Biodivers Conserv (2012) 21:3523–3542
DOI 10.1007/s10531-012-0388-x

REVIEW PAPER

Mangrove conservation: a global perspective

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Received: 29 November 2011 / Accepted: 17 October 2012 / Published online: 27 October 2012

Abstract Mangroves are of great ecological importance and socio-economic significance as a hub for tropical marine biotope. The mangroves are also one of the world's richest storehouses of biological and genetic diversity. Furthermore, 90 % of the marine organisms spend part of their life in this ecosystem and 80 % of the global fish catches are dependent on mangroves. In addition, mangroves and their associated biota are identified as a promising source of natural and novel drugs. On the other hand, scientific community finds such an ecosystem as one among the world's most threatened biome due to human intervention in the long past and on-going climate change. Already many countries lost their huge mangrove wealth within the last two decades. Further, decline of the mangrove cover may cause an irreparable damage of ecosystem service to mankind. Now it is high time to conserve the precious ecosystem in order to maintain a stable and healthy coastal environment.

Keywords Mangroves · Aquaculture · Conservation · Medicinal values

Introduction

Mangroves are the salt-tolerant evergreen forests, found in the intertidal zones of sheltered shores, estuaries, tidal creeks, backwaters, lagoons, marshes and mudflats of the tropical and subtropical latitudes. Paradoxically, the mangroves exist under very hostile and inhospitable conditions. All the organisms living therein are well-adapted to encounter higher salinity,

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wind speed, temperature, muddy anaerobic soils and high tidal interference (Spalding et al. 1997; Spiers 1999; Kathiresan and Bingham 2001; Sandilyan 2010; Sandilyan et al. 2010a, b). In the due course of evolution, the mangrove plants have developed peculiar adaptations such as strong supporting, interlocking and breathing root system, viviparous mode of reproduction, salt regulation and nutrient retention (Kathiresan and Bingham 2001). Notably, mangroves are extraordinary ecosystems, providing many goods and services to humans particularly fisheries, forest products, pollution abatement and coastal protection against natural calamities. However, the need for mangrove conservation has been recently realized in the Asian countries only after the fiery effects of tsunamis and frequent cyclones. This review discusses the importance of mangroves and highlights the vital things to mankind to be lost in near future if mangroves diminish further.

Current status of mangroves

Mangroves are a rare forest type in the world, built by a small group of 73 species of trees and shrubs. Global mangroves have an estimated cover of 15.2 million hectares (0.4 % of all forest, <1 % of tropical forests) in 123 countries and territories (FAO 2007). They are most extensive in Asia (39 %) followed by Africa (21 %), North and Central America (15 %), South America (12.6 %) and Oceania (Australia, Papua New Guinea, New Zealand, south Pacific islands) (12.4 %). The mangroves are largely restricted to the tropics and few warm temperate regions at the latitudes between 30°N and 30°S. Mangroves grow better in wet equatorial climates than they do in seasonally monsoonal or arid climates. The growth and biomass production of mangroves decrease with increasing latitudes. The mangroves have greater abundance and diversity along wet coastlines and in deltas and estuarine areas (FAO 2007).

The mangrove system is continuously in jeopardy. In recent decades, this vital ecosystem has been facing threats due to reckless and ruthless human interventions and other natural calamities (Table 1). This constant interference in mangrove forests has made the system to shrink in an alarming way at a faster rate than inland tropical forests and coral reefs (Duke et al. 2007). The global mangroves disappeared at a rate of 0.66 % per year during 2000–2005 periods (FAO 2007). There was about 35 % of mangrove loss in the world from 1980 to 2000 (MA 2005). Several hectares of mangroves have been lost within two decades in Gabon, Sierra Leone, Guinea-Bissau and Senegal of Africa, Mexico, Panama, USA and Bahamas of North and Central America, Fiji, Northern Mariana Islands, Vanuatu and other Pacific islands of Oceania region (FAO 2007). To make matters worse, it is predicted that relative sea level rise can be the greatest threat to the existing mangroves (Gilman et al. 2008) and the mangrove forests are likely to be totally lost in the next 100 years, if the present situation continues further (Duke et al. 2007). The effects of mangrove loss are given in Fig. 1.

Need to conserve mangroves

Energy depletion, economic collapse or nuclear war is not the worst thing when compared to the habitat loss. Obviously the above said problems can be repaired within few generations. But, it will take millions of years to correct the loss of species and genetic diversity by destruction of natural habitats. For this, our descendants are least-likely to forgive us (Wilson 1988). It is worth to mention here that we are at the brink of losing some of the precious and key plant and animal genomes that may not return in the future (Malhotra 2010). Mangroves are one such system which stands dangerously close to extinction.

Table 1 Factors responsible for mangrove degradation and destruction

S. no.	Factors responsible	References
Natural factors		
1.	Cyclones	Nagarajan and Thiyagesan (1995), Thiyagesan and Nagarajan (1997), Kathiresan (2004), FAO (2007)
2.	Tsunami	Sandilyan (2009), Rajan et al. (2008), Sandilyan et al. (2010a, b)
3.	Disease	Hussain and Acharya (1994)
4	Pest and parasites	Kathiresan (2004)
Man made factors		
1.	War	Rosa (1974)
2.	Invasion of exotic species	Kathiresan (2004)
3.	Cattle grazing	Kathiresan (2002), Sandilyan (2009), Sandilyan et al. (2010a)
4.	Wood cutting	Rosa (1974)
5.	Over exploitation of fisheries resource	Rosa (1974); Selvam et al. (2002)
6.	Conversion of mangroves during urbanization, agriculture and aquaculture	Thiyagesan and Nagarajan (1995), Sandilyan et al. (2010a)
7.	Pollution	Vannucci (2001), Agorammoorthy et al. (2008)
8.	Oil spilling	Kathiresan (2004)
9.	Mining operation	Kathiresan (2004)
10.	Prevention of freshwater flow	Selvam et al. (2002)
11.	Sea level rise and global warming	Gilman et al. (2008), Sandilyan et al. (2010a, b)
12.	Increasing salinity	Sandilyan et al. (2010a, b)
13.	Changes in the chemical nature of the soil	Alongi et al. (2005)
14.	Poor nutrient load	Alongi et al. (2005)
15.	Ecotourism	Sandilyan et al. (2008, 2010a, b)

Mangroves are endowed with immense floral and faunal wealth. For instance, the Indian mangroves alone support 4,011 species (Table 2). But in recent decades, several countries have lost huge mangrove cover due to paucity of interest, knowledge and conservation policies which resulted in dwindling of mangrove diversity. For example, several animal species were already extinct from Sundarbans and 11 species of global mangrove plant species are at elevated level of extinction (Polidoro et al. 2010) (Tables 3, 4, 5). Moreover, loss of mangrove habitats has put at 16 % of mangrove plant species and 40 % of the animal species teetering at the edge of extinction in the world (Polidoro et al. 2010). In addition, some of the mangrove plant species are endemic to the region/continent (e.g. *Aegicera floridum*, *Camptostemon philippinensis*, *Heritiera globsa*). A few are confined to a particular region; for example, *Rhizophora annamalayana* is found only in Pichavaram mangroves of southern India and 171 individuals are left now in the wild (Kathiresan 1999).

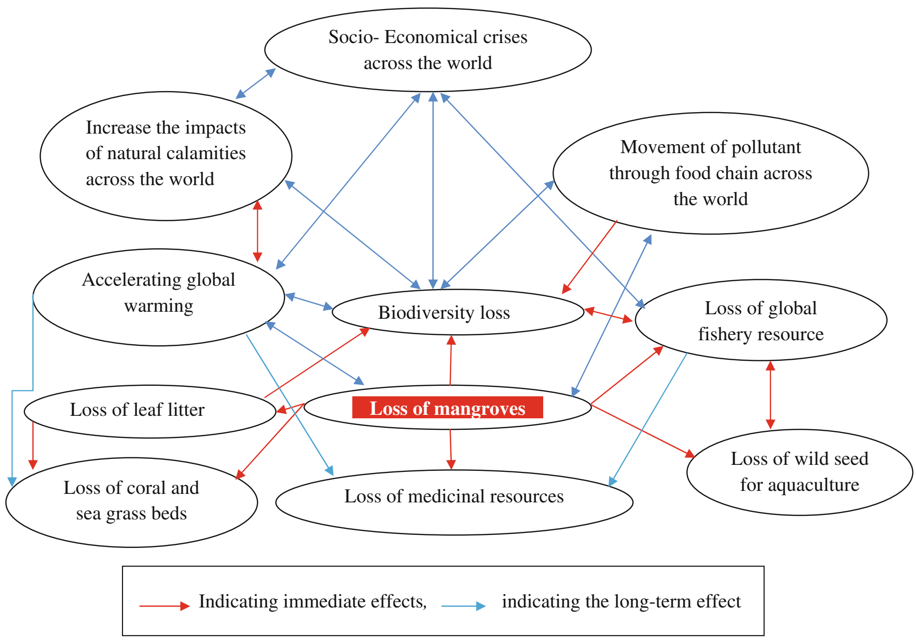

Fig. 1 Schematic diagram showing concomitant effects of mangrove loss

It is well established that a couple of trees or even a single tree can support other life forms efficiently (Ray and Ramachandra 2010). For an example, a disappearing tree can take with it some 10–30 dependent species including insects to higher animals and sometime even other plants too (Balaji 2010). Obviously, if we lose the unique mangrove flora, simultaneously we are losing other dependent species, exclusive soil texture, nutrients and other unknown or unexplored resources such as microorganisms of this ecosystem.

Importance of mangroves

The importance of mangroves for coastal community and humans has been well documented throughout the tropics (Table 6). In a broad sense, the importance of mangrove forest system can be assessed by ecological sustainability (e.g. sediment control, retaining pollutant, nutrient and organic matter cycling), environmental security (mitigating the effects of tsunami, cyclones, floods and green house gas), and economic prosperity (in supporting 80 % of the global fish catch and providing wild seeds for aquaculture industry) (Jennerrjahn and Ittekot 2002; Sandilyan 2007; Farley et al. 2010; Sandilyan and Thiyagesan 2010). The annual economic value of mangroves is estimated by the cost of the products as USD 200,000–900,000 ha^{-1} (Wells et al. 2006; Costanza et al. 1998). Moreover, the unique features such as habitat diversity and genetic diversity offered by the mangroves are immeasurable.

In general, every ecosystem provides life supporting functions as well as other valuable services, many of which are interlaced with human welfare (Farley et al. 2010). Mangroves are one such important system, but ironically the importance of mangrove wetlands began to be acknowledged by scientific community only after 1978. UNESCO's scientific

Table 2 Total number of flora and fauna species recorded from Indian mangroves

No.	Groups	No. of species
Flora		
1.	Mangroves	39
2.	Mangrove associates	86
3.	Sea grasses	11
4.	Marine algae	557
5.	Bacteria	69
6.	Fungi	103
7.	Actinomycetes	23
8.	Lichens	32
Fauna		
9.	Prawns and lobsters	55
10.	Crabs	138
11.	Insects	707
12.	Molluscs	305
13.	Other invertebrates	745
14.	Fish parasites	7
15.	Fin fish	543
16.	Amphibians	13
17.	Reptiles	84
18.	Birds	426
19.	Mammals	68
Total number of species		4,011

Source Kathiresan and Qasim (2005), Kathiresan (2008)

Table 3 Extinct species from world's largest mangroves Sundarbans due to mangrove degeneration

S. no.	Common name	Species name
Reptiles		
1.	Green turtle	*Chelonia mydas*
2.	Hawksbill turtle	*Eretmochelys imbricata*
3.	Loggerhead	*Caretta caretta*
4.	Leatherback sea turtle	*Dermochelys coriacea*
Birds		
5.	Lesser adjutant stork	*Leptoptilos javanicus*
6.	Knob-billed duck	*Sarkiodornis melantous*
7.	White-winged duck	*Cairina suctulata*
Mammals		
8.	Asian water buffalo	*Bubalis bubalis*
9.	Javan rhinoceros	*Rhinoceros sondaicus*
10.	Swamp deer	*Cervus deruchea*
11.	Hog deer	*Axis porcinus*
12.	Barking deer	*Muntiacus muntja*

Source Chaudhuri and Choudhury (1994)

committee on oceanic research established a working group on mangrove ecology during that period in order to assess the importance of the precious system (Tam and Wong 2002). Thereafter, mangrove is continuously under the research light.

Table 4 Critically endangered (CR) endangered (EN), near threatened (NT) and vulnerable (VU) flora species recorded across the global mangrove forests

S. no.	Species	IUCN status
1.	*Sonneratia griffithii*	CR
2.	*Bruguiera hainseii*	CR
3.	*Camptostemon philippinense*	EN
4.	*Heritiera fomes*	EN
5.	*H.* globosa	EN
6.	*Phoenix paludosa*	NT
7.	*S. ovate*	NT
8.	*Brownlowia tersa*	NT
9.	*Aegiceras floridum*	NT
10.	*A. rotundifolia*	NT
11.	*Ceriops decandra*	NT
12.	*Rhizophora samoensis*	NT
13.	*Avicennia bicolor*	VU
14.	*A. intega*	VU
15.	*A. rumphiana*	VU
16.	*Tabebuia palustris*	VU
17.	*Mora oleifera*	VU
18.	*Pelliciera rhizophorae*	VU

Source Polidoro et al. (2010)

The healthy mangrove ecosystem always provides immense benefits to the adjoining systems and mankind. For instance, mangroves and associated soils can sequester approximately 22.8 million metric tons of carbon each year i.e. 11 % of the total input of terrestrial carbon into ocean (Jennerrjahn and Ittekot 2002) and provide more than 10 % of essential organic carbon to the global oceans (Dittmar et al. 2006). Carbon sequestration potential of the mangroves is 50 times greater than many other tropical forests. This is because of high levels of below ground biomass and also considerable storage of organic carbon in mangrove sediment soils. Mangrove deforestation in the world generates emissions of 0.02–0.12 pg of carbon per year—as much as around 10 % of emissions from deforestation globally. Thus, failing to preserve mangrove forests may cause considerable carbon emissions and thus accelerate the global warming (Spalding et al. 2010; Donato et al. 2011). Therefore, mangrove restoration can be a novel and natural counter-measure for global warming.

Mangroves support unique biological diversity by providing vital habitats, spawning grounds, nurseries and nutrients for a number of aquatic and terrestrial animals. These include several endangered reptiles (e.g. crocodiles, iguanas and snakes), birds (herons, egrets, pelicans and eagles) and mammals [the Royal Bengal tiger (*Panthera tigris tigris*) deer, otters, manatees and dolphins] (FAO 2007). Moreover, the role of mangroves in the marine food web is very crucial (FAO 2007). Other important benefits are given in Table 6. Interestingly all the benefits provided by mangroves are in perpetuity with no depreciation or maintenance costs and continuously renewed by solar energy (Farley et al. 2010).

Mangroves—an aqua food basket

Mangroves are known for immense supply and diversity of shrimps, crabs, molluscs and fishes, and it is reported that many marine species spend part of their life in tropical mangroves and this habitat acts as a food basket for many marine and terrestrial organisms

Table 5 Critically endangered (CR) endangered (EN), near threatened (NT) and vulnerable (VU) fauna species recorded across the global mangroves

S. no.	Common name	Species name	IUCN status
Invertebrates			
1.	Giant land crab	*Cardisoma carnifex*	CR
2.	Giant mud clam	*Gelonia erosa*	EN
3.	Fiddler crab	*Uca tetragonon*	EN
4.	Sentinel ghost crab	*Macrophthalamus convexus*	EN
5.	Areolated xanthid crab	*Pilodius nigrocrinitus*	EN
6.	Striped prawn	*Penaeus canaliculatus*	VU
7.	Banded shrimp	*P. japonicus*	VU
Amphibian			
1.	Mangrove frog	*Eleutherodactylus carib*	CR
Reptiles			
1.	Mangrove terrapin	*Malaclemys terrapin*	NT
2.	Water monitor	*Varanus salvator*	NT
3.	Mangrove monitor	*V. indicus*	NT
4.	Little file snake	*Acrochordus granulatus*	NT
5.	Mangrove snake	*Boiga dendrophila*	NT
6.	Yellow-banded water snake	*Cantoria violacea*	NT
7.	Dog-faced water snake	*Cerberus rynchops*	NT
8.	Australian bock dam	*C. australis*	NT
9.	Crab-eating snake	*Fordonia leucobalin*	NT
10.	Glossy marsh snake	*Gerarda prevostiana*	NT
11.	Red-tailed green rat snake	*Gonyosoma oxycephala*	NT
12.	Richardson's mangrove snake	*Myron richardsonii*	NT
Birds			
1.	Saphire-bellied hummingbird	*Lepidopyga lilliae*	CR
2.	Mangrove finch	*Camarhynchus heliobates*	CR
3.	Mangrove hummingbird	*Amazilia boucardi*	EN
4.	Madagascar teal	*Anas bernieri*	EN
5.	Plain-flanked rail	*Rallus wetmorei*	EN
6.	Ruddy kingfisher	*Todiramphus coromanda*	NT
7.	Mangrove pitta	*Pitta megarhyncha*	NT
8.	Asian dowitcher	*Limnodromus semipalmatus*	NT
9.	Lesser flamingo	*Phoenicopterus minor*	NT
10.	Little green heron	*Butorides striatus*	NT
11.	Painted stork	*Mycteria leucocephalus*	NT
12.	Darter	*Anhingan melanogastar*	NT
Mammals			
1.	Pygmy three-toed sloth	*Bradypus pygmaeus*	CR
2.	Garrido's hutia	*Mysateles garridoi*	CR
3.	Cabrera's hutia	*Mesocapromys angelcabrerai*	CR
4.	Proboscis monkey	*Nasalis larvatus*	EN
5.	Royal Bengal tiger	*Panthera tigris*	EN

Table 5 continued

S. no.	Common name	Species name	IUCN status
6.	Short-beaked common dolphins	*Delphinus delphis*	EN
7.	Common bottlenose dolphin	*Tursiop truncatus*	EN

Source Sandilyan (2007), Kathiresan (2008), Luther and Greenberg (2009)

including humans (Sasekumar et al. 1992; Adeel and Pomeroy 2002). Mangroves are identified as a primary nursery area for commercially important fish and shrimp species (WRI and IUCN 1986; Laegdsgaard and Johnson 2001; Ramsar Secretariat 2001; Selvam et al. 2002; Mumby et al. 2004). Globally, 80 % of the fish catches are directly or indirectly dependent on mangroves (Sullivan 2005; Ellison 2008). To support this, Selvam et al. (2002) have reported that the fishermen folk of Pichavaram mangroves of Southern India alone harvest 208 tones of prawn, 19 tones of fish and 9 tones of crab annually. Likewise, the mangroves of Moreton Bay, Australia have been valued in 1988 at USD 4,850 ha^{-1} based only on the catch of marketable fish (Ramsar Secretariat 2001). A study on the effect of mangroves on fisheries income has revealed that a mangrove-rich area provides higher catch of fishes and yields higher fisheries income (about 70 times) than a mangrove-sparse area does (Kathiresan and Rajendran 2002). Thus, value of maintaining mangroves is significant to ensure fishery resources and to support coastal economy.

A positive correlation has been well documented between near shore yields of fish, and shrimp in mangrove area of Malaysia (Macnae 1974), Indonesia (Martosubroto and Naamin 1977), Philippines (Camacho and Bagarinao 1986) and India (Selvam et al. 2002; Kathiresan and Rajendran 2002). Similarly a high proportion of fish catch has been recorded in mangrove areas: 80 % fish catch in Florida, 67 % Eastern Australia, 60 % Fiji, and 49 % in Malacca (Ronnback 1999). Furthermore, it is well established that the coastal aquaculture (fish, shrimp, and prawn) depends heavily on ecosystem services provided by healthy mangroves (Kautsky et al. 2000). The loss of mangroves is known to decline the fish resources. For an example, Ecuador, a global leader in shrimp production during 1980 s witnessed its industry collapsed in the 1990s after the indiscriminate mangrove clearing (Park and Bonifaz 1994) and also in the subsequent years the aqua ponds affected by frequent disease out-break, which led to deplete post larval shrimps used from mangrove waters for stocking in ponds (Kautsky et al. 2000). Above and beyond, mangrove ecosystem produces more aqua food than that of the man-made aqua farms. For an example, aquaculture ponds of 3–9 years old generate $ 1,300–30,000 ha^{-1} $year^{-1}$, while the intact mangroves generate $ 5,000–41,000 ha^{-1} $year^{-1}$ worth of goods and services (Farley et al. 2010).

Besides, mangroves assure the healthy fisheries by capturing and immobilizing the pollutants. In addition, water run off and waste emission from aquaculture are absorbed and thus protecting coral reefs, sea grass beds and other fragile marine fish feeding habitats (Gilbert and Janssen 1998; Tam and Wong 1999; Kathiresan and Qasim 2005). Hence, sustainable and strong global marine fisheries are highly dependent upon the health of tropical mangroves, and if we are failing to conserve this valuable ecosystem, an unprecedented and irreversible disaster to the fishery industry will be witnessed in the near future. For example, largest herbivorous fish of Atlantic (*Scarus guacamaia*) extinct from the wild due to mangrove destruction (Mumby et al. 2004).

Table 6 Goods and services provided by healthy mangroves

Benefits from mangroves	Source
Ecological benefits	
By absorbing more CO, CO_2 and SO_2 reduce the impact of global warming. Increase O_2 level	Ong (1993), Jennerrjahn and Ittekot (2002)
Regulate the regional climate by cloud formation, controlling over evaporation and transport the stored heat energy to the adjoining regions. And maintain a unique microclimate	Farley et al. (2010)
Sequester the pollutants and absorb pollutant from the land including industrial waste agriculture and aqua culture runoffs and other heavy metals and act as sink of pollutants.	Vannucci (2001), Balasubramanian and Vijayalakshmi (2004), Agorammoorthy et al. (2008), Farley et al. (2010)
Hydrological cycle, nutrient cycle and provides large amount of nutrient. For instance the Pichavaram mangroves of southern India alone produce 7457.07 tones of leaf litter per year. It is the only marginal ecosystem which interacts intensely with neighboring systems by the way of supplying large amount of nutrient and help for nutrient cycling.	Gilbert and Janssen (1998)Vannucci (2001), Balasubramanian and Vijayalakshmi (2004)
Inhibit the speed of cyclone and tsunami and minimize the damage caused by the natural disaster. Protect and stabilize coastal zone against the erosive force of marine current. Reduce the impacts of flooding on adjacent marine associated ecosystems such as sea grass beds and coral reefs	Sandilyan (2007), Sandilyan and Thiyagesan (2010), Farley et al. (2010)
Biodiversity values	
Support several globally threatened species including Royal Bengal Tiger (*Panthera tigris*). Most of the plant species are endemic to this ecosystem. It is rich in biodiversity. In a wide spectrum, Indian mangroves alone harbor 4011 biological species including several migratory waterbirds and fishes	Nagarajan and Thiyagesan (1996, 1998), Vannucci (2001), Sandilyan (2007), Kathiresan (2008)
Protect the adjoining important and fragile ecosystems such as sea grass bed, coral reef from natural calamities and supplying nutrients and ensure the diversity	Gilbert and Janssen (1998), Tam and Wong (1999)
Aqua food values	
Support and supply a huge amount of crab, prawn, and fish. Globally 80 % of the fish catches are directly or indirectly dependent on mangroves. Moreover it the vital nursery ground for several marine shrimps, crabs and fishes. Totally 90 % of all marine organisms spend some portion of their life cycle within the mangrove ecosystem. Providing wild seeds for aqua culture industry. Produce more green mussels and oyster. Green mussels have more economic and medicinal values.	Sasekumar et al. (1992), Adeel and Pomeroy (2002), Selvam et al. (2002), Nagarajan and Thiyagesan (2006), The Hindu (2010), Farley et al. (2010)
Medicinal values	
Mangrove plants have been widely used as medicine to control diarrhoea, blood pressure, asthma, leprosy, rheumatism, snake bites, ulcers and other bacterial and viral infections	Kannupandi and Kannan (1998), Agorammoorthy et al. (2008), Sandilyan and Thiyagesan (2010)

Table 6 continued

Benefits from mangroves	Source
Recently drug research groups pointed out that mangrove possess an untapped source of new medicine and in future mangrove ecosystem will be the new frontiers for drug discoveries	Regunathan and Kitto 2009
Mangrove wetland supports unique fungi/microbes which are source of large number of antibiotics, enzymes, hormones, vitamins	Sharma (2009)
Plants and wood values	
Provide raw materials for constructions of house, boat, jetty, charcoal, fire wood, dyes, glue and fodder and poles for fish traps, roots and stems of *Derris trifoliata* used to narcotizing fishes. And also provide edible items such as fruits, honey, sugar, vinegar and alcohol,	Sandilyan (2007), Farley et al. (2010)
Aesthetic and recreation values	
Have aesthetic, artistic, educational, spiritual, and scientific and heritage values	Farley et al. (2010)
Act as good recreation centers, (boating, bird watching and fishing)	Farley et al. (2010

Protect the shore from natural calamities

The tropical coastal areas are affected by frequent cyclones almost in every alternate year (Muniyandi 1986; Dash et al. 2007; Balaram 2009). Besides, evidence suggests that human induced global warming has steadily increased the intensity and the frequency of cyclones and storms (Webster et al. 2005; MA 2005). It is needless to state that these kinds of tropical storms cause severe damage to the coastal and adjoining biodiversity and other economical resources.

Mangroves act as a natural fortress of the coast against wind, waves, water currents and other natural calamities. A number of studies in different parts of the tropical regions elucidate the ability of mangroves to mitigate the effects of cyclones, typhoons and tidal waves (Hensel and Proffitt 2002; EJF 2004; Kathiresan and Rajendran 2005; Kerr and Baird 2007; Sandilyan 2009). In October 1999, Orissa state in India was battered by a 'super' cyclone that killed almost 10,000 people and caused heavy loss of livestock and property. Had the mangrove forests been intact, more than 90 % of the human deaths due to the cyclone would have been avoided. The protection value of one hectare of intact mangroves in Orissa was estimated about USD 8,700. At the time, one hectare of cleared land was fetching only USD 5,000. Thus, protecting mangroves as storm breakers generates more economic value (Das and Vincent 2009). Furthermore, it was reported that the replacement of mangroves with shrimp farms had significantly exacerbated the impact of the cyclone and as a result it had cost many lives in the Orissa coast (Pearce 1999).

Similarly, the role of mangroves in coastal protection against the 26 December 2004 tsunami was remarkable. Mangroves mitigated the deleterious impact of the tsunami waves and protected the shoreline in southeast India (Kathiresan and Rajendran 2005; Sandilyan 2007, 2009). The dense growth of mangroves in Sundarbans saved the West Bengal in India and Bangladesh from the killer impact of the tsunami. An analytical model shows that 30 trees in 10 square meter areas in a 100-metre wide belt may reduce the maximum tsunami flow pressure by more than 90 %, if the wave height is less than 4–5 m. Therefore, conserving or restoring mangroves will save the coast from future events of natural disasters (Hiraishi and Harada 2003). Mangroves also enhance fisheries and forestry productions. These benefits cannot be expected with concrete seawalls, constructed for coastal protection.

Obviously continuous exploitation of mangroves transforms the coastal zone to highly vulnerable one. It is a bitter fact that people who are living near coastal zones are highly prone to cyclone and storms which have been causing all and sundry damages. Nearly half of the world population (44 %) living within 50 km of the coastline (Cohen et al. 1997) and globally several metro cities are situated near/on the coast and every year the population increases in the metros. It merits to state here that the sea level rise along the Asian coastline may increase the frequency of cyclones, which can result in large number of immigrants especially to India (Balaram 2009). Globally these kinds of frequent cyclones will produce more climate refugees, which may affect and alter socio-economical, cultural, aesthetic and ethnic values of any country and finally lead to civil wars.

Stable coastal systems

Healthy mangroves are a depository of heavy metals and other pollutants. By nature the mangrove flora and their soil have the amazing ability to accumulate and immobilize heavy metals, which enter into the system through runoff and industrial effluents (Vannucci 2001).

In recent times, several benchmark studies have disclosed that global mangroves are alarmingly polluted with high concentration of dangerous heavy metals including mercury (Hg), lead (Pb), tin (Sn) and cobalt (Co) due to high industrialization in and around the coastal areas (MacFarlane and Burchett 2000; Sarangi et al. 2002; Agorammoorthy et al. 2008; Rajan et al. 2008; Zhou et al. 2010). Ironically, there is an acute lack of systematic studies in several topical mangrove wetlands related to monitoring and controlling of heavy metal pollution (Agorammoorthy et al. 2008).

As stated earlier the healthy mangroves act as a heavy metal sink, on the other hand diminishing mangroves may act as a source of heavy metal. The stored/deposited heavy metals enter into the biological system through food chain, which will affect the central nervous system, kidneys and circulatory systems of all higher organisms including humans. Moreover, the adjoining vital and fragile coastal systems such as coral reefs, seagrass meadows and seaweed beds becomes highly polluted by the heavy metals, which are released from the diminishing mangroves. Several studies have disclosed the way by which the heavy metals affect the floral and faunal diversity (Herrick and Friedland 1990). Obviously the entry of metals to the adjoining systems may alter the natural state and lead to an imbalance in the coastal ecosystems. So, it is vital to maintain healthy mangroves in order to ensure stable ecosystems in tropical countries.

Medicinal values

The emergence of diseases has quadrupled over the past 50 years. Outbreaks of Ebola, meningitis, SARS, bird flu and swine flu have proved that we are defenseless and highly prone to new pathogens. Human diseases such as cancer, AIDS, Alzheimer etc., have made doctors desperately to seek out for new drugs (Regunathan and Kitto 2009). Drug hunters need to look into new areas especially that are away from terrestrial resources. Ultimately coastal ecosystems such as mangroves are as a potential site for new drugs (Regunathan and Kitto 2009). World Health Organization (WHO) has listed out 20,000 medicinal plants to be present globally (Gupta and Chadha 1995).

Over 80 % of the population in the developing countries depends directly on the medicinal plants for their medication (Mukhopadhyay 1998). For instance, over 2,000 different kinds of drugs from plants are used in India to cure different diseases (Dikshit 1999). Mangrove plants are traditionally used to cure diseases: diarrhoea by *B. gymnorrhiza*; blood pressure by *R. mucronata*; asthma, leprosy and rheumatism by *Acanthus ilicifolius*; snake bites by *Arthrocnemum indicum*; ulcers, bacterial and viral infections by *Sesuvium portulacastrum*. To arrest hemorrhage the fermented juice of *Sonneratia caseolaris* is used and its half-ripe fruit is used to treat cough (Perry 1980; Agorammoorthy et al. 2008; Sandilyan and Thiyagesan 2010). Drug research groups have pointed out that mangrove possess an untapped source of new medicines and in future this ecosystem will be the new frontiers for drug discoveries (Regunathan and Kitto 2009). Fortunately mangroves are blessed with rich diversity of microorganisms of potential medicinal value (Tables 2, 7) particularly fungi which are the sources of large number of antibiotics, enzymes, hormones and vitamins (Sharma 2009).

Biodiversity values

Mangroves are known for their floral and faunal wealth (e.g. Indian mangrove ecosystem alone supports a total of 4,011 species; Table 2). However, there is a lack of full inventory of species found in mangroves. The highest numbers recorded from mangrove habitats of

Table 7 Diversity of mangrove fungi recorded in some important mangroves

S. no.	Country	Number of species
1.	Singapore	41
2.	Belize	46
3.	Philippines	57
4.	Seychelles	63
5.	Malaysia	82
6.	Brunei	95
7.	India	102
8.	Hong Kong	128
9.	Thailand	154

Source Martin et al. (2011), Kathiresan 2008

individual sites or countries are 11 shipworms in Malaysia, 29 bivalves in Atlantic Colombia, 32 copepods in India, 39 gastropod molluscs in Australia, 102 herbivorous insects in Singapore, 107 nematodes in Malaysia, 147 species of sponges in Caribbean, 184 birds in Queensland, Australia and at least 600 species of fish in Indo-West Pacific (Spalding et al. 2010).

Mangrove habitats, especially Australia, Asia and Caribbean regions support more endemic species (Luther and Greenberg 2009). Moreover, in global conservation perspective, mangrove ecosystems support several floral and faunal species of increasing threat of extinction (Tables 4, 5) and also a number of species have been already extinct due to loss of mangrove habitat (Table 3). Ironically mangrove habitats are listed among the world's most threatened biomes (Field 1998; Spalding et al. 2010). Inter alia several studies have emphasized that species, genetic and habitat diversity of mangroves are not properly studied across the world. In fact, the mangroves are in association with one or more of ecosystems such as mudflats, salt marshes, salt pans, freshwater palm forests, flooded forests, seagrasses and coral reefs in offshore waters. This interconnectivity increases the exchange of nutrients and movement of species and also biodiversity of the mangrove ecosystems.

Bacteria

Being detritus based system, fertility of mangrove habitats are highly dependent on bacteria, which play a significant role in the ecological process and they play an important role in controlling the chemical environments of mangroves even though they are the least studied group (Sherman et al. 1998; Purushothaman and Jayalakshmi 2004).

Algae

Algae do play an important role in productivity and better functioning of mangroves. On the other hand, the overall productivity by the algae is low in estuarine mangroves due to turbidity, salinity fluctuations and low light intensity (Robertson and Blaber 1992; Alongi 1994). Apart from that some of the mangrove algae have potential commercial value (e.g. *Gracilaria changii*) (FAO 2003).

Fungi

Fungi in the mangroves are called as manglicolous fungi. These saprophytes are essential for decomposition and energy flow in the mangrove habitats (Hyde and Lee 1995;

Kathiresan and Bingham 2001). In general, fungi predominantly colonize leaf litter and dead woods of mangroves. Hyde (1990) have recorded 120 species of fungi from 29 mangrove forests around the world and reported 87 Ascomycetes, 31 Deuteromycetes and 2 Basidiomycetes. However, the diversity of fungi in mangroves varies with regions, micro habitats and physical requirements (Kathiresan and Bingham 2001) (Table 7).

Invertebrates

Interestingly mangroves support a variety of epibenthic, infaunal, and meiofaunal invertebrates. The common benthic invertebrates include ciliate protozoans, foraminiferans, hydrozoans, archiannelids, kinorhynchs, amphipods, cumaceans brachyuran crabs, hermit crabs gastropods, bivalves, barnacles, sponges, tunicates, polychaetes, sipunculids, turbellarian flatworms and nematodes. For instance small patch of mangrove forest in the Puducherry coast of India supports a total of 76 invertebrate species includes molluscs (16 bivalves and 21 gastropods), crustaceans (22), amphipods (7), polychaetes (6), barnacles (3) and oligochaetes (1) (Satheeshkumar et al. 2012). Molluscs are generally numerous in the mangroves. Crabs and prawns are among the other dominant animals in many mangrove areas.

Mangrove invertebrates often show marked zonation patterns, and colonize a variety of specific micro-habitats within the mangroves (e.g. sediment surface/burrows, pneumatophores/prop-roots, tree trunks, decaying wood, canopies) (Sasekumar 1974; Ashton 1999). Predominately, mangrove roots, trunks and branches attract rich epifaunal communities including sponges, hydroids, anemones, polychaetes, bivalves, barnacles, bryozoans and ascidians (Farnsworth and Ellison 1996).

On the other hand, a number of studies revealed the sediment character as the key factor for the composition of the invertebrates in mangrove habitats (Kathiresan and Bingham 2001). Mangrove sediments usually support higher densities of benthic organisms than do adjacent non-vegetated sediments (Edgar 1990; Sheridan 1997; Sasekumar and Chong 1998; Sandilyan 2009). For instance, a study by Sheridan (1997) has recorded 22,591–52,914 individuals in m^{-2} with higher counts of annelids (31,388 m^{-2}) and tanaids (35,127 m^{-2}).

Fish

Fish are abundant in terms of numbers and diversity with an estimated 600 species recorded from Indo West Pacific mangroves. The mangroves are reportedly an ideal habitat for several fish species by providing diverse habitat, food and shelter. For example, Caribbean mangroves are reported to be an important shelter for fish that forage on adjacent seagrass and coral reef habitats. Mangroves also play an important role in supporting offshore fish communities (Mumby et al. 2004).

Amphibians and reptiles

Amphibian diversity is very poor in mangroves when compared to other chordate classes. Mangrove frog *Eleutherodactylus caribe* in Haiti (Luther and Greenberg 2009) and Crab eating frog widely found in South–East Asian mangroves are the two species reported till date. But commendable reptiles are reported from mangroves including aquatic and terrestrial. The estuarine crocodiles are found from India to Fiji. The mangrove terrapin is observed from Central and South–East Asia and the painted terrapin from the Sundarbans.

The suborder ophidian represents more species. The cat snake of Australia is typical of mangrove habitats. In addition, little file snake *Acrochordus granulatus*, mangrove snake *Boiga dendrophila*, yellow-banded water snake *Cantoria violacea*, crab eating snake *Fordonia leucobalin* and mangrove pit-viper *Ttrimeresurus purpureomaculatus* are the other common snake species reported from mangroves (Luther and Greenberg 2009).

Birds and mammals

Birds are the dominant terrestrial vertebrates in the mangrove biotope. In general the mangrove provides a good habitat for large number of bird species for nesting feeding and resting (Sandilyan 2009, 2011; Sandilyan et al. 2010a). Especially, globally decline water birds heavily depend on tropical mangroves (Sandilyan 2009). For instance, India mangroves alone support 17 different threatened category water birds (Table 8). On the other hand, a detailed account on scientific report of water birds associated with mangroves is globally scanty till date. For instance the detail account on water bird diversity in Pichavaram mangroves is only cursorily known even though it has more than 100 years of natural history (Sandilyan 2009, 2011).

Several mammals are permanently resides in mangrove forests. The best examples are the proboscis monkey, Royal Bengal tiger, spotted and barking deer, fruit bats and the aquatic mammals such as manatees, dugongs and dolphins are often found in mangroves. Apart from that mangroves support huge populations of livestock such as goats, buffalos and camels. Thus, conservation of mangroves for better habitat quality and biodiversity is always needed (Tam and Wong 2002; Duke et al. 2007; Sandilyan 2009; Sandilyan and Thiyagesan 2010). If the destruction continues, the mangrove forests may be reduced to

Table 8 List of endangered (EN), near threatened (NT) and vulnerable (VU) water birds dependent on the Indian mangroves

S. no.	Common name	Species name	Birdlife International (2007)
1.	Spotted greenshank	*Tringa guttifer*	EN
2.	Great adjutant	*Leptoptilos dubibus*	EN
3.	Painted stork	*Mycteria leucocephala*	NT
4.	Black-headed ibis	*Threskiornis melanocephalus*	NT
5.	Black-necked stork	*Ephippiorhynchus asiaticus*	NT
6.	Indian darter	*Anhinga melanogaster*	NT
7.	Black-tailed godwit	*Limosa limosa*	NT
8.	Black-bellied tern	*Sterna acuticauda*	NT
9.	Little green heron	*Butorides striatus*	NT
10.	Lesser flamingo	*Phoenicopterus minor*	NT
11.	Asian dowitcher	*Limnodromus semipalmatus*	NT
12.	Eastern curlew	*Numenius madagascariensis*	NT
13.	Ferruginous pochard	*Aythya nyroca*	NT
14.	Indian skimmer	*Rynchops albicollis*	VU
15.	Spot-billed pelican	*Pelecanus philippensis*	VU
16.	Lesser adjutant	*Leptoptilos javanicus*	VU
17.	Baer's pochard	*Aythya baeri*	VU

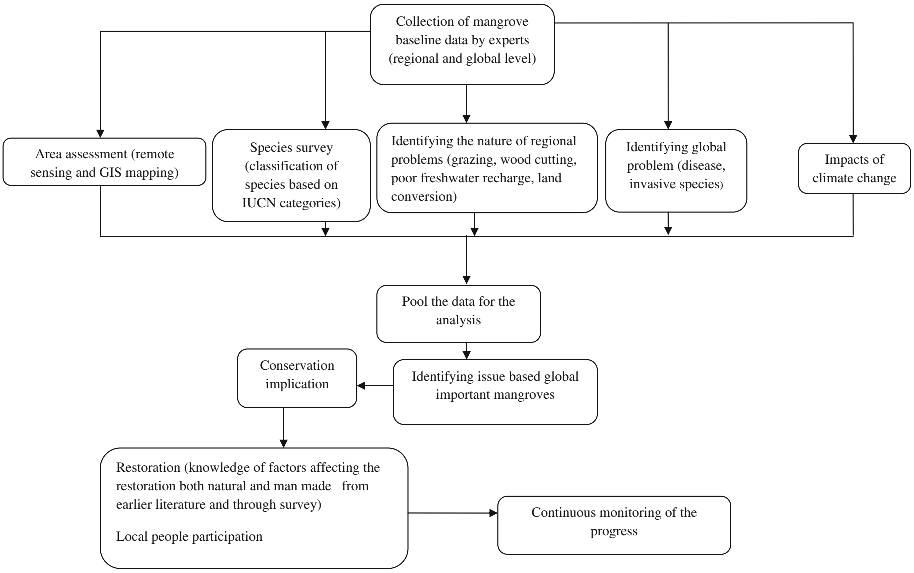

Fig. 2 Implementation of conservation strategies for global mangrove conservation

relic patches too small to support the diversity of organisms that depend on them (Luther and Greenberg 2009). Naturally, loss of mangrove leads to grim feature to the coastal and human community (Fig. 1).

Conclusion

The mangrove ecosystem is as a vital hub of marine environment due to nutrient fluxes, productivity and biodiversity of organisms. It protects the coastal zone from natural disasters, ensures pollution abatement and it operates recycling of nutrients. The values of mangroves in providing the forestry and fisheries products to sustain the coastal livelihood and economy are significant. However, pressures of development including urbanization and industrialization without sufficient enforcement of the legislation have resulted in destruction of mangroves in many places. Hence, there is a vital need to conserve the momentous ecosystem for the global well being, otherwise, the ecosystem services and other benefits offered by mangrove will be diminished or lost forever (Duke et al. 2007). A cleared mangrove forest had failed to recover even after six decades of abandonment, perhaps due to changed hydrodynamics, salinity, and acidity and low nutrient levels (Farley et al. 2010). Moreover, the mangrove restoration has brought out with successful results and also nakedly failed to restore other associated species (FAO 1994; Ellison 2000; Alongi 2002; Walters 2003). It is matter of necessity to draft a workable model of managing the mangrove ecosystems for fisheries resource development, biodiversity enrichment and coastal protection through integrated coastal zone management with participatory approach (Fig. 2). It is concluded with the statement of Vannucci (2001) “Handle with care: mangroves are indeed very special”.

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