An Overview of Crustacean Diversity in Mangrove Ecosystem

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S. Murugan and D. Usha Anandhi

Abstract

Mangrove forests are the protective barrier of coastal inhabitants against natural calamities and prevent soil erosion protecting the land behind. These typical ecosystems provide areas for breeding, nesting, foraging and shelter for economically important organisms. Hence, most of the growing population in the world live within easy reach of coastal areas. Crustaceans like lobsters, crabs, crayfish, shrimps, barnacles, etc. are very important in the nutrient recycling and are most crucial in human economy. Crustaceans are unique source of nutrients like proteins, fats and minerals to aquatic life as well as to human beings. As mangroves act as nursery, high juvenile abundance of many aquatic organisms is seen. Today these economically important ecosystems are among the most threatened habitats with 30–50 % of global loss due to natural and anthropogenic disturbances. Awareness in public through media, Non Government Organisations (NGOs), Government organisations and educational institutes who must come together for restoration, rehabilitation and conservation of this delicate and precious ecosystem.

Keywords

Crustaceans • Conservation • Ecosystem • Mangrove

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5.1 Introduction

Mangrove ecosystems are the woody halophyte-dominated forests located in muddy, loose and wet soils at the junction of terrestrial and marine ecosystem rich in productivity with commercially important fishes, crustaceans and molluscs. Mangrove forests act as a protective barrier to the coastal inhabitants against the natural calamities like flood, tsunami hurricanes and prevent soil erosion protecting the land behind. A number of studies have shown that mangrove ecosystems act as a natural green belt of the world (IUCN 2005).

In India, mangroves are diverse with 125 species, of which 39 species are mangroves and 86 species are mangrove associates, amounting to 56 % of the world's mangrove species with equally diverse fauna of birds, reptiles, fishes, crustaceans, molluscs and insects including both resident and visiting fauna. Reptiles like snakes, turtles, estuarine crocodiles and monitor lizards are common in mangroves which survive the range of salinity. Mammals like various species of monkeys, otters, deers, fishing cats and wild pigs are most common in mangrove forests (http://www.indian-ocean.org/bioinformatics/mangroves/mangcd/fact.htm).

5.2 Mangrove

Mangrove forests are usually dominated by red mangrove (*Rhizophora* sp.), black mangrove (*Avicennia* sp.) and white mangrove (*Laguncularia* sp.) The red mangrove being the tallest with a maximum height of 25 m and acting as a basis for detrital food chain in estuary has been well documented (Hutchings and Saenger 1987). Black mangrove is the second tallest species reaching a height of 20 m, and the white mangrove is the smallest of the three mangroves with a maximum height of 15 m. Mangrove forest are the most productive ecosystems (Por 1984), and they hold an enormous carbon stock per unit area (Twilley et al. 1992). The mangrove has aerial root system, either prop roots or stilt roots (Fig. 5.1) which are important organs of breathing at high tides and help in anchoring of the plant which is a characteristic of *Rhizophora.* They also occur in *Bruguiera*, *Ceriops*, *Avicennia alba* and *A. officinalis*. These roots provide an important nursery ground for crustaceans, molluscs and fishes (Odum and McIvor 1990). Mangrove plants along with the root system help in sedimentation (Krauss et al. 2003) by slowing water velocity (Mazda et al. 1997).

Globally tropical mangroves are the most productive natural ecosystem (Alongi 2009), and their distribution is divided as the Atlantic East Pacific hemisphere and the Indo West Pacific hemisphere, where the former one has less species diversity than the latter (Fig. 5.3). Mangroves are globally distributed in four ecotypes: fringe, riverine, basin and scrub forests (Twilley 1998) with key faunal species richnesses (Lee 2008). The Matang Mangrove Forest Reserve that consists of roughly 40,151 ha of pure and mixed stands of *Rhizophora* and *Bruguiera* had been established in Perak, Malaysia (Gan 1995). The mangrove forest covers about 360,000 ha in India (Govindasamy and Kannan 1996), which is the world's fourth largest mangrove

Fig. 5.1 Prop roots or stilt roots

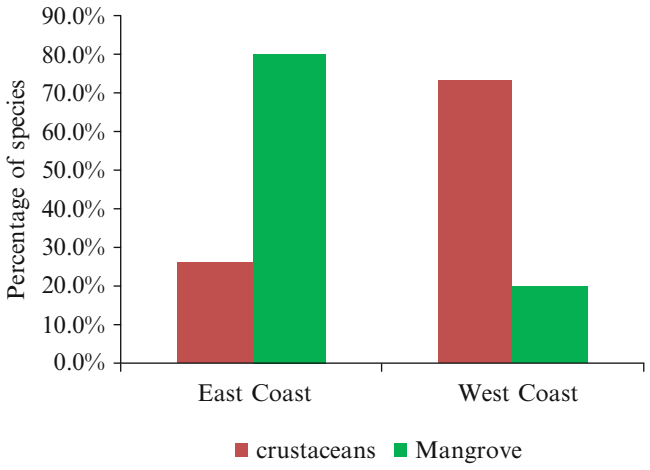

Fig. 5.2 Distribution of crustaceans and mangroves in Indian coasts

area (Mandal et al. 1995), of which 80 % are along the east coast and 20 % on the west coast (Fig. 5.2).

The Forest Survey of India (1997) reported that the total mangrove area of India is 4822 km^2. The major part of mangrove is found in states like West Bengal, Andaman and Nicobar Islands, Orissa, Gujarat, Andhra Pradesh, Tamil Nadu, Kerala, Goa, Maharashtra and Karnataka. The largest area of mangrove occurs at the Sundarbans, West Bengal, followed by Andaman and Nicobar Islands. The mangrove species diversity is highest in Orissa with 101 species, followed by 92 species in West Bengal and in Andaman and Nicobar Islands and the lowest of 40 species in Gujarat (Kathiresan 2000) (Fig. 5.3).

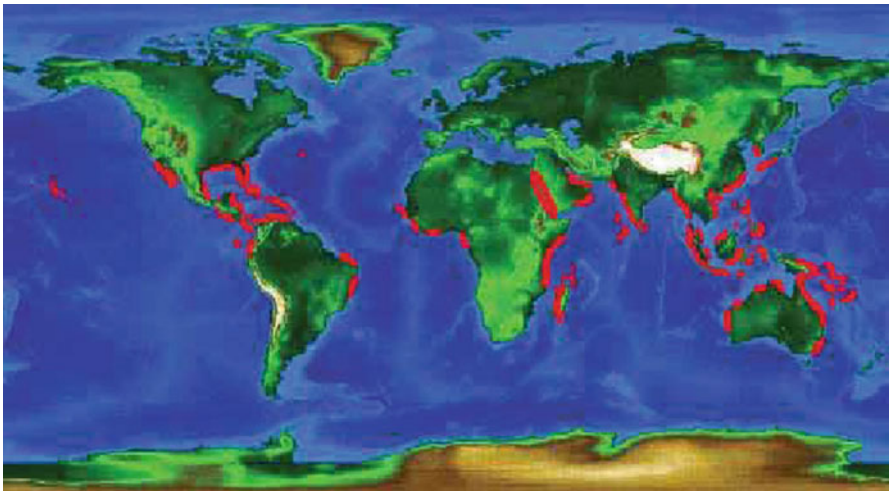

Fig. 5.3 World atlas of mangroves (Source: FAO 2008)

The Sundarbans mangroves are located in the coast of the Bay of Bengal (sharing between India and Bangladesh). Sundarbans got this name, as the forest is dominated by *Heritiera* tree species which is locally called 'sundari' because of its elegance (Jain and Sastry 1983). The mangroves are spread to an area of 4262 km^2, but only 2320 km^2 is the forest, and the rest is water having the highest diversity with 69 species, 49 genera and 35 families, including two species, viz. *Scyphiphora hydrophyllacea* and *Atalantia correa* which are reported for the first time from Indian Sundarbans (Mandal et al. 1995). The royal Bengal tiger is the unique resident species of the Sundarbans. Honeybees occupy an important position in the mangroves of the Sundarbans as honey and beeswax are important products obtained from this ecosystem (Gopal and Chauhan 2002). *Aegiceras corniculatum* flowers form a source of high-quality honey in this region (Wealth of India, vol. I. 1985) followed by *Avicennia marina* and *A. officinalis* (Banerjee et al. 1989).

Pichavaram mangrove forest is located in the Southeast Coast, in the Cuddalore district of Tamil Nadu State, which receives brackish water from Vellar estuary and Coleroon estuary. Pichavaram mangrove ecosystem harbours 35 species of 26 genera and 20 families, including one new species *Rhizophora annamalayana* Kathir (Kathiresan 1995). The dominant mangrove species in Pichavaram is *Avicennia marina* followed by *Avicennia officinalis*, *Excoecaria agallocha*, *Rhizophora apiculata* and *Rhizophora mucronata* (Jyoti Srivastava et al. 2012). Pichavaram mangroves harbour 46 species of crabs from five different stations (Ravichandran and Kannupandi 2007). Being an ideal feeding and breeding ground for many commercially valuable faunal species like fishes, prawns, molluscs, etc., it attracts a large number of birds which in turn attract an appreciable number of tourists. Chandrasekaran and Natarajan (1992) reported an annual harvest of 245 tons of fish, prawn and crab from this mangrove ecosystem, and 3000 traditional poor

Fig. 5.4 Netravathi-Gurupur estuarine mangrove

fishermen living in 14 hamlets depend on this for their livelihood security. Eight prawn species are dominant in Pichavaram mangroves (Kathiresan and Bingham 2001) and finfishes like *Ambassis gymnocephalus*, *A. commersoni*, *Arius subrostratus*, *Chanos chanos*, *Etroplus suratensis*, *Gerres filamentosus*, *G. abbreviatus*, *Liza parsia*, *L. macrolepis*, *L. subviridis*, *Lates calcarifer*, *Lutjanus argentimaculatus*, *Mugil cephalus*, *Osteomugil cunnesius*, *Pomadasys Pondicherry kaakan*, *Plotosus canius*, *Scatophagus argus*, *Siganus javus*, *S. canaliculatus* and *Terapon jarbua* (Kathiresan 1999).

According to the Government of India report (1997), 6000 ha of mangrove cover is present in Karnataka which is spread in estuaries of Netravathi-Gurupur, Mulki-Pavanje, Udyavara-Pangala, Swarna-Sita-Kodi, Chakra-Haladi-Kollur, Baindur hole, Shiroor hole Venkatapur, Sharavathi, Aghanashini, Gangavali and Kali river estuarine complexes. Most mangroves are of the fringing type in linear formations along the river or estuarine banks. Some of the mangrove species present in Karnataka are *Acanthus ilicifolius*, *Lumnitzera racemosa*, *Excoecaria agallocha*, *Aegiceras corniculatum*, *Porteresia coarctata*, *Bruguiera cylindrica*, *Bruguiera gymnorrhiza*, *Kandelia candel*, *Rhizophora apiculata*, *Rhizophora mucronata*, *Sonneratia alba*, *Sonneratia caseolaris*, *Avicennia marina* and *Avicennia officinalis*. Netravathi-Gurupur estuarine mangrove complex is located near Mangalore joining the Arabia Sea at right angle, whereas the Gurupura River runs parallel to the coast before joining the Netravati River which together forms the estuarine mangrove complex (Fig. 5.4). The influence of the tide is felt to a distance of about 20 km inland. This estuarine complex harbours eight mangrove species and many associated plants along with molluscs, polychaetes, crustaceans (*Penaeus indicus*, *P. monodon*, *Metapenaeus monoceros*) and a number of finfishes. Finfish and shellfish

fisheries and aquaculture are important livelihood with clam, prawn and crab collection activities. The benthic animals and planktons play a crucial role in these estuarine and mangrove ecosystems like pelagic and terrestrial communities.

5.3 Crustacean Diversity in Mangrove Ecosystem

Crustaceans are the most diverse arthropod group under water, and few have evolved to live on land, though they still require the damp area or an easy access of water to live. Crustaceans include penaeid prawns, non-penaeid prawns, lobsters, crabs, crayfishes, shrimps, barnacles, etc. which are important in human economy due to their role in the marine and terrestrial food chain. Crustaceans are also very important in the nutrient recycling. They possess hard and flexible exoskeleton, two pairs of antennae, a pair of mandibles, a pair of compound eyes, a pair of maxillae and a pair of appendages in each of the body segments. Most of them are dioecious and free living, few are sessile and few others are parasitic. Reproduction is either through the larval stage nauplius or miniature adults. The crustaceans and molluscs, being the dominant macrofauna of the ecosystem, provide a major contribution to the mangrove forest (Hutchings and Saenger 1987) as they make burrows helping other faunal diversity to get the necessary ground for feeding and to establish the boundary required for breeding. Some organisms like barnacles filter water through these burrows. Globally the high number of juvenile crustaceans is found in mangrove ecosystem. The main reason for this is the high abundance of food, lower predation pressure due to shallow-water, microhabitats with higher turbidity and reduced visibility (Beck et al. 2001) and their complex physical structure, for example, root modifications (Lee 2008; Nagelkerken 2009).

To understand the significance of faunal diversity in mangrove ecosystem, numerous studies have been carried out at the east and west coasts of India (Kumar 2001; Saravanakumar et al. 2007). Mud crabs, hermit crabs, lobsters, shrimps and prawns are predominately present in these ecosystems. As mangroves bloom, germinate and fruit, changes occur in invertebrate populations in response to change in food resource. The mangrove ecosystem is continuously being utilised by the vertebrates in these areas. Some vertebrates visit only during favourable periods. Over 90 % of commercial fishery and 70 % of sport fishery depend on the natural mangrove ecosystem for food and habitat (Lewis et al. 1985). Mangroves are dominated by marsh crabs near upper zones and fiddler crabs (Fig. 5.5) closer to shore. As fiddler crabs feed on detritus and micro-organisms living in the detritus, they play a crucial role in cycling of nutrients in the mangroves (Dev Roy and Sivaperuman 2012). This nutrient cycling from the sediment is due to the digging behaviour of the bottom strata and remineralisation action of the detritus in the ecosystem (Robertson 1991). Digestion of structural carbon aided by cellulase enzymes has been studied on terrestrial detritivorous and herbivorous animals (Linton and Greenaway 2004, 2007). Recent studies also revealed the same in many estuarine animals, particularly detritivorous grapsid crabs (Adachi et al. 2012). The diversity effects in the mangrove ecosystem differ between top-down and bottom-up trophic levels in

Fig. 5.5 Fiddler crabs

detritus-based systems (Srivastava et al. 2009; Kominoski et al. 2010). Most of the species are exclusively visitors including humans exploiting the same.

Comprehensive compiled lists of fishes, molluscs, crustaceans, echinoderms and algae of economic importance associated with mangroves that report 732 species in Western Central Pacific, 640 species in Eastern Indian Ocean and 654 species in Western Indian Ocean have been prepared by Matthes and Kapetsky (1988). The commercially important species among these are *Mugil cephalus*, *Scylla serrata*, *Penaeus* sp., *Crassostrea* sp. and *Meretrix* sp. All over the world, about 65 bird species have been listed as endangered or vulnerable. Saenger et al. (1983) have stated that about 150–250 mangrove bird species would be in each of the main biogeographical regions. Aveline (1980) reports that decapod crustaceans are the primary composition of mangrove forests' invertebrate fauna, and these play a crucial role in the mangrove ecosystem dynamics. Hamilton and Snedaker (1984) report that 60 % of commercial catch depends on mangroves in Fiji.

A total of 3111 mangrove-inhabiting faunal species are distributed in different states of India and include prawns, crabs, molluscs, fishes, insects, reptiles, amphibians and mammals (Kathiresan and Quasim 2005). Till now 26 lobsters, 162 hermit crabs, 705 brachyuran crabs and 84 prawns/shrimp species have been recorded in India (Venkataraman and Wafar 2005). In India 11 species of edible crabs have been identified (*Portunus sanguinolentus*, *P. pelagicus*, *Charybdis feriatus*, *C. hicifem*, *C. annulata*, *C. natator*, *Scylla tranquebarica*, *S. serrata*, *Matuta lunaris*, *Sesarma tetragonum* and *Varuna litterata*), inhabiting the coastal and brackish water environments and supporting the commercial fisheries. A total of 48 prawn species are reported from the mangrove ecosystem of India with 34 in the east coast, 16 in Bay Islands and 20 in the west coast (Kathiresan 2000). Samant (1986) recorded 121 species of birds along the Maharashtra coast. Approximately 60 % of commercially important fish species are associated with mangrove ecosystem (Untavale 1986). Molluscs are abundant in South Canara particularly clams during the non-monsoon

period (Chatterji et al. 2002). The estimation of the Central Marine Fisheries Research Institute (CMFRI), South Canara, showed an increase of bivalves harvest with 4583 tons in 2006, compared to 905 tons in 1997. Boominath et al. (2008) estimate harvest of 22,000 tons of edible bivalves per year from Aghanashini estuary of Honnavar Forest Division worth of Rs. 66 crore at current market prices.

In mangrove ecosystem, copepods are the major planktonic component with zooplanktonic copepods comprising 60–80 % of biomass (López-Ibarra and Palomares-García 2006) and play the role as prey to many juveniles and immature adults (Sommer et al. 2002). These copepods transfer energy and organic matter from the primary producers to higher trophic levels of the aquatic system (Parsons et al. 1984) though the abundance and distribution are influenced by hydrographical conditions (Santhanam and Perumal 2003).

Barnacles are one of the most fouling organisms in the estuarine ecosystem, and there are more than 1000 known species of barnacles (Chan and Lee 2007) in the world. The barnacles in mangrove ecosystem attach to hard submerged object in the estuarine water or other organisms like crabs, molluscs, shell of turtles, etc. or roots and the lower region of mangrove plant (Grunbaum 2010; Madin 2010).

The mud crab *Scylla* sp. the most important large commercial crab species reaching up to 3 kg in weight is found in mangrove habitats in the world. FAO (2012) and Grubert et al. (2012) report 37,000 tons of *Scylla* sp. being caught globally excluding many countries that do not report the mud crab catches to FAO. This clearly shows that the global mud crab catch is much higher than the given figures of FAO. Joel et al. (1985) reported the distribution and zonation of 29 crab species in the Pulicat Lake. Chakraborthy and Chowdhury (1992) studied 18 species of crabs in the island of Sundarbans mangrove. Mangrove leaf litter decomposition by crabs, lobsters and sesarmids plays a key role between primary and secondary producers (Ajmal Khan et al. 2005). Mangrove trees shed about 7.5 tons of leaves per acre per year, and the energies stored in these leaves are utilised by the crabs before these are carried away by tides (Ashton 2002) and crucially contribute towards the secondary production through the coprophagous food chain (Gillikin et al. 2001). The crabs are a unique source of protein to aquatic life as well as to human being (Siddiqui and Zafar 2002). Sesarmids depend on the sediments of mangroves than the leaves for carbon assimilation (Bouillon et al. 2002; Skov and Hartnoll 2002). The other major commercially valuable crustaceans associated in mangrove are prawns though a large part of commercial harvest (Fig. 5.6) of prawn is in offshore sectors (Vance et al. 2002).

The major part of juvenile stage in prawns is dependent on the mangrove ecosystem as they supply all necessary environment and nutrients (Potter et al. 1986). These juveniles spend only few months in the estuaries and then migrate to offshore up to tens of kilometre which makes it difficult to quantify their nursery grounds. The prawn fishery catch varies to a wide extent as the distribution is dependent on the physical factors like salinity and temperature (Vance et al. 1985). Besides all these factors, a greater abundance of prawn juveniles are found in mangrove areas of estuaries than in the other parts (Primavera 1998).

Fig. 5.6 Commercial harvest of prawns

Some of the prawn and shrimp species reported in the Indian mangroves are *Metapenaeopsis coniger*, *Metapenaeus monoceros*, *M. affinis*, *M. brevicornis*, *M. dobsoni*, *M. lysianassa*, *M. kutchensis*, *M. moyebi*, *Parapenaeopsis longipes*, *P. sculptilis*, *P. stylifera*, *P. canaliculatus*, *P. indicus*, *P. japonicus*, *P. latisulcatus*, *P. merguiensis*, *P. monodon*, *P. semisulcatus*, *P. penicillatus*, *Acetes erythraeus*, *A. indicus*, *Solenocera crassicornis*, *Macrobrachium lamarrei*, *M. idella*, *M. idea*, *M. dayanum*, *M. javanicum*, *M. malcolmsonii*, *M. mirabile*, *M. rosenbergii*, *M. rude*, *M. scabriculum*, *Palaemon concinnus*, *P. debilis*, *P. styliferus*, *P. semmelinkii*, *P. tenuipes*, *Alpheus crassimanus*, *A. paludicola*, *Caridina gracilirostris*, *C. brachydactyla*, *Lucifer hanseni* and *Thalassina anomala* (Kathiresan and Rajendran 2005).

As the mangroves provide soft sediment for burrowing animals and hard rooted structure for the animals requiring firm substratum with adequate nutrients, these areas are abundantly inhabited by bivalves. Till date 5070 mollusc species have been recorded in India with 3370 marine species (Venkataraman and Wafar 2005), the rest are freshwater and terrestrial species. As the molluscs are rich in nutrients especially proteins, fats and minerals, mollusc (shell) fishery mainly includes bivalves like clams, mussels and oysters. High juvenile abundance of many aquatic organisms is seen in mangrove-associated areas like coral reefs and seagrasses (Mumby et al. 2004; Jelbart et al. 2007).

5.4 Ecological and Economic Significance

Mangrove ecosystem provides many goods and services though all of which are not quantified in terms of economic value. Mangroves, serving as a critical nursery for many commercially important organisms, play an important role in the health and the economic well-being of fisheries. Mangrove forests being the highly productive ecosystem have also been a potential contributor of timber, poles, food, medicines

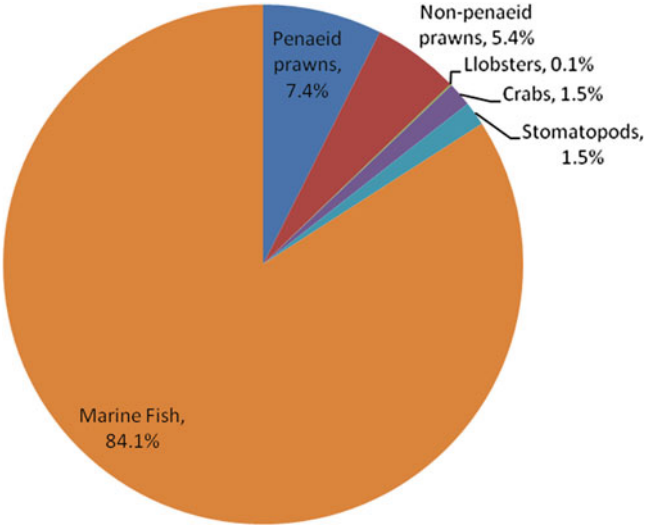

Fig. 5.7 Marine Fish Landing in India (Source: CMFRI 2013)

and a wide variety of other items, indicating conservation of this ecosystem to be a realistic global economic investment (Ronnback 1999). Timber from mangrove is widely used to produce charcoal, tannins and resins for dying and leather making, furniture, bridges, poles for fish cages and traps, alcohol, boats and many other products (Kathiresan and Bingham 2001). The major roles of mangroves and the macrofauna associated with the ecosystem are in providing food security, coastal protection, maintaining water quality, carbon dioxide fixation, source of medicine and salt-resistant genes, dyes, fodder, paper pulp, timber, firewood, manure, fibre, perfumes, recreation and tourism. The leaves, fruits, seeds and seedlings of *Avicennia marina* and vegetative parts of other mangrove species are consumed as vegetables, and some of the mangrove flora also has toxic compounds that are used for their antifungal, antibacterial and pesticidal properties (Bandaranayake 1998).

Mangroves are among the most productive ecosystems as they provide support both directly and indirectly to all life forms. The rich diversity in the mangrove ecosystem influences primary producer abundance, nutrient input, tidal action, annual production and many other factors in the ecosystem. In the past decade, global production of shellfish has doubled in the coastal zone (Naylor et al. 2000). Inhabitants of the estuaries and mangrove forest derive the major direct benefits (Hamilton and Snedaker 1984) as these ecosystems are the important contributors for coastal economy. The economy that depends on mangrove swamps, estuaries, grass beds and coral reefs are severely affected worldwide as these areas are being degraded or destroyed (Wilkinson 1992).

FAO (2012) reports a global consumption of 78.9 million tons of fish, crustaceans and molluscs from oceans contributing to 16.6 % of global protein intake by human in 2011. India has exclusive economic zone of 2.02 million sq. km and 0.53 million sq. km of continental shelf. CMFRI (2013) reports that India has an average annual crustacean resource landing of about 4.36 lakh tons (Fig. 5.7) which

is 15.9 % of marine fish landing that included 7.4 % penaeid prawns, 5.4 % non-penaeid prawns, 0.1 % lobsters, 1.5 % crabs and 1.5 % stomatopods. In India the east coast contributes 26.4 % and the west coast 73.6 % (Fig. 5.2) of the total crustacean landing. The demand for fish, crustaceans, molluscs and their products has seen a dramatic increase in the past decades due to the economic importance and provides employment and livelihood to millions of people. Crustaceans and molluscs take a crucial role in ecological functioning of mangrove ecosystem (Lee 1999). Thus, functioning of mangrove ecosystems is reflected by the richness and abundance of species as they become an indicator of change in mangrove ecosystem. Mangrove swamps, estuaries and lagoons and their grass beds act as 'nurseries' and provide nutrients and shelter for economically important fishes, crustaceans and molluscs, and these areas are among the world's most ecologically critical and threatened resources (Pauly and Ingles 1999). Fishery resources from the mangrove ecosystem are regarded more valuable than the wood and other natural and agricultural goods (Lacerda 1993). Man gets fish, crabs, shellfish, reptile skins, honey and other products from most of the world's mangrove forests (Nurkin 1994). Thus, these ecosystems are an important economic resource and ecological asset to every county. As numbers of molluscs are soft bodied, their shells are used in preparation of a number of medicinal oils and medicines to treat many diseases. Apart from these, molluscs like cuttlefish, squids and octopods are used as fish bait. Mangroves also help greatly towards the recharge of underground water table.

5.5 Loss of Diversity

Hostile habitat and human abuse of mangroves are resulting in endangering this unique ecosystem (Kathiresan and Ravikumar 1995), and today these ecosystems are one among the most threatened ecosystems in the world (Kelleher et al. 1995). Many studies have shown that these ecosystems are being destructed twice faster than the well-publicised destruction of tropical rain forests. The consumption of macro consumers like grapsid crabs and gastropods would significantly reduce the detrital carbon stock in tropical mangroves (Kristensen et al. 2008; Lee 2008). Natural and anthropogenic disturbances at various levels (Wolanski et al. 2000) are serious threats to mangrove ecosystem functioning (Osborn and Polsenberg 1996). Degradation and loss of mangrove are mostly due to salt production, wood extraction, coastal industrialisation and urbanisation, coastal aquaculture and other anthropogenic activities (Macintosh 1996). These activities adversely affect the crustacean fauna and their resources worldwide (Suseelan and Nair 1994). Degradation or deforestation of mangroves has resulted in 1–2 % loss annually, and thus approximately 30–50 % of global mangroves were lost in the past half century (Polidoro et al. 2010). IPCC (2007) predicts that if the present rate of loss continues, 30–40 % of coastal wetlands and 100 % of mangrove forests (Duke et al. 2007) could be lost from the world within the next century. Globally only 6.9 % mangrove

area is covered under the existing protected area network (Giri et al. 2011). The Government of India (1987) reports a loss of 40 % mangrove area in the last century from India. Mangrove area of about 191,300 ha was lost during 1987–1997 all over India. A total of 20 faunal species has been reported to be threatened from Indian mangrove ecosystem (Dev Roy and Sivaperuman 2012).

The brackish water ecosystems that include estuaries, backwaters, saltwater lakes, mangroves, etc., harbouring immense wealth of juvenile prawns, are reported with considerable shrinkage due to an authorised and unauthorised reclamation in the past few decades. Mangrove reforestation is limited to two to three species due to economic reasons of the developing countries (Gan 1995). Overfishing has resulted in depletion in number of fish, crustacean and molluscs. Some popular species, like whales, dolphins and sea turtles, are on the verge of extinction. The recent global mangrove forest estimate reveals that the loss is more than half of what it was once (Spalding et al. 1997) and the remaining is in degraded condition (MAP 2005). The survival of mangrove seedlings has been suggested to be affected by the attachment of the barnacles in many areas (Havanon et al. 1995; Rawangkul et al. 1995). This degradation will result in the reduction or loss of goods and services provided by mangrove ecosystem (Duke et al. 2007). Vietnam, Mexico, Singapore, the Philippines and Thailand have lost most of their mangrove as a result of urbanisation and exploitation (Spalding et al. 1997). All mangrove species are susceptible to herbicide stress (Odum et al. 1982), and stress of single defoliation would kill the entire plant.

Data on carbon storage in mangrove wood or sediments are very less, but the available data suggests that mangrove forests can accumulate enormous carbon (Twilley et al. 1992; Alongi et al. 2000). In Sawi Bay, carbon in mangrove sediments is derived from land and from phytoplankton stimulated by inorganic nutrients (Ayukai and Alongi 2000). As mangroves are an important carbon sink which get converted to biomass, the loss of these crucial ecosystems has resulted in a huge loss of carbon, stored as mangrove biomass (Cebrian 2002). Human beings cut and fill mangroves for agricultural and industrial development and urbanisation (Linden and Jernelov 1980), and these mangroves are converted as salt flats to produce salt (Nurkin 1994). The changed pattern of fishing creates biological damages to important shrimp species, besides it has also generated social problems in many parts of the world. Many countries do not report the actual figures of the resources that are caught from these ecosystems despite producing thousands of tons of resources which makes it difficult to assess the global loss. With the limited data that are available from different countries, FAO has assessed the loss of resources to an alarming level requiring immediate attention.

5.6 Conservation

Natural conservation is the best way of conservation where it is being left alone without interruption, as they are self-sustaining ecosystems. The best effort by human in conservation could be by reducing and preventing future damages and

taking steps to remove the past damages caused. The most common measures adopted in tropical fisheries are restriction of fishing, closed seasons for fishing, catch quotas allotment, mesh size regulation and restriction of juveniles capturing at nursery grounds. These measures are drafted keeping in view of different breeding periods and to have sustainable resource. Implementation of the above measures is only possible by public understanding and participation. Governments and people must understand the social and economic importance of mangrove ecosystem and action to be taken towards the conservation and improvisation of these resources. Following the Charter by the International Society for Mangrove Ecosystems (Field 1995) would be a great step towards the conservation. Restoration and rehabilitation of mangrove plants should also be initiated, which are already being carried out in few of coastal countries, though restoration and natural regrowth are slow (Sherman et al. 2000). Countries like Papua New Guinea, Australia and Belize show no substantial change, and in few countries like Cuba, the restoration projects have helped to regain mangrove forests (Field 2000). But due to the lack of proper planting techniques and adequate site selection, there is a mixed outcome in most restoration and rehabilitation projects (Ellison and Farnsworth 2000).

The Indian Constitution Amendment (1976) states that *it shall be the duty of every citizen of India to protect and improve the natural environment including forests*, *lakes*, *rivers and wildlife*. To advise the Indian Government about mangrove conservation and development, a National Mangrove Committee under the Ministry of Environment and Forests was set up by the Government of India in 1976. The Environment (Protection) Act (1986) declares a Coastal Regulation Zone (CRZ) in which industrial and other activities such as discharge of untreated water and effluents, dumping of waste, land reclamation and bunding are restricted in order to protect the coastal environment. Mangroves are included in the most ecologically sensitive category of coastal stretches.

As most rehabilitation projects adopt the monoculture or low diversity polyculture with an emphasis on silviculture to produce timber, wood chips, charcoal and fuel wood, it is highly difficult to restore fauna and ecosystem function of mangrove forests (Ellison and Farnsworth 2000). Even then, if the hydrological and geomorphological conditions provided at optimal level and seedlings inoculated with bacteria that promote nitrogen fixation and plant growth (Holguin et al. 2001), the rehabilitated forests can reach the biomass, structure and productivity in a long period of 20–25 years (McKee and Faulkner 2000) and can reduce the loss of mangroves worldwide to a level reducing not more than an annual global loss rate of about 1 % (Kaly and Jones 1998). To reach high success in the rehabilitation, less destructive mud crab cultivation has been trailed in most regions of the world (Keenan and Blackshaw 1999). Till date high level of mangrove rehabilitation projects are successful only in Pakistan, Cuba and Bangladesh (Spalding et al. 1997) wherein an impressive attempt along the large portion of tropical coastline has been observed (Saenger and Siddiqi 1993). Though it is well known that the prohibition is not possible due to socio-economic problems, attempts have to be made in controlling the destruction of the juvenile prawns, and alternation for protection of

young prawns in the estuarine systems has to be considered as prawn fishery is mostly dependent on the emerging immature adults from the estuarine ecosystem.

Educating people by providing better vision on mangrove habitats, resources, relevant legislation, policies and conservation strategies by awareness campaigns along with magazines, films, posters, pamphlets, documentaries, exhibitions, study tours, incentives for protection of mangroves, etc. would help in successful restoration and rehabilitation of these ecosystems.

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