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).

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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)

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).

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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 (S*otalia 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.

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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.