15. Nelson, R., Krabill, W. and Maclean, G., *ibid*, 1984, **15**, 201–212.
16. Nelson, R., Krabill, W. and Tonelli, J., *ibid*, 1988, **24**, 247–267.
17. Nelson. R., Oderwald, R. and Gregoire, G., *ibid*, 1997, **60**, 311–326.
18. Nilsson, M., *ibid*, 1996. **56**, 1–7.
19. Naesset, E., *ibid*, 1997, **61**, 246–253.
20. Lefsky, M. A., Harding, D. J., Cohen, W. B., Parker, G. G. and Shugart, H. H., *ibid*, 1999, **67**, 83–98.
21. Means, J. E. *et al*., *ibid*, 1999, **67**, 298–308.
22. Drake, J. B., Dubayah, R. O., Knox, R. G., Clark, D. B. and Blair, J. B., *ibid*, 2002, **81**, 378–392.
23. Lefsky, M. A., Cohen, W. B., Acker, S. A., Parker, G. G., Spies, T. A. and Harding, D. J., *ibid*, 1999, **70**, 339–361.
24. Magnussen, S. and Boudewyn, P., *Can. J. For. Res*., 1998, **28**, 1016–1031.
25. Means, J. E., Acker, S. A., Fitt, B. J., Renslow, M., Emerson, L. and Hendrix, C., *Photogramm. Eng. Remote Sensing*, 2000, **66**, 1367–1371.
26. Magnussen, S., Gougeon, F., Leckie, D. and Wulder, M., Remote Sensing and Forest Monitoring, Conference Proceedings, Rogow, Poland, 1999.
27. Nelson. R., *Remote Sensing Environ*., 1997, **60**, 327–334.
28. Naesset, E., *ISPRS J. Photogramm. Remote Sensing*, 1997, **52**, 49–56.
29. Weltz, M. A., Ritchie, J. C. and Fox, H. D., *Water Resour. Res*., 1994, **30**, 1311–1319.
30. Wulder, M., Olaf, N. K. and Goodenough, D. G., *Remote Sensing Environ*., 2000, **73**, 103–114.
31. Maclean, G. A. and Krabill, W. B., *Can. J. Remote Sensing*, 1986, **12**, 7–18.
32. Menenti, M. and Ritchie, J. C., *Water Resour. Res*., 1994, **30**, 1329–1337.
33. Andersen, H., Reutebuch, S. E. and Schreuder, G. F., Proceedings of the Twenty-third Annual Canadian Symposium on Remote Sensing, Quebec, QC, 20–24 August 2001.
34. Lillesand, T. and Kiefer, R., *Remote Sensing and Image Interpretation*, Wiley, New York, 2000, 4th edn.
35. Hyyppa, J., Pyysalo, U., Hyyppa, H. and Samberg, A., 20th EARSeL Symposium and Workshop, Dresden, Germany, 2000.
36. Saito, Y., Saito, R., Kawahara, T. D., Nomura, A. and Takeda, S., *For. Ecol. Manage*., 2000, **128**, 129–137.
37. Naesset, E., *Remote Sensing Environ*., 2002. **80**, 88–99.
38. Leckie, D., Gougeon, F., Quinn, R., Hill, D., Armstrong, L., Hiemstra, R. and Shreenan, R., Proceedings of the Twenty-third Annual Canadian Symposium on Remote Sensing, Quebec, QC, 20–24 August 2001.
39. Lim, K., Tretiz, P., Groot, A and St-Onge, B., *ibid*.
40. Weishampel, J. F., Ranson, K. J. and Harding, D. J., *Selbyana*, 1996, **17**, 6–14.
41. Blair, J. B., Rabine, D. L. and Hofton, M. A., *ISPRS J. Photogramm. Remote Sensing*, 1999, **54**, 115–122.
42. Lohani, B., Indian Society for Remote Sensing Symposium-2000, Kanpur.
43. Drake, J. B. *et al*., *Remote Sensing Environ*., 2002, **79**, 305–319.
44. Blair, J. B. and Hofton, M. A., *Geophys. Res. Lett*., 1999, **26**, 2509–2512.
45. Ritchie, J. C., Menenti, M. and Weltz, M. A., *Int. J. Remote Sensing*, 1996, **17**, 3705–3724.
46. Drake, J. B. and Weishampel, J. F., *Forest Ecol. Manage.*, 2000, **128**, 121–127.

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Human–mangrove conflicts: The way out

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Mangrove resources are available in approximately 117 countries, covering an area of 190,000 to 240,000 km^2. Countries like Indonesia, Nigeria and Australia have the largest mangrove areas. These ecosystems harbour 193 plant species, 397 fishes, 259 crabs, 256 molluscs, 450 insects and more than 250 other associated species. Mangrove ecosystem has the highest level of productivity among natural ecosystems, and performs several ecosystem services. The continued exploitation of mangroves worldwide has led to habitat loss, changes in species composition, loss of biodiversity and shifts in dominance and survival ability. Worldwide, about half of the mangroves have been destroyed. The Indian mangrove biodiversity is rather high. The increase in the biotic pressure on mangroves in India has been mainly due to land use changes and on account of multiple uses such as for fodder, fuel wood, fibre, timber, alcohol, paper, charcoal and medicine. Along the west coast alone, almost 40% of the mangrove area has been converted to agriculture and urban development. Our understanding of the natural processes in this vulnerable and fragile ecosystem is far from adequate. Environmental awareness, proper management plan and greater thrust on ecological research on mangrove ecosystems may help save and restore these unique ecosystems.

MANGROVE ecosystems are open systems which exchange matter and energy with adjacent marine, freshwater and terrestrial ecosystems. The extent of wave and tidal coping between mangrove and offshore marine biotopes controls the intensity of interaction between the systems[1]. These ecosystems are effective in storing large amounts of inorganic and organic nutrients which are washed into mangroves from the rivers and continental drainage. They also process huge amounts of organic matter, dissolved nutrients, pesticides and other pollutants which

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are dumped into mangrove areas due to anthropogenic activities. These ecosystems occur on coastal lowlands of tropical and subtropical intertidal region and near river mouths. Mangroves are found between latitudes 32°N and 38°S along the tropical coasts of Africa, Australia, Asia and America. They grow in high- and low-tide areas and experience the alternation of ebb and flow. Mangrove forests once covered three-fourths of the coastlines of the tropical and subtropical countries, of which less than 50% remains today, and half of the remaining forests are degraded[2]. Scientific knowledge on the structural and functional characteristics of the mangroves and the natural processes operating in these vulnerable and fragile ecosystems, is rather poor.

The present article highlights the ecological stresses in mangrove ecosystems and traces the causes of their degradation. The management issues have been explored and certain strategies for conservation and restoration of mangrove ecosystems are indicated.

Mangroves and mangrove ecosystem

The term mangrove refers to an ecological group of halophytic plant species as well as to a variety of complex plant communities dominated by these species, found along sheltered tropical and subtropical shores. Globally, the mangroves are estimated to include 16–24 families and 54–75 species[2]. The earliest mangrove species appear to have originated in the Indo-Malayan region and subsequently spread with the help of their floating fruits, seeds and seedlings, both westward and eastward, occupying the relatively sheltered lagoons, estuaries and quiet backwaters. Evolutionary adaptation to coastal marine environments, characterized by brackish water and muddy substrata in the intertidal zone, led to such characters as prop roots, knee roots, plank buttresses and pneumatophores, sclerophyllous leaves with sunken stomata, and vivipary. The control of tissue water potential through specialized leaves and stems, exclusion of salt through rhizofiltration and excretion through leaf salt glands, and the ability to deposit salt in older leaves, bark and pneumatophores, conferred a high level of salt tolerance[3,4]. The dominant salt-tolerant, sclerophyllous broadleaved trees form a unique ecosystem with associated plants, including epiphytic and terrestrial ferns, orchids, lichens, non-mangrove halophytes, sea grasses and seaweeds, and fauna such as fish, shrimp, shellfish, crabs, lobsters, reptiles and birds. The mangroves make an enormous contribution to the food chain that supports the coastal fisheries. These ecosystems are quite productive (350–500 g C m^{-2} yr^{-1})[5] and may show a strong, weak or no spatial zonation[3,6], although the abundance of individual species may follow the gradient of salinity[7]. Most of the species are quite plastic to salinity, and prefer a salinity range of 5–30 parts per thousand.

Mangroves can be divided into New World and Old World groups[8]. The New World group includes North, Central and Southern America, and Western Africa. Ten dominant mangrove species available in these regions are not found in the Old World group. In the Old World, mangroves are confined to the Persian Gulf, Madagascar, Indo-Malaysian and Australian regions. India, Pakistan, Bangladesh, Myanmar, Indonesia, North Australia and Papua New Guinea represent the Indo-Malaysian group. Sixty-five mangrove species found in the Old World group are not present in the New World group[8].

The mangrove forests are found in approximately 117 countries. There is a lack of exact statistics on the global and regional extent of the mangrove area. According to the report of the World Resources Institute[9], mangroves cover an area of 190,000 to 240,000 km^2, occupying about one-quarter of the world's coastal line. Largest mangrove areas occur in Indonesia (30%) followed by

Table 1. Mangrove extent and loss in selected countries (source: ref. 9)

Region and country	Current extent ($\times 10^3$ ha)	Approximate per cent lost	Period covered
Asia			
India	100–700	50	1963–77
Peninsular Malaysia	98.3	17	1965–85
Philippines	140 +	70	1920s to circa 1990
Singapore	0.5–0.6	20–30 +	Pre-agricultural period to present
Thailand	196.4–68.7	25	1979–87
Vietnam	200	50	1943 to early 1990s
Latin America			
Puerto Rico	6.5	75	Pre-colonial to present
Ecuador	117 +	30 +	Pre-agricultural to present
Guatemala	16	30 +	1965–90
Africa			
Cameroon	306	40	Pre-agricultural to mid-1980s
Kenya	53.0–61.6	70	Pre-agricultural to mid-1980s
Guinea-Bissau	236.6	75 +	Pre-agricultural to mid-1980s
Liberia	20	70	Pre-agricultural to mid-1980s

Nigeria (10%), Australia (8%) and Mexico (7%). India contributes approximately 3% to the world mangrove area. Table 1 includes estimates of the extent of mangroves in selected countries.

Status of Indian mangroves

The Indo-Malaysian region is considered as the cradle of evolution of mangrove vegetation[10]. It is believed that India was under the Tethys sea which, by the end of the Cretaceous, started receding, and the present Indian position came into existence in the Miocene, about 55 m.y. ago. Even prior to this period (i.e. from Cretaceous to Miocene) mangrove vegetation occurred luxuriantly along the Indian coast according to available fossil records[11].

According to one estimate, the mangrove forest cover in India has reduced from 6000 km^2 in 1953 to 2000–3000 km^2 in 1989 (ref. 12). These forests now occupy an area of about 4871 km^2 area. The district-wise mangrove forest cover[13,14] is given in Table 2. These forests are found in the river basins of the Ganges, Brahmaputra, Mahanadi, Godavari, Krishna and Kaveri. The east coast

Table 2. District-wise mangrove forest cover in India (based on refs 13 and 14)

State	District	Area assessment (km^2) 1997	1999	Change from 1995 assessment	Change from 1997 assessment
Andaman and Nicobar Islands	Andamans	929	929		
	Nicobar	37	37		
	Total	966	966	Nil	Nil
Andhra Pradesh	Godavari	216	241		
	Krishna	111	104		
	Nellore, Prakasam, Kurnool	56			
	Guntur	–	52		
	Total	383	397	+ 5	+ 14
Goa	Goa	5	5	+ 2	Nil
Gujarat	Bharuch	13	6		
	Bhavnagar	20	25		
	Jamnagar	118	140		
	Kachchh	836	854		
	Surat	4	4		
	Junagarh	–	1		
	Valsad	–	1		
	Total	991	1031	+ 302	+ 40
Karnataka	Dakshina Kannada	2	2		
	Uttara Kannada	1	1		
	Total	3	3	+ 1	Nil
Maharashtra	Mumbai city	2	2		
	Mumbai	46	32		
	Colaba	34	–		
	Thane	42	24		
	Raigarh	–	38		
	Ratnagiri	–	12		
	Total	124	108	– 31	– 16
Orissa	Baleshwar	3	3		
	Bhadrak	17	18		
	Jagatsinghpur	10	10		
	Kendarpara	181	184		
	Total	211	215	+ 16	+ 4
West Bengal*	Medinipur		3		
	24 Parganas North		29		
	24 Parganas South		2093		
	Total	2123	2125	+ 4	+ 2
Tamil Nadu	South Arcot	9	9		
	Thanjavur, Trichirapalli, Pudukkotai	12	12		
	Total	21	21	Nil	Nil
Grand total		4827	4871	+ 294	+ 44

*District-wise data for 1997 not reported.

is endowed with the world's largest mangrove forest, with Gangetic Sunderbans in West Bengal having the largest area under mangrove forest (2125 km^2). The Forest Survey of India data indicate that in most of the states, mangrove forest cover has gained or has remained unchanged since 1995, except for Maharashtra which continues to lose these forests (47 km^2 lost since 1995). Nevertheless, large stretches in almost all mangrove areas in the country are in severely degraded conditions, having reduced or negligible vegetal cover.

An Indian National Mangrove Management Committee was formed by the Ministry of Environment and Forests to collect more ecological data and information, and to evolve a management plan for mangroves. This committee recommended a nation-wide mapping of the mangrove area, preferably by remote sensing coupled with land surveys and time-series data to make an assessment of the rate of degradation of mangrove ecosystem[15]. The Space Applications Centre, Ahmedabad in collaboration with various coastal state agencies, carried out the mapping of the coastal wetlands using landsat TM/IRS LISS II data in 1 : 250,000 scale for the entire Indian coast and in 1 : 50,000 scale for all coastal states[16].

Floristic diversity

The species diversity is higher in the Indian mangrove ecosystems compared to that of Latin America and Africa. Large physical forces in tide water, salinity level and lack of stable substratum are some of the natural factors which affect the species diversity. The status of ecological investigation of Indian mangroves is so poor that it is difficult to get correct information on species number and diversity. One hundred and sixteen plant species have been recorded by Banerjee *et al.*[17] which include 59 mangrove species, 47 algae and 10 species of sea grasses. About 65 vascular plant species belonging to 31 families and 59 genera have been reported from the mangrove ecosystems of India. The east coast has 64 vascular species from 42 genera and 29 families. The west coast has 33 species from 24 genera and 19 families, and Andaman and Nicobar Islands represent 43 species from 30 genera and 23 families[8]. Eight species of mangroves occurring on the east coast are not represented in the mangrove areas of the west coast. Reports indicate that Sunderbans alone has 62 species[18]. Families Combretaceae, Rhizophoraceae and Avicenniaceae predominate. Major genera include *Avicennia*, *Acanthus*, *Acrostichum*, *Aegialitis*, *Aegiceras*, *Brownlowia*, *Bruguiera*, *Caesalpinia*, *Cerbora*, *Ceriops*, *Clerodendron*, *Cynometra*, *Dalbergia*, *Derris*, *Dolichandrone*, *Excoecaria*, *Finlaysonia*, *Heritiera*, *Hibiscus*, *Hoya*, *Intsia*, *Ipomoea*, *Kandelia*, *Lumnitzera*, *Merope*, *Mucuna*, *Myriostachya*, *Nypa*, *Phoenix*, *Porteresia*, *Rhizophora*, *Salvadora*, *Sarcolobus*, *Scyphiphora*, *Sonneratia*, *Thespesia*, *Tylophora* and *Xylocarpus*. Mangrove vegetation also includes several ferns, orchids, palms and sedges. The lack of systematic and ecological studies, and availability of only fragmented information on Indian mangrove ecosystems warrants a comprehensive research plan.

Animal diversity

Mangrove areas harbour a variety of fish and prawn species. Robertson and Blaber[19] reported 26 to 197 species in tidal forests. Odum and Heald[20] collected a large number of fishes, crabs and insect larvae from mangroves in southern Florida. Fifty-three species of fishes, five species of Decapoda, five species of Amphipoda and 3–80 species each of Isopod, Cumacea, Mysidecca, Copepoda, Ostracoda, Mollusca, Ciliata and Chironomid larvae were identified. About 400 species of fishes are reported to depend on mangrove habitat[9]. A more comprehensive data set produced by Rao[21] indicates that mangrove ecosystems of the world have 193 plant species, 397 fishes, 259 crab species, 256 molluscan species, 450 insect species and more than 250 species of mammals and other associated species of plants and animals.

Indian mangrove areas are excellent nursery grounds for a variety of commercially important prawns, crabs and fin-fishes, as they provide abundant food and shelter for these organisms. These ecosystems provide food, roosting and nesting site and shelter to a large variety of birds. The evergreen canopies of mangroves are inhabited by several insects, reptiles, birds and mammals. The mangroves support many trophic levels of aquatic and terrestrial organisms, by enriching the fertility of estuarine waters for production of planktons. Table 3 summarizes the faunal diversity in Indian mangrove ecosystems.

The conflicts

The mangrove ecosystem provides a variety of ecosystem services; their economic value, if calculated, would be staggering. These services include prevention of coastal erosion, barrier against typhoons, cyclones and hurricanes, protection of coral reefs from siltation, and soil

Table 3. Faunal diversity in mangrove forests of India (based on ref. 33)

Taxonomic group	India	West coast
Crustaceans	229	229
Molluscs	212	–
Wood borers	25	26
Fishes	185	105
Reptiles	39	3
Birds	117	119
Mammals	36	2
Microbenthos	111	–
Shellfishes	–	20

–, Estimates not available.

accretion (Figures 1–3). Indirectly, forests are responsible for extension of islands. These systems act as biological waste-water treatment plants, lowering the biological oxygen demand (BOD), and possibly performing bio-remediation by removing toxic elements. These forests also provide breeding, nursery and feeding grounds for harvestable marine fauna[22]. Pecuniary benefits include wood for fuel, furniture and construction, green leaves and fruits for fodder, source for charcoal, tannin, paper, dyes and chemicals, thatch, honey and incense. Good quality of charcoal is produced from the wood of *Rhizophora* species. The foliage of mangrove species is used as fodder for cattle, camels and goats. *Avicennia* is largely used as fodder for camels and other cattle as it grows in the arid region of Gujarat as well as in Konkan and Goa[23]. Over-exploitation for these pecuniary benefits has led to mangrove degradation at many places.

Several mangrove plants are used in indigenous medicine, such as *Bruguiera gymnorrhiza* for diarrhoea and blood pressure, *Rhizophora mucronata* for angina, *Acanthus ilicifolius* for asthma and rheumatism, *Lumnitzera racemosa* for herpes and itches, and *Cynometra ramiflore* and *Excoecaria agallocha* for leprosy[24,25]. These plants are used for curing elephantiasis, abdominal troubles and skin diseases[26]. They also cure sores, leprosy, headaches, rheumatism, snake bites, boils, ulcers, diarrhoea and haemorrhages[27,28].

Figure 1. Tropical forests of little Andamans. Coastal forests and mangroves act as natural agents in prevention of coastal erosion and act as a barrier against cyclones.

These unique coastal, tropical forests are now among the most threatened habitats in the world, due to expanding human population and resultant unsustainable economic development. Exploitation for firewood, charcoal and timber, deliberate land reclamation for urban and industrial development, shrimp farming and dumping of pollutants include the serious causes of mangrove forest loss. Shrimp farming alone caused a loss of 65,000 ha of mangroves in Thailand[29]. Java has lost 70% of its mangrove area, Sulawesi 49% and Sumatra 36% (ref. 30). Globally, the rate of decline in mangrove forest cover is estimated at 2–8% yr^{-1} (ref. 31). According to a study[32], 70% of the total coastline in Europe and 52% in Asia are under high potential threat of degradation. World's average coastline under the above category is 34%. Due to various types of coastal developmental activities, 75% of marine protected areas each in Asia and Europe and 68% in Africa are at high risk of degradation[9]. Table 1 includes estimates of loss of mangroves for selected countries.

During the last three decades, as much as 40% of the mangrove area has been converted to agriculture or urban centres along the west coast[33]. As a result of continuous biotic pressure, the mangrove and other marine resources are experiencing habitat loss, changes in species composition, shifts in dominance, loss in biodiversity and threat to survival. Some of the mangrove species are on the way to extinction from the west coast. Examples are *Xylocarpus granatum*, *Bruguiera cylindrical*, *Sonneratia acida* and *Cynometra ramiflora*. Similarly, *Nypa fruticans*,

Figure 2. Mangroves on creeks help providing breeding, nursery and feeding grounds to a variety of brackish-water and marine fauna.

Figure 3. Root structure of mangroves helps in preventing coastal erosion and soil accretion. Mangroves act as an eco-tone between aquatic and land habitats.

Heritiera minor and *H. formes* have all but disappeared from the Sunderbans.

Activities like bunding, erosion and deposition cause changes in the tides and currents, which in turn have strong impact on mangroves in particular and coastal ecology in general. The herbicides and defoliants applied in the coastal crop lands are polluting the mangrove habitats through surface run-off. Mangroves are very sensitive to these types of chemicals[34]. The mangroves have a large capacity to metabolize organic wastes and have been termed as natural sewage-treatment works. They can utilize the excess nutrients to increase the productivity. However, continuous excessive inputs of nutrients may adversely affect the ecology of mangroves[35]. Table 4 summarizes the pressures on Indian mangrove ecosystems[16,23].

The mangrove vegetation of Kavery delta has substantially suffered due to geomorphic and anthropogenic interferences[36]. Narayanan[37] has observed simultaneous sedimentation and erosion in Pichavaram mangrove areas. Structural changes have been noticed in Pichavaram and Muthupet areas due to clear felling, reduction in freshwater and tidal water inflow[38]. The above study also recorded 5–30% and 20–60% degraded mangrove vegetation out of 6986 and 6559 ha of mangrove area respectively, in Bhitarkanika and Mahanadi sites in Orissa. About 20 villages in Mahanadi area and 59 villages in Bhitarkanika area depend on mangroves for their livelihood. In Orissa, the mangroves from Chilka, Hetamundia, Kujang and from estuaries of Subernarekha and Jatadhar have already disappeared. The forests of Bagapatia and Sunei-Rupei were cleared for rehabilitation purposes[39]. The conflicts between traditional and commercial fishing practices are also a major factor contributing to mangrove degradation.

Conservation strategies

Legal provisions

The Ministry of Environment and Forests has notified Coastal Regulation Zone (CRZ) to regulate various activities in coastal areas. The coastal zones (up to 500 m from high tideline towards the landward side) have been

Table 4. Biotic and other pressures on Indian mangrove ecosystems

State/Area	Pressure
Gujarat	
Gulf of Kachchh	Continuous grazing, timber and fuel wood harvest, erosion of shoreline, industrial impact, grazing pressure
Gulf of Kambhat	Marine National Park activities, stunted growth, barren. In many areas stunted and sparse *Avicennia marina*
South Gujarat	Coral reef degradation, conversion of high tidal mud-flats into agriculture and residential development
Maharashtra	
Thane, Rajpur and Dharmatar Creeks, Mumbai region, Mahim Estuary	Industrial pollution and domestic sewage, erosion
Karnataka	
Kali, Honavara, Bhatkal, Mangalore	Deposition and erosion
Kerala	
Cochin backwater	Sparse in all areas, reclamation of backwaters
Vembanad Estuary	Developmental activities, indiscriminate cutting for fuel wood, bio-pollution
Tamil Nadu	
Vellar Estuary, Muthupet, Adyar and Ennore	Erosion, illicit cutting for timber and fuelwood, grazing, aquaculture and agriculture effluents, accumulation of heavy metals
Goa	
Mandovi Estuary	Higher concentration of dissolved metals, mining
Andhra Pradesh	
Machilipatnam, Polakayatipa, Tutipalam	Erosion, land reclamation
Orissa	
Bhitarakanika, Jatadhar, Muhan Devi River, Balasore	Shoreline change, settlements, conversion for agriculture, aquaculture
West Bengal	
Sunderbans, Sagar Island, Hooghly Estuary, Haldia	Huge exploitation of *Phoenix paludosa*, erosion and deposition, paper and petro-chemical effluents
Andaman and Nicobar Islands	Reclamation and deforestation for agriculture

classified into four categories on the basis of ecological sensitivity and development along the coast. The CRZ-I areas are the most sensitive ones, where no developmental activity is permitted. In CRZ-II areas, certain developmental activities are permitted on the landward side of the existing road/structure. No activity is permitted towards the seaward side of the existing road/structure. In CRZ-III areas, no construction is allowed up to 200 m from high tideline. Beyond 200 m, clearance is required to be obtained for any construction activity. The approved coastal zone management plans of each coastal state demarcate all mangrove areas as CRZ-I. According to the above plan, all mangroves with an area of 100 m^2 or more are classified as CRZ-I, with a buffer zone of at least 50 m. Thus, the CRZ notification 1991 and approved coastal zone management plans of each coastal state have clearly emphasized the importance of mangrove ecosystems by imposing restrictions on use of these sensitive areas for any developmental activity. Keeping in view the importance of mangrove ecosystem, a total ban was imposed in 1987 on felling of trees.

Although legal restrictions have been imposed to prevent conversion of mangrove areas, these areas are still being converted due to various types of biotic pressures and developmental activities. The coastal states need to enhance vigil and take immediate action to prevent conversion of mangrove forests. The provisions of CRZ notification, 1991 and coastal zone management plans need to be strictly enforced.

Protected areas

Establishment of protected area network is among the best conservation strategies. Mangrove areas of the country are represented in the Sunderbans Tiger Reserve, Bhitarkanika, Coringa, Nelapattu and Point Calimere Wildlife Sanctuaries and Pirotan National Park. Among these protected areas (PAs), Sunderbans has been recognized as a Natural World Heritage Site. However, most of these PAs suffer from a lack of manpower and infrastructure, continued human activities, and encroachments. Management plans for the PAs need be based on ecological principles, and should include pragmatic strategies for ecodevelopment of the adjacent areas. A research component, and inclusion of scientists in the management teams are needed. A transboundary approach (India and Bangladesh) for mangrove conservation is highly desirable.

Restoration

There is need for the forest departments to undertake human-assisted restoration of those areas which have been made barren or have degraded due to biotic pressures or other factors. It would be advisable to prepare a time-bound management plan, specifically for mangrove regeneration. Regeneration research must be given top priority among such management plans. Mangrove forest regeneration depends on natural seedlings. If proper protection is given, the system will regenerate itself. However, if the habitat is completely destroyed, recovery will be difficult due to changed environmental conditions such as soil salinity, tidal pattern, altered land use, enhanced biotic pressure, etc. In such cases, intensive human assistance is needed.

Most of the mangrove plants are viviparous, i.e. the seeds mature and germinate on the tree. After falling down, many of the germinated seeds drift away with the currents. The seeds may be collected from natural habitats and directly sown in the mangrove areas during low tide period, generally at a spacing of 30 cm × 30 cm. Seedlings can also be raised in nurseries near natural habitats under partial shade. Seedlings can be raised in standard polyethylene bags with the soil of mangrove area as the medium. Preference should be given to the soil where the seedlings are going to be planted. Such seedlings should be irrigated with brackish water. It is desirable to keep the seedlings in the nursery for about nine months before transporting them to the planting site. The plantation should be raised during the premonsoon showers, preferably at a spacing of 1 m × 1 m, in 30 cm^3 pits.

Some efforts have been made to raise mangrove plantations in degraded forests in Orissa, West Bengal, etc. by the respective Forest Departments. With adequate protection, mangroves regenerate and cover the exploited area in a short period. This process needs to be augmented with human intervention. For example, harvesting of mangroves on sustained yield basis with defined period of rotation should be mandated to ensure sufficient regeneration. Clear felling of mangroves promotes fast growing of unwanted weed species which inhibit mangrove regeneration.

Natural regeneration and recovery can also be promoted by reducing the anthropogenic pressure due to fuel-wood demand on natural populations. There is an urgent need to undertake massive afforestation programmes with improved fuel-wood yielding trees in the buffer areas, to sustain the requirements of the local people. These plantations will act as a major energy source to local communities in future. Plantation of fast-growing species, should also be taken up in the villages, which will reduce the dependence of coastal communities for conventional firewood from mangrove forests.

Sustainable use and public participation

The local governments should formulate proper management policy by involving local people who have a stake in the conservation and management of mangrove forests in their areas. The mangrove areas are ideal to undertake

conventional aquaculture practices which do not cause damage to the ecosystem. Small-scale community-based fisheries must be encouraged, as 95% of the coastal population is engaged in this sector. These communities use only 10% of the energy of large-scale fisheries corporate sector to contribute half of the world catch. The interest and rights of local communities must be safeguarded[40,41]. The prawn-farming projects, which are established close to mangrove and estuarine areas, for earning large sums of money in the shortest possible time, need be discouraged. Such aquaculture severely affects the ecology of these ecosystems. Silvofisheries, a form of integrated mangrove tree culture with brackish-water aquaculture, wherein the mangroves are cultured on a slightly raised central, earthen platform within the aquaculture pond, or mangroves are maintained around the aquaculture pond units, can potentially be a sustainable management strategy for integrating livelihood with conservation[42]. The development of a system of village community forests, in which each village is given the responsibility to manage and sustain a small area of mangrove forest in lieu of accruing benefits from capture of larger quantities of marine fauna for food and trade as the system recovers, is also a viable conservation option. The mangrove areas can be used for the development of eco-tourism, recreation, education and for creating public awareness on aspects of nature conservation (Figure 4).

Public awareness and research

Efforts should be made at village, district and state levels by the policy makers and NGOs, to educate the local people about the economic and ecological values and functions of mangrove forests, and the negative results of their mismanagement. There is a need to involve people at the grassroots level, in protection of these forests. With better management practices, they can derive their bona-fide needs of firewood sustainably. The government should also encourage and involve ecologists, researchers and specialists to work on various aspects of ecological management of this resource. Long-term research activities should be undertaken in collaboration with various premier organizations to increase the productivity of mangrove forests and also to develop various management models which can give added benefits to local communities involved in protection and conservation. Research is needed to exploit the capability of artificially constructed mangrove ecosystems to lower the BOD of waste water and to remove toxic elements through bio-remediation.

Figure 4. Mangrove areas being rich in biodiversity and having specialized organs, may attract eco-tourism.

1. Wolanski, E., Mazda, Y. and Ridd, P., in *Tropical Mangrove Ecosystems* (eds Robertson, A. I and Alongi, D. M.), Coastal and Estuarine Studies, 41, American Geophysical Union, Washington, 1992, pp. 43–62.
2. Mangrove Action Project, www.earthisland.org, 2002.
3. Tomlinson, P. B., *The Botany of Mangroves*, Cambridge University Press, Cambridge, 1986.
4. Archibold, O. W., *Ecology of World Vegetation*, Chapman & Hall, London, 1995.
5. Mann, K. H., *Ecology of Coastal Waters*, University of California Press, Berkeley, 1982.
6. Ellison, A. M., Mukherjee, B. B. and Karim, A., *J. Ecol.*, 2000, **88**, 813–824.
7. Helalsiddiqui, A. S. M., *Indian J. For.*, 1999, **22**, 197–202.
8. Banerjee, L. K. and Ghosh, D., in *An Anthology of Indian Mangroves*, ENVIS Publication, Annamalai University, 1998, pp. 20–24.
9. *World Resources: A Guide to the Global Environment*, Oxford University Press, World Resources Institute, Washington DC, 1996–97.
10. Krishnamurthy, K., *The Mangroves*, ENVIS, Annamalai University, 1993, vol. 1, pp. 1–3.
11. Kathiresan, K., *Seshaiyana*, 1998, **5**, 15–19.
12. *Marine Protected Area Needs in South Asian Seas Region, India*, IUCN, Gland, Switzerland, 1998, vol. 2.
13. State of Forest Report, 1997, Forest Survey of India, Dehra Dun, 1997.
14. State of Forest Report, 1999, Forest Survey of India, Dehra Dun, 1999.
15. Mangroves in India (Status Report), Ministry of Environment and Forests, Govt of India, New Delhi, 1987.
16. *Coastal Environment*, Space Applications Centre, Ahmedabad, 1992.
17. Banerjee, L. K., Shastry, A. R. K. and Nayar, M. P., *Mangroves in India – Identification Manual*, Botanical Survey of India, Kolkata, 1989.
18. Azariah, J. and Govindasamy, C., see ref. 8, pp. 7–14.
19. Robertson, A. I. and Blaber, S. J. M., see ref. 1, pp. 173–224.
20. Odum, W. E. and Heald, E. J., *Bull. Mar. Sci.*, 1972, **22**, 671–738.
21. Rao, A. N., in Mangroves of Asia and Pacific. Status and Management (ed. Umali, R. M.), Technical Report UNDP/UNESCO, 1987, pp. 1–48.
22. Hellier, C., *Ecologist*, 1988, **18,** 77–79.
23. *Environmental Information System Newsletter*, ENVIS, Annamalai University, 1998, vol. 5, pp. 1–66.
24. Kothari, M. J. and Rao, K. M., in *Taxonomy and Biodiversity* (ed. Pandey, A. K.), C.B.S. Publishers & Distributors, Delhi, 1995, pp. 52–58.
25. Untawale, A. G., Wafer, S. and Wafer, M., in *Conserving the Sacred for Biodiversity Management* (eds Ramakrishnan, P. S.,

Saxena, K. G. and Chandrashekara, U. M.), Oxford and IBH, New Delhi, 1995, pp. 247–252.
26. Selvaraj, A. M., Santhana Kumar, G. and Xavier, A., Biomass production through mangrove coastal social forestry, Mahatma Gandhi Institute of Integrated Rural Energy Planning and Development, Bakoli, New Delhi, 1995.
27. Khosoo, T. N., *Environmental Concerns and Strategies*, Ashish Publ. House, New Delhi, 1984.
28. Untawale, A. G., see ref. 8, pp. 52–55.
29. Mukerjee, M., *Sci. Am.*, 1996, **275**, 26–27.
30. Briggs, M. R. P. and Funge-Smith, S. J., Unsustainable Shrimp Culture, Causes and Potential Solutions from Experience in Thailand, Overseas Development Administration, Washington DC.
31. Kunstadter, P., Bird, E. and Sabhasri, S., *Man in the Mangroves*, United Nations University, Singapore, 1985.
32. Bryant, Dirk *et al*., Coastlines at Risk; An Index of Potential Development-related Threats to Coastal Ecosystems, WRI Indicator Brief, World Resources Institute, Washington DC, 1995.
33. Jagtap, T. G., in *Biodiversity in the Western Ghats: An Information Kit*, World Wide Fund, India and International Institute of Rural Reconstruction, Goa, 1994, pp. 3–6.
34. Kemf, E., *New Sci.*, 1988, **118**, 53–57.
35. Saenger, Hegerl, P. E. J. and Davie, J. P. S., *Environmentalist*, 1983, **3**, 1–88.
36. Tissot, C., *J. Mar. Biol. Assoc. India*, 1987, **29**, 16–22.
37. Narayanan, L. R. A., *The Hindu*, Chennai, 30 November 1997.
38. Eighth Annual Report, Centre for Research on Sustainable Agriculture and Rural Development, M.S. Swaminathan Research Foundation, Chennai, 1998.
39. Chaudhury, B. P., in *Biodiversity Conservation: Problems and Prospects* (ed. Patra, H. C.), Orissa Environment Society, Bhubaneswar, 1998, pp. 59–67.
40. IUCN, UNEP and WWF, Caring for the Earth: A Strategy for Sustainable Living, IUCN, Gland, Switzerland, 1991.
41. Thorne-Miller, B. and Catena, J., *The Living Ocean: Understanding and Protecting Marine Biodiversity*, Island Press, Cavelo, California, 1991.
42. Fitzgerald, W. J., *Aquacult. Asia*, 1997, 9–17.

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