4 Potential Impacts of Climate Change and Implications for Biodiversity and Human Wellbeing

Introduction

A holistic perspective on global climate change has emerged out of the discernible trends: that human activities are responsible for these recent shifts and variability in the physical and biological systems. Climate change is projected to compound pressures on natural resources and the environment associated with rapid urbanisation, industrialisation, and economic development. The impacts of climate change vary across regions and communities. In general, these impacts are most severe in regions that display high vulnerability as a result of a number of factors, including poverty. From the AR4 (IPCC 2007a), it is clear that the countries most vulnerable to climate change impacts also tend to be the poorest ones, with limited capacity in terms of the instruments needed to address the situation they face (e.g, data and observations, methods and tools, and technical and institutional infrastructure capacity building). The biggest challenge for the EH is to adapt to the impacts of climate change by integrating responses to climate change and adaptation measures into strategies for poverty reduction at the local level to ensure sustainable development. This synthesis also warns that unprecedented stresses on ecosystems from the combination of climate change, associated disturbances (e.g., floods, drought, wildfire, insects, disease), and other global change drivers (e.g., land use change, pollution, fragmentation of natural systems, overexploitation of resources) may exceed the natural resilience of ecosystems. The interaction of climate impacts with rapid economic and population growth, and migration from rural to urban areas, is likely to affect development. Net carbon uptake by terrestrial ecosystems is expected to peak before mid-century, and then weaken or even reverse, thus amplifying climate change.

Mountains are susceptible to the impacts of a rapidly changing climate, and provide interesting and unique locations for the early detection and study of the signals of climatic change and the assessment of climate-related impacts on hydrological, ecological, and societal systems. Climate changes rapidly with altitude over relatively short horizontal distances, as does vegetation and hydrology (Whiteman 2000). In places where climatic change may lead to warmer and drier conditions, mountain vegetation is expected to suffer as a result of increased evapotranspiration. However, contrary to the expectations from the models, Chen et al. (2006) found that average PET trends (1961–2000) on the Tibetan Plateau were negative in all seasons and annually, with an average annual PET trend of –13.1 mm/decade. Such contradictory evidence highlights the reality that ecosystems are complex and highly interconnected, making the effects of climate change extremely difficult to predict. The loss of wetlands is equally difficult to predict. Knowledge of temperature change is particularly important for prediction because it influences activity, feeding, growth, metabolism, and reproduction.

Impacts on Ecosystems and Consequences for Biodiversity

Impacts on biodiversity are also a matter of degree between extremes of significance, as judged by humans, and the 'middle path', a notion of sustainability that ecosystems and biological processes are able to tolerate and absorb certain thresholds of climate change and human activity. As mentioned already, there may be positive as well as negative impacts of climate change. Recent warming is strongly linked to the changes observed in terrestrial biological systems, including the

Impacts on biodiversity and ecosystems: IPCC projection and consequences for human wellbeing

IPCC projection: There is a high confidence probability that the resilience of many ecosystems will be undermined by climate change, with rising CO_2 levels reducing biodiversity, damaging ecosystems, and compromising the services that they provide. Over the past three decades, the lines marking regions in which average temperatures prevail (isotherms) have been moving pole-ward at a rate of about 56 kilometres per decade. Changes in flowering seasons, migratory patterns, and the distribution of flora and fauna have been detected. Alpine plants are most at risk and are being pushed towards higher altitudes and literally off the planet. But when the pace of climate change is too rapid, or when natural barriers block migration routes, extinction looms. According to the IPCC, 20-30% of plant and animal species are likely to be at increased risk of extinction if global average temperature increases exceed 1.5-2.5°C (medium confidence).

Human wellbeing projection: At temperature increases in excess of 2°C, rates of extinction will start to increase. Environmental degradation will gather pace, with wetland and forest systems suffering rapid losses. The loss of ecosystems and biodiversity is intrinsically bad for human development and the poor, who depend most heavily on ecosystem services, will bear the brunt of the cost.

earlier timing of spring events like leaf-unfolding, bird migration, and egg-laying; and pole-ward and upward shifts in ranges of plants and animal species. The present distribution of species in high-elevation ecosystems is projected to shift to even higher elevations, although rates of vegetation change are expected to be slow and colonisation success will be constrained by the limitations of the highly dissected and steep terrain of the EH mountain range. Studies of satellite observations since the early 1980s indicate that there has been a trend towards the early 'greening' of vegetation in the spring, linked to longer thermal growing seasons due to recent warming (Dye and Tucker 2003). However, observations of such changes are difficult to use in future projections because of the complexities involved in human-nature interactions (e.g., land use change). Declining snow cover may also be at least partially responsible for the higher NDVI (normalized difference vegetation index) values associated with the greening trend (Shabanov et al. 2002). Nevertheless, the observed changes are compelling examples of how rising temperatures can affect the natural world and raise questions about how vulnerable populations will adapt to direct and indirect effects associated with climate change (IPCC 2001a).

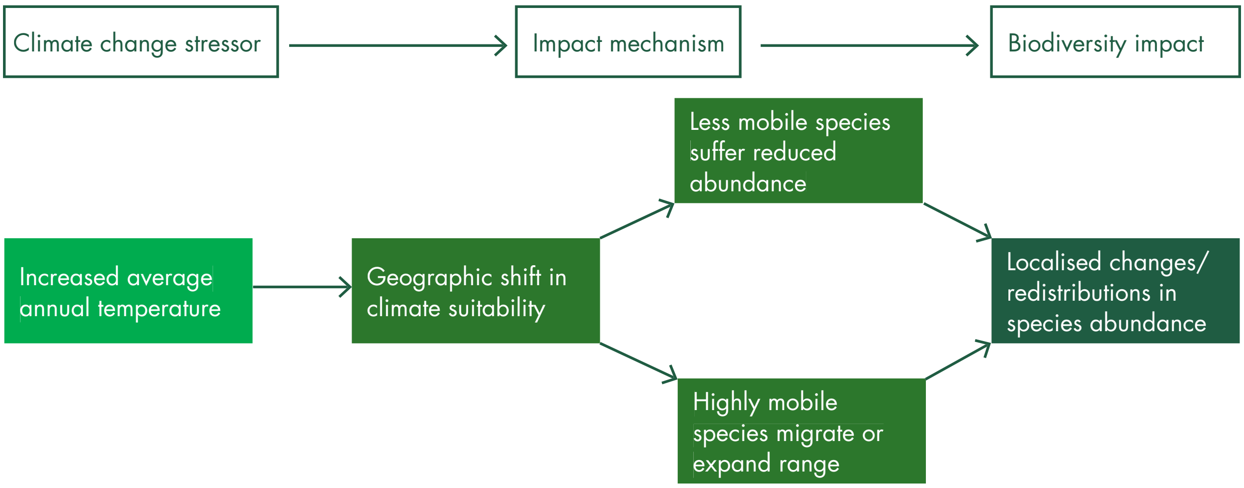
Climate change is expected to affect the boundaries of forest types and areas, primary productivity, species populations and migration, the occurrence of pests and diseases, and forest regeneration. The increase in GHGs also affects species composition and the structure of ecosystems, which, in turn, affects ecosystem functions (Schutze and Mooney 1994). The interaction between elevated CO_2 and climate change plays an important role in the overall response of net primary productivity to climate change at elevated CO_2 (Xiao et al. 1998). Climate change will have a profound effect on the future distribution, productivity, and health of forests. There may be a significant reduction in alpine and cryospheric ecosystems. Tropical zones are expected to expand to cover most of the middle mountains and inner valleys of the region.

Species responses

Species may respond to changes in climatic variables by adapting, shifting their range, changing their abundance, or disappearing altogether (Figure 9). Species will shift their geographic ranges at different rates, and some may be unsuccessful in reaching or colonising new habitats. As temperature decreases with altitude by 5-10°C/1000 m, species will respond to climate change by migrating upwards to find climatic conditions in tomorrow's climate that are similar to today's (McArthur 1972; Peters and Darling 1985). Past tree species migration rates are believed to be in the order of 4 to 200 m per century. For the EH, an average warming of 1 to 3.5°C over the next 100 years (as predicted by the IPCC-AR4) would be equivalent to an altitude shift of about 150 to 550 m (IPCC 2007a).

According to this paradigm, the expected impacts of climate change in mountains would include the loss of the coolest climatic zones at the peaks of the mountains and a linear shift in all remaining vegetation belts upslope. Because mountain tops are smaller than bases, the present belts would occupy smaller and smaller areas at higher elevations, and the population of corresponding species would decrease, becoming more vulnerable to genetic and environmental pressure (Hansen-Bristow et al. 1988). However, the migration hypothesis may not always be applicable because of the different climatic tolerance of species involved, including genetic variability between species, different longevities and survival rates, and competition from invading species.

Figure 9: **Climate change impact: Species-level range and abundance shifts**

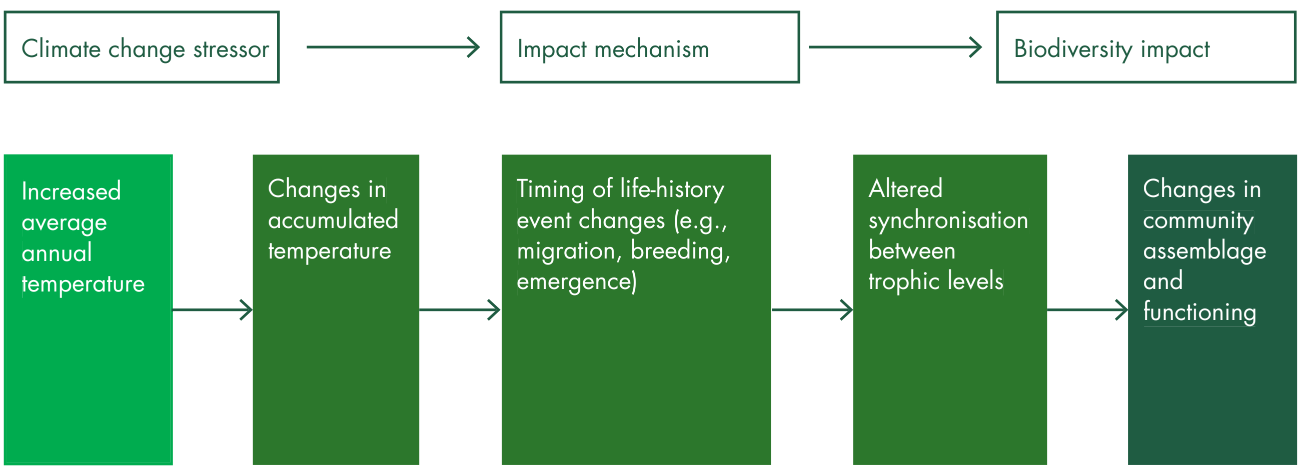


Lifecycle changes

Snow cover provides frost protection for plants in winter and water supply in spring. Vegetation communities that live in snow beds and hollows will be the most vulnerable to climate change because they will be subject to summer desiccation. As species will be affected differently by climatic changes, relationships among species will be altered. Ecosystem functions that depend upon interactions among species could be affected. Changes in phenology are expected to be the primary short-term response to climate change (Root and Hughes 2005). The lifecycle events of many plants, insects, and animals depend on 'accumulated temperature' – the amount of heat energy available over time (Figure 10). These organisms will hatch, bud, or breed earlier in the year in response to warming trends. Long-living plants that cannot migrate will see climate change occur within their lifetime, so their ability to undergo phenological adaptations will determine their individual survival.

In the animal world, these lifecycle changes are likely to disrupt communities, interfering with breeding seasons, potentially uncoupling predator-prey and competitive interactions between species, and ultimately influencing community composition (Root and Hughes 2005). Migratory species are particularly vulnerable as a discrepancy could develop between the timing of migration and the availability of food. Hence, both the structure and functioning of ecosystems could change. Rapid evolution might help species with short generation times, such as insects and annual plants, to adapt to climate change. Evolution may be slower in long-lived species, such as trees. The probability of ecosystem disruption and species extinction is positively related to the rate of climate change (IPCC 1998). If climate change is more rapid than the migration capacity of species, the probability of species extinction and disruption of ecosystems is great (Halpin 1994).

Figure 10: **Climate change impact: Lifecycle changes**



Evolutionary impacts

Changes in species abundance, distribution, and phenology suggest changes in species fitness in response to climate change. Individuals within one species may have different capacities for expressing new phenotypes (e.g., hatching or budding earlier in the year) and, as such, climate change might select individuals with greater genetic capacity for adaptation (Figure 11). New community assemblages and interactions resulting from climate change will also exert evolutionary pressure on species. Subpopulations at the warmer edges of species ranges are being extirpated, causing a loss in genetic diversity (Thomas 2005).

Adaptation pathways in the face of changing climate include the progressive replacement of currently dominant species by more thermophilous (heat-loving) species. A further mechanism is that dominant species are replaced by pioneer species from the same community that have enhanced adaptation capabilities (Halpin 1994; Pauli et al. 1998). A third possibility is that climate change may favour less dominant species, which then replace dominant species through competition (Street and Semenov 1990). These scenarios are based on the assumption that other limiting factors, such as soil type and moisture, will remain relatively unaffected by the changing environment.

Pest species may shift north or to higher elevations, and/or increase in abundance if temperatures increase. Shifts in fish species from cool and cold water species to warmer water species are likely. Species or whole ecosystems could fail to shift their range if they cannot disperse fast enough to keep pace with change, or if landscape features (such as cities) block their movement, or if new suitable habitats are simply not available. A species may fail to colonise a prospective habitat if it cannot adapt to that habitat's soil, or its level of human development, or if it cannot coexist with other species already in residence. Invasive species share a set of traits that predispose them to successfully invade pre-existing communities. These traits include a high rate of population growth, which contributes to rapid colonisation; the ability to move long distances, which contributes to the colonisation of distant habitats; tolerance of close association with humans; and tolerance of a broad range of physical conditions.

Landscape level processes

Climate change has the potential to have a profound effect on landscape-level processes, altering both the frequency and extent of major disturbance events (Figure 12). Droughts can lead to insect epidemics and major wildfires over vast areas with significant effects, and both frequency and severity can be expected to increase significantly with climate change. Disturbance processes, such as fire, may lead to some forest ecosystems being converted to grassland ecosystems. Besides direct habitat loss, the interaction between climate and fire regimes has the potential to overshadow the direct effects of climate change on the distribution and migration of forest species. Changes in disturbance regimes are, therefore, expected to be a major driver of ecosystem-level changes that may include changes in structure (e.g., dominant vegetation, age class distribution, species composition), functioning (e.g., productivity, decomposition, nutrient cycling), and distribution within and across landscapes.

Figure 11: **Climate change impacts: Evolutionary effects**

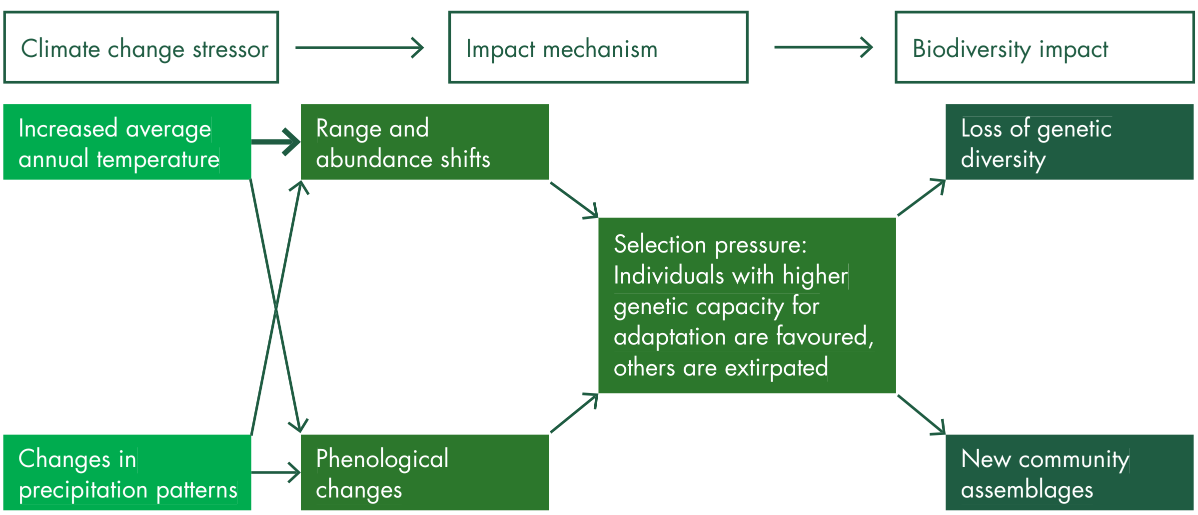
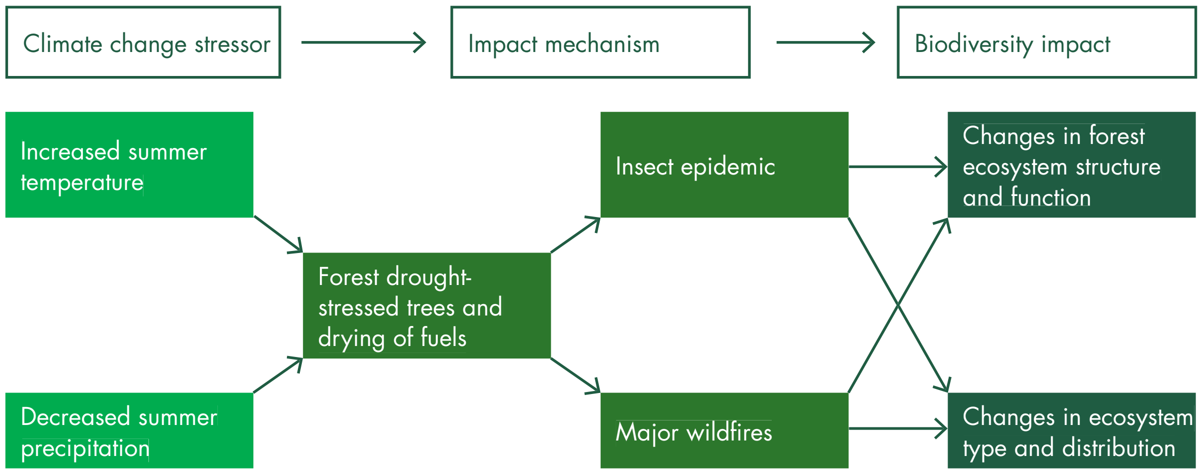


Figure 12: **Climate change impacts: Disturbance regimes and ecosystem-level change**



Observed and projected impacts and threats

Table 18 presents a list of observed and projected impacts of climate change on biodiversity in the EH. The list has been compiled based on literature, stakeholders' workshops, and a stakeholder survey. The list is not intended to be comprehensive, but rather to present an overview of impacts that have been identified in the EH. The circle coding in the table provides a broad differentiation between impacts that have been observed (or documented scientifically), versus those that are projected (or otherwise hypothesised).

Based on a broad review of impact literature, people's perception surveys, and the outcome of a series of stakeholder dialogues, sufficient evidence has been collected to postulate impact characteristics traversing systems and impact mechanisms that are synergistically coupled with other biodiversity impact mechanisms (e.g., habitat loss, invasive species). Impacts on genetic diversity are poorly studied relative to impacts at the species or ecosystem levels. Some of the highest priority threats to biodiversity in the EH from climate change are summarised in Table 19, as assessed on the basis of the information currently available for the EH (Table 18) and the broader literature on potential climate change impacts. A more detailed assessment of observed, perceived, and projected impacts of climate change on the components of mountain ecosystems is given in the separate technical reports that complement this assessment.

Impacts on Water, Wetlands and Hazards, and Consequences for Biodiversity

The EH plays a critical role in the provision of water to the Asia continental monsoon. Because of the sensitivity of mountain glaciers to temperature and precipitation, the behaviour of glaciers provides some of the clearest evidence of atmospheric warming and changes in the precipitation regime, both modulated by atmospheric circulation and flow patterns over the past decades (Haeberli and Beniston 1998; WGMS 2000). As mountains are the source of the region's rivers, the impact of climatic change on hydrology is likely to have significant repercussions, not only in the mountains themselves, but also in populated lowland regions that depend on mountain water resources for domestic, agricultural, hydropower generation, and industrial purposes. Significant shifts in climatic conditions will also have an effect on social and economic systems in the region through changes in demand, supply, and water quality. Any shortfall in water supply will enhance competition for water use for a wide range of economic, social, and environmental applications. Such competition will be sharpened as a result of larger populations downstream, leading to heightened demand for irrigation and perhaps also industrialisation, at the expense of drinking water (Noble and Gitay 1998).

Natural systems related to snow, ice, and frozen ground (including permafrost) are being affected through the enlargement and increased number of glacial lakes, increasing ground instability in permafrost regions, and

Table 18: **Observed and projected impacts of climate change on biodiversity in the Eastern Himalayas**

Biodiversity impact	System		Level			Range			
Description	**Terrestrial**	**Freshwater**	**Ecosystem**	**Species**	**Genetic**	**Local**	**Widespread**	**Impact mechanism/ hypothesis**	**Climate change driver**
Loss and fragmentation of habitat	●		●				●	Ecological shift, land use change, exploitation	Temp change
Vertical species migration and extinction	○			○		○		Ecological shifts	Temp change
Decrease in fish species (in Koshi river)		●		●		●		Less oxygen, siltation	Temp change, extreme weather events
Reduced forest biodiversity	○●		○●				○●	Ecological shift, habitat alteration, forest fire, phenological changes	Temp change, precipitation change, land use change, overexploitation
Change in ecotone and micro-environmental endemism	○		○	○		○		Ecological shifts, microclimate	Temp change
Peculiar tendencies in phenophases, in terms of synchronisation and temporal variabilities	●			●		●		Phenological changes	Temp change
Wetland degradation (Umiam Lake, Barapani in Meghalaya) (climate attribution is strongly contested)		●	●		●			Siltation	Precipitation change
Degradation of riverine island ecosystems (Majuli) and associated aquatic biodiversity (refuted, but not overlooked)		●	●		●			Flooding	Extreme weather events
Loss or degradation of natural scenic beauty	○	○	○				○	Drought, reduced snowfall	Less precipitation
Reduced agrobiodiversity	○●		○●				○●	Monoculture, inorganic chemicals, modern crop varieties, degeneration of crop wild relatives	Higher temp and more precipitation
Change in utility values of alpine and sub-alpine meadows	○		○			○		Biomass productivity, species displacement, phenological changes	Higher temp and more precipitation
Loss of species	○	○		○			○	Deforestion, land use change, land degradation	Higher temp and more precipitation
Increase in exotic, invasive, noxious weeds (mimosa in Kaziranga)	●			●		●		Species introduction and removal, land use change, tourism	Higher temp and more precipitation
Decline in other resources (forage and fodder) leading to resource conflicts	●		●				●	Reduced net primary productivity	Higher temp and less precipitation
Successional shift from wetlands to terrestrial ecosystems, and shrinkage of wetlands at low altitudes (Loktak Lake, Deepor Beel)	●○		●○			●○		Habitat alteration, drought, eutrophication	Higher temp and less precipitation
Increase in forest fires (Bhutan)	●		●			●		Forest fire, land degradation	Higher temp and extreme weather events like long dry spells
Invasion by alien or introduced species with declining competency of extant and dominance by xeric species (e.g., Mikania, Eupatorium, Lantana)	●○			●○			●○	Species introduction, land use change	Higher temp and less precipitation
Increased crop diversity and cropping pattern	○			○		○		Demographic and socio-economic change	Variable temp and variable precipitation
Drying and desertification of alpine zones			○				○	Drought, overgrazing	Higher temp and less precipitation

Cont...

Biodiversity impact	System		Level			Range			
Change in land use patterns	●		●				●	Development policy, socioeconomic change	Variable temp and precipitation
Soil fertility degradation	●		●				●	External inputs, land use intensification, desertification	Higher temp and less precipitation
High species mortality	○	○		○		○		Range shift, pollution, deforestion	Higher temp and less precipitation, less days/ hours of sunshine
More growth/biomass production in forests, variable productivity in agriculture (orange)	○●		○●			○●		Carbon enrichment, external input, reduced grazing	Increased CO_2 level, higher temp
Net methane emission from wetlands (Thoubal, Vishnupur)		○●	○●			○●		Resource use, drainage, eutrophication, flow obstruction	Increased CO_2 level, higher temp
Increased degradation and destruction of peatlands (bog, marshland, swamps, bayou)		○	○		○			Land conversion, drainage, removal of ground cover	Higher temp and less precipitation
Land use change that increases soil degradation	●		●				●	Overpopulation, unsustainable agriculture	Variable temp and variable precipitation

● Observed/documented response; ○ Projected/hypothesised response

Source: ICIMOD 2009

Table 19: **Summary of priority climate change threats to biodiversity in the EH**

Species at risk	Although there could be some benefits for at risk species, in general, there is significant concern for species at risk that are already threatened by small population size, loss of unique habitats, and low reproduction/ dispersal rates (among others). Any potential for climate change to further exacerbate these existing causes could greatly increase the risk of extinction.
Aquatic habitats	Extended summer low flow periods are expected in rainfed streams. This will further increase water temperature, favouring warm water species and altering community structure and functioning. Conversely, in snowmelt and glacier-fed streams, the magnitude and duration of summer floods is expected to increase. In either case, significant impacts on aquatic habitats are expected.
Wetlands	Wetlands are particularly vulnerable to climate change. As physiographically limited systems, they are unable to migrate and, hence, are vulnerable to changes in hydrology, nutrient inputs, and others.
Alpine ecosystems	Given their restricted geographic area and narrow elevation range, alpine ecosystems are particularly vulnerable to climate change. Climate and vegetation change rapidly with altitude over relatively short distances in mountainous terrain. As a result, alpine ecosystems are particularly vulnerable to encroachment by lower elevation ecosystems.
Forest and grassland ecosystems	The current pine bark beetle epidemic is a matter of serious concern. Ongoing concerns include the increased potential for major widespread wildfires and the subsequent potential for transformations in disturbed ecosystems, such as colonisation by invasive species and resultant new species assemblages. Grassland ecosystems may expand in range, yet face threats in terms of lost species diversity.
Invasive species	Climate change may expedite the colonisation of some areas by invasive species in both terrestrial and freshwater realms. Increased frequency and magnitude of forest disturbances will create openings vulnerable to colonisation by invasive plants.
Protected area ecosystems	Protected areas are widely acknowledged as one of the most important management instruments for biodiversity conservation. In the EH, protected area systems are some of the most intricate and complex, maintaining a delicate balance between conservation and sustainable use. The potential for major, long-term ecosystem shifts under a changing climate suggests a need to re-evaluate the protection of representative ecosystems with a stronger focus on the landscape approach as it is based on broad topographical features that do not shift with climate change.

Impacts on water, hydrology, wetlands and hazards: IPCC projection and consequences for human wellbeing

IPCC projection: It is very likely that mountain glaciers and snow cover will continue to retreat. With rising temperatures, changes in runoff patterns and increased water evaporation will impact on the distribution of water and on the timing of flows. It is likely that tropical cyclones will become more intense as oceans warm, with higher peak speeds and heavier precipitation. Droughts and floods will become more frequent and widespread.

Human wellbeing projection: There is an imminent prospect of increased water stress. Water supply stored in glaciers and snow cover will decline, groundwater levels will fall rapidly (threshold = 1000 cubic metres per capita per annum). The thousands of glaciers located across the 2,400 kilometres of the extended Himalayan range are at the epicentre of an emerging crisis. The largest mass of ice outside the polar caps is shrinking. Avalanches, floods, and flash floods, including GLOFs, pose special risks to densely populated mountain regions. As glacial water stores are reduced, water flows will diminish. The Ganges could lose two-thirds of its July to September flow, causing water shortages for over 500 million people and one-third of India's irrigated land area. Projections for the Brahmaputra indicate reduction in flows of between 14 and 20% by 2050.

Extreme and unpredictable weather events bring short-term human insecurity and destroy long-term efforts aimed at raising productivity, improving health, and developing education, perpetuating the poverty trap. Climate change is one of the forces that will influence the profile of risk exposure in the decades ahead. However, climate change will reconfigure patterns of risk and vulnerability. The combination of increasing climate hazards and declining resilience is likely to prove a lethal mix for human development. Rainfed production may suffer from drought as length of growing period is determined by water availability. Settlements located on mountainsides are vulnerable to flooding and landslides.

rock avalanches in mountain regions. Widespread mass losses from glaciers and reductions in snow cover over recent decades are projected to accelerate throughout the 21st Century, reducing water availability, hydropower potential, and changing the seasonality of flows in basins supplied by meltwater from snow and ice. For example, during the 20th Century, glaciers and ice caps in the EH experienced widespread losses, which are likely to have major consequences for water supply in several adjoining areas. The mountain hydrology is being affected in terms of increased runoff and earlier spring peak discharge into many glacier-fed and snow-fed rivers. Runoff is projected to increase up till the 2030s time range and gradually reduce thereafter, contrary to what the IPCC has predicted for the region. In Nepal, a preliminary analysis of river discharge some years ago showed decreasing trends for the Karnali and Sapta Koshi rivers, but an increasing trend for the Narayani river (DHM 1996). Increased temperatures will further affect the physical, chemical, and biological properties of wetlands, freshwater lakes, and rivers, with predominantly adverse impacts on their thermal structures, freshwater species, community composition, and water quality. Winter precipitation in the form of snowfall has declined over the years and the area under snow cover is projected to contract. Widespread increases in thaw depth are projected over most permafrost regions. Drought-affected areas are projected to increase in extent, with large increases in irrigation water demand.

The beneficial impact of increased annual runoff in some areas is likely to be tempered by the negative effects of increased precipitation variability and seasonal runoff shifts on water supply, water quality, and flood risk. Available research suggests a significant future increase in heavy rainfall events will result in increased flood risk to society, physical infrastructure, and water quality. Increases in the frequency and severity of floods and droughts are projected to adversely affect sustainable development. Shrestha et al. (2003) suggest that the number of flood days and consecutive days of flood events have been increasing in Nepal. Increases in glacier melting and likely increases in runoff will heighten the risk of glacial lake outburst floods. According to Qin Dahe (1999), there are 2,968 glaciers in the EH with a total area of 4,160 km^2 and a total ice volume of 415 km^3. Retreat of glacier fronts and negative mass balances characterise most glaciers in the Eastern Himalayas (since around 1900 with only brief interruptions). Himalayan glaciers are retreating at an average rate of 18 to

20 m/yr (PC-GOI 2006). In Nepal, the Department of Hydrology and Meteorology (DHM 2004) found that almost 20% of the present glaciated area above 5000 m in altitude is likely to become snow and glacier free with an increase in air temperature of 1°C. A rise of 3 to 4°C would result in the loss of 58 to 70% of snow and glaciated areas accompanied by an increased threat of GLOFs.

Impact on surface water availability

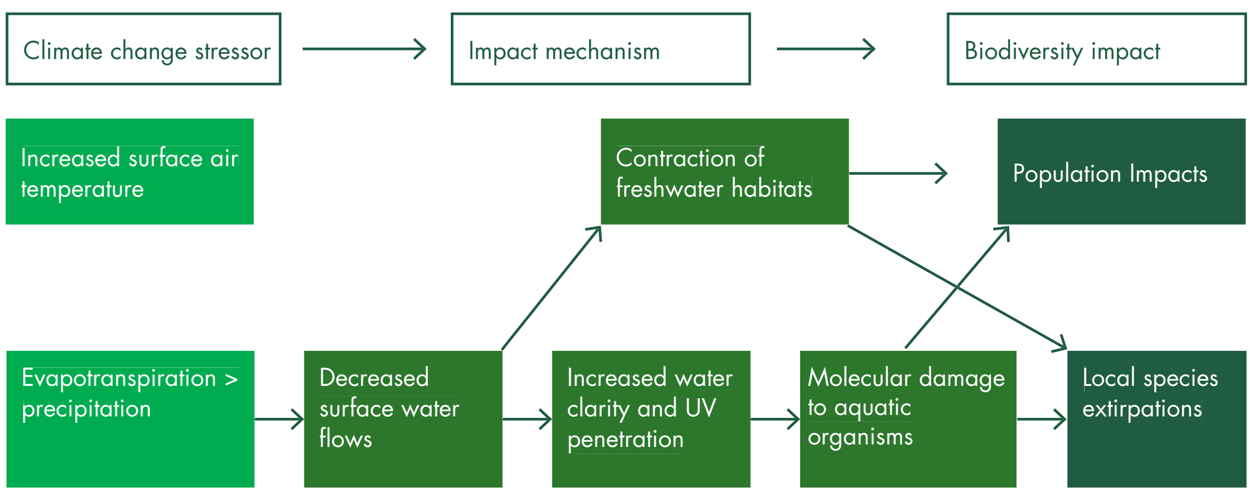
Water availability, in terms of both temporal and spatial distribution, is expected to be highly vulnerable to climate change. Growing populations and the concentration of the population in urban areas will exert increasing pressure on water availability and water quality. Some areas are expected to experience increases in water availability; other areas will have reduced water resources. The majority of the perennial rivers in the EH receive water from snow and glaciers. The contribution of snow to the runoff of major rivers in the EH is about 10% (Sharma 1993), in contrast to more than 60% in the western Himalayas (Vohra 1981). Because the melting season for snow coincides with the summer monsoon season, any intensification of the monsoon is likely to contribute to flood disasters in the catchments in the EH, although the impact will be less than in the western Himalayas. An increase in surface runoff during autumn and a decrease in spring are projected for the EH. The increase in surface temperature will contribute to a rise in the snow line, which in turn will increase the risk of flooding during the wet season as less precipitation is stored in the form of snow.

The supply of water in the EH is limited and governed by the renewal processes associated with the hydrological cycle (Figure 13). A warming climate will generally enhance the hydrological cycle resulting in higher rates of evaporation and a greater proportion of liquid precipitation (more rain and less snow). The potential changes in precipitation (amount and seasonality) will affect soil moisture, groundwater reserves, and the frequency of flood and drought episodes. Hydrological systems are also controlled by soil moisture, which largely determines the distribution of ecosystems, groundwater recharge, and runoff; the latter two factors sustain river flow and can lead to floods. However, the impacts of these on freshwater biodiversity are uncertain. Given these possibilities, different impacts of these changes to the water cycle will have different consequences in different watersheds.

When summer evapotranspiration is greater than precipitation, surface water flow will decrease in freshwater systems that are not glacier-fed, resulting in shrinkage and desiccation. This will cause small ponds and wetlands that are surface-water fed to contract. A contraction in these water bodies will reduce freshwater habitats, which in turn will reduce freshwater biodiversity through the contraction of habitats, acidification of lakes, and molecular damage associated with UV exposure. Reduced surface water flows will reduce the amount of available cations and thus the buffering capacity of softwater lakes, accelerating acidification and impacting negatively on organisms that cannot tolerate reductions in pH. The clear water of acidic lakes offers less protection against damaging UV rays.

The seasonal character and amount of runoff in the EH is closely linked to its wetland ecosystems and the cryospheric processes of snow, ice, and glaciers. Glacier melt influences discharge rates and timing in the rivers

Figure 13: **Climate change impact: Hydrological cycle change to reduce surface water availability**



that originate in the mountains. The timing of peak runoff, associated with the monsoon in many EH river basins, may change in the future. Shifts in the timing and intensity of the monsoon, and the manner in which the Himalayan range intercepts the available precipitable water content in the atmosphere, will have major impacts on the timing and amount of runoff in river basins such as the Ganges, the Brahmaputra, and the Irrawaddy. For every 1°C increase in temperature, the snowline will rise by about 135 m. Shifts in snowpack duration and amount as a consequence of sustained changes in climate will be crucial factors in water availability in hydrological basins. As glaciers melt rapidly, they will provide enhanced runoff, but as the ice mass diminishes, the runoff will wane. Availability of water from snow-fed rivers may increase in the short term, but will decrease in the long term.

When evapotranspiration is less than precipitation, water flow will increase. Increased glacial runoff and the thawing of permafrost due to warming will add to increases in flow in glacier-fed systems (for a period of decades, until this runoff eventually subsides). Increased water flow could change stream channel morphology by causing erosion along the banks and depositing sediments elsewhere. Such changes in channel morphology have direct links to freshwater species' lifecycles and habitat requirements (e.g., fish spawning and rearing), which in turn can have direct population-level impacts (Figure 14).

Impacts on freshwater ecosystems

There is growing concern that climate change may accelerate the damage to wetlands and freshwater ecosystems such as lakes, marshes, and rivers. The response of lakes and streams to climate change will involve complex interactions between the effects of climate on runoff, flow volume, hydrology, catchments, and in-lake processes. Climate change is expected to increase the temperature of lakes, streams, and other water bodies. Increases in water temperature may lower dissolved oxygen concentrations, particularly in summer low-flow periods (IPCC 1998). This will be detrimental to cold-water species in two ways: firstly, a direct temperature increase will reduce their survival or potentially extirpate species from asphyxiation and extremes beyond their narrow temperature range. Secondly, particularly in smaller lakes, warmer temperatures will generally occur at the surface layer enhancing production as most aquatic organisms are cold-blooded. This increase in production can quickly lead to eutrophication, increasing biological oxygen demand and causing the lower, cooler layer to become anoxic, potentially suffocating cool-water species. Larger lakes, however, may be able to maintain their temperature gradients despite some warming of surface layers. Such lakes may see increases in biodiversity if they are large enough to buffer the temperature effects, and cool water species could actually benefit from increased production (Figure 15).

In lakes and streams, warming will have the greatest biological effects at high altitudes – where biological productivity will increase and lead to the expansion of cool-water species' ranges – and at the low-altitude boundaries of cold- and cool-water species ranges, where extinctions would be greatest. Altered precipitation and temperature patterns will affect the seasonal pattern and variability of water levels in wetlands, potentially affecting valued aspects of their functioning, such as flood protection, carbon storage, water cleansing, and waterfowl/wildlife habitat (IPCC 1998). The geographical distribution of wetlands is likely to shift

Figure 14: **Climate change impact: Hydrological cycle change to increase surface water availability**

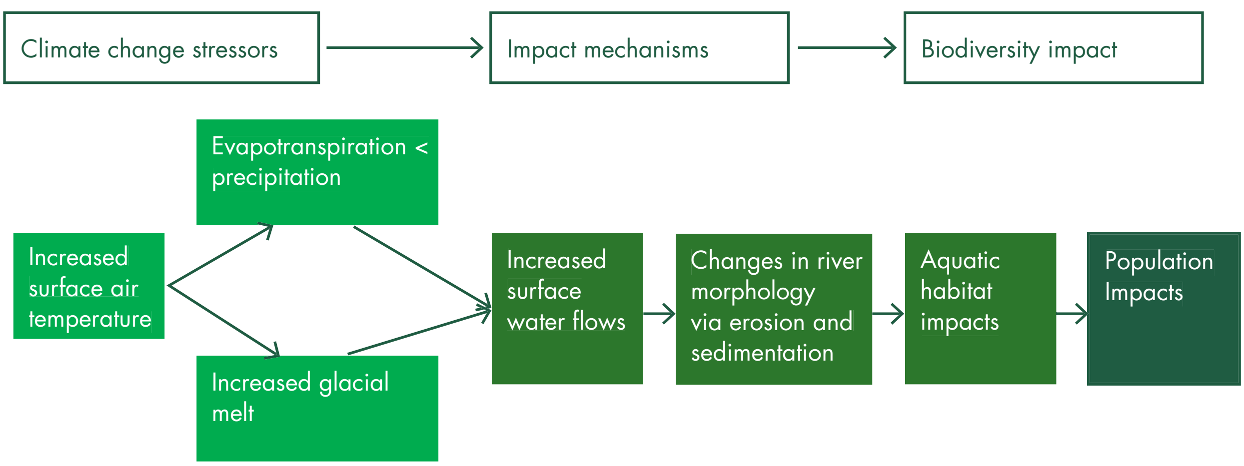


Figure 15: **Climate change impact: Changes in lake productivity**

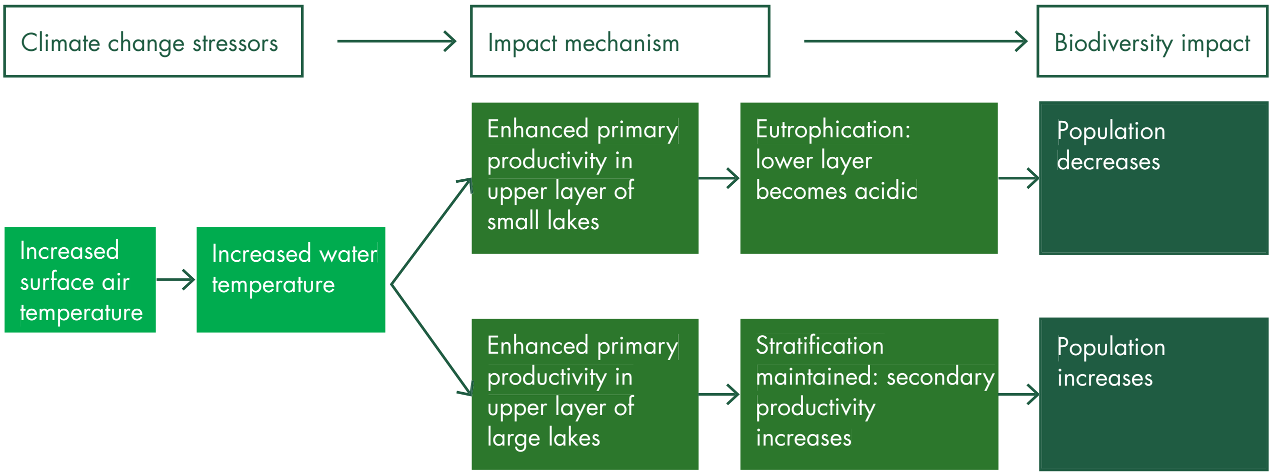
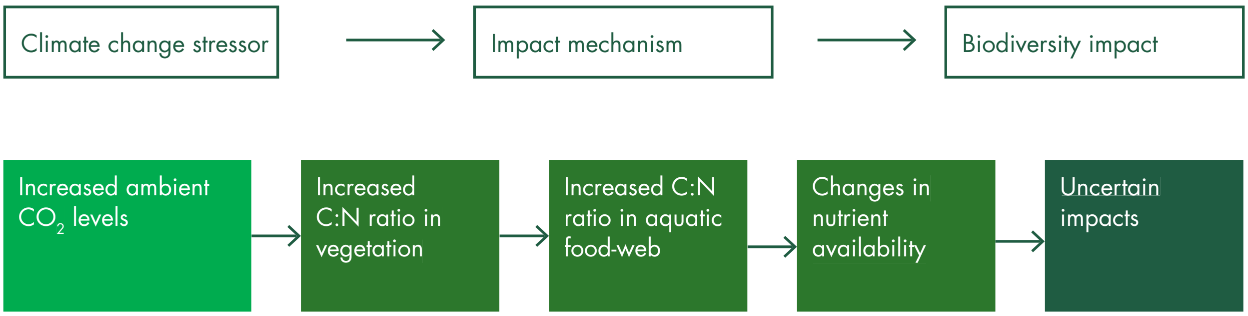


Figure 16: **Climate change impact: Changes in food-web dynamics**



with changes in temperature and precipitation, with uncertain implications for net greenhouse gas emissions from wetlands. Changes in these ecosystems could have major negative effects on freshwater supplies, fisheries, biodiversity, and tourism. Inputs of nutrients and other pollutants into aquatic habitats will vary with rainfall and other characteristics of the watershed.

One of the ways that climate change could affect freshwater biodiversity is by altering the carbon to nitrogen (C:N) ratio in riparian vegetation (Allan et al. 2005) (Figure 16). Increased ambient CO_2 generally increases the carbon to nitrogen ratio in plants. Plant litter provides important nutrient input to water bodies with corresponding increases in carbon in their nutrient pools. This change in nutrient quality could lead to corresponding changes in biological assemblages, enhancing organisms that use carbon efficiently, while suppressing those that depend on larger nitrogen inputs. Such changes in aquatic assemblages are highly uncertain, but would likely be noticeable throughout the entire food-web.

Impacts on Human Wellbeing

Rising prosperity and climate security are not conflicting objectives. Climate change is providing us with a reminder of the symbiotic relationship between human culture and ecological systems. This relationship is very evident in the EH, where some of the world's most fragile ecosystems are being affected by rapid warming. Indigenous people have become sentinels for a world undergoing climate change and the EH, in effect, a global climate change barometer. The livelihoods of subsistence farmers and pastoral peoples, who make up a large portion of the rural populations, could be negatively affected by such changes.

Livelihoods

A major area of serious impacts is in the field of agricultural production. Agriculture is the direct or indirect source of livelihood for over 70% of the population in the EH and is a substantial contributor to national incomes. Agriculture is highly sensitive to climate change and is expected to impact on the region differently, with some

Impacts on livelihoods and health: IPCC projections and consequences for human wellbeing

IPCC projection: There will very likely be decreases in precipitation. Warming in the EH is likely to be above the global average, and is expected to further reduce water availability through increased frequency of droughts, increased evaporation, and changes in patterns of rainfall and runoff.

Climate change will affect human health through complex systems involving changes in temperature, exposure to extreme events, access to nutrition, air quality, and other vectors. Small health effects can be expected with very high confidence to progressively increase in the EH, with the most adverse effects on low-income groups.

Human wellbeing projection: Major losses in agricultural production leading to increased malnutrition and reduced opportunities for poverty reduction are expected. Overall, climate change will lower incomes and reduce the opportunities for vulnerable populations. By the 2080s, agricultural potential could fall by 9%.

Ill health is one of the most powerful forces holding back the human development potential of poor households. Climate change will intensify this problem. Rainfall, temperature, humidity, and flooding are variables that most influence the transmission of malaria, cholera, diarrhoea, kala-azar, and dengue fever; climate change will affect all of these.

places projected to experience a decline in potentially good agricultural land, while others will benefit from substantial increases in suitable areas and production potentials (Fischer et al. 2002a). Management of climate hazards and climate change impacts in the agricultural sector and rural communities will be critical for success. The main direct effects of climate change will be through changes in factors such as temperature, precipitation, length of growing season, and timing of extreme or critical threshold events relative to crop development, as well as through changes in atmospheric CO_2 concentrations (which may have a beneficial effect on the growth of many crop types). Watershed responses to climate change are complex in terms of the simulated impacts of elevated concentrations of carbon dioxide and temperature and precipitation changes upon simulated fluxes of energy, water, carbon, and nutrients. The positive effects of climate change – such as longer growing seasons, lower natural winter mortality, and faster growth rates at higher altitudes – may be offset by negative factors such as changes in established reproductive patterns, migration routes, and ecosystem relationships. Indirect effects will include potentially detrimental changes in diseases, pests, and weeds, the effects of which have not yet been quantified. The extent of agricultural pollution will, thus, depend upon both human responses to climate change and changes in runoff associated with altered precipitation patterns.

Several studies in the past have shown that the production of rice, corn, and wheat has declined due to increasing water stress arising partly from increasing temperature, the increasing frequency of El Niño, and a reduction in the number of rainy days (Agarwal et al. 2000; Jin et al. 2001; Fischer et al. 2002b; Tao et al. 2004).

Climatic changes are predicted to reduce the livelihood assets of poor people, alter the path and rate of national economic growth, and undermine regional food security due to changes in natural systems and infrastructure impacts. Malnutrition, for example, will be further exacerbated due to disruptions to the growing conditions and environmental stresses at critical phenological stages. The flowering and fruiting phenology of many species will alter. Late snowfall could trigger the relative immobilisation of bees due to low temperatures, indirectly affecting the processes of pollination. As its cryospheric water towers are depleted, the EH is expected to experience excess runoff until the middle of this century, with meltwater flow declining thereafter. Extremes in floods and droughts through much of the century may destroy the food production base of the region (Bruinsma 2003). The food security and wellbeing of its people could suffer as a consequence of greater exposure to water-related hazards.

Fischer et al. (2002a) using agro-ecological zone (AEZ) methodology, quantified regional impacts and geographical shifts in agricultural land and productivity potentials, and the implications for food security resulting from climate change and variability. The analysis indicated likely increases in general in crop yield potential for temperature increases of 1 to 3°C, depending on crop. However, in specific cases, especially in seasonally dry and tropical regions, crop productivity is projected to decrease for even small local temperature increases (1 to 2°C), which would increase the risk of hunger. Accordingly, a temperature increase above 1.5 to 2.5°C is expected to lead to a decline in the agricultural productivity of crops such as rice, maize, and wheat. In a study by the International Rice Research Institute, the yield of rice was observed to decrease by 10% for every 1°C rise in growing-season minimum temperature (Peng et al. 2004). In all likelihood, the wheat crop in the EH is already being adversely affected by climate change, as the area under wheat cultivation has been declining over the years. The regional aggregation of results, based on the HadCM3-A1FI 2080s scenario, showed a substantial decrease in wheat production potential in South Asia (20-75%), a distinct downward trend in the production potential of rainfed sugar crops (6-38%), and a loss of 23% to a gain of 20% for roots and tubers depending on location.

Higher temperatures during flowering may counter CO_2 effects (which lead to higher yields) by reducing grain number, size, and quality (Caldwell et al. 2005). Increased water demand under warming may also reduce CO_2 effects. Studies concentrated on the region have revealed that the net effect of temperature and carbon fertilisation is negative on rice yield (Karim et al. 1996). Yields of rainfed wheat grown at 450 ppm CO_2 increased up to 0.8°C warming, then declined beyond 1.5°C warming; additional irrigation was needed to counterbalance these negative effects (Xiao et al. 2005). Net cereal production in the region is projected to decline at least between 4 to 10% by the end of this century under the most conservative climate change scenario (Lal 2005). India could lose 125 million tons, equivalent to 18% of its rainfed cereal production; in contrast, China's rainfed cereal production potential of 360 million tons could increase by 15%.

Upland crop production, practised close to the margins of viable production, can be highly sensitive to variations in climate. The upward shift in thermal regimes due to warming will result in upward shifts of agricultural zones to higher elevations. For example, the buckwheat-barley belt will give way to rice cultivation, a trend already observed in Bumthang Dzongkhag in Bhutan at an altitude of more than 3000 masl. A temperature increase of 2°C would theoretically shift rice cultivation to even higher elevations, but here landforms are mainly steep, craggy slopes, appropriate only for protection forests. Warming may have positive impacts on some crop yields in some regions, but only if moisture is not a constraint. However, increases in the occurrence of extreme events or pests may offset any potential benefits.

Climate change is likely to represent an additional stress in areas experiencing rapid social change, as in many of the EH rangelands. Likewise, rangeland and pastoral production systems are likely to be affected by a decline in forage quality and quantity, heat stress, and diseases like foot and mouth in livestock. Grassland productivity is expected to decline by as much as 40 to 90% for an increase in temperature of 2 to 3°C combined with reduced precipitation (Smith et al. 1996). Fisheries and fish production are also sensitive to changes in climate and are currently at risk from overfishing, diminishing spawning areas, and extensive pollution. Inland freshwater fisheries at higher elevations are likely to be adversely affected by lower availability of oxygen due to a rise in surface air temperatures. In the plains, the timing and amount of precipitation could also affect the migration of fish species from rivers to the floodplains for spawning, dispersal, and growth (Bruinsma 2003). Climate change has the potential to substantially alter fish breeding habitats, the food supply for fish, and, ultimately, the abundance of freshwater fish populations (IPCC 2001a). Finally, both crops and livestock will be affected by increased incidence of alien/invasive pests and diseases.

Health

It is extremely difficult to make any projections about the extent and direction of the potential impacts of climate variability and change on human health with any confidence, because of the many confounding and poorly-understood factors associated with potential health problems. Equally, the complex interactions between climate stresses on the ecology of infectious diseases and other factors will determine how effectively prospective problems can be dealt with. The sensitivity of human health to various aspects of weather and climate, differences in the vulnerability of different socioeconomic, demographic and geographic segments of the population, movement of disease vectors, and health sector reforms are some of the factors that determine exposure, transmission, infection results, treatment, and prognosis. Forecasting climate change impacts on health is complex, because populations have different susceptibilities to disease and modelling health impacts is, therefore, that much more difficult. Consequently, there are very few studies that have attempted to look at the effects of climate change on health in the region. Data on health surveillance in the EH are not readily available, making predictions and comparisons difficult. These inadequacies notwithstanding, climate influence on human health is certain, and it is likely that newly affected populations will initially experience higher fatality rates.

Climate change will have a wide range of health impacts all across the EH through, for example, increases in malnutrition due to the failure of food security strategies, stress, disease, and injury due to extreme weather events (Epstein et al. 1995); increased burden of diarrhoeal diseases from deteriorating water quality; altered spatial distribution of some infectious diseases; and increased frequency of cardio-respiratory diseases from high concentrations of air pollutants such as nitrogen dioxide (NO_2), lower tropospheric and ground-level ozone, and air-borne particulates in large urban areas. A reduction in winter-time deaths is anticipated; however, human health is likely to suffer chronically from impacts related to heat stress (Bouchama et al. 1991; Ando 1998). Overall, climate change is expected to result in negative health effects associated with rising temperatures. Combined exposure to higher temperatures and air pollutants appears to be a critical risk factor for health during the summer months (Piver et al. 1999).

Endemic morbidity and mortality due to diseases primarily associated with floods and droughts are expected to rise with projected changes in the hydrological cycle. In the lowlands, hygrothermal stresses (warmer and wetter conditions) will also influence the epidemiology and increase the incidence of heat-related and vector-borne infectious diseases with increases in transmission windows (Martens et al. 1999). Malaria, schistosomiasis, and dengue are very sensitive to climate and are likely to spread into new regions on the margins of presently endemic areas because of climate change. Vectors require specific ecosystems for survival and reproduction; epidemics of these diseases can occur when their natural ecology is disturbed by environmental changes, including changes in climate (McMichael et al. 2001). With a rise in surface temperature and changes in rainfall patterns, the distribution of vector mosquito species may change (Patz and Martens 1996; Reiter 1998). Temperature can directly influence the breeding of malaria protozoa and suitable climate conditions can intensify the invasiveness of mosquitoes (Tong et al. 2000). Another concern is that changes in climate may allow more virulent strains of disease or more efficient vectors to emerge or be introduced to new areas.

Changes in temperature and precipitation could also expand vector-borne diseases into high altitude locations that hitherto have been uninfected. Expanding the geographic range of vectors and pathogens into new areas, increasing the area of suitable habitat and number of disease vectors in already endemic areas, and extending transmission seasons could expose more people to vector-borne diseases. Studies carried out in Nepal indicate that the present subtropical and warm temperate regions are particularly vulnerable to malaria and kala-azar. Climate change-attributable water-borne diseases including cholera, diarrhoea, salmonellosis, and giardiasis are prevalent in Bhutan, India, Myanmar, and Nepal. The relative risk of these conditions in 2030 is expected to increase as a result of elevated temperatures and increased flooding (Patz et al. 2005).

Other components of human wellbeing

Climate change is also poised to have an adverse impact on other components of human wellbeing, unless policies, legislation, and institutions are put in place to make development sectors more resilient to climatic perturbations. For years, too many viewed global warming simply as an environmental or economic issue. We now need to consider it as a security concern. The adverse impacts of climate change will place additional stress on socioeconomic and physical systems. These pressures may induce changes in demographic processes. Demographic trends, including the stability and size of populations, will be influenced directly through the impacts of climate change on human health and indirectly through the impacts of climate change on food security, human settlements, and the viability of natural resource-based economic activity. If the incidence and magnitude of extreme events such as droughts and floods increase, there could be large-scale demographic responses like migration. The annual rate of growth in migration has been disturbing in the countries of the EH, and the number of internally displaced people is expected to rise. Motivations for migration are diverse, with much of the rural-to-urban migration taking place as a result of increased economic opportunities and access to social services in urban centres. The situation is exacerbated by regular floods and droughts affecting the livelihoods of the landless and poor farmers in the region. Climate change will act in concert with other complex social, cultural, and economic motivations to spiral migration (Pebley 1998; Conway et al. 2000; Kates 2000).

Recreation is one of many cultural ecosystem services (MEA 2003). A rise in the elevation of the snow line will impact on winter tourism and change the seasonality of mountain runoff. In socioeconomic terms, mountain landscapes attract large numbers of people in search of opportunities for recreation and tourism. However, the environmental stress imposed by growing numbers of tourists is placing an increasingly heavy burden on mountain resources (Godde et al. 2000) and local communities. Tourism is, thus, both a significant economic driver for many mountain communities, but also an industry capable of adversely affecting the environmental quality of mountains and uplands.