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)

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BOX 11

European and North American birds show similar northward shifts

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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

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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

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).

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)

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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.

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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).