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Bioresources and Bioprocess in Biotechnology

Volume 1: Status and Strategies for Exploration

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Climate Change and Biodiversity

5

A. Biju Kumar and R. Ravinesh

Abstract

Climate change is a vital environmental issue affecting nature and distribution of biodiversity. As the economy of developing countries depends primarily upon climate-sensitive sectors such as agriculture, fisheries and forestry, a holistic analysis of climate change and its implications on biodiversity is warranted in order to achieve sustainable development. The impacts of climate change on critical ecosystems and livelihood activities and on insert biological resources, especially those that are vulnerable due to other prevailing anthropogenic interventions, are discussed in the chapter. The strategies to reduce climate change impacts, including adaptation and mitigation measures, which integrate ecosystem approach into broader cross-sectoral policies as a compliment to structural and technological measures, would ultimately help achieving the targets set for biodiversity conservation. The ecosystem approach of the Convention on Biological Diversity provides a flexible management framework to address climate change mitigation and adaptation activities in a broad perspective and can help to balance ecological, economic and social considerations in projects, programmes and policies related to climate change mitigation and adaptation. The research options on the appropriate mitigation and adaptation strategies so as to manage the rich biodiversity and to specifically address the impacts of climate change on species and ecosystems coupled with the need to integrate biodiversity into developmental plans and policies are discussed.

Keywords

Biodiversity • Climate change • Mitigation • Adaptation • Sustainable development • Aichi target • IPCC • Ocean acidification

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5.1 Introduction

The United Nations Framework Convention on Climate Change (UNFCCC), in its Article 1, defines climate change as ‘a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods’. The Intergovernmental Panel on Climate Change (IPCC) reports unequivocally established the warming of climate system, and since the 1950s, many of the observed changes are unprecedented over decades to millennia. The atmospheric concentrations of the greenhouse gases (GHG) such as carbon dioxide, methane and nitrous oxides responsible for climate change have increased alarmingly in the last five decades compared to any other era in planetary history (IPCC 2014a, b).

Some changes in extreme weather and climate events observed since 1950s are linked to human activity, resulting in impacts such as decrease and increase in temperature extremes, increase in extreme high sea levels due to melting of glaciers and increase in the number of heavy precipitation events. Projections of IPCC suggest an increase in global mean temperature in 2100 of 3.7–4.8 °C, relative to pre-industrial levels, in the absence of new policies to mitigate climate change. While the per capita contribution of greenhouse gas emission of industrialised countries is on average 2.5 times of those from developing countries, global GHG emissions have continued to grow and reached 49.5 billion tons (gigatons or Gt) of carbon dioxide equivalents (CO_2eq) in the year 2010, higher than any level prior to that date, with an uncertainty estimate at ± 10% for the 90% confidence interval (Victor et al. 2014).

The first report published by Indian Network for Climate Change Assessment (INCCA) of the Ministry of Environment and Forests and Climate Change projected a net increase in annual temperatures in the 2030s ranging between 1.7 °C and 2.2 °C, with extreme temperatures increasing by 1–4 °C, with maximum increase in coastal regions; seasons may be warmer by around 2 °C towards the 2030s (INCCA 2010). Trend analysis of past precipitation data in India has not shown any major widespread change in the patterns, though general circulation models (GCMs) show that in the future, these patterns are likely to change. Potential climate change impacts affecting water availability include changes in precipitation amount, intensity, timing and form (rain or snow), changes in snowmelt timing and changes to evapotranspiration. In India, winter precipitation is projected to decline, and this is likely to lead to higher need for rabi irrigation, lesser storage and increased water stress during the pre-monsoon months (INCCA 2010).

The current trajectory of global greenhouse gas emissions is not consistent with limiting global warming to below 1.5 relative to pre-industrial levels, as suggested in the United Nations Paris Climate Change Conference in December 2015, with a global effort to significantly reduce the risks and impacts of climate change. With increasing evidences of human interferences in the climate system, there are mounting numbers of reports highlighting the risks of climate change on both human and natural systems (Field et al. 2014). The social impacts of climate change include food and water shortages, increased poverty, increased displacement of people (often referred to as climate refugees) and coastal flooding. Globally, habitat loss and degradation, unsustainable exploitation, invasive species and climate change are the main threats facing the biodiversity, the natural capital of earth, and they have contributed to a decline of over half of the Living Planet Index since 1970, including the species of mammals, birds, reptiles, amphibians and fish (WWF 2016).

5.2 Climate-Biodiversity Linkages

Biodiversity, the variety of genes, species and ecosystems that constitute life on earth and the intricate interrelations of living creatures and the environment that evolved along with time, is the basis of human development and sustenance, as it ensures the sustainability of life support systems—air, water and food—besides the scope for future values, which remains unknown for many species. The biodiversity loss or the 'sixth extinction' is currently at its peak, with everyday species extinctions continuing at up to 1000 times or more the natural rate, highlighting the need for effective conservation programmes (Barnosky et al. 2011).

The United Nations Convention on Biological Diversity (CBD), agreed at the 1992 UN Conference on Environment and Development (Earth Summit), is one of the most widely ratified treaties in the world, with the fundamental objectives to conserve biodiversity, sustainable utilisation of biodiversity and sharing of benefits arising out of biodiversity. Since the World Summit on Sustainable Development in 2002, 193 parties to the CBD have committed themselves to substantially reducing rates of biodiversity loss by 2010 ('Biodiversity Target'), and this goal was incorporated into the UN Millennium Development Goals (MDG) in 2005. Following this, a wide array of international, national and regional strategies and action plans have been forwarded to achieve the goals of biodiversity conservation. There are also a series of conservation initiatives by civil society organisations across the globe. India also prepared the National Biodiversity Strategies and Action Plan (NBSAP) and enacted the Biological Diversity Act (2002) and the Biological Diversity Rules (2004). The United Nations has declared 2010 as the International Year of Biodiversity (IYB) to create awareness about the crucial importance of biodiversity to society, to communicate the human costs of biodiversity loss and to enthuse people, particularly youth, throughout the world in the fight to protect biodiversity.

In October 2010, in Japan, governments agreed to the 'Strategic Plan for Biodiversity 2011–2020 and the Aichi Targets' as the basis for halting and eventually reversing the loss of biodiversity of the planet. To build support and momentum for this urgent task, the United Nations General Assembly declared the period 2011–2020 to be 'the United Nations Decade on Biodiversity, with a view to contributing to the implementation of the Strategic Plan for Biodiversity for the period 2011–2020'. The United Nations Decade on Biodiversity will serve to support the implementation of the Strategic Plan for Biodiversity and promote its overall vision of living in harmony with nature, with a goal to mainstream biodiversity at different

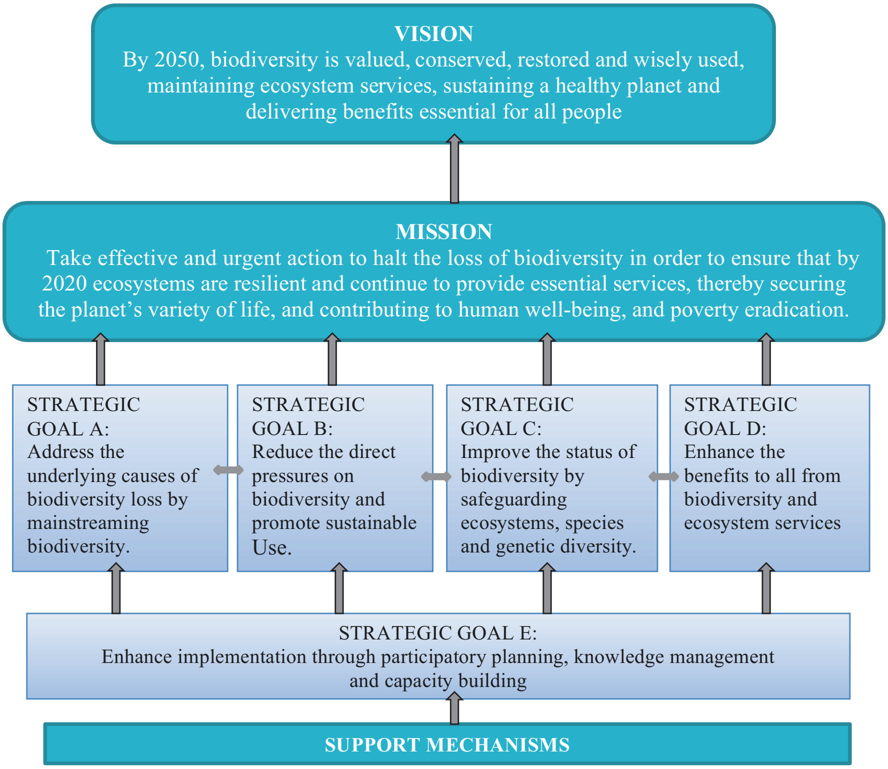

Fig. 5.1 Strategic Plan for Biodiversity 2011–2020: vision, mission and strategic goals

levels (Fig. 5.1). At the national and regional levels, this period should serve as a time to develop, implement and communicate the results of national strategies for implementation of the Strategic Plan for Biodiversity.

For achieving the Aichi Targets by 2020, especially the five strategic goals such as addressing the underlying causes of biodiversity loss by mainstreaming biodiversity across government and society, reducing the direct pressures such as climate change on biodiversity and promote sustainable use, improving the status of biodiversity by safeguarding ecosystems, species and genetic diversity, enhancing the benefits to all from biodiversity and ecosystem services and enhancing implementation through participatory planning, knowledge management and capacity building, better planning and concerted action are required. Aichi Target 14 requires that 'by 2020, ecosystems that provide essential services, including services related to water, and contribute to health, livelihoods and well-being, are restored and safeguarded, taking into account the needs of women, indigenous and local communities and the poor and vulnerable' (SCBD 2010).

The origin and expansion of life on earth can be linked to various climatic conditions prevailed on earth. Climate is one of the most important factors controlling the growth, abundance, survival and distribution of species as well as regulating natural ecosystems in a variety of ways. In recent decades, changes in climate have caused impacts on natural and human systems globally. Impacts due to climate change are observed in almost every part of the natural world and its interdependent social and economic systems (Field et al. 2014). Many terrestrial, freshwater and marine species have shifted their geographic ranges and activities in response to climate change. Past climate changes were slower than those anticipated for the twenty-first century, but even these drove significant ecosystem shifts and extinctions (Williams et al. 2011). Climate change will compound the impacts of other drivers of biodiversity loss such as habitat modification, over-exploitation, pollution and invasive species (Field et al. 2014). The economy of developing countries like India depends primarily upon climate-sensitive sectors such as agriculture, fisheries and forestry (Chaturvedi et al. 2014), and therefore climate change and its impacts on biodiversity need to be monitored closely in order to achieve sustainable development.

5.3 Impacts of Climate Change

Although many anthropogenic interventions (changing land-use patterns, pollution, habitat loss, modification and fragmentation, over-exploitation of species and introduction of non-native species) impact biodiversity, the effects of climate change are becoming much more effervescent on natural and human systems on all continents and across the oceans. The climate changes, especially global warming, have affected the timing of reproduction of flora and fauna, migration of animals, the length of the growing season, species distributions and population sizes, spread of invasive species and the frequency of pest and disease outbreaks (IPCC 2002). Climate change is projected to affect individual organisms, populations, species distributions and ecosystem composition and function both directly (e.g., through vagaries in precipitation, temperature, sea level changes, ocean acidification, etc.) and indirectly (e.g., through climate changing the intensity and frequency of events such as forest fires, storms, etc.). Other environmental issues such as habitat loss and fragmentation, pollution and invasive alien species would further exacerbate the implications of climate change on biodiversity.

The IPCC reports, which analysed the impacts of climate change on biodiversity, reveal that there has been a discernible impact of regional climate change on species and ecosystems, and the impacts are pronounced in high-altitude and high-latitude ecosystems (IPCC 2002, 2014a, b). The risk of extinction of species will further increase for many species that are already vulnerable due to various reasons referred above. Species with limited climate ranges and smaller populations enjoying narrow distributional ranges such as highly endemic species in the Western Ghats and Himalayas, biota restricted to islands and climate-sensitive species found in the coastal and marine ecosystems such as mangroves, coastal wetlands and coral reefs are more vulnerable to extinction (IPCC 2002).

Evidence of climate change impacts is strongest and most comprehensive for natural systems, and it impacts lives, livelihoods, health, ecosystems, economies, societies, cultures, services and infrastructure due to the interaction of climate changes or hazardous climate events occurring within a specific time period and the vulnerability of an exposed society or system (Field et al. 2014). The discussion is limited to impact analysis of climate change on key ecosystems and sectors where the impacts will be primarily on biodiversity and various livelihood activities.

5.3.1 Water Resources

Evidence of regional climate change impacts on elements of the hydrological cycle suggests that warmer temperatures in some regions lead to intensification of the hydrological cycle. Changes in stream flow, floods, droughts, water temperature and water quality have been observed, and they have affected biodiversity and the goods and services ecosystems provide (IPCC 2002). Gosain et al. (2011) projected the impact of climate change on the 17 most important river basins in India up to mid-century and towards the end of the century. They estimated a decline in rainfall in 14 out of the 17 river basins towards the 2030s and the 2080s. In almost all river basins, rainfall declines from 4 to 23%, following changes in precipitation, resulting in decline in water yield in river basins. Rajendran et al. (2013) project spatially heterogeneous increase in warm days and extreme hot events (highest decile) over India; projected changes in extreme rainfall events (above 95 percentile) show intensification of extreme rainfall over most parts of India by the end of the century with opposite change over the west coast. The reduction in surface water availability may influence hydropower generation and environmental flow in river basins (INCCA 2010).

Altered water temperature due to global warming also impacts water quality, and, in reservoirs and lakes, it influences the potential for algal blooms, which can further reduce oxygen levels (IPCC 2014a, b). Climatic variables such as air temperature and precipitation affect environmental flows in rivers and the mobility and dilution of contaminants, hence affecting water quantity as well as water quality parameters (Dhanya and Arun Kumar 2015). Further, changes in water availability may affect concentrations of suspended sediment, nutrients and chemical contaminants in rivers and lakes. Changes in precipitation intensity and frequency will also influence non-point source pollution, and overall changes in water quality may lead to increased incidence of water-borne diseases. Increase in river water temperatures is likely to affect fish breeding, migration and harvests, as many endemic species have restricted distribution, especially in biodiversity hotspots such as the Western Ghats.

5.3.2 Forest Ecosystems

India is one of the 12 mega biodiversity countries of the world, which represents 11% of world's flora in about 2.4% of global land mass (MoEF 2014). The role of forest in addressing the issues related to climate change is better realised due to the dynamic functions and ecosystem services offered by the rich biodiversity in these areas. O' Briena et al. (O'Briena et al. 2004) estimated the vulnerability of India under multiple stressors such as climate change, and Chaturvedi et al. (2011) project that 39% and 35% of the forest grids in India will likely undergo change due to climate impacts; forests of northeast and southern Western Ghats and eastern parts of India are projected to be least vulnerable on account of their high biodiversity, low fragmentation, high tree density as well as low rates of vegetation change.

Chitale et al. (2014) studied the future distribution of 637 endemic plant species from three biodiversity hotspots in India, including Himalaya, Western Ghats and Indo-Burma, based on modelling studies and suggested that the endemic flora will be adversely impacted, even under moderate climate scenario, with predicted shifts in northern and north-eastern direction in Himalaya and Indo-Burma, while in southern and south-western direction in Western Ghats, due to cooler climatic conditions in these regions. The model predicts a 23.99% range reduction and a 7.70% range expansion in future distribution by 2050, while a 41.34% range reduction and a 24.10% range expansion by 2080.

The Western Ghats region, part of the Western Ghats-Sri Lanka biodiversity hotspot, harbours species with extremely high levels of endemism, and climate change variations may severely impact the rich biodiversity and their distribution pattern. Eighty five percent of threatened vertebrates are inadequately represented in the existing global network of protected areas (PAs), with only a marginal progress in coverage since the last decade (Venter et al. 2014). Endemic species with restricted distribution and/or small populations are in particular vulnerable to extinctions (Hawkins et al. 2000) and of priority in conservation policy-making (Rosenfield 2002). Yet, many endemic species, particularly invertebrates, and those from the lower vertebrate groups are often ignored in both policy-making and conservation action, with freshwater-dependent fauna being the most affected (Darwall et al. 2011). A stronger baseline data on endemic biodiversity is one of the prerequisites for conservation as climate impacts will be much pronounced in these species.

5.3.3 Agriculture and Food Security

In an agrarian society like India, climate plays a vital role in deciding the success of agriculture, and even minimal warming will lead to loss in crop yields (Parry et al. 2007). IPCC has projected that by the end of the twenty-first century, rainfall over India will increase by 10–12%, and the mean annual temperature will rise by 3–5 °C (IPCC 2014a, b). Climate change and global warming may precariously affect agricultural production, reduction in crop area, pest and diseases and labour and livelihood of farmers by unpredictably changing the abundance of seasonal rainfall and extreme events (Chaturvedi et al. 2014). Farmers can no longer rely on the timing of seasons and the availability of rainfall, and this scenario is rather disturbing for the farmers in India as they rely on monsoon for agriculture. Studies conducted by the Indian Agricultural Research Institute (IARI) indicate the possibility of loss of 4–5 million tons in wheat production with every rise of 1 °C temperature throughout the growing period, and the losses for other crops are expected to be smaller, especially for kharif crops (Aggarwal et al. 2009). Erratic monsoons will have serious effects on rain-fed agriculture with projected decreases in the productivity of crops including rice, maize and sorghum (especially in the Western Ghats, coastal region and north-eastern regions) and apples (in the Himalayan region) (Kumar et al. 2011).

Studies indicate that increased droughts and floods are likely to increase production variability and lead to considerable effects on microbes, pathogens and insects needed for the maintenance of healthy agricultural systems (Gautam et al. 2013). Increasing glacier melt in Himalayas could affect availability of irrigation especially in the Indo-Gangetic plains, which, in turn, would have consequences on food production. Aggarwal et al. (2011) estimated the impact of climate change on livestock and concluded that animal distress could lead to effects on reproduction and subsequently loss of 1.5 million tons of milk by 2020. The resilience of many ecosystems (their ability to adapt naturally) is likely to be exceeded by an unprecedented combination of change in climate; associated disturbances such as flooding, drought, wildfire, pests, ocean acidification; and other global change drivers such as land-use change, pollution and over-exploitation of resources (IPCC 2014a, b). Smallholder and subsistence farmers and fisher folk are likely to suffer multiple and localised impacts of climate change. Frequent exposure to flooding may lead to ecological changes in the agricultural fields.

5.3.4 Coastal and Marine Ecosystems

Sea level along the Indian coast has been rising at the rate of 1.3 mm/year and is likely to rise in consonance with the global sea level rise (SLR). Significant coastal inundation may occur with a 1 m sea level rise, especially in low-lying areas, with increase in environment-related health risks (INCCA 2010). In the coastal and marine ecosystems, pattern of species richness, especially that of fish and invertebrates, is strongly related to climatic factors. Species in the marine ecosystems respond to ocean warming by shifting their latitudinal range (Perry et al. 2005) and depth range (Dulvy et al. 2008), which may lead to local extinctions and invasions, resulting in changes in pattern of marine species richness and disrupting marine biodiversity and ecosystems, and impact commercial fisheries (Cheung et al. 2009).

Another emerging issue in oceans in recent times is the frequent incidences of jellyfish blooms worldwide in marine ecosystems, indicating a state shift in pelagic ecosystems (Purcell et al. 2007). The coastal waters around India are suspected to be the areas prone for jellyfish blooms (Brotz et al. 2012). Jellyfish exhibits wide fluctuation in biomass in response to anthropogenic perturbations or changing oceanographic condition such as eutrophication, hypoxia and climate-induced regional regime shift, and researchers opine that global warming might lead to increasing populations of jellyfish because it could affect the distribution, growth and larval production (Lee et al. 2013). Because climate changes have complex ecosystem-level effects, the proximate causes of jellyfish increases are difficult to deduce. There are, however, reports that global warming might lead to increasing populations of jellyfish because it could affect the distribution, growth and larval production (Richardson et al. 2009). In the clear absence of predatory fish species and turtles capable of feeding specifically on jellyfish, the population of jellyfish in Indian waters also would increase in the coming years (Biju Kumar 2012).

In the past 200 years, it is estimated that the ocean has absorbed more than a quarter of the carbon dioxide released by human activity, increasing ocean acidity, a phenomenon often referred to as ocean acidification. Marine organisms such as corals, molluscs, crustaceans and echinoderms which play an important roles in ecosystem functioning may exhibit growth retardation and low survival rates with ocean acidification, though these responses are variable, and some species can live at low pH conditions (CBD 2014). Non-calcifying phytoplankton can show increased photosynthesis and growth under high carbon dioxide conditions that rely on carbonate ions to form their calcareous shells or skeletons in a process known as calcification. Ocean acidification may result in destabilisation of skeletal structures of marine organisms with calcareous exoskeleton.

Changes in precipitation frequency and intensity coupled with variations in pH, water temperature, wind, dissolved oxygen, dissolved CO_2, salinity variations and pollution may lead to poor water quality of marine ecosystems. Human activities, especially increased nutrient loads that set in motion a cascading chain of events related to eutrophication, accelerate development of hypoxia (lower oxygen concentration) in many areas of the world's coastal ocean. The changed environmental conditions could favour the growth of harmful algal blooms (HABs). Increase in HABs may negatively impact the environment, human health and economy of the communities (Wells et al. 2015). Occurrence, increase in frequency, intensity and spatial coverage of harmful algal blooms in the EEZ of India indicated a sharp increase, with the frequent contribution of toxic species such as *Alexandrium* spp., *Gymnodinium* spp., *Dinophysis* spp., *Coolia monotis*, *Prorocentrum lima* and *Pseudonitzschia* spp. (Padmakumar et al. 2012).

It was generally held that there is an increase in the biomass of phytoplankton during the recent decades in western Indian Ocean as a result of climate change and global warming. However, the current study points out an alarming decrease of up to 20% in phytoplankton in this region over the past six decades, and these trends in chlorophyll are driven by enhanced ocean stratification due to rapid warming in the Indian Ocean, which suppresses nutrient mixing from subsurface layers. Future climate projections suggest that the Indian Ocean will continue to warm, driving this productive region into an ecological desert (Roxy et al. 2016).

Coral reefs are the most diverse, biologically complex and economically important marine ecosystems on earth. The reef-building scleractinian corals are currently facing multiple stresses caused by shifts in the marine environment associated with global warming, ocean acidification, sedimentation, pollution and eutrophication. In the Indian Ocean, for example, 45% of living coral was killed across the 1998 warm temperature anomaly, and the recovery of corals from the impact varied amongst various regions (Ateweberhan and McClanahan 2010). Many of the corals have undergone coral bleaching events due to the loss of intracellular endosymbionts (*Symbiodinium* or zooxanthellae) through either expulsion or loss of algal

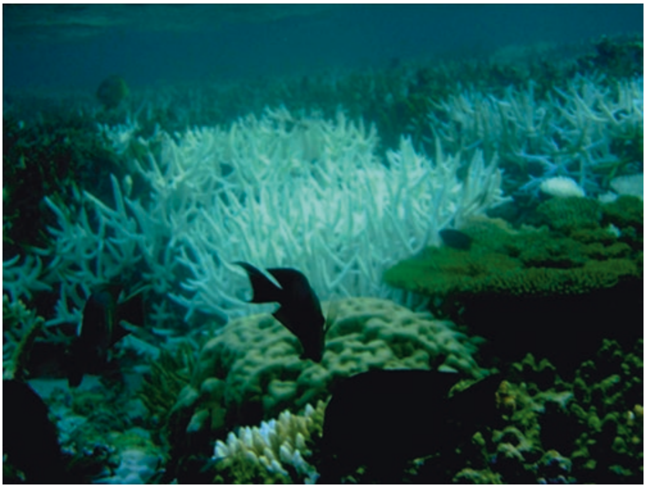

Fig. 5.2 Coral bleaching observed at Lakshadweep Islands, India

pigmentation under elevated temperature regime (Fig. 5.2). Though coral bleaching may be reversible under normal temperature regime, if that sea temperature stays too high for too long, the corals may eventually die. Widespread coral bleaching events and mass mortalities occurred in the Pacific Ocean due to El Niño events which began in the early 1980s due to strong temperature anomalies, and the 1997–1998 El Niño-Southern Oscillation (ENSO) event, which elevated sea surface temperatures (SSTs) of tropical oceans by more than 3 °C, triggered massive coral bleaching in the east and west coasts of India and in Lakshadweep (Arthur 2000). Climate change impacts on coral bleaching have also been reported from Pirotan Island, Gulf of Kachchh Marine National Park, Gujarat (Adhavan et al. 2014). By using the relationship between past temperatures and bleaching events and the predicted SST for another 100 years, Vivekanandan et al. (2009) predicted that reefs should soon start to decline in terms of coral cover and appearance.

Mangroves, which show an amazing example of natural adaptation to their unique location at the interface of the sea, are vulnerable to climatic change and resultant sea level rise (Table 5.1). By altering ecobiological processes, the intertidal and supratidal zones may extend further inland, and limitation of the landward margin results in a vertical rise, leading to waterlogging and ultimately killing the mangroves and dependent biodiversity (Jagtap and Nagle 2007). Changes in growth pattern of dominant species of mangroves such as *Sonneratia apetala*, *Avicennia alba* and *Excoecaria agallocha* have been recorded from Indian Sundarbans due to climate change (Raha et al. 2012).

Coastal freshwater wetlands may be vulnerable to saltwater intrusion with rising sea levels, but in most river deltas, local subsidence for non-climatic reasons will be more important (Syvitski et al. 2009). Humans have been the primary drivers of changes in coastal aquifers, lagoons, estuaries, deltas and wetlands and are expected to further exacerbate human pressures on coastal ecosystems resulting from excess nutrient input, changes in run-off and reduced sediment delivery (IPCC 2014a, b).

Table 5.1 Predicted effects of climate change factors on mangrove

Factors	Processes affected	Impacts
Rising sea level	Forest health	Forest mortality, dieback from the seaward edge
	Forest productivity	Migration landward, but dependent on sediment inputs, topography and human modifications
	Recruitment	
	Inundation period	
	Sedimentation rates	
Extreme storms	Forest productivity	Forests damaged or destroyed
	Recruitment	Ground elevation change
	Sedimentation rates	Erosion or sediment smothering
Increased waves and wind	Sedimentation rates	Changes in forest coverage, depending on whether coasts are accreting or eroding
	Recruitment	
Increased air and sea temperature	Respiration	Reduced productivity at low latitudes and increased winter productivity at high latitudes
	Photosynthesis	
	Forest productivity	
Enhanced CO_2	Photosynthesis	Increased productivity, subject to limiting factors of salinity, humidity and nutrients
	Respiration	Soil elevation gain
	Biomass allocation	
	Forest productivity	
Increased rainfall	Sediment inputs	Increased sediments and maintenance of surface elevation
	Ground water	Increased ground water
	Salinity	Increased diversity
	Productivity	Increased productivity
		Increased recruitment
Reduced rainfall	Sediment inputs	Reduced sediments and relative subsidence
	Ground water	Migration landward
	Salinity	Reduced ground water
		Reduced photosynthesis
		Reduced productivity
		Species turnover
		Reduced diversity
Reduced humidity	Photosynthesis	Reduced productivity
	Forest productivity	Species turnover
		Reduced diversity

Ellison (2012)

The sea level rise recorded in Indian seas during 1970–2010 was more than 8 cm (Unnikrishnan and Shankar 2007), and the projection for 2050 and 2100 is more than 20–40 and 50–70 cm, respectively. Under the influence of climate change, beaches, sand dunes and cliffs currently eroding will continue to do so under increasing sea level. The human settlements (especially those of the fisher folks), transportation and tourism infrastructure at or near the coast are vulnerable to more frequent flooding, rising sea levels and possible increase in the magnitude and frequency of tropical storms and other natural calamities due to climate change.

5.3.5 Vulnerable Species

Many species in terrestrial, coastal and marine ecosystems are on imminent threat of extinction due to various ecosystem changes including climate change. Endemic species restricted to narrow environmental niches, especially those in mountainous ecosystems and islands, may face impacts of climate change more seriously than other species in similar ecosystems. Further, climate-sensitive species with specific phenological or physiological requirements (e.g., species with temperature-dependent sex determination such as turtles and crocodiles and amphibians with permeable skin and eggs) are more susceptible. Impacts of climate change are likely due to direct physiological stress, habitat changes and change in disturbance regime (IPCC 2002). The risk of extinction is always high for species with restricted distribution and limited climatic ranges, with lesser population densities. This demands extension of protected areas and measures to ensure connectivity between critical habitats.

Marine turtles, which are otherwise facing lot of struggles towards survival, are seriously impacted by changing climatic conditions, and the issues include (i) erosion of turtle nesting beaches, (ii) skewed sex ratios of hatchlings, (iii) destruction of feeding niches, (iv) modification of migration pathways and (v) flooding of nesting sites (Hawkes et al. 2009). They occupy a wide range of marine habitats, and many aspects of their life history have been demonstrated to be closely tied to climatic variables such as ambient temperature and storminess and therefore could be used as indicators of climate change. As a species with temperature-dependent sex determination, one of the serious challenges will be that warmer incubation temperatures may produce female hatchlings. Laloë et al. (2014) estimated that light-coloured beaches produce 70.10% females, whereas dark-coloured beaches produce 93.46% females in Cape Verde Islands, Atlantic, one of the largest sea turtles rookeries in the world.

Gahirmatha Marine Sanctuary in Orissa, India, is one of the biggest mass nesting grounds of olive ridley turtles in the world. Delaying of nesting of the olive ridley turtle in this coast could be attributed to the accretion of sand on the nesting beach due to the northerly winds; turtles always prefer to nest after the accretion of new sand that occurs around this time. If they nest during the accretion, the eggs will get buried and hatchling success will be reduced. The changes in beach morphology in Kerala coast due to natural and anthropogenic reasons have reduced turtle nesting sites.

Fisheries play an important role in food supply, food security and livelihood security of thousands of fishermen and associated fish supply chains living in coastal areas. Temperature is known to affect fish distribution and migration; the combined

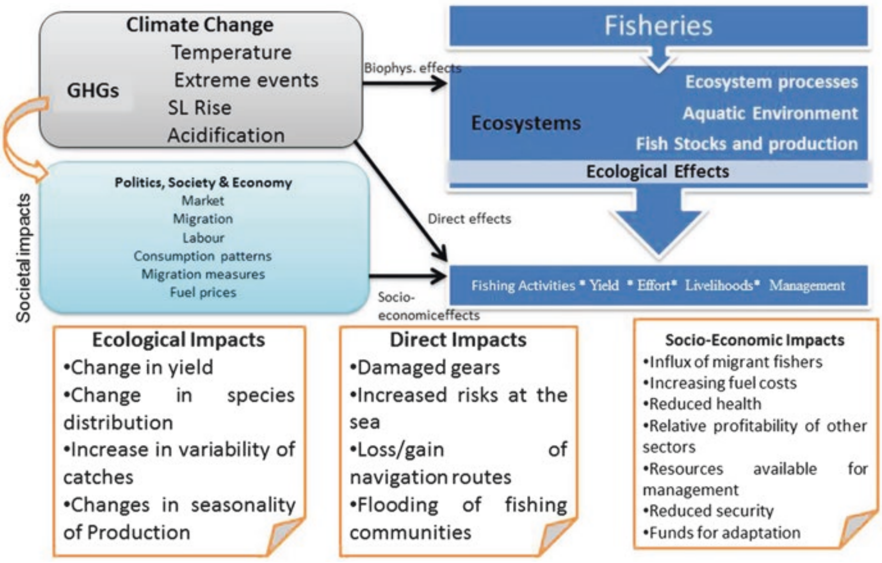

Fig. 5.3 Impacts of climate change on fisheries

effects of changes in distribution, abundance and physiology may reduce the body size of marine fishes, particularly in the tropics and intermediate latitudes (Cheung et al. 2013). Growth rate of fish increases with increasing temperature within the optimal temperature window. It is likely that the food utilisation parameters may be operating at an elevated level in fishes at higher temperatures, demanding higher food supply to attain faster growth rate. Fishes may change their phenology of reproductive activity to adapt to elevated temperatures for spawning and larval survival. At population level, temperature and other factors related to climate change may strongly influence distribution and abundance, evidences for which are accumulating in Indian seas; extension of distributional boundary of small pelagics, extension of depth of occurrence and phenological changes were recorded from Indian waters (Vivekanandan 2013). All these climate change implications would ultimately affect the fishery sector and coastal livelihood activities (Fig. 5.3).

Studies on the impact of climate change on fisheries carried out by the Central Marine Fisheries Research Institute (CMFRI) show that different Indian marine species respond to climate change as follows: (i) small pelagic fishes that may extend their boundaries, (ii) some species that may be migrated to deeper waters as well and (iii) phenological changes. The major pelagic species that represent major portion of marine fish landings in Indian coast are the oil sardine (*Sardinella longiceps*) and the Indian mackerel (*Rastrelliger kanagurta*), contributing up to 40% marine fisheries. The oil sardine is restricted in distribution between latitude 8°N and 14°N and longitude 75°E and 77°E (Malabar upwelling zone along the southwest coast of India) where the annual average sea surface temperature ranges from 27 to 29 °C. While almost the entire catch of oil sardine was from the Malabar upwelling zone till 1985, their landings from latitude 14°N to 20°N are consistently increasing in the last few decades (Vivekanandan et al. 2009). The surface waters of the Indian seas are warming by 0.04 °C per decade, and the warmer tongue (27–28.5 °C) of the surface waters is expanding to latitudes north of 14°N, enabling the oil sardine to extend their distributional range to northern latitudes (Anon. 2010). The studies done by the Central Marine Fisheries Research Institute (CMFRI) showed that elevated SST, favourable wind (and perhaps current) and increasing CUI have induced higher chlorophyll—a concentration during southwest monsoon, which has resulted in increasing the recruitment and catches of oil sardine during post-southwest monsoon season along the Kerala coast (Vivekanandan et al. 2009).

The Indian mackerel is commonly found in the Indian and West Pacific Oceans and their surrounding seas; in India, they are abundantly found along the southwest coast. Recent reports indicate that this fish, in addition to extension of northern boundaries, is found to descend to deeper waters in the last few decades. The mackerel populations normally occupying surface and subsurface waters have now started moving down the water column and are often caught in large numbers in bottom trawl nets operated by large mechanised boats at about 50–100 m depth (Vivekanandan et al. 2009).

The increase in catch of puffer fish *Lagocephalus inermis* biomass along Kerala coast in the recent decades may be related to the decline of predators (Mohamed et al. 2013). The examples recorded from Kerala coast show that differential physiological effects of temperature on individual species are key to understanding and projecting climate-induced changes in species interactions and in community composition (Portner and Farrell 2008). Further, habitat destruction, pollution, energy production, mining and aquaculture are all affecting marine ecosystems and may exacerbate the effects of climate change.

Amphibians are particularly vulnerable to climate change. As they occupy a vital position in the food web, susceptibility to water-soluble toxins through permeable skin and a life history that requires both terrestrial and aquatic habitats, frogs are good indicators of environmental conditions. Frogs in high mountainous areas are most affected by global warming. Of the more than 7000 amphibian species known globally, about 32% are threatened with extinction, according to the International Union for Conservation of Nature (IUCN). Climate change may also exacerbate the spread of chytridiomycosis, caused by the parasitic fungus *Batrachochytrium dendrobatidis* (Bd), and has led to the recent decline or extinction of 200 frog species worldwide (Catenazzi et al. 2014).

5.4 Strategies to Combat Climate Change

Climate change involves complex interactions between climatic, environmental, economic, political, institutional, social and technological processes. It cannot be addressed or comprehended in isolation of broader societal goals (such as equity or sustainable development), or other existing or probable future sources of stress. Strategies to reduce climate change impacts on biodiversity therefore include a mixture of adaptation and mitigation measures such as containing human population growth, reducing greenhouse gas emissions as per agreed targets, promotion of biodiversity to ensure carbon capture, addressing pre-existing stressors on biodiversity and taking adequate steps to adapt to climate change and to improve conservation efforts by expanding protected areas for conservation of biodiversity.

5.4.1 Adaptation

The IPCC defined adaptation as adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderate harm or exploit beneficial opportunities. Adaptation is also defined as an understanding of how individuals, groups and natural systems can prepare for and respond to changes in climate or their environment and is crucial to reducing vulnerability to climate change. Biodiversity and healthy well-functioning ecosystems provide natural solutions that build resilience and help society adapt to the adverse impacts of climate change. They also support poverty alleviation by providing safer and more secure livelihoods, especially for the poor and vulnerable. With climate change already well underway and further change unavoidable, adaptation is gaining significantly more focus, especially in countries like India where the economy is dependent on climate-sensitive sectors.

Biodiversity is linked to climate change adaptation through three ways:

1. It can play a role in societal adaptation, and ecosystem-based adaptation can provide cost-effective strategies across the major sectors involved in adaptation (e.g., coastal defence, water sector, agriculture, etc.).
2. Societal adaptation strategies can have significant impacts on biodiversity, and these impacts are negative, but where appropriate natural resource management is used (e.g., in improved agricultural practices), adaptation strategies may prove beneficial for biodiversity (CBD 2009).
3. Biodiversity conservation itself is a sector that requires its own adaptation strategies. Such strategies, which involve improved protected area design, maintaining habitat connectivity in the wider landscape and reducing other anthropogenic pressures, are likely to increase the resilience of biodiversity to climate change (CBD 2009).

In short, the benefits of adaptation activities can be achieved through maintaining and restoring native ecosystems; protecting and enhancing ecosystem services; actively preventing and controlling invasive alien species; managing habitats for rare, threatened and endangered species; developing agroforestry systems at transition zones; paying attention to traditional knowledge and monitoring results and changing management regimes accordingly. Adaptation activities that can be beneficial to biodiversity include the establishment of a mosaic of interconnected terrestrial, freshwater and marine multiple-use reserve protected areas designed to take into account projected changes in climate and integrated land and water management activities that reduce non-climate pressure on the biodiversity and hence make the system less vulnerable to changes in climate. Adaptation activities can also threaten biodiversity either directly through the destruction of habitats (e.g., building sea walls), thus affecting coastal ecosystems, or indirectly through the introduction of new species or changed management practices such as aquaculture.

Agriculture can be used as an example to explain the adaptation strategies to climate change. The sustainable use of genetic resources for food and agriculture will be the foundation for many of the adaptation strategies required in food and agriculture. Agricultural biodiversity has never been properly integrated in agricultural adaptation strategies to climate change, which creates a challenge for the future. Enhancing ecosystem services through use of agricultural biodiversity will be crucial, given that it contributes to adaptation, mitigation and resilience. For example, farmers in Kuttanad area of Kerala have been practising below sea-level farming for several decades using salt-resistant strains of paddy ('Pokkali'), and popularisation and genetic improvement of this variety could facilitate farming in coastal flood plains.

Good management of agricultural biodiversity allows production systems to adapt to changing conditions while maintaining productivity. Enabling the sustainable use of agricultural biodiversity has a huge potential for developing win-win strategies with multiple benefits such as coping with climate change, conserving biodiversity and improving human well-being. Huge gains can be made for a greener future by simply reducing agricultural waste and inefficiency. Nearly 50% of food produced is lost through crop loss or waste during storage, distribution, marketing and household use. Some of these inefficiencies—especially crop and storage losses—can be addressed with small investments in simple farming and storage technologies.

The sea level rise recorded in Indian seas during 1970–2010 was more than 8 cm (Unnikrishnan and Shankar 2007), and the projection for 2050 and 2100 is more than 20–40 and 50–70 cm, respectively. Under the influence of climate change, beaches, sand dunes and cliffs currently eroding will continue to do so under increasing sea level. The human settlements (especially those of the fisher folks), transportation and tourism infrastructure at or near the coast are vulnerable to more frequent flooding, rising sea levels and possible increase in the magnitude and frequency of tropical storms and other natural calamities due to climate change. Main threats could be salinity ingress in water bodies and inundation of low-lying areas, with resultant loss of fertile agricultural lands in coastal areas. However, aquatic biodiversity like fishery resources may provide opportunity for adaptive livelihood measures for food security in the coastal area (Anon. 2010). Conventionally coastal defences have relied upon 'hard defence' structures such as sea walls. However, evidence suggest that resilient coastal ecosystems such as mangroves, coral reefs, sand dunes and salt marshes can play an effective role in coastal protection as buffer against extreme events. Further, they also ensure resources for the livelihoods of local farmers and fishermen, thereby allowing more flexibility to adaption process. Considering the fact that coastal ecosystems alone would not ultimately help in

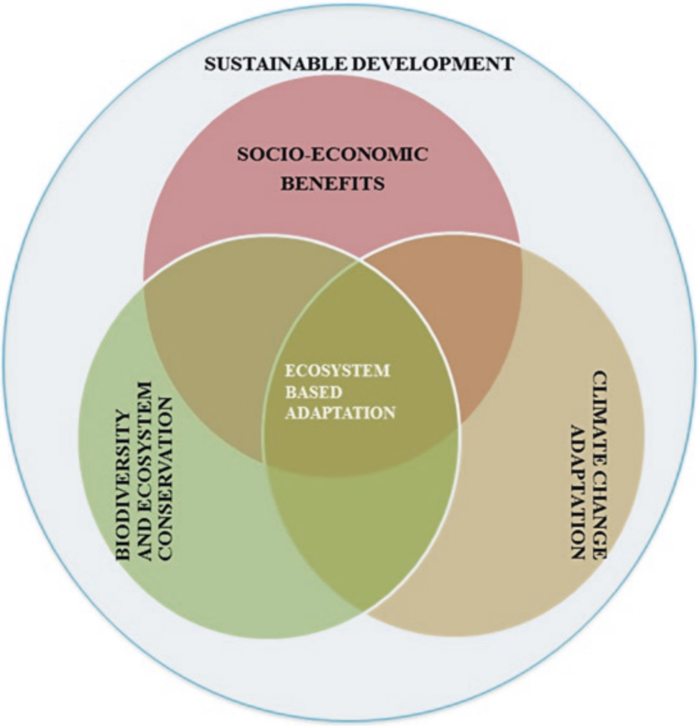

Fig. 5.4 Linkages of ecosystem-based adaptation and sustainable development

addressing the climate change impacts, integration of 'hard defence' measures with proper land-use planning and ecosystem management is being popularised.

As with coastal ecosystems, natural freshwater ecosystems provide vital water regulation services and can play a role in adaptation to water scarcity as well as flooding. Actions to reduce degradation of watersheds, through reduced deforestation, afforestation and soil conservation, can lower vulnerability to drought, and the maintenance and restoration of water-regulating services of wetlands are important for flood control. The need of the hour is to integrate conventional and modern watershed management practices in order to make adaptation a practical reality at the grass roots.

Ecosystem-based adaptation (EbA) is an important approach for achieving multiple benefits in the context of sustainable development. EbA has been defined by the CBD as 'the use of biodiversity and ecosystem services as part of an overall adaptation strategy to help people to adapt to the adverse effects of climate change'. This definition clearly identifies a strong link between biodiversity, ecosystem services, climate change adaptation and societal resilience. In order to achieve sustainable development, a synergy between biodiversity and ecosystem conservation, socio-economic benefits and climate change adaptation is necessary (Fig. 5.4). In addition to protection from climate change impacts, EbA also provides many other benefits to communities, for example, through the maintenance and enhancement of ecosystem services crucial for livelihoods and human well-being, such as clean water and food. Appropriately designed ecosystem management initiatives can also contribute to climate change mitigation by reducing emissions from ecosystem loss and degradation and enhancing carbon sequestration.

The contribution of biodiversity to societal adaptation varies according to the local situations. However, the available evidences make it clear that integrated management strategies incorporating ecosystem approach into broader cross-sectoral adaptation policies as a compliment to structural and technological measures would assist in more sustainable adaptation strategies. However, these efforts in developing countries would require more institutional and financial support, which at present are not fully available.

5.4.2 Mitigation

'Mitigation', in the context of climate change, is a human intervention to reduce the sources or enhance the sinks of greenhouse gases (GHGs). Because mitigation is intended to reduce the harmful effects of climate change, it is part of a broader policy framework that also includes adaptation to climate impacts. Mitigation can mean using new technologies and renewable energies, making older equipment more energy efficient, or changing management practices or consumer behaviour. Protecting natural carbon sinks like forests and oceans and creating new sinks through silviculture or green agriculture are also elements of mitigation.

The IPCC provided growing evidence of the importance of natural ecosystems in the carbon cycle (especially in carbon storage and sequestration) and therefore in mitigation policies. Climate mitigation polices focused on reducing CO_2 emissions can have both positive and negative impacts on biodiversity. A series of renewable energy projects such as biofuel or wind farms and monoculture plantations are being planned without consideration of their biodiversity impacts. Mitigation strategies have the potential to be directly beneficial to biodiversity by focusing on protecting carbon-rich land, such as forests, on managing or restoring sensitive ecosystems such as wetlands, or by promoting best practice management.

India is a party to the United Nations Framework Convention on Climate Change (UNFCCC). The Paris Agreement agreed that future global warming should be limited to below 1.5 °C relative to pre-industrial levels. India has already prepared an Intended Nationally Determined Contributions (INDCs) to plan for mitigation measures. Better land-use management, including conserved habitats, can reduce carbon emissions from land-use change and help remove carbon dioxide from the atmosphere, thus helping to mitigate global warming (e.g.,, reducing emissions from deforestation and degradation, improving soil carbon storage in soils). A portfolio of land-use management activities, including the protection of natural forest and wetland carbon stocks, the sustainable management of forests, the use of native assemblages of forest species in reforestation activities, sustainable wetland management, restoration of degraded wetlands and carbon-friendly agricultural practices, can contribute to the objectives of both the UNFCCC and CBD. Reducing emissions from deforestation and forest degradation (REDD) activities should take biodiversity conservation and sustainable use into account, as this helps maintain forest ecosystem resilience and the long-term stability of the carbon pool as well as providing co-benefits in terms of the delivery of other ecosystem services, including supporting sustainable livelihoods.

Agricultural soils are important carbon sinks with great potential to mitigate climate change, and soil biodiversity plays an important role in soil carbon cycles. There are a large number of agricultural management activities (e.g., conservation tillage, erosion control practices and irrigation) that will sequester carbon in soils and which may have positive or negative effects on biodiversity, depending on the practice and the context in which they are applied. Better understanding and management of soils have potential to bring important conservation and use benefits, mitigate climate change, avoid land degradation and improve water retention and productivity. Bio-based agricultural systems that require less external energy input could also contribute to mitigating climate change.

The use of erosion control practices, which include water conservation structures, vegetative strips used as filters for riparian zone management and agroforestry shelterbelts for wind erosion control, can reduce the displacement of soil organic carbon and provide opportunities to increase biodiversity. The irrigation can increase crop production, but will degrade water resources and aquatic ecosystems. It is important to include farmer-centred participatory approaches and consideration of local or indigenous knowledge and technologies, promote cycling and use of organic materials in low-input farming systems and use a diverse array of locally adapted crop varieties voiding degradation of wetlands. These are beneficial mitigation options. Revegetation activities that increase plant cover on eroded, severely degraded or otherwise disturbed lands have a high potential to increase carbon sequestration and enhance biodiversity. Sequestration rates will depend on various factors, including revegetation method, plant selection, soil characteristics and site preparation and climate.

Some marine ecosystems, such as mangroves, salt marshes and seaweed ecosystems, beyond having high biodiversity values and providing breeding grounds and nurseries for fisheries, can also play a key role in mitigating global climate change through their ability to store carbon. These blue carbon ecosystems are being degraded at a very high level in Kerala, and the current stretch of mangrove forests in Kerala is only 663.09 ha (Anon. 2012) as against 70,000 ha reported by Blasco (1975) in earlier period, and climate change-related changes would seriously hamper their sustainability. Climate change assessment report documents that sea level rise along the Indian coast would submerge the mangroves as well as increase the salinity of the wetland, and this would favour mangrove plants that tolerate higher salinity (Anon. 2010).

Marine ecosystems may offer mitigation opportunities, but the potential implications for ecosystem function and biodiversity are not well understood. Oceans are substantial reservoirs of carbon with approximately 50 times more carbon than is presently in the atmosphere. There have been suggestions to fertilise the ocean to promote greater biomass production and thereby sequester carbon and to mechanically store carbon deep in the ocean. However, the potential for either of these approaches to be effective for carbon storage is poorly understood, and their potentially large negative impacts on ocean and marine ecosystems and their associated biodiversity are unknown.

Renewable energy sources (crop waste, solar and wind power) may have positive or negative effects on biodiversity depending upon site selection and management practices. Replacement of fuel wood by crop waste, the use of more efficient wood stoves and solar energy and improved techniques to produce charcoal can also take pressure from forests, woodlots and hedgerows. Most studies have demonstrated low rates of bird collision with windmills, but the mortality may be significant for rare species. Hydropower has been promoted as a technology with significant potential to mitigate climate change by reducing the greenhouse gas intensity of energy production but has potential adverse effects on biodiversity. In some cases, emissions of carbon dioxide and methane caused by dams and reservoirs may be a limiting factor on the use of hydropower to mitigate climate change.

Large-scale hydropower development can also have other high environmental and social costs such as loss of biodiversity and land, disruption of migratory pathways and displacement of local communities. The ecosystem impacts of specific hydropower projects vary widely and may be minimised depending on factors including type and condition of pre-dam ecosystems, type and operation of the dam (e.g., water flow management) and the depth, area and length of the reservoir.

It is clear from the foregoing that climate mitigation policies have the potential to impact biodiversity in both positive and negative manner. Therefore mitigation efforts, especially those involving larger infrastructure and investment, should be implemented with proper impact assessment so as to develop 'win-win' mitigation policies that are beneficial for both climate change mitigation and biodiversity.

5.5 Research and Awareness

In order to enable informed decisions on the appropriate mitigation and adaptation strategies, there is a growing need to strengthen the wealth of climate data and information and transform the knowledge into action. Further, a fundamental restructuring of the way energy, land, water and biological resources are managed is needed to achieve a cost-effective transition to low-carbon economy and society. Research and innovation will play an important role in defining cost-effective decarbonisation pathways, developing alternative technological and socio-economic solutions for decision-makers and for the society as a whole, while informing them on related risks and costs, besides planning suitable adaptation and mitigation programmes.

In the case of biodiversity, the responses of individual species to climate variables, role of smaller biomes in regulating climate, adaptation required for specific cases and integrated mitigation programmes with due consideration of biodiversity are the areas that requires more intensive research. At the species level, there are numerous correlative modelling studies simulating the potential impact of climate change on their distribution. Experimental studies are extremely useful in determining the effect of climate change on aspects of ecosystem composition, structure and function. Improvement of regional scale climate models coupled with transient ecosystem models that deal with multiple pressures with appropriate spatial and temporal resolution and that include spatial interactions between ecosystem and landscapes is also needed (IPCC 2002). Further, at each local ecosystem, identification of biodiversity conservation and sustainable use activities and policies that would beneficially affect climate change adaptation and mitigation options is yet another priority area of research.

The Conference of the Parties to the United Nations Framework Convention on Climate Change held at Paris in 2015 has decided for Green Climate Fund (GCF) to expedite support for the least developed countries and parties of other developing countries for the formulation of national adaptation plans and for the subsequent implementation of policies, projects and programmes identified by them. The GCF is a unique global initiative to respond to climate change by investing into low-emission and climate-resilient development. Given the urgency and seriousness of the challenge, the fund is mandated to make an ambitious contribution to the united global response to climate change.

India's National Action Plan on Climate Change Assessment (NAPCC) envisages National Mission on Strategic Knowledge for Climate Change as one of the missions with the objective of vulnerability assessment, research and observation and data management implemented through the Department of Science and Technology. Considering that climate change is a relatively new challenge, the focus of the conservation action plan should be on generating awareness and building capacity, and this should be done across all levels of the government and external stakeholders involved in the different sectors. This strong drive towards building capacity will result in empowering people and organisations to be able to address, manage and respond to climate change concerns. Information, education and communication (IEC) technologies should be better utilised for the purpose. Climate change should also be included as a topic in academic curricula in education.

There is a need to involve stakeholders, particularly coastal community, in a more proactive way in the climate action plan implementation. This involvement will relate to:

1. Promoting much greater climate change awareness within community
2. Identifying problematic issues relevant to climate change
3. Support in monitoring of climate-induced problems
4. Ensuring greater accountability to the people on climate change issues

Stakeholder involvement will be an effective tool with stakeholders, who play an important part in bringing out the solutions.

Climate change is an interdisciplinary subject that cuts across physics, chemistry, biology, earth sciences, economics, technology development, etc. Therefore, multiple data sets are required even to simulate the current situations by different models. So, current data on observations on climate, natural ecosystems, soils, water from different sources, agricultural productivity and inputs and socio-economic parameters amongst others are continuously required. In this context, it is essential to have accessibility to databases at micro levels prepared with various agencies and to continuously monitor the impacts. Further, there is also a need for capacity building to co-ordinate world-class climate change research in India.

5.6 Policy

IPCC reports make it clear that climate change and associated impacts will continue for centuries, even if anthropogenic emissions of greenhouse gases are stopped. There is a clear opportunity to implement mutually beneficial activities (policies and projects) that take advantage of the synergies between the United Nations Framework Convention on Climate Change and its Paris Climate Agreement (2015), the Convention on Biological Diversity and broader national development objectives. However, these opportunities are rarely being realised due to a lack of national coordination amongst sectoral agencies to design policy measures that exploit potential synergies between national economic development objectives and environmentally focused projects and policies.

Many countries have established specific policies and strategies on climate change adaptation, mitigation and adaptation. However, there is a need for greater integration between the CBD and UNFCCC to maximise the synergies in environmental protection, not only for climate change but for poverty alleviation, food and water security and long-term sustainability, besides addressing the impacts of climate change. Developing a sound and pragmatic Climate Change Action Plan and its subsequent implementation requires strengthening/evolving supportive institutions, information, finance, technology and public support. The strategy has to be developed in consonance with national and regional developmental objectives and contexts, based on available sound scientific information and by following a participatory approach including consultation with local stakeholders and communities.

India's National Action Plan on Climate Change (NAPCC) and its subsequent eight missions such as National Solar Mission, National Mission for Enhanced Energy Efficiency, National Mission on Sustainable Habitat, National Water Mission, National Mission for Sustaining the Himalayan Ecosystem, National Mission for a 'Green India', National Mission for Sustainable Agriculture and National Mission on Strategic Knowledge for Climate Change represent 'multi-pronged, long-term and integrated strategies for achieving key goals in the context of climate change. NAPCC outlines a strategy by which India will adapt to and mitigate challenges of climate change, while maintaining a high growth rate, protecting poor and vulnerable sections of society and achieving national growth objectives. The government's proposals, while void of specific targets and details, put forward action plans that could be easily developed through regional and state-level strategies as well as to incorporate into current and future developmental plans.

Integration of biodiversity into developmental plans and policies would pave the way for ecosystem-based approach for climate change mitigation and adaptation, besides ensuring sustainability of resources.

5.7 Conclusions

The impacts of climate change and its linkage with biodiversity are better understood, and there are growing demands for reducing the ecological footprint in human species to protect, preserve and restore our rich biodiversity for posterity. In order to avoid escalating threats on biodiversity with changing climate and to plan and implement mitigation and adaptation programmes, there are growing demands to mainstream the strategies and action into policy framework.

References

Adhavan D, Kamboj RD, Marimuthu N, Bhalodi MM (2014) Seasonal variation and climate change influence coral bleaching in Pirotan Island, Gulf of Kachchh Marine National Park, Gujarat. Curr Sci 107:1780–1781

Aggarwal PK, Pathak H, Kumar N (2009) Global climate change and Indian agriculture: a review of adaptation strategies, trust for advancement of agricultural sciences, New Delhi

Aggarwal, PK, Kumar SN, Chauhan N, Saxena R, Jain S, Rani S (2011) Impact of climate change on crop productivity in Western Ghats, coastal and north-eastern regions of India. Curr Sci, Special Issue, 101(3) 332–341

Anonymous (2010) Climate change and India: a 4x4 assessment. A sectoral and regional analysis for 2030s. Ministry of Environment and Forests, Government of India, p 24

Anonymous (2012) Coastal zones of India. Space Application Centre, ISRO, Ahmedabad, p 597

Ateweberhan M, McClanahan TR (2010) Historical sea-surface temperature variability predicts climate change-induced coral mortality. Mar Pollut Bull 60:964–970

Arthur R (2000) Coral bleaching and mortality in three Indian reef regions during an El Niño southern oscillation event. Curr Sci 79:1723–1729

Barnosky AD, Matzke N, Tomiya S, Wogan GO, Swartz B, Quental TB, Marshall C, McGuire JL, Lindsey EL, Maguire KC, Mersey B, Ferrer EA (2011) Has the Earth's sixth mass extinction already arrived? Nature 471:51–57

Biju kumar A (2012) Shifting baselines and jellyfish blooms: importance of research in relation to jelly fish export potential. Fishing Chimes 32(7):30–31

Blasco F (1975) The mangroves in India. Institut Francais de Pondicherry, Pondicherry, p 175

Brotz L, Cheung WL, Kleisner K, Pakhomov E, Pauly D (2012) Increasing jellyfish populations: trends in Large Marine Ecosystems. Hydrobiologia 690:3–20

Catenazzi A, Lehr E, Vredenburg VT (2014) Thermal physiology, disease, and amphibian declines on the eastern slopes of the Andes. Conserv Biol 28:509–517

CBD (2009) Connecting biodiversity and climate change mitigation and adaptation. Report of the Second Ad Hoc Technical Expert Group on Biodiversity and Climate Change. Montreal, Technical series no. 41, p 126

CBD (2014) An updated synthesis of the impacts of ocean acidification on marine biodiversity, In: Hennige S, Roberts JM, Williamson P (eds) Montreal, Technical series no. 75, p 99

Chaturvedi RK, Gopalakrishnan R, Jayaraman M, Bala G, Joshi NV, Sukumar R, Ravindranath NH (2011) Impact of climate change on Indian forests: a dynamic vegetation modelling approach. Mitig Adapt Strateg Glob Chang 16(2):119–142

Chaturvedi RK, Kattumuri R, Ravindranath D (2014) Mainstreaming adaptation to climate change in Indian policy planning. Int J Appl Econ Econ 22(1):23–56
Cheung WWL, Lam VWY, Sarmiento JL et al (2009) Projecting global marine biodiversity impacts under climate change scenarios. Fish Fish 10:235–251
Cheung WWL, Watson R, Pauly D (2013) Significance of ocean warming in global fisheries in catch. Nature. doi:10.1038/nature12156
Chitale VS, Behera MD, Roy PS (2014) Future of endemic flora of biodiversity hotspots in India. PLoS One 9(12):e115264, 1–15
Darwall WRT, Holland RA, Smith KG, Allen D, Brooks EGE, Katarya V, Pollock CM, Shi Y, Clausnitzer V, Cumberlidge N, Cuttelod A, Dijkstra KDB, Diop MD, Garcia N, Seddon MB, Skelton PH, Snoeks J, Tweddle D, Christophe J (2011) Implications of bias in conservation research and investment for freshwater species. Conserv Lett 4:474–482
Dhanya CT, Kumar A (2015) Making a case for estimating environmental flow under climate change. Curr Sci 109:1019–1020
Dulvy NK, Rogers SI, Jennings S, Stelzenmüller V, Dye SR, Skjoldal HR (2008) Climate change and deepening of the North Sea fish assemblage: a biotic indicator of warming seas. J Appl Ecol 45:1029–1039
Ellison JC (2012) Climate change vulnerability assessment and adaptation planning for mangrove systems. World Wildlife Fund (WWF), Washington, DC
Field CB, Barros VR, Mastrandrea MD et al (2014) Summary for policymakers. In: IPCC. Climate Change 2014: impacts, adaptation, and vulnerability. Working group II contribution to the IPCC 5th assessment report. Cambridge University Press, Cambridge/New York
Gautam HR, Bhardwaj ML, Kumar R (2013) Climate change and its impact on plant diseases. Curr Sci 105(12) 25: 1685–1691
Gosain AK, Sandhya R, Anamika A (2011) Climate change impact assessment of water resources of India. Curr Sci 101(3):356–371
Hawkes LA, Broderick AC, Godfrey MH, Godley BJ (2009) Climate change and marine turtles. Endanger Species Res 7:137–154
Hawkins JP, Roberts CM, Clark V (2000) The threatened status of restricted-range coral reef fish species. Anim Conserv 3:81–88
INCCA (2010) Climate change and India: a 4X4 assessment – a sectoral and regional analysis for 2030s. Ministry of Environment and Forests, Govt of India, 160pp
IPCC (2002) Climate change and biodiversity. IPCC Technical paper V. Intergovernmental panel on climate change. Geneva, p 77
IPCC (2014a) Climate Change 2014. In: Pachauri RK, Myer LA (eds) Synthesis report. Contribution of working groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on climate change. IPCC, Geneva, p 151
IPCC (2014b) Summary for policymakers. In: Field CB, Barros VR, Dokken DJ, Mach KJ, Mastrandrea MD, Bilir TE, Chatterjee M, Ebi KL, Estrada YO, Genova RC, Girma B, Kissel ES, Levy AN, MacCracken S, Mastrandrea PR, White LL (eds) Climate change 2014: impacts, adaptation, and vulnerability. Part A: Global and sectoral aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge/New York, USA, 32pp
Jagtap TG, Nagle VL (2007) Response and adaptability of mangrove habitats from the Indian subcontinent to changing climate. Ambio 36:328–334
Kumar NS, Aggarwal PK, Rani S et al (2011) Impact of climate change on crop productivity in Western Ghats, coastal and northeastern regions of India. Curr Sci 101:332–341
Laloë JO, Cozens J, Renom B, Taxonera A, Hays GC (2014) Effects of rising temperature on the viability of an important sea turtle rookery. Nat Clim Chang 4:513–518
Lee PLM, Dawson MN, Neill SP, Robins PE, Houghton JDR, Doyle TK, Hays GC (2013) Identification of genetically and oceanographically distinct blooms of jellyfish. J R Soc Interface 10(80):1–11

MoEF (2014) India's fifth national report to the convention on biological diversity. Ministry of Environment and Forests, New Delhi, 100p

Mohamed KS, Sathianandan TV, Kripa V, Zacharia PU (2013) Puffer fish menace in Kerala: a case of decline in predatory control in the south-eastern Arabian Sea. Curr Sci 104:426–429

O'Briena K, Leichenko R, Kelkar U, Venemad H, Aandahla G, Tompkinsa H, Javedc A, Bhadwalc S, Bargd S, Nygaarda L, Westa J (2004) Mapping vulnerability to multiple stressors: climate change and globalization in India. Glob Environ Chang 14(4):303–313

Padmakumar KB, Menon NR, Sanjeevan VN (2012) Is occurrence of harmful algal blooms in the exclusive economic zone of India on the rise? Int J Oceanograph, Article ID 263946, 7 pp. doi:10.1155/2012/263946

Parry ML, Canziani OF, Palutikof JP, Linden PJ Hanson CE (eds) (2007) Climate change 2007. Impacts, adaptation and vulnerability. Contribution of Working Group II to Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, p 982

Perry AL, Low PJ, Ellis JR, Reynolds JD (2005) Climate change and distribution shifts in marine fishes. Science 308:1912–1915

Portner HO, Farrell AP (2008) Physiology and climate change. Science 322:690–692

Purcell JE, Uye SI, Lo WT (2007) Anthropogenic causes of jellyfish blooms and their direct consequences for humans: a review. Mar Ecol Prog Ser 350:153–174

Raha A, Das S, Banerjee K, Mitra A (2012) Climate change impacts on Indian Sunderbans: a time series analysis (1924–2008). Biodivers Conserv 21:1289–1307

Rajendran K, Sajani S, Jayasankar CB, Kitoh A (2013) How dependent is climate change projection of Indian summer monsoon rainfall and extreme events on model resolution? Curr Sci 104:1409–1418

Richardson AJ, Bakun A, Hays GC, Gibbons MJ (2009) The jellyfish joyride: causes, consequences and management responses to a more gelatinous future. Trends Ecol Evol 24(6):312–322

Rosenfield JA (2002) Pattern and process in the geographical ranges of freshwater fishes. Glob Ecol Biogeogr 11:323–332

Roxy MK, Modi A, Murtugudde R, Valsala V, Panickal S, Prasanna Kumar S, Ravichandran M, Vichi M, Lévy M (2016) A reduction in marine primary productivity driven by rapid warming over the tropical Indian Ocean. Geophys Res Lett 43:1–8. doi:10.1002/2015GL066979

SCBD (2010) Strategic action plan for biodiversity 2011–2020 and the Aichi targets. Secretariat of the Convention on Biological Diversity, Montreal

Syvitski JPM, Kettner AJ, Overeem I, Hutton EWH, Hannon MT, Brakenridge GR, Day J, Vörösmarty C, Saito Y, Giosan L, Nicholls RJ (2009) Sinking deltas due to human activities. Nat Geosci 2:681–686

Unnikrishnan AS, Shankar D (2007) Are sea level rise trends along the coasts of northern Indian Ocean consistent with global estimates? Glob Planet Chang 57:301–307

Venter O, Fuller RA, Segan DB, Carwardine J, Brooks T, Butchart SHM, Marco M, Iwamura T, Joseph L, O'Grady D, Possingham HP, Rondinini C, Smith RJ, Venter M, Watson JEM (2014) Targeting global protected area expansion for imperilled biodiversity. PLoS Biol 12(6):e1001891, 1–7

Victor DG, Zhou D, Ahmed EHM, Dadhich PK, Olivier JGJ, Rogner HH, Sheikho K, Yamaguchi M (2014) Introductory chapter. In: Edenhofer O, Pichs-Madruga R, Sokona Y, Farahani E, Kadner S, Seyboth K, Adler A, Baum I, Brunner S, Eickemeier P, Kriemann B, Savolainen J, Schlömer S, Stechow C, Zwickel T, Minx JC (eds) Climate change 2014: mitigation of climate change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge/New York, USA, pp 113–150

Vivekanandan E (2013) Climate change: challenging the sustainability of marine fisheries and ecosystems. J Aquat Biol Fish 1(1 & 2):54–67

Vivekanandan E, Rajagopalan M, Pillai NGK (2009) Recent trends in sea surface temperature and its impact on oil sardine. In: Aggarwal PK (ed) Global climate change and Indian agriculture. Indian Council of Agriculture Research, New Delhi, pp 89–92

Wells ML, Trainer VL, Smayda TJ (2015) Harmful algal blooms and climate change: learning from the past and present to forecast the future. Harmful Algae 49:68. doi:10.1016/j.hal.2015.07.009

Williams JW, Blois JL, Shuman BN (2011) Extrinsic and intrinsic forcing of abrupt ecological change: case studies from the late quaternary. J Ecol 99(3):664–677

WWF (2014) Living Planet Report 2014. Species and spaces, people and places. WWF International, Gland, p 36