MAINTAINING CURRENT ECOSYSTEMS

There is increasing evidence that large, healthy and intact ecosystems are best able to withstand climate change (e.g. Noss, 2001 for forests). In addition, highly diverse ecosystems are likely to be most resilient in the face of rapid environmental changes (Thompson *et al.*, 2009). It is also recognized that the ecosystems that are most likely to retain their current form are those located in so-called "climate refugia", areas that are for various meteorological, geographic, geological and historical reasons predicted to be relatively unaffected by climate change.

Maintaining current ecosystems implies strengthening, extending and in some cases refining global protected area networks to focus on maintaining large blocks of intact habitat with a particular emphasis on climate refugia. Research suggests that protected areas are effective tools for maintaining ecosystems, as compared with other approaches, and can play a critical role in safeguarding wildlife in the face of climate change. Importantly, such areas also help sequester carbon by retaining natural vegetation and provide many of the ecosystem services that human communities need to withstand a rapidly changing climate, such as mitigation of natural disasters, provision of freshwater and maintenance of soils (Dudley *et al.*, 2010).

Many authors have recommended increasing the number and size of reserves as a means of providing greater habitat diversity and a higher likelihood of species persistence in a changing climate (Lawler *et al.*, 2009; Noss, 2001). It is important to integrate climate change models with the design and location of protected areas to ensure that they will be able to safeguard species over the long term (Lawler *et al.*, 2009). More and larger reserves would facilitate other proposed adaptation strategies such as the protection of climate refugia, the increase in connectivity and the reduction of non-climatic stressors on forests. Additionally, reserves and protected areas provide many important benefits, including recreational and economic values (Stolton and Dudley, 2010). Proven forest and biodiversity protection strategies such as reserves are particularly important in ecosystems where a high sensitivity to climate change, combined with extensive land conversion, represents a particularly acute threat.

5.2 ADAPTING MANAGEMENT TO ADDRESS CLIMATE CHANGE

In many cases, interventions will be needed to maintain wildlife under rapidly changing situations. The following section outlines a number of possible management strategies for addressing climate change.

Moving protected areas: If a reserve is created to protect a certain habitat and that habitat moves in response to changing conditions, it may be necessary to extend the protected area boundaries in one direction and to de-gazette areas that no longer contain the target habitat (for example, to move a coastal protected area inshore as sea level rises or to move a mountain protected area further uphill). Communities living in the path of a moving protected area will likely resist such a move unless they are compensated and given new land (possibly in the de-gazetted area). It is recognized that the practical challenges of such a strategy are daunting in most places. Ecologists are also considering options for allowing the temporary set-aside of land areas for a period of a few years or decades to allow natural migration to more suitable habitat.

Translocation: If a geographical barrier prevents their natural movement in response to climate change, it may be necessary to relocate animals and plants. This supposes that there is a suitable area that is not already populated by similar species. Experience in translocation has not always been successful: several translocations (e.g. for biological control) have resulted in the spread of alien invasive species, and there are now stricter guidelines governing movement of species (e.g. IUCN/SSC Reintroduction Specialist Group, 1998).

Artificial feeding: In the short term, it may be necessary to provide key populations with supplementary feed and water to keep them alive until a more sustainable solution is found, for example, in the event of a drought causing a mass die-off of species with limited distribution (see Box 2). This type of intervention has has been carried out in the Al-Talila Wildlife Reserve (Al Badia Steppe, Syrian Arab Republic) for the Arabian oryx (*Oryx leucoryx*) and the Arabian sand gazelle (*Gazella subgutturosa marica*; FAO, 2005b) and for hippopotamus populations, which were saved by providing feed during droughts in both Kenya (Born Free Foundation, 2009) and Zimbabwe (Paolillo, 2011).

Habitat modification: If certain food plants that are critical for the survival of particular species are dying as a result of climate change, it may be possible to enrich the habitat by planting alternative food plants better able to thrive at higher temperatures. Droughts have also necessitated the artificial filling of key wetlands in some countries, as in the case of Keoladeo National Park in Rajasthan, India, although this can be controversial if it is seen to be taking water away from agriculture.

Habitat creation: In a worst-case scenario, for instance where rainforests are replaced by arid conditions, it may be necessary to attempt to move entire ecological communities of plant, animal and fungi species to areas that are newly watered by changing rainfall patterns. Some projections indicate that the Sahel in Africa and parts of Antarctica might experience increased rainfall and, while there will be tremendous pressure from land-hungry human migrants seeking new plots to cultivate, some areas might be designated in these regions for the re-building of ecosystems.

EDGAR KAESLIN

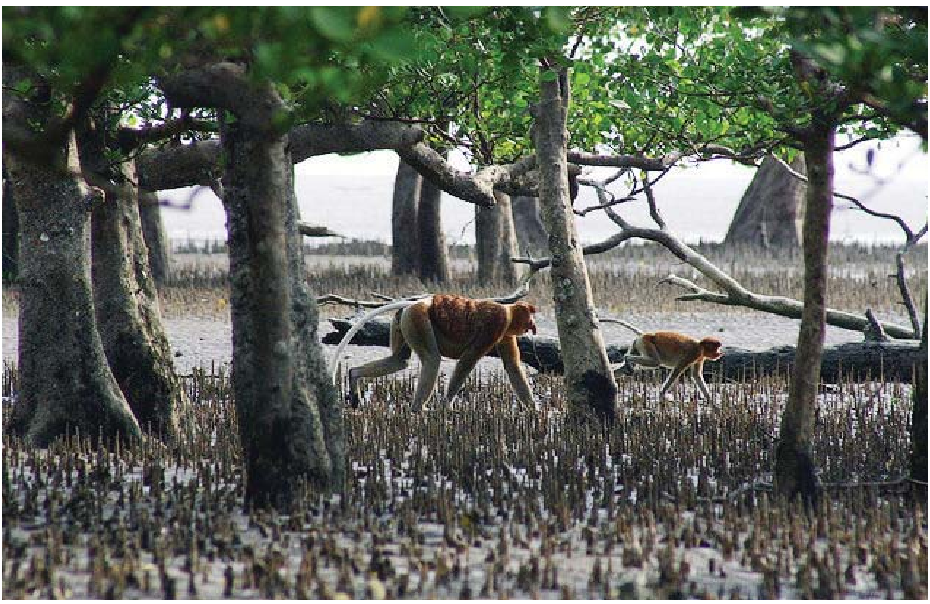
Arabian oryx (Oryx leucoryx) *being fed and watered in the Al-Talila Wildlife Reserve, the Syrian Arab Republic.*

5.3 RESTORING DAMAGED OR CHANGING ECOSYSTEMS

The wholesale movement of habitats extends considerably beyond what is usually understood as management. Similarly, in a growing number of places, ecosystem degradation has already gone so far that management responses necessarily approach full-scale restoration. The new UNEP Rapid Assessment Report *Dead Planet, Living Planet* (Nellemann and Corcoran, 2010) gives many examples of ecosystem restoration, such as the West African Mangrove Initiative and the Mekong Delta Mangrove Forest Restoration. Both of these initiatives sought to reverse the loss of mangrove forests, which protect the hinterland from extreme weather events, such as storm-surges and hurricanes. Given the key role that restoration is likely to play in wildlife management in the future, this issue is addressed in greater detail below.

5.3.1 Mangrove restoration

Swamps have a reputation for being dangerous, smelly and of little value until drained and converted to agriculture or other land uses. Concerns over biodiversity loss and fear of runaway dangerous climate change have, however, led to a reappraisal of their worth. In terms of ecosystem services, wetlands and mangroves have a huge value. They act as breeding grounds for many commercially valuable fish and shellfish and help to protect low-lying areas from storm-surges and tsunamis. Freshwater wetlands act as water-filtration systems and, in the case of peat bogs, store huge quantities of carbon that has been sequestered over millennia. In many places, improved land use planning and restoration of these important ecosystems have led to a dramatic resolution of problems associated with their destruction or degradation.



CHEM7

Endangered proboscis monkeys (Nasalis larvatus) *foraging in mangroves of coastal Borneo.*

In the 2004 tsunami in the Indian Ocean, areas with healthy mangroves were less damaged by the tsunami, but the need of timber for reconstruction meant that mangrove forests were under greater threat after the tsunami than ever before. The restoration and protection of mangroves has multiple benefits and provides ecosystem services, such as carbon sequestration, improved fish stocks, local climate regulation (cooling through transpiration, shade and wind protection), local erosion control (slope stabilization) and coastal protection (Mangroves for the Future Secretariat, 2010). Unlike some other habitat types, mangroves are also relatively easy to restore, providing short-term benefits for both local and more distant communities.

BOX 19

Mangrove restoration helps people and wildlife in Gazi Bay

The natural mangroves of Gazi Bay on the southern coast of Kenya have been exploited for many years. In the 1970s, the wood was used as industrial fuel and for building poles. Between 1991 and 1994, the area became the site of experimental reforestation activities. These included local communities, who participated in planting saplings. The local fishing community was interested in participating because the resources they relied upon were decreasing at an alarming pace and their conditions were worsening. Local goat-keepers agreed not to let their animals enter the new plantations to graze and to tie the animals up until the trees had become established. (Bosire *et al.*, 2004)

Bosire *et al.*'s 2004 study reported on the richness of species found in the reforested stands, comparing the number of crab and fish species present in the regenerated areas with those in open areas without mangroves and relatively undisturbed areas. A higher density of crabs was found in the reforested sites as compared to the natural sites, although no difference was recorded in the crab species diversity between the sites. When comparing the number of species between regenerated sites and bare areas, however, it appeared that new species of crabs had been recruited into the reforested areas, which did not occur in the bare sites.

Sediment infauna was found at highest densities in reforested sites, with new taxa found in these sites. Mangrove reforestation had led to the recovery of ecosystem functioning, in terms of habitat provisioning for the sediment infauna and crab species. Subsequently, the area was managed for tourism, with women from the local communities participating in the Mangrove Boardwalk Project. The project enables visitors to enjoy a 300 m walk through the mangrove forest and offers fishing products for sale. (Bosire *et al.*, 2004; Wahinya, 2010)

5.3.2 Inland waters restoration

Drainage, pollution, damming waterways for irrigation and hydroelectric power, straightening water channels, canalizing and the introduction of invasive fish species have all created massive changes in freshwaters throughout the world. Many of these changes have had direct impacts on wildlife; others are being


NIGEL DUDLEY

Removal of the common water hyacinth (Eichhornia crassipes)*, an Amazon native, in Keoladeo National Park, Rajasthan, India.*

questioned because of their potential impacts on humans. For example, damming natural floodplains causes greater flood impacts downstream. Pollution can cause catastrophic losses to local fishing communities.

Restoration can range from pollution control to removal of invasive species, re-establishment of traditional flow or flooding patterns and the wholesale recreation of wetland areas. While it is difficult, if not impossible, to restore a freshwater community to its exact original composition and functioning, small changes can make major differences in its ability to support wildlife.

Under conditions of climate change, some local authorities are proposing to abandon certain areas of low-lying land to seasonal flooding or tidal incursion, thus providing space for rising water, which could also have major benefits for wildlife. In addition, the restoration of natural floodplains and freshwater ecosystems can reduce flood control costs while restoring habitats for water birds and freshwater species. It can also reduce water purification costs for domestic use by serving as a natural filter (Bergkamp *et al.*, 2003).

BOX 20

Wetland restoration brings power to the people

Rwanda, with its abundant rainfall and undulating terrain, generates much of its electricity from hydroelectric power stations. Ninety percent of its electricity comes from two stations: the Ntaruka and the Mukungwa. Ntaruka is fed by water from Lake Bulera flowing into Lake Ruhondo, both of which are fed from the Rugezi wetlands. These wetlands are Rwanda’s only Ramsar Site, meaning they are listed as of international importance by the Ramsar Convention (The Convention on Wetlands of International Importance), and host what is probably the world’s largest population

Continues

Box 20 continued

of Grauer's scrub-warbler (*Bradypterus graueri*). This watershed encompasses one of the most densely populated areas in rural Africa, with more than 500 people per km^2 eking out a living off the land. (Hove, Parry and Lujara, 2011)

In 2003–2004, the country experienced a serious power shortage when reduced water levels meant that the Ntaruka power station could operate only one of its three turbines at a time. As the hydroplant's output declined, the Rwandan Government had to make up the shortfall by using generators that burned fuel imported by road from the East African coast – at a cost of up to US$65 000 per day – making Rwanda's electricity among the most expensive in the world at that time. In addition, the lowered water table also adversely affected local fishing communities, soil loss from erosion damaged farms on steep hillsides and water turbidity increased. (Hove, Parry and Lujara, 2011)

The power crisis led the Government of the Republic of Rwanda to implement the National Environmental Policy: all draining and agricultural activities in the Rugezi wetlands were banned and drainage ditches were filled in, but at the same time the subsistence farmers were helped with watershed protection training and support. This assistance included erosion-control initiatives, such as planting a belt of bamboo and grasses around the wetlands, planting trees on the surrounding hillsides and distributing fuel-efficient stoves to reduce demand for firewood and charcoal. (Hove, Parry and Lujara, 2011)

Today, the flow from Lake Bulera has been restored and the power station is operating at full capacity. The loss of biodiversity has been halted and people have benefited from the restoration of the system in many ways, such as through improved fishing in the lake, cleaner water supply, increased tourism providing job opportunities and training in other livelihoods. The World Wetland Network presented Rwanda with a Green Globe Award for the restoration of the Rugezi-Bulera-Ruhondo wetland system in 2010 (Kagire, 2010), in recognition of the importance of the ecosystem as a corridor for migratory birds and vast improvements of the wetland ecosystem following the removal of the drainage channels.

Although these successful measures were not triggered directly by climate change, they will make the country more resilient to changes in temperature and precipitation, and serve as a model for the benefits of land use planning (Hove, Parry and Lujara, 2011).

BOX 21

Restoring wetland connectivity in Somerset

The county of Somerset in southwest England, the United Kingdom of Great Britain and Northern Ireland, contains extensive low-lying areas that are naturally flooded every winter. Somerset literally means "summer settlement" because in prehistoric times farmers moved to higher ground with their livestock during the winter to avoid the rising water. Over the centuries, most wetlands were drained and peat cutting destroyed most heathland and fragmented other natural habitats. But in spite of these

Continues

Box 21 continued

changes, Somerset still retains a quarter of the country's coastal and floodplain grazing marsh, over 75 000 hectares, much of which is important bird habitat. (ADAS, 1995)

A number of natural habitats have been included in a series of state- and NGO-protected areas and further safeguarded through conservation controls on 25 Sites of Special Scientific Interest (a legal designation) and through the European Union's Environmentally Sensitive Area designation. Peatlands previously harvested for fuel have been bought by government or NGOs and restored by digging a series of interconnected lakes and encouraging native vegetation. As a result, populations of wading birds and raptors are increasing and the once-threatened European otter (*Lutra lutra*) has returned. Conservation is linking remaining native habitats through restoration and bringing back natural flooding patterns, which also connect sites on a temporary basis, allowing the dispersal of aquatic creatures. (English Nature, 1997; Dudley and Rao, 2008)

These efforts are being given further impetus by the likely impacts of climate change. In the next few decades, the frequency and scale of flood events are likely to increase and rising sea levels will only accelerate this process (Heathwaite, 1993). National and local governments recognize that it will be too costly to protect the whole county and are aiming instead to focus on centres of population, allowing seasonal flooding to return to some low-lying and marginal farmlands. Changes over the next century could bring back habitat types that have been declining or absent for thousands of years. A combination of pragmatic attempts to address likely climate change with focused restoration could create habitat links throughout the county, and, because of the presence of migratory water birds, have important regional impacts as well.

BOX 22

Peatland restoration brings multiple benefits

Peat only covers 3 percent of the world's land surface, but it is the planet's largest single carbon store. It has been estimated that 550 billion tonnes of carbon are stored in peat around the world. But the breakdown of peat habitats is releasing this carbon and most predictions on runaway climate change are based on the potential for boreal peatlands to break down further, creating a vicious cycle between carbon release and climate change (Parish *et al*., 2007; Sabine *et al*., 2004). The restoration of peat has therefore become an urgent priority. Such restoration actions can also have a positive impact on wildlife populations in peat areas, which over the past few decades have frequently been converted to other uses, including plantations. Conservation is likely to benefit particularly native flora and wildlife associated with wetland areas.

Projects are taking place in many countries. In Belarus, for instance, 40 000 ha of degraded peatlands have been restored to their natural state and a further 150 000 ha are awaiting restoration. Half of these areas are already located in officially protected areas so that their future should be assured; the rest will be protected once they have been restored. It is calculated that the work already completed has led to an

Continues

Box 22 continued

annual reduction of greenhouse gas emissions equivalent to 448 000 tonnes of CO_2 from peatland fires and mineralization. The rehabilitation of degraded peatlands also saves the Government some US$1.5 million annually in terms of the avoided costs of fire-fighting operations. The restoration projects are widely supported by local communities, who benefit from access to wetland hunting and fishing grounds and from collecting medicinal plants and wild berries. (Rakovich and Bambalov, in press)

5.3.3 Forest restoration

Deforestation has been a human activity for thousands of years. Estimates suggest that we have destroyed about half of the earth's forests and that, over the past century, the rate of destruction has been increasing. Recently, however, there are signs that the trend is beginning to be reversed. Forest restoration is part of this change, and projects to restore denuded hillsides have proliferated, though often on an ad hoc basis. A more systematic approach that addresses the causes of deforestation and landscape planning for future use is more likely to succeed (Hobbs and Norton, 1996). In some cases, the use of indigenous tree species results in the recreation of an ecosystem similar to one that was lost decades or even centuries before. In others, planting exotic trees for timber or wood-pulp may increase the area of land that is covered in trees, though some would question whether monoculture plantations can be called forests.

Forest restoration can be divided into three main types (Mansourian, Vallauri and Dudley, 2005), listed here in order of increasing cost:

1. *A natural process:* This occurs when existing pressures on the forests are removed, such as the abandonment of farmland in Europe, which has led to major forest re-establishment.
2. *Planned restoration:* This occurs when areas are artificially removed from pressures, such as fencing to protect against grazing animals, and regrowth occurs through natural processes.
3. *Active tree planting:* This occurs when public and private organizations, as well as individuals, transplant tree seedlings.

Wildlife conservation and forest restoration are often mutually supportive. Use of natural seed dispersal agents to enhance reforestation has proved successful in several cases. Up to 95 percent of tropical tree species have their seeds dispersed by animals – including birds, bats, primates, elephants, ungulates and even (in seasonally flooded Amazonian forests) fish. In African and Asian forests, elephants (*Loxodonta* spp. and *Elephas maximus*) disperse more seeds than any other species in terms of quantity, number of species and distance from the parent plant, leading them to be described as the "mega-gardeners of the forest" (Campos-Arceiz and Blake, in press). Some tree species, such as *Balanites wilsoniana,* produce such large seeds that only elephants are able to disperse them (Babweteera, Savill and Brown 2007). Primates also play a critical role in maintaining forest diversity. In Taï National Park, Côte d'Ivoire, monkeys were found to disperse 75 species of tree, of which 69 percent were dispersed almost exclusively by them (Koné *et al.*, 2008).


BODHI SURF SCHOOL

Toucans (Ramphastidae *spp.*) *are important seed dispersal agents in neotropical forests.*

Protecting seed dispersers is therefore an important element of reforestation, if restoring a biodiversity-rich forest is the aim. If a corridor between an existing natural forest and the reforested area can be maintained, animals will carry seeds in their gut after feeding on fruit in the natural forest and deposit them in the newly reforested area. The likelihood of this occurring can be increased by planting "framework species," which produce fruit that attracts frugivores from neighbouring forests. Even if no corridor survives, birds and bats will fly to the reforested area as soon as the new trees begin fruiting and some animals, such as primates and elephants, will even venture across agricultural landscapes to access new food sources.

BOX 23

Restoration of dry tropical forests aided by birds and mammals

The northern highlands of Thailand are characterized by seasonally dry tropical forests, which are likely to be exposed to additional stress from even drier conditions under climate change. Commercial logging represents the main immediate threat to their conservation, leading to increasing problems of forest degradation and fragmentation. The Government has banned logging in response to the threats and has established protected areas to stop destructive human activities in key zones. In a few cases, international collaboration has led to the development of management practices to combat forest clearing and degradation. These practices include forest restoration activities in Doi Suthep-Pui National Park (DSPNP), northwest of Chiang Mai in the Northern Thailand region (Blakesley and Elliot, 2003).

Continues

Box 23 continued

The area experiences a monsoon-like climate with pronounced wet and dry seasons. The natural regeneration of native vegetation is not enough to reverse forest degradation processes, which include not just logging, but also diverse climatic conditions and fire exposure during dry seasons (Blakesley and Elliot, 2003).

The Forest Restoration Research Unit (FORRU) of Chiang Mai University, in collaboration with DSPNP Headquarters and the United Kingdom of Great Britain and Northern Ireland's Horticulture Research International, has adapted the framework species method to restore seasonally dry forests in degraded watershed sites in the mountains of Northern Thailand. The basic structure and function of the forests are rapidly re-established by planting a mixture of 20–30 carefully selected native forest tree species (both pioneer and climax), including fruiting species that attract frugivores, mainly birds and mammals. When the planted trees yield fruit, they attract seed-dispersing animals from nearby natural forests and biodiversity starts to recover. The animals' droppings contain the seeds of additional plant species, thereby adding to the diversity of the restored sites (Blakesley and Elliot, 2003).

Experiments were designed in the nursery to develop horticultural practices that optimize seedling vigour and health. Since 1998, experimental plots have been established annually in partnership with a Hmong hill-tribe community living in DSPNP. FORRU helped the villagers to establish their own community tree nursery to test, in a village environment, the practicability of the new methods developed on the research plots (Blakesley and Elliot, 2003).

The project showed that forest cover can be returned to highly degraded hillsides at 1 300 m elevation within 3–4 years. Canopy closure starts to occur by the end of the second year after planting and is nearly complete by the end of the fourth. Increasing numbers of insects in the planted plots also attract potential seed-dispersing birds and mammals with mixed diets. In this way, the degraded sites gradually return to the tree species composition of the original native forest (Blakesley and Elliot, 2003).

5.3.4 Savannah and grassland restoration

Grasslands and savannahs often survive through achieving a delicate balance of grazing, fire and climatic conditions: changes to any of these can disrupt the ecosystem and thus both ecosystems are likely to require frequent restoration activities under conditions of climate change.

Restoration falls into three main types:

1. *To counter degradation:* Restoring grassland and savannah in areas where they have degraded, in extreme cases, into semi-desert or desert.
2. *To counter alteration:* Restoring native species mixtures and ecosystem functioning to grasslands that have been radically altered by overgrazing, incursions by invasive species or deliberate planting of non-native species.
3. *To counter invasion:* Restoring grassland and savannah where either deliberate planting or the removal of herbivores has resulted in scrub or woodland invasion.

In the long term, restoring soil biomass may be as important as restoring living plants in terms of stabilizing the system. It is likely that climate changes resulting in greater droughts and more unstable weather patterns, which in arid areas increase the risk of dust storms and sand storms, will increase the need for restoration. In practical terms, restoration often involves reducing grazing pressure, which can create the need for careful negotiations with farmers and herders. Focusing restoration on key areas, for example along the migration pathway of birds or mammals, can help to maximize returns on investment.

The cork oak savannahs in the Mediterranean (see Box 8) are an example of how beneficial well-managed cultural ecosystems can be for a variety of wildlife. Cork oak savannahs are threatened by a combination of management and environment related factors throughout their range. Management factors include poor policy and governance, a lack of technical capacity and inadequate investment in sustainable management and restoration practices. These are exacerbated by the impacts of climate change: increased vulnerability of oak trees to diseases, pests and large scale forest fires, which ultimately lead to further biodiversity loss.

BOX 24

Grassland and herbivore recovery after drought in Amboseli

The Amboseli Basin of southern Kenya, comprising Amboseli National Park at its core and the wider Amboseli ecosystem, is a seasonal refuge for herbivores during the dry season. Melt water from Mount Kilimanjaro feeds the basin and provides a permanent water source in the form of large swamps in Amboseli National Park, while seasonal rains fill the floodplain of Lake Amboseli. Migratory herbivores, whose movements are directly linked to seasonal rainfall and water availability, congregate at these water sources during the dry season (Ogutu *et al.*, 2008; Western, 2007).

The Amboseli Basin has undergone great changes in recent decades: the previous woodland–grassland mosaic habitat has shifted to open grassland and daily maximum temperatures have increased dramatically (Altmann *et al.*, 2002; Western and Maitumo, 2004). More importantly, rain patterns have become more stochastic, with annual rainfall varying more than four-fold and the long dry season often preceded by a period of drought (Altmann *et al.*, 2002).

The most recent severe drought, for example, was the result of poor rains in 2008 and a total failure of the main rainy season in 2009. The shrinking water sources attracted high aggregations of herbivores, which promptly overgrazed the area. This resulted in an exceptionally rapid population collapse over the course of the drought. The overall mortality rate of over 75 percent was nearly four times higher than recorded levels dating back to 1967, which never exceeded 20 percent of herbivore populations. Wildebeest (*Connochaetes taurinus*) populations dropped by 92 percent between September and November 2009 and zebra (*Equus quagga*) populations by 71–85 percent, leaving only 312 wildebeest and 1 828 zebra surviving in the Amboseli

Continues

Box 24 continued

Basin. Other species affected by the drought include the African buffalo (*Syncerus caffer*) and Grant's gazelle (*Nanger granti*), which decreased by 65 percent and 66 percent, respectively, as well as large numbers of elephants (*Loxodonta africana*) and hippopotamuses (*Hippopotamus amphibius*) (Kenya Wildlife Service *et al*., 2010; Western, 2010; Western and Amboseli Conservation Program, 2010; Worden, Mose and Western, 2010).

Heavy and prolonged rains broke the drought in December 2009 and began restoring the ecosystem. Vegetation recovered quickly, benefiting from the rains and the lower grazing pressure as a result of drought mortality. Herbivore populations soon began to recover, aided (in the case of the wildebeest) by immigration from neighbouring ecosystems, such as Tsavo National Park. By July 2010, the wildebeest population had reached 1 667. Still, this is nowhere near the species' population of 7 000 in 2007 (Western and Amboseli Conservation Program, 2010).

The natural restocking of Amboseli herbivores from neighbouring populations illustrates the importance of maintaining wildlife corridors. Had the Amboseli ecosystem been isolated, the herbivore population may have been too low to recover, particularly given the high predation pressure in the basin. The dependence of herbivore populations on Amboseli National Park's swamps as permanent water sources in times of drought again stresses the need to maintain ecosystem connectivity.

The Kenya Wildlife Service is contributing to the restoration of Amboseli National Park in two ways. To restock herbivore populations, it plans to relocate 3 000 wildebeest and 4 000 zebra from neighbouring ranches in phases (Kenya Wildlife Service, 2010b). A first phase began in February 2010 with the capture and translocation of 137 zebra (Wildlife Extra, 2010).

The Kenya Wildlife Service further endorsed a plan to create restoration plots in woodland and swamp areas, while existing restoration plots and enclosures have been rebuilt (Kenya Wildlife Service *et al*., 2010; Western and Amboseli Conservation Program, 2010). Fencing off areas has been shown to be a cost-effective way to encourage the regeneration of vegetation (Western and Maitumo, 2004).

5.4 ADOPTING INTEGRATED AND LANDSCAPE APPROACHES

Adaptation to climate change is already occurring, although in a reactive way, since most societies are not yet well prepared to adapt to changes and cope with extreme weather events. Given that land use and climate change both contribute to the major environmental changes we are currently experiencing (Costa and Foley, 2000; Pielke, 2005), the best way to adapt to different climatic conditions and mitigate their effects is through a preventative approach and by integrating the environmental effects of changing climate into land use planning. Such approaches are particularly useful in addressing events that affect ecosystems on a large scale, like wildfires and invasive species. Proper resource planning should be part of this planning process.

Public policies and legislation play an important role in facilitating adaptation to climate change. Land use planning should be regulated by policies that take steady changes as well as likely extreme events into consideration (FAO, 2011b). The integration of information on climate and changing ecosystems into resource use planning is now being implemented in countries around the world, with national and international funds being allocated for this purpose (Parry *et al*., 2007). When putting such integrated land use plans into place, the direct causes of climate change should be considered, together with its immediate and long-term effects. Hazard mitigation can only be successful if land use planning takes into consideration the impacts of changed climatic conditions, particularly with respect to the displacement of human activities and development. Plans also need to address how existing hazards may change in frequency and extent, and whether new hazards are likely to emerge.

Planning usually involves the integration of various approaches. Under conditions of increasing drought, for example, the management of grazing permits for livestock are not always effective on their own to avoid land degradation. In such cases, enhanced land use planning should also address the restoration of degraded land and sustainability as well as human livelihood benefits (Curtin, 2002).

A number of studies have modelled the future effects of climate change at both local and regional scales and the results can be used for improved land use planning (e.g. Colls, Ash and Ikkala, 2009). Some of these studies have resulted in successful land use planning, although costs can be high and international funding may be needed, particularly in developing countries. New technological tools have made it possible to integrate information on different land characteristics in computer models to predict vulnerability to climate change. Such models can help identify the best management practices for specific areas. They not only make it possible to predict the potential effects of climate change, but also the activities (and their extent) that the land can sustain without incurring ecosystem loss.

The application of enhanced land use planning should include participatory approaches that engage local communities in the process of planning, informing them about predicted changes in their area and taking into consideration the interests of the whole community. In the Sudan, for example, a management plan was adopted that expands the traditional techniques for harvesting and conserving water and foresees the development of wind barriers to counter the effects of decreased precipitation on land degradation and drought (Osman-Elasha *et al*., 2006). In Florida, the United States of America, a workshop involving local communities focused on the need for increased community resilience to storm-surge hazards and identified strategies to combat the widening storm-surge hazard zones (Frazier, Wood and Yarnal, 2010).

The Ethiopian Government developed a Climate Change National Adaptation Programme of Action (National Meteorological Agency, 2007). The programme was part of a GEF-funded project developed with the assistance of UNDP as a consequence of the detected increase in mean annual temperature of 0.37 °C every ten years from 1961 to 2005, leading to an increased frequency of droughts. The plan included a list of 37 adaptation actions, ranging from the institution of crop-insurance to increasing capacity-building for small scale irrigation systems, the establishment of a natural reserve in the Great Rift Valley and the enhancement of land resource use in rangelands.

These integrated plans will become increasingly important and complex as we learn more about the likely impacts of and possible responses to climate change. From a wildlife management perspective, such integration implies, for example, that different species groups are addressed equally. There is still much to be learned about how integration can work in practice. Integrated approaches are described below, with respect to the key issues of fire and invasive species, although the principles can be applied to other situations as well.

5.4.1 Wildland fire management

Fires have been identified as critical change factors in an altered climate. Responses cannot be limited to individual site management, but rather require a wider landscape approach. Fire regimes have changed over the course of the last century and continue to change (Dale *et al.*, 2001). This change has led to some significant environmental responses, including shifts to more fire-adapted species, shifts in forest type to either non-native species or lower value forests or conversion to scrublands, grasslands and even deserts. Many of these environmental changes have led to water quality deterioration and quantity reduction, the reduction of the carbon sequestration potential of forests (potentially exacerbating the speed of climate change) and the loss of livelihoods for local communities. Adapting forests to a changing climate and the increasing impacts of fire will be technically challenging and may incur significant costs. On the other hand, failure to confront this challenge will mean an even greater cost to society and the environment.

Fire-sensitive ecosystems

The crux of the problem in fire-sensitive ecosystems is not so much the introduction of fires, but their frequency. Historical records and charcoal in soil profiles show that tropical forest fires, even in wetter forests, are not unprecedented. Fire can be considered endemic in some areas, but usually only occurs in tropical rainforests at intervals of hundreds if not thousands of years. Wetter forests burn less frequently, but are more vulnerable to fire than drier forests because they have thinner protective layers of bark and suffer much higher mortality rates. Periodic disturbances by fire in these ecosystems may also be important in favouring the reproduction and abundance of some important tropical timber species and maintaining biodiversity (Otterstrom and Schwarts, 2006; Snook, 1993).

One of the key adaptation strategies for wildland fires is to use Integrated Fire Management, a comprehensive framework for managing fire, and emissions from fire, in both fire-sensitive and fire-dependent ecosystems (FAO, 2006; Myers, 2006).

This framework involves:

- Assessment and analysis of context.
- Definition of fire management goals and desired ecosystem condition.
- Assessment of laws, policy and institutional framework.
- Fire prevention and education.
- Fire preparedness and response.
- Ecosystem restoration, recovery and maintenance.
- Adaptive management, research and information transfer.
- Promotion of secure land tenure and community-based solutions.

Land tenure issues are as critical to successful fire management as they are to other land management issues. Landholders sometimes tend to avoid the use of fire as a land-management tool and invest more in the prevention of accidental fire, as a result accumulating fire-sensitive species on their properties (Nepstad *et al.*, 2001). In some situations, the overuse of regular fires causes other kinds of problems. Successful fire management strategies, within an Integrated Fire Management framework, engage the local stakeholders who are causing forest-degrading fires in fire-sensitive systems. Local communities are logical partners in fire suppression and management because they are both the first line of attack and the most affected by unwanted fires (Ganz, 2001; Ganz *et al.*, 2007; FAO and FireFight South East Asia, 2002). Such communities should be given incentives for preventing escaped agricultural fires and putting out unwanted fires in a timely manner. Successful strategies require plans and procedures that link local and regional fire-fighting support for large fire suppression as a function of expected size, duration and complexity. The mobilization of local communities is further enhanced by providing training in early detection, initial attack and decentralized communications. As with fire suppression and management, local communities are logical partners for rehabilitating degraded landscapes and reducing fire susceptibility before conversion to agricultural or degraded non-forested lands (Ganz *et al.*, 2007).

Fire-dependent ecosystems

As with fire-sensitive systems, Integrated Fire Management also offers a similar framework for ecosystem-based adaptation in fire-dependent ecosystems. Ecosystem-based adaptation entails the use of biodiversity and ecosystem services as part of an overall adaptation strategy, in order to help people adapt to the adverse effects of climate change. The distinction for fire-dependent systems is that fire itself is used as a tool in fire management (Myers, 2006; FAO, 2006).

There are many forest and savannah/grassland ecosystems that have evolved positively in response to frequent fires from both natural and human causes, maintaining high biodiversity and a changing steady state for low intensity disturbance regimes. The practice of fire-suppression in these fire-adapted environments results in the decline of fire-maintained habitats and the wildlife species that depend on them, such as the migratory woodland caribou (*Rangifer tarandus caribou*) (Canadian Forest Service, 2005; van Lear and Harlow, 2002; see

Box 25). Another major side effect is the accumulation of fuel on the forest floor, which increases the threat of fires of a scale and intensity for which the forests have not been adapted (Bancroft *et al.*, 1985). This effect of fire-suppression in fire-dependent systems is well-established in the literature (Agee and Skinner, 2005; Baeza *et al.*, 2002; Grady and Hart, 2006; Liu, 2004; Myers, 2006; Perry, 1994; Piñol, Beven and Viegas, 2005; Pollet and Omi, 2002; Stocks, 1991).

Natural variability within species and their differing capacities to respond, which is evident in different species of trees, provide opportunities to maintain forests in the face of changing disturbance regimes. The intentional usage of important disturbance types in forest management, such as fire, can build resistance, resilience and gradually lead to forest transitions. Gradually increasing the frequency of prescribed burning could help prepare forests for the increased fire frequency predicted in climate change models. Natural selection can be intense and rapid among seedlings and prescribed fire can quickly promote species and genotypes that are appropriate for altered fire regimes (Galatowitsch, Frehlich and Phillips-Mao, 2009). The use of fire and other disturbances should be used in controlled research settings to aid in the identification of climate-ready genotypes to be used in replanting efforts following catastrophic fire.

Financial calculation of fire-related losses

High-intensity wildfires often lead to a loss of benefits for ecosystems and people, including, but not limited to, those dependent on wildlife habitat, especially in the area of forage production. The owners of large properties in Mato Grosso, Brazil, report that undesired fires cause losses of at least US$11 000 per year (per landholding) in lost cattle forage and fencing. Additional losses from fire include timber, wildlife, buildings and livestock (Nepstad *et al.*, 2001). In the forest concessions of East Kalimantan, Indonesia, the loss of 23 million m^3 of harvestable timber – due to the 1997–1998 fires – was estimated to be worth approximately US$2 billion (Hinrichs, 2000). Economic costs were estimated at more than US$9.3 billion in the same fires (Asian Development Bank and National Development Planning Agency, 1999; Barber and Schweithelm, 2000). The value of these losses has been estimated based on the replacement costs or the value of the market resources that were burned (Merlo and Croitoru, 2005) and may include lost income-generating capacity, lost recreation opportunities, airport closures and degradation of ecosystem services, such as clean water and wildlife habitat (Asian Development Bank and National Development Planning Agency, 1999; Dunn, Gonzalez-Caban and Solari, 2005).

Accounting for ecosystem goods and services is rarely comprehensive, but will nonetheless be necessary if we are to understand the true costs of unwanted fires and the impacts of long-term site degradation on wildlife and ecosystem services (TSS Consultants and Spatial Informatics Group LLC, 2005). Such calculations are an important first step in the overall evaluation of environmental costs, so that the appropriate incentives can be factored into fire-management strategies.

BOX 25

Protecting the winter habitat of reindeer through fire management

The reindeer (*Rangifer tarandus*), known as caribou in North America, is an Arctic and Subarctic deer species with both migratory and resident populations ranging across the tundra, taiga and boreal forests of Asia, Europe and North America. The species is widespread and numerous and is categorized in the IUCN Red List as being of least concern with stable population trends (Henttonen and Tikhonov, 2008), although some subspecies are considered endangered (e.g. woodland caribou, *R. t. caribou*) or of special conservation concern (e.g. barren-ground caribou, *R. t. groenlandicus*) by regional committees (e.g. COSEWIC, 2010).

Ground-dwelling lichens constitute the primary winter forage for migratory populations of reindeer and this dependence makes the species highly vulnerable to fire disturbance. The destruction of lichen by fire has been the major cause for population declines in barren-ground and woodland caribou across North America (Cumming, 1992). After a fire, it takes 20–40 years for the first lichen species to return, 40–60 years for the species favoured by caribou to recover, 60–80 years for a suitable grazing cover of lichen to develop and up to 150 years for preferred lichen species such as *Cladonia mitis*, *Cladonia rangiferina* and *Cetraria nivalis* to reach pre-fire peak levels (Thomas, D.C., Barry, S.J. & Alaie, 1995). Caribou distribution was found to match lichen abundance, with very limited distribution in areas burned less than 50–60 years ago (Joly, Bente & Dau. 2007) and extensive occurrence in old forests (150–250 years post-fire) (Thomas, 1998).

Wildfires are expected to increase in number, extent and intensity throughout the tundra ecosystem (Joly, Bente and Dau, 2007). This will reduce the availability of the preferred winter habitat of the species. Simulations predict that an increased frequency of wildfires will result in an immature forest age structure (i.e. few areas older than 100 years), which is at the lower end of the range of the reindeer's preferred winter habitat (Rupp *et al.*, 2006).

Given this strong effect of wildfires on reindeer and the dependence of rural communities on the species for everything from food, clothing and shelter to tools and transportation, it is not surprising that fire management is an important conservation tool (see Cumming, 1992; Joly, Bente, and Dau, 2007; Stevenson *et al.*, 2003; Thomas, 1998). Most management measures aim to maintain mature and old-growth (> 100 years old) vegetation through fire-suppression in order to safeguard winter-forage habitat. Such measures include: 1) defining minimum areas of mature habitat (> 55 years old), 2) defining maximum burn areas of winter range, 3) identifying optimum burn rates (about 0.25–0.5 percent annually), 4) annually mapping burned winter range areas over 1 000 ha and 5) suppressing fire in winter ranges to maintain adequate forest age distribution. Rather than a single-species approach tailored towards reindeer alone, however, fire management should be based on an ecosystem approach that considers the effects of fire regimes on a broad number of species (Thomas, 1998).

5.4.2 Management of invasive species and wildlife diseases

The effects of the interactions between global warming and biological invasions are alarming and more effective conservation policies are urgently required. These should not only aim to respond to invasions, but also to explore proactive measures to counteract predicted climate changes.

In general, it is crucial that governments enforce coordinated strategies to mitigate the impacts of invasions. These should be based, in the first instance, on the prevention of new incursions, but also should ensure prompt and effective management of invasive species when prevention fails. As a general principle, it is globally acknowledged that prevention should be the first line of defence because preventing the arrival or introduction into the wild of a potentially invasive species, is far more cost-effective than dealing with the problem afterwards. It is clear, however, that a prevention framework will not entirely halt the occurrence of new introductions, and so it is important to enforce a hierarchical approach: prevention is the first priority, then early detection and rapid response when prevention fails, followed by the eradication of invasive species and, finally, control as the last option.

It must be stressed that all of the measures required to mitigate the impact of invasions are potentially affected by climate change, and it is therefore urgent that we develop our strategies with this in mind. Rapid response, for example, is by far the most effective management approach to invasions; in general, the removal of a species is easiest – and often only feasible – immediately after the introduction has occurred, when populations are still small and are confined to restricted areas (Genovesi *et al.,* 2010). The successful eradication of the American beaver (*Castor canadensis*) from France, for example, or of the Indian porcupine (*Hystrix indica*) from the United Kingdom of Great Britain and Northern Ireland were made possible by a prompt reaction, which started before these species became widely established in the wild (Genovesi, 2005). Rapid response also requires the prediction of which species are more likely to invade. The potential of a species to arrive and to become established depends largely on the climatic conditions of the invaded area. Many tropical species now arriving in Europe find temperatures that may permit them to establish in that region.

Rapid removal is not the only response to invasions: there are many examples of the successful eradication of well-established populations of invasive species. Globally, 1 129 eradication programmes have been recorded, targeting alien species of plants or animals in all environments, with outstanding results in terms of biodiversity recovery (Genovesi, 2011). The successful eradication of the coypu (*Myocastor coypus*) from East Anglia in the United Kingdom of Great Britain and Northern Ireland, for example, was facilitated by cold winters that reduced the population before the removal campaign started (Gosling, 1981; Panzacchi *et al.*, 2007; see Box 26). Climate warming, however, could facilitate a rapid expansion of this neotropical invasive rodent to a large portion of Europe. It is already causing huge economic losses in Italy. The encouraging results also depend on the great advancements in the science of eradications; in recent years a number of sophisticated techniques and protocols have been developed, which allow highly selective removal methods that minimize undesired impacts on the environment. Many techniques have been used in eradications – often in an integrated manner – from trapping or shooting vertebrates, to poisoning invertebrates, as well the use of toxicants, pesticides and herbicides for targeting weeds. There are also a growing number of coordinated programmes that target multiple species at the same time, reducing overall costs and multiplying the positive outcomes of the campaigns (Genovesi, 2007).

The efficacy of the different techniques depends heavily on the climatic conditions; for example, precipitation can deeply alter the effect of toxicants, change the vulnerability of the target species and influence the response of invaders to removal. The potential effect of climate change on removal methods is even more notable in the case of permanent control, which is the only remaining management alternative when eradication is not feasible.

Global warming poses new challenges for the management of invasions, affecting the potential for new incursions and the manageability of species and altering the effectiveness of control measures. It is therefore critical to consider such effects when formulating response strategies for biological invasions at all scales, from the global to the local level. Population modelling should consider the possible effects of global changes. The development of more effective early warning and rapid-response frameworks to guide and support responses carried out by countries is urgent, and the management methods currently used to combat invasions should be tested with regard to the possible effects of climate change (US Environmental Protection Agency, 2008).

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Climate change facilitates the spread of invasive species such as the coypu (Myocastor coypus).

Similarly, climate conditions also affect the management of pathogens entering new environments and niches, with the potential for changes in disease dynamics related to climate change. In areas affected by increases in temperature and rainfall as well as other shifts in climatic factors, there should be increased vigilance in monitoring for change in current endemic disease patterns, as well as recognition of newly emerging pathogen trends. Epidemiological studies to model the climactic factors associated with disease outbreaks can help identify triggers for increased surveillance or preventative measures. The identification of risk factors associated with pathogen exchange between wildlife, domestic animals and people can assist in developing response plans when disease outbreaks occur. This process requires the cooperation and sharing of information between public health, veterinary and wildlife officials in a region. The health of ecosystems and wildlife is directly related to the health of people and the livestock on which they depend. It is critical that we develop the capacity within countries to monitor, recognize and respond to unusual disease events using a multidisciplinary "One Health" approach (FAO, 2011c; Newman, Slingenbergh and Lubroth, 2010).

BOX 26

Coypu invasion and eradication in Europe

The coypu or nutria (*Myocastor coypus*) is a large semi-aquatic rodent native to South America, which has been introduced in many areas of the world for its fur. As a consequence of escapes and releases, the species is now established in many countries of Asia, Europe and North America where it impacts natural vegetation as well as crops through overgrazing and causes significant damage to riverbanks and dykes because of its burrowing behaviour. The coypu can also negatively affect insect, bird and fish species and alter the functionality of freshwater ecosystems. The economic losses caused by the coypu can be severe. In Italy, for example, average yearly costs of coypu damage exceed €4 million, and are expected to rise to over €12 million in the future (Panzacchi *et al.*, 2007). The species is listed among the world's 100 worst invasive species by IUCN's Species Survival Commission Invasive Species Specialist Group (Lowe *et al.*, 2000).

To mitigate its impacts, the coypu is intensively controlled in many areas of the world and has been the target of several eradication programmes. Its eradication from West Anglia, United Kingdom of Great Britain and Northern Ireland, in the 1980s is one of the most successful removal programmes ever carried out on a mainland area (Gosling and Baker, 1989; Genovesi, 2005). The success of that eradication was facilitated by the coypu's susceptibility to cold winters, when mortality rate can exceed 80 percent of the population (Carter and Leonard, 2002). Some populations completely collapse during harsh winters (Doncaster and Micol, 1990). On the contrary, following mild winters, coypu populations can show impressive demographic growth with increased reproduction and survival rates.

Continues

Box 26 continued

Many areas of Europe and North America where the coypu has been introduced have a continental climate, with cold winters that limit the expansion of the species. Ongoing global warming could massively increase the damage caused by this invasive rodent, by fostering the growth of populations, facilitating its spread to currently unsuitable areas and limiting the effectiveness of control programmes. The consequences could be severe, not only for the biological diversity in freshwater ecosystems, but also for the economy of many rural areas. A major invasion could even affect the safety of human communities living in proximity to rivers and streams. The coypu can weaken riverbanks by digging, causing the collapse of the banks and, in some cases, causing floods.

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Spraying of a biological insecticide as part of an eradication programme for the gypsy moth (Lymantria dispar).

6. Conclusions

The United Nations Decade on Biodiversity was inaugurated in October 2010 at the 10th Conference of the Parties to the Convention on Biological Diversity, in Nagoya, Japan. Despite this and other efforts to reverse the trend, biodiversity loss continues unabated in almost every country. The authors of a major review of the impact of conservation action on vertebrates (Hoffman *et al.*, 2010) concluded that "current conservation efforts remain insufficient to offset the main drivers of biodiversity loss in these groups: agricultural expansion, logging, overexploitation, and invasive alien species."

The same can be said for virtually all other wildlife groups. On Cat Ba Island, at the edge of the iconic UNESCO World Heritage site of Ha Long Bay in Viet Nam, an estimated 63 specimens of the endemic golden-headed langur, also known as the Cat Ba langur (*Trachypithecus poliocephalus poliocephaus*), hang onto survival by a thread, supported by a full-time German conservation project, efforts by staff at the Cat Ba National Park and Biosphere Reserve and by social taboos in many local communities that prevent them from harming the langur. The species remains under threat from poaching by outsiders and erosion of its habitat by tourist development. Similar stories can be told about thousands of other species around the world. Yet there is not enough time, money or dedicated people to give conservation attention to more than a fraction of the species currently at risk.

If one adds climate change into the mix and assumes no radical changes in policy and approach, we are spiralling towards a world that will be dramatically poorer in species and consequently less stable, less interesting and less rich in resources for ourselves. Climate change is likely to exacerbate all of the traditional threats to wildlife, as well as introducing new ones. This will make conservation actions even more difficult than in the past. Nevertheless, as the case studies in this paper indicate, target species and habitats *can* be saved given sufficient resources, political will and public support.

New resources are being promised for biodiversity conservation and there is a growing realization among decision-makers that biodiversity is not an optional bonus in human affairs, but the very foundation of our existence. Moreover, biodiversity conservation tailored to changing climatic conditions is not only necessary to help species and habitats to adapt to change, but such action is also likely to mitigate climate change. This is particularly true for ecosystems that sequester and store carbon, such as forests and peat swamps. Nevertheless, there has apparently been little sense of urgency.

There is, however, reason to hope. Recognition of the scale of the problem is coming, albeit at the very last minute, and governments and others are waking up to the need for action at a larger scale than ever before. Taking a series of conceptual and practical steps can help start to reverse the current momentum towards loss.

RECOGNIZE AND PROMOTE THE FULL VALUE OF WILDLIFE, INCLUDING PRACTICAL, CULTURAL AND ETHICAL CONSIDERATIONS

In practice, decisions about natural resources are seldom made due to a single factor, but are based on the cumulative weight of many different considerations. The value of wildlife to human subsistence, its economic worth and the ecosystem benefits it provides are all important. Additional critical factors may also be far less tangible, such as the link between a particular species and a faith group, or the emotions it creates in some people. Recognizing the value of wildlife is a vital step in building the motivation needed for effective management and conservation.

STRESS THE KEY ROLE OF PROTECTED AREAS IN CONSERVING WILDLIFE IN THE FACE OF CLIMATE CHANGE

Although protected areas are by no means a perfect conservation tool, their existence and effective management remain the best chance for maintaining viable populations of many wildlife species. Protected areas located in climate refugia are particularly important; nevertheless, those in changing or vulnerable ecosystems can also play a critical role in conservation strategies. Protected areas should not be confined to private, community or state-owned and managed lands and waters. Indigenous peoples' and co-managed areas can all be equally or more effective (Dudley, 2008). To consolidate, secure and expand the world's protected areas network, as agreed by signatories to the Convention on Biological Diversity, it is also important that such areas are seen as more than simply wildlife management sites and their values to ecosystem services, culture, recreation, health and livelihoods are all fully appreciated and costed (Stolton and Dudley, 2010).

MAINSTREAM BIODIVERSITY CONSERVATION

Protected areas can never protect all wildlife, and, in some situations, well-managed lands can be more effective vehicles for wildlife conservation than badly managed or under-resourced protected areas. Forestry managers have a critical role to play by 1) ensuring that forest management is compatible with the survival of native wildlife; 2) protecting unmanaged edges and patches within the forest estate; 3) protecting watercourses; 4) controlling poaching and the bushmeat trade; and 5) halting incursions by invasive species. A vast array of tools, guidance and best practices for biodiversity conservation already exists. The twenty-year debate about the impacts of forest management on the environment has, to some extent, meant that this sector is better equipped than others to ensure the best possible mix of production and wildlife conservation, assuming the relevant policies and support structures are in place.

MAINTAIN RESEARCH AND MONITORING EFFORTS

There is still a great deal that we do not know about the impacts of climate change on wildlife. Most of the papers published on this issue have emerged only in the last decade; we are still at the very beginning of our understanding. Ensuring that there are sufficient resources, expertise and time to measure and understand what is happening and to develop comprehensive response strategies will greatly increase our chances of passing on a world still rich in wildlife species to future generations.

One thing is clear: biodiversity loss cannot be halted if we fail to stabilize the climate, and if we are to stabilize the climate as well as to move into the era of low-carbon living, we must protect the biosphere – the very life-support system of our planet.

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FAO FORESTRY PAPER

Wildlife in a changing climate

This publication examines the likely consequences of climate change for wildlife, including altered ecosystems and species composition and increased incidence of human–wildlife conflict, wildland fires, and spread of invasive species and infectious diseases. The main focus is on tropical terrestrial wildlife and its habitats, but other fauna, ecosystems and geographical regions are covered, as well. Adequate responses to climate change are also discussed, such as maintaining current ecosystems, adaptive management, restoring ecosystems and adopting integrated and landscape approaches to biodiversity conservation. Case studies are presented throughout to illustrate the issues.

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