Climate Change and India: Vulnerability Assessment and Adaptation

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8. Climate Change Impacts on Natural Ecosystems

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Summary

This chapter reviews the existing status of natural ecosystems in the country and ascertains the likely vulnerabilities of these systems due to climate change, based on climate scenarios derived from the models (chapter 3) and on people's perception. The natural ecosystems covered include mountain ecosystems, grasslands, wetlands, and marine ecosystems of India. The biodiversity of these systems is already threatened in the existing climate, mostly due to economic activities. Climate change will be an additional stress. Linked with this is the livelihood of people dependent on the products of these natural systems and the integrity of the environment of the country. Considering the need to protect such systems, this chapter discusses some measures for averting degradation of biodiversity and also the ongoing efforts by the government towards this. Reducing the present stresses on natural ecosystems will provide them with space and time to grow. This, coupled with suitable coping strategies, will reduce the cumulative impacts of future climate change and other stresses on Indian natural ecosystems.

8.1 Introduction

The large geographical area, varied topography and climatic regimes, long coastline and the possession of oceanic islands have endowed India with a diversity of natural biomes from deserts to alpine meadows, from tropical rainforest to temperate pine forests, from mangroves to coral reefs, and from marshland to high altitude lakes. The natural ecosystems of the country have also been subject to exploitation and alteration by humans for several thousand years, and thus only a small fraction of these probably remain in a pristine state. Nevertheless, about one-fifth to one-fourth of the country's geographical area still comprises relatively "natural" ecosystems (Fig. 8.1) including forests. The present chapter assesses the current situation of the mountain ecosystems including wetlands, grasslands, mangroves, coral reefs and mountain ecosystems and their vulnerability to climate change. Vulnerability of the systems to climate change is measured in terms of the extent to which environmental and economic changes influence the capacity of human and ecological systems to respond to this change. The most vulnerable systems will be the ones that are most exposed to perturbations, have limited capacity of adaptation and are least resilient (Liechenko and O'Brien, 2002). As climate change is coupled with other global changes, vulnerability needs to be evaluated against a background of dynamic flux of both anthropogenic and biophysical factors.

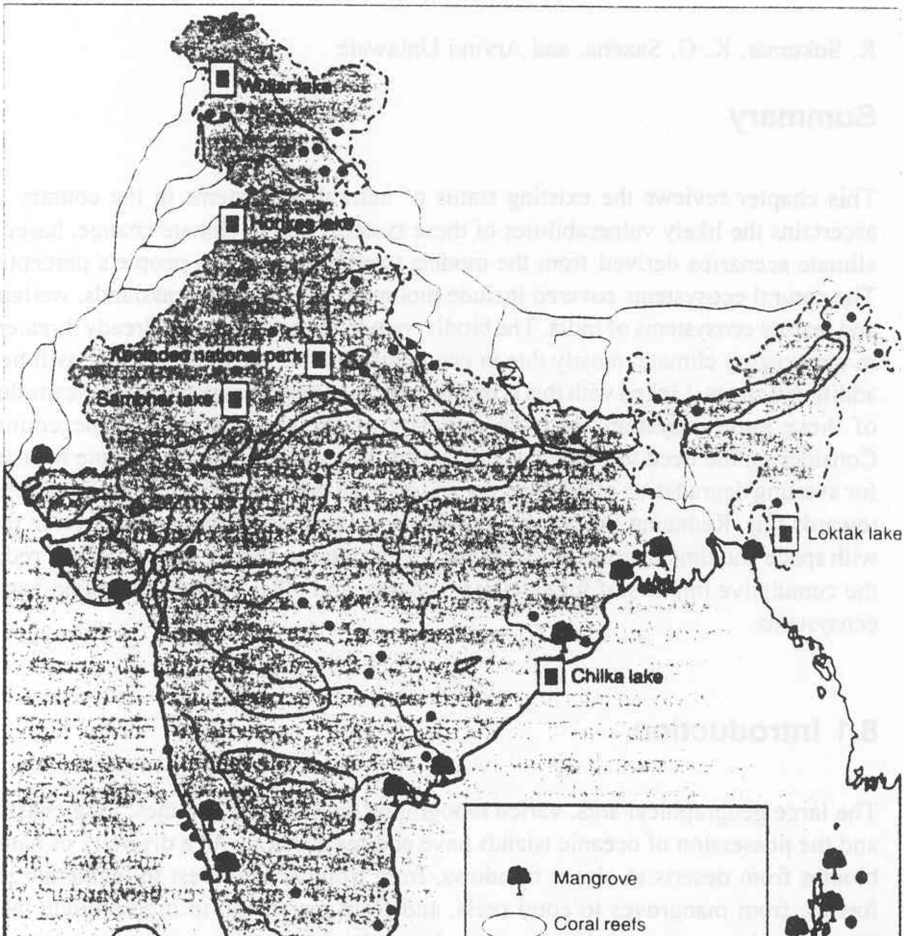

Fig. 8.1 Distribution of natural inland lakes, mangroves, coral reefs, and wetland systems in India (see color plates)

Source: Centre for Environment Education, Ahmedabad

8.2 Climate Change – Understanding Through Models and People's Perception

Precision of predictions about vulnerability to climate change depends on our understanding of the nature and magnitude of these changes. The capacity of available scientific tools to predict climate change is limited, more so in the mountains. The studies of Brazel and Marcus (1991) in the northern Himalayas show that the Oregon State University model and the UK British Meteorological model predict increased aridity on the humid slopes and reduced aridity on the arid slopes, while the Goddard Institute Space Studies model and the Geophysical Fluid Dynamics Laboratory model bring out the opposite trend. The uncertainty associated with scientific predictions about climate change may be qualified as irremediable for all practical purposes. Hence, corrective actions will have to be tentatively identified based on an imperfect knowledge base and revised with improvement therein (Steffen et al., 2002).

Many traditional communities have responded to changing environments (Grove, 1996). Analysis of indigenous knowledge could provide insights on changing climate and its impacts. Deductions from people's perceptions, however, will be limited to a time scale, which is within the range of human memory. Farmers may hide or provide inaccurate information and hence crosschecking of their perceptions is warranted (Sen et al., 2002). People's perceptions derive not from any direct measurements of climate but from the way climate affects their immediate surroundings and livelihood. For people in central Himalayas, a 'good climate' meant: sporadic low rainfall during March-mid-May, peak rainfall during July-August, moderate rainfall/heavy snowfall during December/January and absence of cloudburst events. People consider the onset of the monsoon to be more uncertain compared to other phases of rainfall. Climate changes felt in the recent decades included a shift in peak rainfall time from July/August to August/September and winter precipitation from December/January to

Table 8.1 People's perceptions on climate change in central Himalaya

Kind of change	Evidence
Warming	Decline in snowfall period, depth and persistence, decline in apple yield, success of cabbage/ pea/ tomato cultivation in high elevations in recent years, shortening of maturity period of winter crops, increased pest infestation
Decline in rainfall during March-May	Large scale mortality, abandonment of *Panicum miliaceum* in rainfed areas, declining yields of Amaranths
High rainfall during August/ September instead of the normal peak in July/August	Damage to rainy season crops when they are close to maturity, increased frequency and severity of land slides
Winter precipitation in January/ February instead of December/January and decline in intensity of snowfall	Delayed sowing of winter crops, decline in barley and wheat yields
Increase in instances of cloudburst	Heavy losses of life and property

January/February, increase in frequency of cloudburst and warming (Table 8.1).

The following sections review the status of the various natural ecosystems in the country and assess the likely impacts that each of them might be subjected to due to climate change in the future.

8.3 Wetlands

The Ramsar Convention on Wetlands defined wetlands in 1971 as "areas of marsh, fen, peat land, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six meters" and later proposed that wetlands "may incorporate riparian and coastal zones adjacent to the wetlands, and islands or bodies of marine water deeper than six meters at low tide lying within the wetland".

A comprehensive wetland inventory for India was prepared by the Space Application Center (SAC) of the Indian Space Research Organization using satellite imagery for the years 1991-92 (Garg et al., 1998). This inventory has listed 27,403 wetland units in the country occupying a total area of 75,819 km^2 with the coastal wetlands comprising 53% and the rest being inland wetlands.

Table 8.2 Type-wise estimates of inland wetlands reported by the SAC

Inland	Wetland Category	Number	Area (ha)
	Natural Lakes/Ponds	4646	679530
	Ox-bow lakes	3197	151051
	Waterlogged (Seasonal)	4921	285744
	Playas	79	118519
	Swamp/Marsh	1814	197784
Man-made	Reservoirs	2208	1481987
	Tanks	5549	558344
	Waterlogged	892	77302
	Abandoned Quarries (water)	105	5774
	Ash pond/Cooling ponds	33	2881
Total Inland Wetlands		23444	3558915

Source: Vijayan and Prasad, 2003

The inland wetlands include a large number of natural lakes and swamps or marshes as well as man-made reservoirs and tanks. A study by Vijayan and Prasad (2003), lists 23,444 inland wetland units covering an area of 35,589 km^2 in total (Table 8.2). Of these the natural inland wetlands, with which we are concerned in this report, number 14,657 units and cover an area of 14,326 km^2 (see Fig. 8.1).

Inland wetlands in India have been transformed in a large way by urban settlement, agricultural development, road construction and pollution. Climate change impacts on the inland wetlands will be a complex issue dependent on several variables including temperature increase, rate of evaporation, changes in precipitation of the catchment, changes in nutrient cycling and the responses of a variety of aquatic species. These have been elaborated in the IPCC (2001b).

8.4 Marine Ecosystems: Mangroves and Coral Reefs

The Indian coastline is over 7,500 km including the islands of Lakshadweep and the Andaman & Nicobars. Of this the island coastline constitutes 22% and the mainland coastline the rest. Most of India's coastline is densely populated and thus, much of the natural ecosystems have been converted to other forms of land use.

As many as 3959 coastal wetland sites, classified under 13 major wetland types, and covering a geographical area of 40,230 km^2 have been mapped by the Space Application Centre across nine states and four Union Territories (Garg et al. 1998). Of these 426 sites (1,424 km^2) are man-made wetlands (salt pans and aquaculture ponds) and the rest are natural coastal wetlands. The state of Gujarat has the largest area (25,083 km^2) under coastal wetlands (about one-fifth of the area is under salt pans) followed by Tamil Nadu (3,987 km^2), West Bengal (3,604 km^2), Orissa (1,854 km^2), Andhra Pradesh (1,855 km^2), and the Andaman & Nicobars (1,078 km^2). Of the various wetland types, the tidal mudflats (23,621 km^2) and mangroves (4,871 km^2) constitute the major areas, the former mainly in the state of Gujarat and the latter in the state of West Bengal and the Andaman and Nicobars (see Table 8.3 for areas under other wetland types).

Table 8.3 Area under various coastal wetland types

Types of Coastal Wetlands	Area (in km^2)
Tidal Mudflats	23621
Mangroves	4871
Estuaries	1540
Lagoons	1564
Sand Beach	4210
Marsh	1698
Other Vegetated Wetlands	1391
Coral Reefs	841
Creeks	192
Backwater	171
Rocky Coast	177
Salt Pan	655
Aqua-culture Ponds	769

Source: Garg et al., 1998

The coastal wetlands play an important role in the economy of this region, especially in fisheries. The mangroves and the coral reefs in particular are important nurseries for several fishes, prawns and crabs. Of the annual fish catch of about 5.6 million tons, about half is from marine fisheries; the coral reefs and associated shelves and lagoons alone have the potential for about 10% of the total marine fish yields (Anon, 2000; Anon, 2001). Climate change impacts on the coastal wetlands will thus have serious consequences for the livelihoods of people as well as the integrity of the coastal environment of the country.

8.4.1 Mangrove ecosystems

Mangroves are distributed along both the east and the west coasts of the country (Table 8.4; also see Selvam, 2003 for a review). They can be classified as tide-dominated (e.g. Sunderbans and Mahanadi mangroves), river-dominated (Godavari, Krishna, Pichavaram and Muthupet), drowned river valley (e.g. in Gujarat), and mangroves on carbonate platforms on low energy coasts as in the Andaman and Nicobars (Thom, 1984; Selvam, 2003).

Mangroves are associated with the estuarine areas of the deltas of rivers. The area of the delta thus dictates the size of a mangrove. The mangroves of the east coast associated with the large rivers flowing into the Bay of Bengal are characterized by large brackish water-bodies and a complex network of tidal creeks and canals; they also harbour much larger mangroves with more diversity in their biota (Selvam, 2003). The Sunderbans, covering an area of about 10,000 km^2 along the Ganges-Brahmaputra delta, constitute the largest mangrove wetland in the world: of this area about 40% is found in the West Bengal state of India and the rest in Bangladesh. Other important mangroves include the Mahanadi mangrove in Orissa, the Godavari and Krishna mangroves in Andhra Pradesh, the Pichavaram and Muthupet mangroves in the Cauvery delta of Tamil Nadu, and the mangroves in the Gulf of Kachchh in Gujarat. Most of the mangroves along the west coast are small because of the small deltas of the swift west-flowing rivers in the peninsula.

The environment of a mangrove wetland is shaped by the coastal geomorphology, the nature of the tides, local climate, and the fresh water flow of the river. This complex interplay of environmental factors also determines the character of the mangrove vegetation and the aquatic fauna of the mangrove swamps. The environmental characteristics of some of the Indian mangroves with contrasting settings are summarized by Selvam (2003) as follows:

Sundarbans: Because of the large volume of freshwater, both from snow melt and from precipitation, from the Ganges, the Brahmaputra and their tributaries, the salinity of the water within the mangroves and near the sea is lower than that of the seawater even during the summer. The mean sea level in the Sundarbans is about 3.30 m, the mean highest water level 5.94 m and the mean lowest water level 0.94 m (Untawale, 1986). This mangrove estuary is characterized by many linear tidal mud flats and a network of tidal channels. The tidal water penetrates inland to an average distance of 110 km, with the tidal effect being felt as much as 300 km from the shoreline in some places.

Table 8.4 Distribution and area under mangrove wetlands in India

State	Mangrove Wetland	Total Area of the Wetland (ha)*	Actual Forest Cover (ha)
East Coast			
West Bengal	Sunderbans	426000	212500
Orissa	Mahanadi	67000	21500
Andhra Pradesh	Godavari	33250	24100
	Krishna	25000	15600
Tamil Nadu	Pichavaram	1300	900
	Muthupet	13000	1200
West Coast			
Gujarat	Gulf of Kachchh	58200	85400
	Gulf of Khambat	53123	17700
Other Mangroves	—	—	11600
Andaman and	Andaman island	—	92900
Nicobar islandss	Nicobar islands		3700
Total			487100

* Records of the State Forest Department
Source: Selvam, 2003

Pichavaram/Muthupet: Located at the mouth of the Cauvery delta, these mangroves receive freshwater flows mainly during the winter (northeast) monsoon season from October to December. Due to the long dry season, the salinity is high, about 35-45 ppt on an average and as much as 75 ppt in parts of Muthupet. The tidal amplitude is low with a mean water level of 0.34 m (mean high level of 0.67 m and mean low level of 0.03 m). The Pichavaram mangrove is located in the redundant delta of the Cauvery, while vegetation is absent in the active delta of its distributary, the Coleroon.

Gulf of Kachchh/Kambat: The mangroves here have developed under extreme environmental conditions of arid climate, hot summers and cool winters, and absence of any freshwater flows from major rivers. The Gulf of Khambat has, in fact, been described as "an extension of the sea on the land". Sea levels have increased by about 20m during the past 8000-9000 years.

Andaman and Nicobars: The Andaman-Nicobar archipelago has a complex geology, with a diversity of sedimentary rocks (dominated by sandstone), calcareous rocks forming cliffs, and even some of the southern islands showing recent volcanic activity. With a very humid climate and high annual rainfall of about 300 cm, the tidal amplitude is relatively high at about 1.9 m. The mangroves are found along the extensive network of tidal creeks, bays and lagoons. Rain-fed streams carry silt through the tidal creeks to the shores, thus forming muddy plains and facilitating the growth and spread of mangrove vegetation.

The plant diversity and biomass in a mangrove are related to the salinity of the local environment, with mangroves that receive more freshwater through rivers or higher local rainfall having a greater diversity of plants. In mangroves with highly saline waters due to low river discharge, low precipitation, long dry season and high temperatures, the community is dominated by a few species such as *Avicennia marina* that has the highest tolerance to salinity (Blasco, 1975). Diversity is highest in the mangroves of the Sundarbans and Mahanadi (26 species in each), as well as the Andaman and Nicobars (24 species), and is the lowest in the Gulf of Kachchh/ Kambat (eight species).

Current levels of degradation: With the exception of the mangroves of the Andaman and Nicobars, the mangroves of the country are already considerably degraded. The development of agriculture in the deltas of the major rivers, the reclamation of coastal wetland for settlement, and unsustainable use of mangroves to supply products such as fuel wood have resulted in considerable shrinkage of the mangrove areas.

In recent decades, the Indian mangroves have already undergone several changes that could provide clues as to how they may respond to future climate change. Some of these changes could be clearly related to human-induced changes in the environment; for instance, the impounding and diversion of river waters upstream for irrigation and power generation has reduced the freshwater flows into the estuaries on an absolute and seasonal basis. With the exception of the Andaman and Nicobars, all other mangrove regions in the country have been affected to varying degrees by reduced freshwater flows. In some cases such as at Pichavaram, the flow from the Coleroon river (a distributary of the Cauvery) has reduced by as much as 95% since the 1920s (Selvam et al., 2000). At the same time, true mangrove species of the family Rhizophoraceae, once common here, have become locally extinct. In the Sundarbans, the most abundant tree in the past was *Heriteria fomes* but this species has almost completely disappeared from the Indian part and has a restricted distribution in the Bangladesh part of the mangrove system (Selvam, 2003). In the Godavari mangroves, trees such as *Avicennia officinalis, Excoecaria agallocha* and *Luminitzera racemosa* that constituted 90% of the stand during the 1950s have now reduced to only 37% of the population; correspondingly halophytes such as *Suaeda maritime* and *S. monica* have increased to 40% of the population (Azariah et al., 1992).

Driving forces for climate change impacts on mangroves: Climate change impacts on the mangrove ecosystems will be governed by factors such as sea level changes, storm surges, freshwater flows in rivers both from precipitation in their catchments as well as from snow melt in the mountains, local precipitation, and temperature changes that will influence evapotranspiration.

Sea level rise as a consequence of thermal expansion of water as well as melting of polar ice will submerge the mangroves as well as increase the salinity of the wetland. This will favour mangrove plants that tolerate higher salinity. At the same time, increased snow melt in the western Himalayas could bring larger quantities of freshwater into the Gangetic delta. This will have significant consequences for the composition of the Sundarbans mangroves. Changes in local temperature and precipitation will also influence the salinity of the mangrove wetlands and have a bearing on plant composition. Any increase in freshwater flows will favour mangrove species that have the least tolerance to salinity.

The impact of sea level rise on mangroves is still controversial. Much depends on the tidal range and sediment supply. Predictions for mangroves globally have ranged from complete collapse (e.g. Alleng, 1998), inability of low- and high-island mangroves to adapt to sea-level rise (e.g. Ellison and Stoddart, 1991), adaptation by low-island mangroves to sea-level rise through sediment supply (e.g. Snedaker et al., 1994) to even progressive expansion of mangroves from coastal inundation (Richmond et al., 1997). Because the tidal amplitudes today are quite large in some mangroves (cited as 5m in the Sundarbans), it has also been argued that the predicted sea-level rise of 0.09-0.88 m between the years 1990 and 2100 (IPCC, 2001a) is well within the ability of a mangrove ecosystem to adapt (Untawale, 2003). This may not be true for other mangroves such as the ones at Pichavaram and Muthupet where tidal amplitudes are much lower at 0.64 m and much of the inland areas are already developed for agriculture.

It is, therefore, necessary to model the specific scenarios for the various mangrove ecosystems using climate change projections, changes in freshwater and sediment flows, geomorphology, sea level change and the land use of the coastal region.

8.4.2 Coral reefs

Coral reefs are distributed in six major regions along the Indian coastline. These are the Gulf of Kachchh in Gujarat, the Malwan coast in Maharashtra, Lakshadweep islands, Gulf of Mannar and Palk Bay in Tamil Nadu, and the Andaman and Nicobar Islands. Built up during the Tertiary and the Quaternary Periods, the coral reefs in the Indian Ocean include sea level atolls (Lakshadweep archipelago), fringing reefs (Gulf of Mannar, Palk Bay, and Andaman and Nicobars), reef barriers (Andaman and Nicobars), elevated reefs and submerged reef platforms (Singh, 2002). The area under various reef types is given in Table 8.5.

The biodiversity of the coral reefs includes a variety of marine organisms including sea grasses, corals, several invertebrate groups, fishes, amphibians, birds (nesting on the reefs) and mammals. The reefs of the Andaman and Nicobar islands have the highest recorded diversity with 203 coral species, 120 algal species, and 70 sponges in addition to fishes, sea turtles, dugong and dolphins. About 1200 species of fishes have been recorded in the seas around the islands including 571 species of reef fish. The reefs of the Gulf of Mannar and Lakshadweep islands have intermediate levels of diversity with 117 species and 95 species of hard corals, respectively. The Gulf of Kachchh is the least diverse with only 37 species of corals and an absence of ramose forms.

Current status and threats to coral reefs: The coral reefs in the Indian region are already under threat from several anthropogenic and natural factors, including destructive fishing, mining, sedimentation, and invasion by alien species (Rajasuriya et al., 2000). In the Gulf of Mannar there are 47 fishing villages along the 140 km coastline. Exploitation of seaweeds, sea horses, sea cucumbers, pipe fishes, and sharks is intense. Marine turtles and dugongs are also harvested. Blast fishing is particularly destructive. Sand mining, extraction of trochus shells and sedimentation degrade the coral formations, besides sewage pollution along the Keelakarai coast has promoted the overgrowth of corals by green algae. In addition, about 250 m² of coral is directly quarried each day. Deforestation on some islands of the Andaman and Nicobars has resulted in an increased flow of freshwater and sediment that have affected the corals. Pollution around Port Blair has also affected the corals here. In the Gulf of Kachchh region the development of industries, ports and offshore moorings has impacted the coral reefs. The alien crown-of-thorns starfish was first recorded during 1977 at Agatti in the Lakshadweep islands. This has spread to other islands and suppressed the corals.

Table 8.5 Distribution and area estimates of coral reefs in India

Category	Coral Reef Area (in sq. km)			
	Gujarat	Tamil Nadu	Lakshadweep	Andaman & Nicobar
Reef flat	148.4	64.9	136.5	795.7
Sand over reef	11.8	12.0	7.3	73.3
Mud over reef	117.1	—	—	8.4
Coraline shelf	—	—	230.9	45.0
Coral heads	—	—	6.8	17.5
Live coral platform	—	—	43.3	—
Algae	53.8	0.4	0.4	—
Seaweeds	—	—	0.7	—
Sea grass	—	—	10.9	—
Reef vegetation	112.1	13.3	—	8.9
Vegetation over sand	17.0	3.6	0.4	10.5
Lagoon	—	0.1	322.8	—
Sandy substrate	—	—	(67.4)	—
Reef patch	—	—	(13.4)	—
Deep	—	—	(98.5)	—
Uncertain	—	—	(143.5)	—
Total	460.2	94.3	816.1	959.3

Source: Singh, 2002; Naik, 1997

Driving forces for climate change impacts on coral reefs: It is well known that increased sea surface temperature (SST) results in "bleaching" of corals. SSTs are projected to increase by 1-2° C in the tropical oceans by the year 2100 relative to the present (IPCC, 2001b). Warming events associated with El Nino-Southern Oscillation are also expected to increase in frequency and intensity (Timmermann, et al., 1999). Although corals may bleach on an annual basis in response to seasonal variations in temperature and radiation (Brown et al., 2000), major bleaching events of corals occur when SSTs exceed seasonal maximums by >1° C (Brown et al., 1996). The

1998 mass-bleaching event could thus be a valuable indicator of the potential impacts of climate change on coral reefs (Wilkinson et al., 1999).

The term bleaching refers to the loss of colour in reef-building corals with the underlying skeleton becoming visible (white). The bleaching results from the expulsion of zooxanthellae (the symbiotic algae, a type of dinoflagellate) by the coral polyps and/or the loss of chlorophyll by the zooxanthellae themselves. While bleaching is a normal event and is reversible, a prolonged increase in SSTs and/or intense bleaching may result in the death of the corals.

Reasonably complete records of coral bleaching worldwide are available since 1979. The most widespread and intense bleaching of corals ("mass bleaching") occurred during the years 1997-98 associated with the El Niño event at this time when SSTs were enhanced by over 3° C, the warmest in modern record. Some of the most intense bleaching events occurred in the corals of the Indian Ocean. While the coral reefs of India too were adversely affected, the precise extent of bleaching and mortality of the corals is not clear. Some of the early accounts, mostly anecdotal, suggested that the corals of the Andaman and Nicobar islands were severely affected with up to 80% bleaching or mortality but later investigations showed that these estimates were exaggerated. There are clearly large variations in the extent of bleaching across this island chain: for instance, one survey reported only about 10% live cover of corals in the Little Andamans but about 70% live cover in the Middle Andamans.

On the other hand, the corals of the Lakshadweep islands were clearly significantly affected by this event with bleaching of 82% of coral cover and mortality of 26% of corals (Arthur, 2000). Bleaching/mortality was very variable across reefs but more uniform within a reef. On the Agatti and Kadamat islands, the dead skeletons of *Acopora* were clearly breaking down and turf and coralline algae grew on dead coral at all sites. There were however signs of recovery with many small colonies of *Acopora* recruited after the bleaching event, growing on the reef surfaces.

The corals of the Gulf of Mannar were equally affected with 89% bleaching and 23% mortality (Arthur, 2000). Some observations in the Gulf of Mannar provide us with clues as to the type of corals that are most vulnerable to bleaching and mortality from increased SSTs. On an average about 60-75% of corals in this region are thought to have been bleached during 1998. The most affected were shallow water corals such as the branching *Acopora* and *Pocillopora* that were almost completely wiped out. Bleaching also affected the massive corals but these recovered and now dominate the reefs.

The least affected coral reefs were those in the Gulf of Kachchh with an average of 11% bleaching and little mortality (Arthur, 2000). The coral community here seems better adapted to higher SSTs in the northern Arabian Sea.

Coral reefs could also be potentially impacted by sea level rise. Healthy reef flats seem able to adapt through vertical reef growth of 1 cm per year observed during the Holocene; (see Schlager, 1999) that is within the range of projected sea level rise over the next century. However, the same may not be true for degraded reefs that are characteristic of densely populated regions such as South and Southeast Asia (Bryant et al., 1998).

8.5 Sand Dune Ecosystems

Coastal dunes are made of sand, which is piled high by the wind. Sand is the by-product of weathered rocks from inland regions. These inland rock formations have been eroded by rain and wind and washed into the rivers that eventually flow into the Ocean. Once in the sea, the sand is shifted up the coast by currents and wave action. Sand on the continental shelf gets shifted around continuously between the sea-floor, beach and dunes. Wave action deposits the sand containing heavy minerals onto the beach and, thereafter, the sand is blown into dunes by the prevailing onshore winds. Shells, corals and other skeletal fragments provide sediments to some beaches especially to those in the tropics.

Untawale (1980) classifies the sand dune vegetation forming a natural triangle with the herbaceous pioneer zone at the base, and back shore zone covered with trees at the apex. This vegetational profile diverts the wind flow upward, controlling the erosion. On the pioneer zone, the herbs with creeping stolen grow. In the mid-shore zone, herbs and shrubs with comparatively deeper root system are seen to be naturally growing. And further on the backshore, dune trees are found. This natural vegetation has to be maintained as they successfully utilize the groundwater. Any change in the growth pattern will interfere with the dynamic system of sand dunes. Therefore, sea level rise could potentially impact the sand dune ecosystem.

8.6 Grasslands

A natural grassland can be defined as one in which the dominant plant species are grasses (family Poaceae) in association with herbs and sedges, but with few shrubs and practically no trees. Grasslands of various types constitute major ecosystems globally and presently cover an estimated 20% of the land surface. While grasslands in many parts of the world represent the "climatic climax", there are few regions in India where it can be said that grasslands represent the natural state. However, the grasslands occupy a significant area of the country, and are largely maintained by livestock grazing and fire.

There have been several schemes of classification of grasslands of India on the basis of species associations, geographical location, climatic factors and soil moisture (e.g. Puri, 1960; Whyte, 1964; Dabadghao and Shankarnarayan, 1973; Yadava and Singh, 1977). For the purpose of this paper, we adopt a relatively simple classification based on several of these factors and has been used by Rahmani (1996) to describe avian communities. Five major grassland types can be recognised:

- Alpine grasslands of the Himalayas
- Moist fluvial grasslands of the Himalayan foothills
- Arid grasslands of northwestern India
- Semi-arid grasslands of central and peninsular India
- Montane grasslands of the Western Ghats

8.6.1 Current levels of degradation

As pointed out by Rahmani (1988), it is ironic that the very anthropogenic factors such as livestock grazing and fire that were responsible for creating many of the grassland types in the country are also involved in the degradation of these same grasslands. India has a very large livestock population that has grown considerably over the past five decades for which statistics are available. Between 1951 and 1992, the cattle population of the country increased from 155 to 205 million heads while the total livestock (including buffalo, sheep, goat, pigs and other animals) population reached 470 million by 1992. While moderate levels of grazing could be sustainable and even promote plant species diversity, heavy grazing reduces the plant cover and eliminates palatable grasses and herbs while promoting the growth of unpalatable plants (Debadghao and Shankarnarayan, 1973). This also causes soil erosion as well as compaction.

8.6.2 Driving forces for climate change impacts on grasslands

When considering the likely impact of future climate change on natural grasslands we need to consider several factors including the direct response of grasses to enhanced atmospheric CO_2 as well as changes in temperature, precipitation and soil moisture.

It is well known that plants with the C3 and the C4 pathways of photosynthesis respond differently to atmospheric CO_2 levels and also to temperature and soil moisture levels. The C3 plants include the cool, temperate grasses and practically all woody dicots, while the C4 plants include the warm, tropical grasses, many sedges and some dicots. The C4 plants that constitute much of the biomass of tropical grasslands, including the arid, semi-arid and moist grasslands in India, thrive well under conditions of lower atmospheric CO_2 levels, higher temperatures and lower soil moisture, while the C3 plants exhibit the opposing traits. Increasing atmospheric CO_2 levels should, therefore, favour C3 plants over C4 grasses, but the projected increases in temperature will favour the C4 plants. The outcome of climate change will thus be region-specific and involve a complex interaction of factors.

GCM model projections (e.g., Hadley Centre's HADCM2) for India indicate an increase in precipitation by upto 30% for the northeastern region in addition to a relatively moderate increase in temperature of about 2°C by the period 2041-60. This could increase the incidence of flooding in the Brahmaputra basin and thus favour the maintenance of the moist grasslands in the regions.

The HADCM2 projections for the rest of the country (southern, central and northwestern India) are a steep increase in temperature of 3°C in the south (except along the coast) to over 4°C in the northwest, and a decrease in precipitation of over 30% in the northwest though little change in parts of the south. This combination of temperature increase and rainfall decrease would cause major changes in the composition of present-day vegetation in these regions with an overall shift to a more arid type (Ravindranath et al., 2003, chapter 7 of this book for details of model results from BIOME3 for vegetation changes).

Paleoecological studies of montane grasslands in the Western Ghats show that the relative extent of C3 and C4 plants during the past 40,000 years has varied in response to natural changes in temperature, precipitation (and soil moisture) and possibly atmospheric CO_2 levels (Sukumar et al., 1993; Sukumar et al., 1995; Rajagopalan et al., 1997; Robinson, 1994). It is expected that increased atmospheric CO_2 levels and temperatures, resulting in lowered incidence of frost, will favour C3 plants including exotic weeds such as wattle (*Acacia spp.*) that could invade these montane grasslands (Sukumar et al., 1995; Ravindranath et al., 1997).

The cool, temperate grasslands of the Himalayas could also be impacted by rising temperatures that will promote the upward migration of woody plants from lower elevations (Deshingkar et al., 1997).

8.7 Mountain Ecosystems

Conventional scientific hypothesis testing cannot always be used to elucidate ecosystem responses to climate change. Impacts can be inferred based on responses of limited species/area to factors such as higher temperatures and CO_2 levels, and on differentiation of the ecosystem in space as related to climatic variability (Table 8.6). However, responses to steep increase in the CO_2 level over the short-term in enrichment experiments may not precisely reflect long-term responses to slow increase in the biosphere (Luo and Reynolds, 1999).

Table 8.6 Ecological responses of plants to climate change and their implications for vulnerability and adaptation

Change driving factor	Impacts and implications
Increase in photosynthesis and water use efficiency as a result of increase in CO_2 concentration	More intact forests at lower elevations will respond to a greater degree compared to degraded forests at higher elevations. Ever green early successional fodder trees will respond to a greater degree compared to deciduous timber trees. However, shortening of life span of leaves, changes in biomass allocation patterns/architecture and poor quality litter (high C/N ratio) production may counterbalance the CO_2 enrichment effect. Medicinal herbs and fuelwood/fodder trees which coppice profusely are not likely to be as much down-regulated as those that are not utilized or that are used but coppice poorly. Higher CO_2 concentration can induce self-compatibility in otherwise self-incompatible species, species composition will change due to reduced fitness of many species over time.
Increase in temperature	Warming induced stimulation of growth will increase with increase in elevation. It may result in higher yields of some crops if warm ing is not coupled with water and nutrient stress, but will not be favourable for alpine species, which require chilling for germina-

	tion and fruiting. Leaf life span reduces with increase in temperature in the north-eastern Himalaya but an opposite trend is observed in the western Himalaya suggesting varied patterns of changes in leaf dynamics in response to warming. *Quercus leucotrichophora*, a species with high ecological as well as socio-economic values, shows low acorn production at lower elevation compared to higher elevations and hence is likely to be negatively affected by warming.
Change in precipitation	Ecosystems with clayey-loamy soils, high soil organic matter and higher degree of water stress in north-western Himalaya will be more responsive than the ones with sandy soil, low organic matter content and low water stress in the north-eastern Himalaya. Late successional species with a greater capacity of storing resources in root system will have an advantage in coping with the nutrient stress. If shedding of leaves is a strategy to avoid low temperature and related water stress, increase in rainfall coupled with increase in temperature is likely to increase the life-span of leaves.
Change in phenology	Reduction in length of the dry season under higher temperature-rainfall scenario may intensify competition for shared pollinators or may increase the density of some pollinators which may compensate for overlap of flowering. As the proportion of evergreen and deciduous species or winter, summer and spring flowering species and of wind pollinated and insect pollinated species is not uniform across the region, impacts of climate changes on ecosystem properties mediated through phenological changes will vary within the region. As most locally valued species have a poor soil seed bank, they will be threatened if seed production on a landscape scale declines.
Change in soil carbon stock	Higher rates of removal of leaf litter and deadwood from forest floor with increase in population pressure coupled with higher soil respiration under warmer regimes will reduce downward movement of organic carbon, more so in open environments.
Upward movement of biomes	Upward progression of species in response to warming is almost certain, but the rates of range expansion are difficult to predict because of interaction of climate and non-climate factors determining species abundance. As responses to temperature differ by species and elevation, new altitudinal belts of vegetation will differ from the present pattern. Alpine vegetation, particularly on convex slopes is likely to be the most sensitive to warming. The proportion of grasses, forbs and shrubs are likely to increase and that of sedges to decrease with warming leading to changes in economic and ecological functions of meadows.
Changes in species composition	Competitive interactions are intensified under elevated CO_2. Vines may profit more. A climbing invader like *Mikania micrantha* may reduce tree growth. Species with narrow niches will undergo stress and will have less chances of survival compared to wide niche species. Migration of species to favorable niches will be limited by habitat fragmentation.

Recent experiments with mature tree stands do show that growth stimulations to CO_2 enrichment are unlikely to be long-term responses (Norby et al., 2001), a conclusion also supported by the trends in the non-structural carbohydrate pool which indicates a degree of carbon limitation in trees (Korner, 2003). In the Himalaya, high altitude areas (>3000 m amsl) show the present CO_2 level close to pre-industrial levels and valleys at lower elevations close to present global average (Saxena and Purohit, 1993). Thus, impact of CO_2 enrichment will vary spatially. Decline in biomass accumultion with decline in elevation in alpine species of the Himalaya like *Aconitum balfourii* and *Aconitum heterophyllum* (Nautiyal, 1996) suggest that their growth is not limited by low CO_2-low temperature conditions. Warming enhanced growth of *Allium stracheyi*, *Arnebia benthamii* and *Dactlvorrhiza hatagirea* and reduced growth of *Angelica glauca* and *Rheum emodi*, though these species resemble in their ecological distribution. Rawat and Purohit (1991) observed that stomatal conductance was regulated more by endogenous rhythms than by atmospheric conditions in some alpine species. Thus, an uncertainty is inherent to conclusions on long-term ecosystem responses based on scaling-up of short-term experimental observations on a few species.

While warming will drive biomes upward, changes in ranges of species are also certain. There are several sources of uncertainty to forecast which species are most likely to be threatened or favoured partly because the importance of non-climate factors in influencing vegetation dynamics has not been given due consideration in the prediction models (Higgins et al., 2003). In the Himalaya, moraines exposed as a result of glacial retreat due to warming will drive alpine species upward but colonization may be constrained by erosion and nutrient limitations. The dominance of tree species such as *Abies*, *Betula* and *Acer* spp. derives from their physiological adaptations to extremely low temperatures. These species with a narrow ecological niche may be exterminated if they fail to compete with the new arrivals under warmer regime and/or to expand their ranges. Mid-altitude species such as *Pinus roxburghii*, *Cedrus deodara*, *Cupressus torulosa*, *Quercus* spp. and *Rhododendron arboreum* have a wider altitudinal spread as compared to the alpine/subalpine species and hence extermination of the former is less likely compared to the latter. *Quercus* dominates on the southern steep slopes and conifers on the northern dip slopes. *P. roxburghii* is largely confined to areas with quartzite and conglomerates. *Aesculus indica* and *Alnus nepalensis* forests seem to represent edaphic rather than climatic climax. In alpine areas, Junipers are found to prefer drier limestone areas rich in calcium and Rhododendrons in moist areas with calcium-poor schists (Puri, 1960). As altitudinal belts differ in topographic and geological attributes influencing species dominance and distribution, the landscape scale composition of forests and meadows observed at present is going to be different from the future scenario. Low altitude/ foothill forests dominated by *Shorea robusta* are not likely to be as sensitive as higher elevation vegetation because this species can withstand much warmer-humid/dry climates.

One way of assessing the impacts of climate change on mountain ecosystems could be to make an inventory of land-cover changes and identify their causal factors. Such an approach (Table 8.7) shows a greater influence of non-climate factors compared to climate factors in the Himalaya. Indeed, farmers' perceptions are likely to be biased towards responses of agricultural crops, components of natural ecosystems that affect their livelihood or that are very conspicuous such as *Rhododendron arboreum* with mass production of large red flowers. Advancement of flowering in *R. arboreum* and upward expansion of *Tagetis minuta*, *Lantana camara* and *Eupatorium* spp. seem to be driven primarily by climate change. Nonetheless, the possibility of modification of climate change driven changes by those driven by non-climate factors cannot be ruled out.

Table 8.7 Common changes in forests/meadows and driving factors identified by people/ reported in scientific studies in the Central Himalayan region

Kind of change	Change driving factors
Conversion of dense to open forest	Population pressure, market forces, erosion of traditional forest manage-mentinstitutions, limitations of introduced technologies and institutions to fulfill local needs
Dense forest converted to scrub	Intensive timber extraction on steep slopes with poor regeneration capacity, market forces
Degraded forest converted to agricultural land	Increase in livestock population, erosion of traditions favoring diffusion of grazing pressure, failure of formal institutions to check illicit grazing, decline in fodder production on farmland, policies limiting direct eco nomic benefits from forests
Conversion of pastures to agriculture	Population pressure, limitations of forest protection mechanisms, increas-ing stress on cash crops
Scrub land converted to forest	Protection and plantation of multipurpose trees by local communities
Conversion of grasslands to scrubs	Decline in nomadic grazing due to enforcement and/or cultural change
Increase in mult-ipurpose trees in farmland	Degradation of natural forests, restrictions on access to meadows and forests, policies favouring timber and other industrially important trees, limited indigenous capacity to enhance productivity of community forests
Conversion of agr-iculture to agrohorticulture	Subsidy on horticultural inputs and marketing
Increase in forest species richness	Strict enforcement of protection
Conversion of oak to pure pine stands	Commercial charcoal making, selective protection of pine to maximise government revenue, ground fire
Domestication of new crops	Emerging market for medicinal plant products, restrictions on extraction from the wild
Expansion of weeds	Habitat changes together with climate change
Phenological changes	Shift in flowering time of *Rhododendron* from March/April to Feb-March due to climate change

Agriculture is a minor land use in terms of spatial extent but has significant influence on vulnerability of forests and meadows that supply livestock feed and manure. Agricultural expansion coupled with changes in management practices is widespread. Local crops/ cultivars selected to cope with the uncertainties of the monsoon have suffered the greatest loss due to increasing stress on 'maximisation of income'. Cash crops are being grown where climatic conditions are sub-optimal for them. The ongoing changes in agricultural land use are such that fuelwood and fodder production from cropland is declining while rate of manure (livestock excreta mixed with forest leaf litter) input is increasing. These changes imply increasing pressure on forests and meadows (Maikhuri et al., 2000a). Cash crops like tomato, cabbage and chilly will be favoured in a higher temperature-higher rainfall regime and potato under a higher temperature- no change/lower rainfall regime. Alpine/ temperate zones are likely to be the most threatened ones because here replacement of oak forests by pine forest (due to warming driven upward progression of biomes) will reduce quality as well as quantity of forest products needed to sustain livelihood.

8.8 Adaptation Responses

Policy decisions at the governmental level for protecting the natural ecosystems from the adverse impacts of climate change need special attention. Existing policies of the government to protect and preserve the natural ecosystems may also be useful in the climate change regime. The following section touches briefly upon some of the measures and the existing protection strategies of the government that can be used to protect these natural ecosystems. Reducing the present stresses on natural ecosystems will provide them with space and time to grow. This, coupled with suitable coping strategies, will reduce the cumulative impacts of future climate change and other stresses on Indian natural ecosystems.

8.8.1 Conservation of wild biodiversity: Strengthening of Protected Area Network

Redundancy associated with species richness is likely to increase the probability of compensation of negative impacts of changing environmental conditions. Conservation of biodiversity is, perhaps, the most desirable need for adaptation and mitigation. Though we have a long history of planned conservation (9% area of Himalaya is legally protected), our knowledge on people-biodiversity-vulnerability linkages is very limited. Unsustainability of traditional grazing is more an assumption than a scientific conclusion (Maikhuri et al., 2000a). Rarity of medicinal species is largely attributed to over-exploitation (Samant et al., 1996), though this could also be due to inherent biological constraints delimiting their populations or to climate change (Simon and Hay, 2003). Ecological capital of protected areas derives from the ethos of sustainable resource use ingrained in traditional practices. Coping with climate risks is an important factor in shaping the indigenous biodiversity management (Table 8.8). Nevertheless, indigenous practices may succumb to new global forces. Participatory research/management could turn the people's callous/ negative attitudes to positive attitudes towards protected areas (Maikhuri et al., 2000a) together with improvement in scientific knowledge related to potential uses of biodiversity for adaptation and mitigation.

Table 8. 8: Risks and coping mechanisms in mountain regions

Type of risk	Coping mechanisms
Risks arising from inaccessibility	Local production based food self-sufficiency as the primary goal of agriculture, export of farm/wild products limited to income needed to procure essential products not produced locally
Risks arising from climate variability and extremes: landscape scale adaptation strategy	Agricultural land use limited in extent and adapted to ecological opportunities/constraints; maintenance of a variety of agroecosystem types differing in their abilities to withstand different types of risks, low intensity disturbance in natural ecosystems
Risks arising from reclimate variability and extremes: farm scale adaptation strategies	More intensive cropping in valleys compared to that on slopes, ducing erosion due to cropping by terracing, huge manure input, maintaining proper drainage, diversified crop system and balance between negative (crop-weed competition) and positive effects (availability of fodder, nutrient conservation, soil conservation) of weeds to avoid absolute crop failure in bad climate years, mainte nance of multipurpose trees in farm land to ensure availability of forest products when access to forests is constrained by climate
Risks arising from climate variability and extreme events: forest management	Forest resource uses limited to subsistence needs, strict protection of forests and meadows (in the form of sacred forests/meadows) around critical areas
Risks arising from climate variability and extremes: socio-cultural adaptation strategies	Traditions favoring agricultural sustainability, forest resource utili zation-regeneration balance and environmental services, privileges to small holders in respect of income from forest products, exchange of seeds without any profit motive, collective responsibility for main taining drainage to cope with very high rainfall events

8.8.2 Sustainable improvement in traditional agriculture to protect forests and meadows

To avoid the possibility of agricultural land use aggravating the threats from climate change to forests/meadows, interventions enabling improvement in agro ecosystem production with reduction in pressure on natural ecosystems are needed.

- *Shifting agriculture:* Failure of interventions that tried to replace shifting agriculture in the northeastern Himalaya demand redevelopment of this land use through incremental, rather than quantum change; anything drastic may not find acceptance by the people. To elaborate on such an approach, s *Alnus nepalensis* is extensively used by tribal societies for soil fertility management. Introduction of this tree could recover all nitrogen depleted due to cropping during a five year period compared to a minimum of 10 years required in traditional shifting agriculture. Participatory researches on traditional ecological knowledge can unravel more beneficial keystone species. Sustainability of a shorter cycle will reduce the threats of shifting agriculture to forests (Ramakrishnan et al., 2003).

- *Settled farming:* Can be done through improvement in traditional agroforestry tree management. Scattered agroforestry trees are distinguishing features of settled upland farming. Lopping is a tool to regulate tree-crop competition for optimizing multiple benefits from the system. Farmers usually lop all branches during winter when access to as well as availability of fodder/fuelwood from forests are constrained by harsh climate. Semwal et al. (2002) have shown that retention of 25% of branches together with an increase in tree density in private farmland will improve tree vigour and ecological functions without any decline in crop yields. Research is needed to identify interventions that lead to agricultural sustainability such that the pressure on forests is reduced.
- *Improvement in traditional manure management practices*: Manure derived from leaf litter of oak forests supports higher crop yields and labor productivity compared to that from pine forests (Rao et al., 2003). In addition, oak forests are more valuable from the point of view of other tangible and intangible benefits to people compared to pine forests. Rejuvenation of oak forests in degraded lands could thus improve agricultural productivity together with enhancement of forest biodiversity and ecosystem services.
- *Rehabilitation of degraded forestlands:* About 59 million ha area of the Indian Himalaya is degraded. Though tree planting has been widely promoted, its impact has, by and large, been poor largely because people's needs were ignored. Indeed, people's priorities may not necessarily fall in line with environmental goals. The challenge is to overcome the weaknesses in people's rehabilitation framework through scientific and policy interventions. Plantation of ecologically compatible and locally valued trees, shrubs and herbs/crops, amelioration of soil stresses through improved traditional technologies and involvement of people in implementation and monitoring can enable restoration/conservation of forest/meadow biodiversity and increase carbon sequestration together with local socio-economic upliftment (Maikhuri et al., 1997; Maikhuri et al., 2000b; Rao et al., 1999; Saxena et al., 2001). Indeed, any strategy combining economic and environmental concerns will cost more compared to conventional tree plantations, but investment in the former is more secured. Introduction of 'nurse species' or 'keystone species' will enable accelerated recovery at reduced cost but will be appreciated by people only when they satisfy their immediate needs.

8.8.3 Protection of the marine ecosystems

The Coastal Zone, i.e. from the Supratidal region to the Infratidal and subtidal region is a very productive, dynamic and sensitive part of the marine system. In addition, this zone has perhaps the highest marine biodiversity. There are various marine living ecosystems like sand dune vegetation, mangroves, corals, benthic as well as associated marine biota. The Government of India keeping in view the environmental.

ecological, social and economical changes, which has taken place in these regions, has taken several measures for their sustainable development, conservation and management of the coastal zone and its sensitive ecosystems.

The Protected areas include:

- Marine Biosphere Reserves
- Marine Wildlife Sanctuaries
- Marine Parks and
- Genetic Resource Centers

8.8.4 Protection of the coastal zones

The coastal zone is very dynamic and productive but at the same time, prone to the effects of sea level rise, floods and cyclones etc. The intertidal region (area between the Lowest Low Tide to Highest High Tide Line) and 500m beyond the high tide line is considered the Coastal Regulation Zone (1991). The first 200m from the HTL is considered a No Development Zone, while the other 300m may be considered for restricted developments. In addition to the conservation and management of the sensitive coastal zone, the Ministry of Environment and Forests, Govt. of India, also spends a sizable amount on the implementation of Management Action Plans (MAPS).

Other than this, mangrove forests can be developed along the estuaries and backwaters while sandy beaches can be used for growing sand dune plants in a planned way. In view of this, the following points can be of great significance in protecting the coastline from the sea level rise and other impacts (Untawale, 2001). Coastal Shelter Belts consisting of mangroves and sand dune vegetation should be continuous, densely vegetated regions extending from 'Pioneer zone' to the hinterland (Backshore zone) varying from 1 to 5 km in width depending upon the edaphic and environmental features of the coast. This can be combined with the 'agroforestry belt' in the hinterland for further protection.

Policies should be designed to address problems in coastal zones with a view to strengthening the natural capacity of coastal ecosystems in respond to changes. In simple terms, a dead coral reef cannot grow, while a healthy reef has the potential to grow and provide continued protection against rising sea levels. Policies designed to halt reef degradations or restore damaged reef ecosystems maximize the potential for reefs to respond to climate change and sea level rise. In addition, such policies provide for the sustainable use of the renewable living resources of reef ecosystems and hence even in the absence of climate change, such policies will provide benefit to future generations (Pernetta and Elder, 1992, 1993).

8.8.5 Protection of fresh water wetlands

Creating buffer zones limiting anthropogenic activities around the demarcated corridor of the wetland could revive its natural functioning. The criteria for determining adequate buffer size to protect wetlands and other aquatic resources depend on (Castelle et al., 1994):

- Identifying the functional values by evaluating resources generated by wetlands in terms of the economic costs, etc.
- Identifying the magnitude and the source of disturbance, adjacent land use and projecting the possible impact of such stress in the long term, etc.
- Buffer characteristics - vegetation density and structural complexity, soil condition and factors.

A fully formed functional buffer must consider the magnitude of the identified problems, resource to be protected, and the function it has to perform. Such a buffer zone could be consisting of diverse vegetation along the perimeter of the water body, preferably an indigenous one serving as a trap for sediments, nutrients, metals and other pollutants, reducing human impacts by limiting easy access and acting as a barrier to invasion of weeds and other stress inducing activities (Stockdale, 1991).

A National Wetland Management Committee has been constituted with a view to advising the Government on the policy and measures to be taken and selection of wetlands for conservation and management.

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