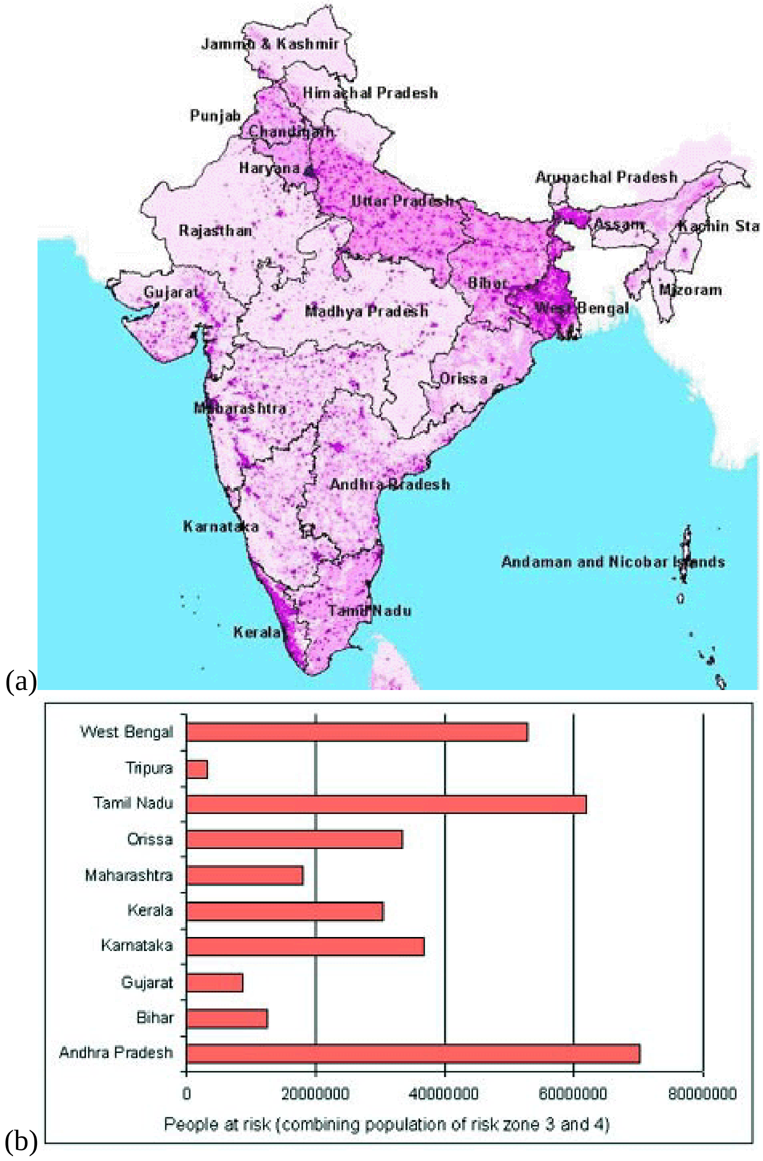


Figure 2.7 (a) Population density of India (b) population of high-risk states in India

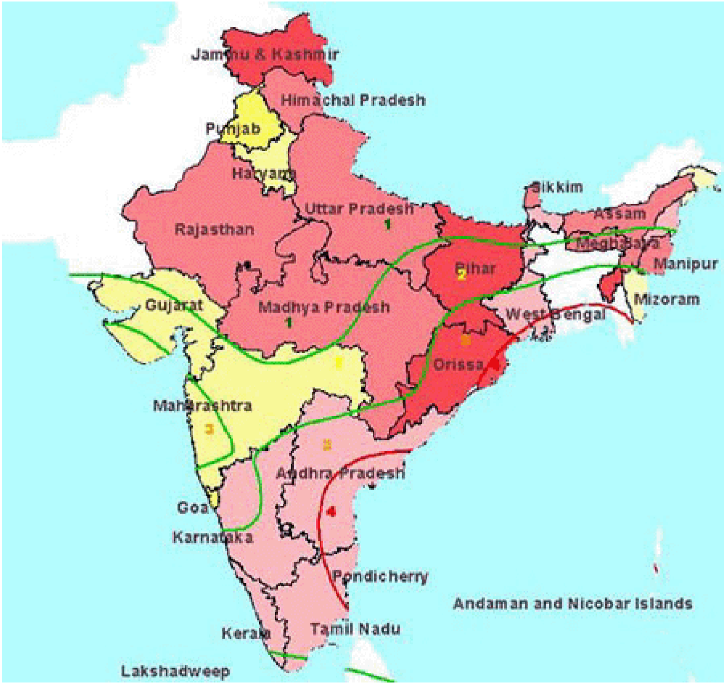
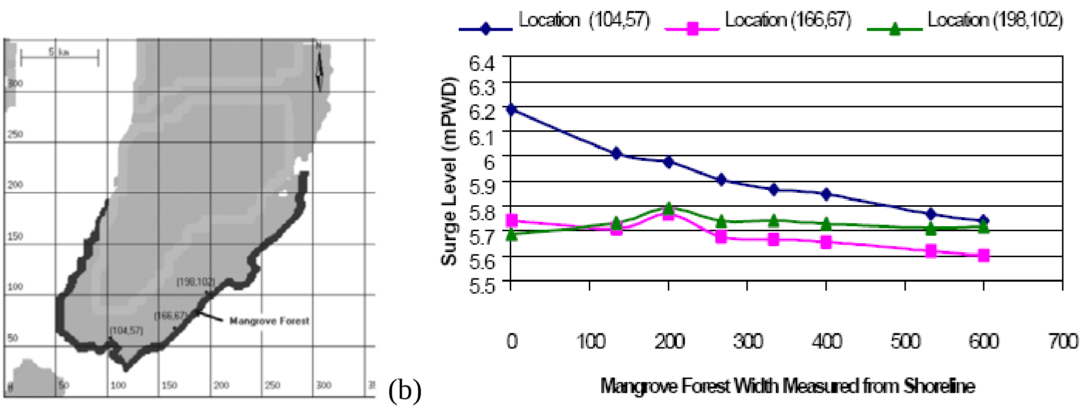


Figure 2.8 Per capita income of different states in India and risk level. Dark red areas equal low per capita income and yellow areas equal high per capita income

3.3 MANGROVE FOREST PROTECTION AGAINST CYCLONES

According to Kabir *et al.* (2006), forests are considered a low-cost and natural form of protection for lands subjected to strong currents and surges. For their study, development of mangrove forests was considered to be one measure for coastal protection in Bangladesh. A model based on the MIKE 21 numerical model was created to study the effect of mangrove forests on storm surges that hit Hatia Island in southeastern Bangladesh. For the model, mangrove forests were laid on the southern tip of Hatia (Figure 2.14a) in bands that ranged from 133 to 600 metres, and eight total simulations were conducted using the 1970 cyclone. Three fixed locations 600 metres from the shoreline were chosen. The variation of surge height with respect to forest band widths at the fixed locations 600 metres inland are shown in Figure 2.14b and the results are summarized in Table 2.10. The results show the reduction at fixed locations 600 metres inland and do not represent transects from the shoreline to the test locations.

(a)


(b)

Figure 2.9 (a) Hatia Island locations of simulations (b) surge variations at fixed locations 600 m inland from the shoreline with different forest widths between the locations and the coastline (Kabir *et al.*, 2006)

Table 2.10 Summary of computed storm surge reductions by mangrove bands of various widths (Kabir *et al.*, 2006)

Mangrove Forest			*Maximum Surge Level (m) at Locations (local co-ordinates)*		
Nota-tion	*No. of Rows*	*Total width (m)*	*(104, 57)*	*(166, 67)*	*(198, 102)*
Mg0	0	0	6.186	5.74	5.685
Mg2	2	133	6.01	5.708	5.73
Mg3	3	200	5.976	5.765	5.79
Mg4	4	267	5.906	5.674	5.737
Mg5	5	333	5.866	5.664	5.739
Mg6	6	400	5.846	5.653	5.727
Mg8	8	533	5.765	5.617	5.71
Mg9	9	600	5.738	5.599	5.717

According to the model, the most effective area of forest cover for the 1970 cyclone would have been along the southern tip of Hatia Island. This location would have seen a decrease in surge of 0.45 metre with a 600-metre strip of mangroves and a 0.18-metre decrease at the test location 600 metres inland for a 133-metre strip of mangroves. The site in the middle would have seen little decrease in surge height (0.15 metre with a 600-metre strip). The base flooding with no mangroves was 6.2 metres at this location 600 metres inland. Hence, a storm surge height reduction of seven percent was achieved by adding 600 metres of forest between the shoreline and the test location 600 metres inland. In the case of the northernmost site, the surge level would have increased slightly due to the forests' trapping of flow coming from other parts of the island. This illustrates the importance of site characteristics in determining that the effect of the forest will vary according to the site characteristics. Similarly, coastal forests can also funnel flows along creeks, thereby increasing surge heights in some cases. The main conclusion is that narrow coastal forests have minimal effects on the storm surge height and inland flooding. In order to significantly reduce the impact of the storm surge —usually the most devastating cyclone hazard — kilometres of coastal forests are required. Few other storm surge reductions by mangrove models were readily available to the authors.

However, there are many documented studies on the hydrodynamics within mangrove swamps and their wave attenuation properties. These include Mazda *et al.* (2005), Mazda *et al.* (1997), Liu *et al.* (2003), Wu *et al.* (2001), Brinkman (1997) and Massel *et al.* (1999). Mangroves trap and stabilize sediment and reduce the risk of shoreline erosion because they dissipate surface wave energy. It is this attribute that makes mangroves a potential natural solution for particular coastal protection problems. Field observations of surface wave attenuation in mangrove forests were undertaken in both Townsville, Australia and on Iriomote Island, Japan. High resolution wave gauges were deployed throughout the mangroves along transects in line with the dominant direction of wave propagation. Data were gathered to verify a numerical model of wave attenuation. The numerical model was based on the fact that surface waves propagating within a mangrove forest are subject to substantial energy loss due to two main energy dissipation mechanisms: (1) multiple interactions of wave motion with mangrove trunks and roots; and (2) bottom friction. The dissipative characteristics of the mangrove forest were estimated from physical parameters such as trunk diameter, spatial density and vegetation structure, which were not necessarily vertically and horizontally uniform. The resulting rate of wave energy attenuation depended strongly on the density of the mangrove forest, the diameter of the mangrove roots and trunks and on the spectral characteristics of the incident waves. The numerical model results were supported by field observations, which showed substantial attenuation of wave energy within the mangrove forest (Figure 2.15). Typically, wave energy is attenuated by a factor of 2 within 50 metres of the front of the mangrove forest. Hence, the wave heights are typically attenuated by a factor of square root 2 given that the wave energy is related to the square of the wave height. Both field and model results also indicated that longer period waves, such as swell waves, are subjected to less attenuation, while short period waves with frequencies typical of locally generated wind waves lose substantial energy due to interactions with the vegetation. Also, it is evident that as water level increases, wave energy is transmitted further into the forest. This is not only due to more of the forest being inundated, but also to the structure of the mangrove roots and trunks. The obstruction density caused by the mangrove wood structure decreases rapidly with height and, therefore, as the water level increases because of the storm surge there is proportionally less flow resistance and less reduction of wave energy. Unfortunately, this effect severely reduces wave attenuation with increasing cyclone intensity, storm surge height and wave period. All of the aforesaid studies analysed only wave attenuation at normal sea levels and not during cyclones with elevated storm tide levels.

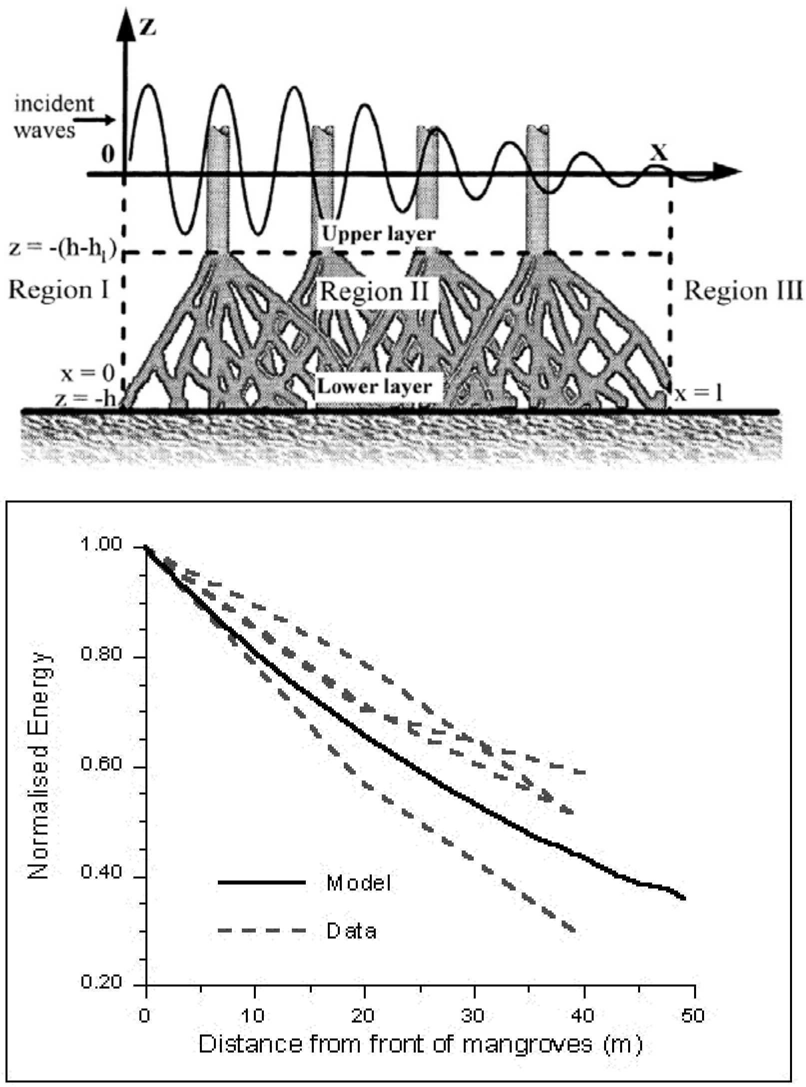


Figure 2.10 Surface wave attenuation in mangrove forests:
(a) Schematic used in the analytical study by Massel *et al.* (1999)
(b) comparison between field data and numerical simulations
(http://www.aims.gov.au/ibm/pages/news/mangwave.html)

Badola and Hussain (2005) evaluated the protective function of mangroves in Bhitarkanika in the eastern state of Orissa, India. The Bhitarkanika mangrove ecosystem is the second largest mangrove forest of mainland India (Figure 2.16). Originally around 672 km^2, it is now limited to an area of 145 km^2 and is a wildlife sanctuary. This mangrove forest and the associated coast house the highest diversity of Indian mangrove flora and fauna. The mangrove forests of Bhitarkanika differ considerably from other mangroves because of the dominant tree species — *Sonneratia apetal, Heritiera fomes, H. littoralis* and several *Avicennia* species.

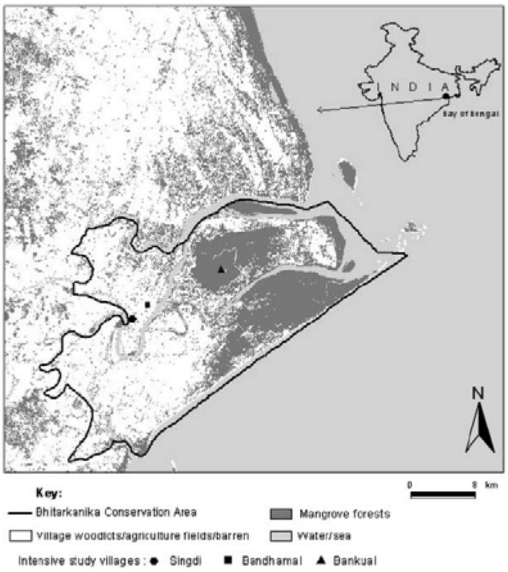


Figure 2.11 Kendarapara and Bhadrak districts of Orissa, India, with the location of Bhitarkanika Conservation Area and the extent of mangrove forests

The report aimed to measure the economic losses attributed to the 1999 supercyclone relative to the prevailing socio-economic conditions of the study villages. It evaluated the extent of damage caused in areas that were under the umbrella of mangrove forests and areas that were not, in the wake of this supercyclone. In 1971, an embankment was created along the entire Orissa coast to prevent seawater intrusion into reclaimed paddy fields. Therefore, the report also studied the effectiveness of such artificial structures in providing storm protection, as opposed to mangrove forests.

Hence, the following three situations were identified: (1) A village in the shadow of mangroves; (2) a village not in the shadow of mangroves and with no embankment; and (3) a village not in the shadow of mangroves, but with an embankment on the seaward side. Bankual village was in the shadow of a mangrove forest, Singidi village was neither in the shadow of mangroves nor protected by an embankment from storm surge and Bandhamal village was not in the shadow of mangroves, but had a seaward side embankment. The report indicated that the intensity of the impact of the 1999 cyclone on these villages should have been fairly uniform, as all the three selected villages were equidistant from the seashore and had similar aspects. The two villages outside mangrove cover were located close to each other, but both were far from the mangrove forest in order to eliminate any effect of mangrove forest presence.

Services provided by the Bhitarkanika mangrove ecosystem in India and estimated cyclone damage avoided in the three selected villages, taking the supercyclone of 1999 as a reference point, were evaluated by assessing the socio-economic status of the villages, the cyclone damage to houses, livestock, fisheries, trees and other assets owned by the people, and the level and duration of flooding. Eleven variables were used to compare damage in the villages (Table 2.11). Attitude surveys were carried out in 10 percent of the households in 35 villages located in the Bhitarkanika

Conservation Area to assess local people's perceptions regarding the storm protection function of mangroves and their attitudes towards mangrove forests in general. In the mangrove-protected village, variables had either the lowest values for adverse factors (such as damage to houses), or the highest values for positive factors (such as crop yield). The loss incurred per household was greatest (US$153.74) in the village that was not sheltered by mangroves but had an embankment, followed by the village that was neither in the shadow of mangroves or the embankment (US$44.02) and the village that was protected by mangrove forests (US$33.31). The local people were aware of and appreciated the functions performed by the mangrove forests in protecting their lives and property from cyclones and were willing to cooperate with the forest department with regard to mangrove restoration.

Table 2.11 Basic description and mean values of the variables (per household) in the three study villages in Bhitarkanika Conservation Area, India (US$1.00 = INR 45, August 2004)

		Villages		
Variables	*Description*	*Singdi*	*Bankual*	*Bandhamal*
DR	Damage to houses (0–19 scale)	9.40	5.34	10.44
PTD	Tree damage (%)	21.0	3.3	15.5
DPP	Damage to other personal property (INR)	108.11	0.00	2375.00
DL	Damage to livestock in money terms (INR)	54.05	127.63	1044.37
FP	Flooding in premises (m)	0.34	0.29	0.58
FF	Flooding in fields (m)	1.99	1.09	1.39
WLF	Water logging in fields (days)	9.46	5.63	12.87
CR	Cost of repair and reconstruction (INR)	996.97	682.86	973.21
Y99	Yield for the year 1999 (kg ha^{-1})	531	1479.5	335.9
LFS	Loss of fish seedlings (fingerlings) released prior to cyclone (INR)	310.81	69.74	260.94
TML	Total quantifiable variables (INR)	1983.3	61454.13	6918.62

Although only indicative, the report shows that the damage attributed to the cyclone was more extensive in the village further away from the mangrove shadow. The embankments constructed in 1971, after a previous cyclone, to prevent the intrusion of salt water into agricultural fields and villages were ineffective during the high storm surge; in fact, they acted as a barrier to runoff when the water was receding. The embankments suffered a number of breaches that resulted in the flooding of villages such as Bandhamal, which was surrounded on all sides by the embankment. Singdi village, with no mangrove cover and no embankment, suffered the highest level of field inundation; however, the seawater receded quickly, resulting in less damage to agricultural crops. Bankual village, which was in the shadow of mangrove forest and had minimal embankment around it, suffered the least. Although this study is not conclusive, the lack of breaches in the embankment closer to the forest is indicative of the protection provided by mangroves to the embankment. In areas far from the forest, several breaches in the embankment were observed. Water levels were higher and the flooding was of longer duration in Bandhamal.

Extensive *Casuarina* plantations established as a storm protection measure along the Orissa coast were ineffective in preventing damage; rather, they caused destruction to Olive Ridley sea turtle (*Lepidochelys olivacea*) nesting beaches. The cyclone uprooted almost all the trees in the immediate vicinity of the coast and caused much damage to trees several kilometres inland. However, mangrove forests and trees in the shadow of mangrove forests remained intact. The report contends that the vulnerability of many coastal communities to cyclones is heightened by the removal of mangroves for development, agriculture and habitation purposes. Mangrove forests are natural buffers against storm surges and protect tropical shores from erosion by tides and currents. Ecological functions such as storm protection may be very important components in the total economic value of a wetland and may constitute almost 80 percent of the estimated value. These major benefits are often the principal reasons for restoring mangrove forests along much of the low-lying deltaic coasts. In the aforementioned study in Orissa, there was a 20 to 30 percent reduction in repair and maintenance costs of sea dyke systems due to the presence of mangroves in front of the dyke. The report realized that the artificial sea defenses were not only expensive to build and repair, but they were also, in many cases, ineffective.

3.4 CYCLONE DAMAGE TO MANGROVE FORESTS

Hurricane Mitch (1998) was the second deadliest hurricane on record at the time. The eye of the storm passed directly over three countries (Honduras, Guatemala and Mexico). Damage to the region’s coastal mangrove ecosystems resulted from three different mechanisms: winds, waves and sediment burial. Extreme winds (up to 287 kilometres/hour) defoliated and uprooted mangrove trees along the Caribbean coast, most notably in the Bay Island of Guanaja, which lost some 97 percent of its mangrove forest cover as shown in Plate 2.1 (Hensel and Proffitt, 2000). High wave activity eroded shorelines some 200 kilometres to the southwest, along the Caribbean coast of Guatemala (Punta de Manabique). Mangrove forests within the eroded zone were destroyed, and the remaining mangroves were buried with up to 1.2 metres of sand. Along the Pacific coast, damage was primarily attributable to the burial of mangrove forests by upland sediments, brought to the coastal area by massive flooding, upland erosion and mud and debris flows. These three mechanisms of hurricane damage had different impacts on coastal mangroves and led to different trajectories of recovery. The area of greatest damage was the Bay Island of Guanaja, where high mortality and the lack of natural regeneration made active restoration a priority. Over 27 months after the cyclone, severe chronic impacts remain evident, as recovery has not progressed to any significant degree. Wave-induced erosion and sedimentation some 200 kilometres away from the hurricane track also caused significant mangrove mortality.

(a) 

(b)  (c) 

Plate 2.1 Mangrove damage after Hurricane Mitch on the Bay Island of Guanaja, Honduras: (a) defoliation (b) uprooting (c) erosion of shallow roots (Hensel and Proffitt, 2000)

The negative example of the Bay Island of Guanaja shows that natural recovery is not always possible, even after several years in the aftermath of a cyclone. Unfortunately, cyclones tend to hit the most vulnerable coastlines with storms of various magnitudes within a few years. The possibility of multiple cyclone hits within a few years, or even within the same cyclone season prior to any significant recovery of mangrove forests, cannot be neglected when considering mangroves as protective shields.

Conclusions

The main conclusion is that narrow coastal forests have minimal effects on storm surge height and inland flooding. In order to significantly reduce the impact of the storm surge —usually the most devastating cyclone hazard — several kilometres of coastal forests are required. Mangroves are more efficient at attenuating surface waves and wind as well as providing protection against erosion. Typically, the wave energy is attenuated by a factor of two within 50 metres in front of the mangrove forest at normal sea level. The obstruction density caused by the mangrove wood structure decreases rapidly with height and, therefore, as the water level increases because of the storm surge there is proportionally less flow resistance and less reduction of wave energy. Unfortunately, this effect severely reduces wave attenuation with increasing cyclone intensity, storm surge height and wave period. Finally, the possibility of multiple cyclone hits prior to significant mangrove forest recovery needs to be considered.

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Field study presentation: Cyclone disaster mitigation in Bangladesh

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Bangladesh has witnessed many natural calamities. Between 1797 and 1998, 67 major cyclones occurred. The 1991 cyclone killed approximately 139 000 people and generated economic losses of US$2.07 billion. The coastal zone comprises 19 southern districts with 35 million inhabitants (28 percent of the country).

The Bangladesh Meteorological Department provides cyclone warnings. The Standing Orders for Cyclone constitute the basic plan for addressing cyclone disasters with guidelines for action at various stages during calamitous events. Elaborate institutional arrangements are in place to deal with disasters. The most dedicated agency is the Cyclone Preparedness Programme, which is an organization of 33 000 volunteers in the field who mobilize people at the community level to cope with cyclones. Structural mitigational measures such as cyclone shelters, coastal embankments and improved housing, as well as non-structural mitigation measures including coastal afforestation, public awareness, community preparedness, local level contingency planning and social mobilization are in place to a limited extent. Coastal afforestation activities were initiated in 1966. The protection afforded by natural mangrove forest has prompted afforestation in the five coastal districts. A coastal zone policy has been formulated with emphasis on sea dykes and afforestation, planned tree plantation, social forestry, plant care and maintenance, afforestation of new chars *(accreted land) and their conservation. A number of recommendations have been made to: improve storm surge forecasting; enhance public awareness; increase investment in warning presentation; promote information dissemination and comprehension; simplify warning contents; address knowledge and attitudes; carry out surveys on cyclones; and integrate disaster management in development planning.*

The conclusions pointed to the need for mainstreaming disaster management activities, increasing the interface between disaster and development, and conducting sustained awareness and advocacy programmes. All of these issues call for a higher level of investment in preparedness, shelter construction, afforestation, institutional arrangement, policy formulation and community involvement for improved cyclone disaster mitigation.

Field study presentation: Evaluation of storm protection functions — a case study of mangrove forest in Orissa, India and the 1999 super cyclone

Saudamini Das, University of Delhi Enclave, India

The research aimed at making a quantitative assessment of the storm protection functions of mangrove forests. In October 1999, the state of Orissa was battered by a super cyclone that caused tremendous loss of life and property in the coastal region. It was widely reported in the national as well as international press that areas with mangrove forest on their coastlines experienced comparatively less damage. Using village level human casualty data, cyclone damage (taking into account wind velocity, storm surge velocity and the socio-economic status of the villages separately) was estimated; an attempt was made to evaluate how many human lives had been saved by the presence of mangroves in some areas.

Key points and observations emphasized in the discussions

Cyclones are composite phenomena, consisting of winds, multiple storm waves, storm surges (which generally last from several hours up to a day) and inland flooding generated by heavy rainfall. This inland flooding often causes more fatalities than the wind. Cyclones generally cause massive erosion or deposition – both long- and cross-shore. In recent years important discussions on multihazard approaches for coastal protection have been ongoing; however, it should be noted that often coasts vulnerable to cyclone storm surges are less (or the least) vulnerable to tsunamis, and therefore require different protective measures.

Coastal forests and mangroves can help to mitigate cyclone damage, but are not effective against all hazards. Their mitigation effect is limited (or absent) during cyclones of categories exceeding 4 on the Saffir–Simpson Scale and super cyclones. Narrow belts of coastal forest do not reduce storm surges; several square kilometres of forests or coastal wetlands are required to significantly absorb massive inland inundation caused by cyclones of high intensity. Preliminary analysis of the 1999 Orissa super cyclone showed that the mitigation effects of *Casuarina* plantations were lower in comparison to mixed indigenous forests.

The following factors were identified:

1. Coastal forests are efficient in reducing wind and storm wave impacts up to a certain level.
2. Coastal forests and mangroves in narrow belts do not reduce storm surge efficiently; they can, however, help to decelerate flooding velocity and trap floating debris.
3. A dense forest can reduce 0.5 metres of surge for each kilometre of forest.
4. Extensive wetland systems are also important as mitigating measures and the loss of wetlands makes the coast more vulnerable. Mangroves and coastal wetlands must be preserved.

When planning a green belt for protective purposes, several factors should be taken into account.

1. Space availability: A very wide belt of forest is needed to ensure an appropriate reduction of cyclone strength. Because the coasts of several Asian countries (for example, Bangladesh) often have very high population densities, this space may not be available and consequently a green belt cannot be prepared to the required width. In this case environmental and hard engineering structures should be used in combination with – or as an alternative to – the green belt.
2. Social involvement in planning and management of protective forests is essential for the long-term success of the project. The green belt should also be a source of additional yield to local communities (for example, controlled harvesting of wood and non-wood forest products, ecotourism, etc.), which will avoid illegal felling and damage to the green belt.

Additional factors which would benefit the ultimate goal of saving lives and resources in cyclone-prone countries are as follows:

1. The creation or enhancement of an appropriate cyclone warning system (together with reliable storm forecasting) at the national level, which should be easily understood by rural people and which should also extend to remote areas and communities.
2. Investment in public awareness on cyclone mitigation, including the protective role of forests (knowledge–attitude–practice).

3. The encouragement of local community participation in prevention and rehabilitation activities (for example, volunteer groups).
4. Improvement or initiation of institutional arrangements (for example, collaboration between disaster managers and other government agencies).