Chapter 13
Conservation and Management of Mangrove Ecosystem in Diverse Perspectives

E. S. Bindiya, P. M. Sreekanth, and Sarita G. Bhat

Abstract The mangrove ecosystem is a dynamic hub of the oceanic environment due to nutrient fluidities, yield, and biodiversity of organisms. It guards the seaside zone against natural catastrophes, confirms pollution reduction, and functions by recycling nutrients. The value of mangroves in providing the forestry and fisheries products to meet the shoreline livelihood and economy is significant. Mangroves are of great ecological significance and socioeconomic implication as a core tropical marine habitat. The mangroves are also one of the world's richest granaries of biological and genetic diversity. They support complex communities where thousands of other species interact, from bacteria to human beings. They provide a valuable nursery habitat for fish and crustaceans, a food source for other faunas. Anthropogenic pressures, development pressures including urbanization and industrialization, and rapid environmental changes have turned tropical and subtropical mangrove forests into one of the Earth's most-threatened ecosystems, causing worldwide loss of coastal livelihoods and ecosystem services. The scientific community finds such an ecosystem as one among the world's most-threatened biomes due to human intervention in the long past and on-going climate change. Many countries have already lost their huge mangrove wealth within the last two decades. Further, the decline of the mangrove cover may cause irreparable damage to the ecosystem to the service of mankind. Now is the time to conserve the precious ecosystem for overall well-being based on in situ or ex situ conservation methods preferable to each species; else, the ecosystem services and other benefits offered by mangroves will be diminished or lost forever.

Keywords Mangrove forests · Geographical distribution · Diversity · Genomic conservation · In situ conservation · Ex situ conservation

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S. T. Sukumaran, K. T R (eds.), *Conservation and Sustainable Utilization of Bioresources*, Sustainable Development and Biodiversity 30,
https://doi.org/10.1007/978-981-19-5841-0_13

13.1 Introduction

Mangroves are a group of trees and shrubs which are derived from more than one ancestral stock. Mangroves exhibit different kinds of morphological and physiological adaptations to their habitat, which include tolerance of high salinity, deviating desiccation and saturation of soils across tidal cycles, and exposure of roots to hypoxic, sulfide-rich soils (Friis et al. 2020).

The origin of the word mangrove was well explained by Vanucci (1989). It is said that the word mangrove was derived from West Africa, Senegal, Gambia and Guinea in the fifteenth century. The Portuguese spread these words throughout the world and was later converted into “mangle” and “manglar” by the Spaniards. The English word mangrove is a combination of the Portuguese and Spanish, which means grove made of mangue (Macintosh and Ashton 2002).

Worldwide, natural resources fall under various levels of management and ownership, ranging from private to government ownership (Berkes 2004). Because of the recognized importance of mangroves and the continuing threats to their persistence, actions have been taken internationally for the conservation and sustainable use of wetlands. Protective authorities include the United Nations Forum on Forests (UNFF), Convention on International Trade in Endangered Species, Species of Wild Fauna and Flora (CITES), Convention on Biological Diversity (CBD), United Nations Framework Convention on Climate Change (UNFCCC), Convention on Wetlands of International Importance especially as Waterfowl Habitat (Ramsar Convention), Convention for the Protection of World Cultural and Natural Heritage, and the Convention on the Conservation of Migratory Species of Wild Animals. These agreements have resulted in the protection of large areas of mangrove forests globally. In addition to conservation agreements at the international level, efforts by individual nations to protect or restore these forests have varied from mandated protection by governments to locally initiated efforts. Human use of those resources varies depending on the level of protection. Overall, the global decline of mangroves has slowed, but additional actions need to be taken to ensure their long-term survival (Alongi 2002).

Successful management, conservation, and restoration require the commitment of local, state, and national level government as well as local communities. As patterns of human settlement around the world continue, people are increasingly distanced from nature and therefore may be less concerned about nature conservation (Miller 2005; Zaradic et al. 2009). Additionally, as with many conservation programs, benefits from mangroves might be indirect or poorly understood by local residents, or they may perceive that they are being excluded from access to previously utilized resources (Shackelton et al. 2002).

13.2 Geographical Distribution

Mangroves are usually seen distributed between the Tropic of Cancer and the Tropic of Capricorn on all continents. The biogeographic patterns indicate that a higher species richness is observed in the tropics (especially in Asia) and lower in temperate regions (Koch 1998). Mammals and amphibians follow a similar pattern of highest diversity in the tropics (Wiens et al. 2006; Schreier et al. 2009), and this pattern extends to mangrove forests. They occupy less than 1% of the world's surface and mainly cover an estimated 75% of the tropical coastline worldwide within 123 countries. These forests of the tide collectively make up less than 1% of all tropical forests and less than 0.4% of the total global forest estate.

The first attempt at estimating the total mangrove area in the world was undertaken as part of the Food and Agriculture Organization of United Nations (FAO/UNEP) Tropical Forest Resources Assessment in 1980, where the world total was estimated as 15.6 million hectares. More recent estimates in 2020 are up to 14.8 million hectares. According to the assessment, the most extensive area of mangroves is found in Asia (5.55 million ha—38% of total mangroves), followed by Africa, North and Central America, South America, and Oceania. Mangrove areas were absent in Europe. Indonesia, Brazil, Nigeria, and Australia account for 60% of the total mangrove area found in just ten countries and about 41% of all mangroves. Figure 13.1 represents the region-wise distribution of mangrove forests as per FAO (2020).

13.2.1 Asia

The subregional distribution of mangrove forests is divided into East Asia, South and Southeast Asia, and Western and Central Asia. The major area of mangrove forest is distributed in South and southeast Asia (5.3 million Ha), which includes

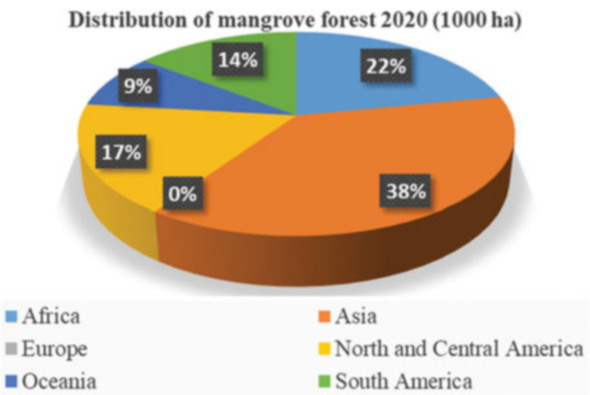

Fig. 13.1 The region-wise distribution of mangrove forests as per FAO 2020

Nepal, Bangladesh, India, Sri Lanka, Pakistan, Myanmar, Vietnam, Thailand, Indonesia, Philippines, Singapore, and Malaysia, which accounts for the majority of mangrove forests.

The total mangrove area in Malaysia is estimated to be approximately 575,000 Ha, of which 60% is found in Sabah, 23% in Sarawak, and the remaining 17% in the Peninsula (Eco-Business 2013) of which 77.8% is considered productive. According to Eco-Business, the vegetated mangrove area in Indonesia is estimated to be 3.5 million Ha. In South Asia alone, the aerial extent of mangrove forests is approximately 1,187,476 Ha, representing ~7% of the global total.

Mangroves in Sri Lanka are restricted to estuaries along the coasts, the extent of which ranges from 15,670 Ha (Edirisinghe et al. 2012). The Puttalam Lagoon–Dutch Bay, Portugal Bay complex, Batticaloa, and Trincomalee are the sites of the largest mangrove patches of Sri Lanka. In Pakistan, approximately 95% (~600,000 hectares) of mangroves are located in the Indus Deltaic swamps of the Sindh Province along the Arabian Sea coastline with Sandspit, Sonmiani (Miani Hor), Kalmat Khor, and Jiwani (Gwadar) as other major areas of distribution and are considered the largest dry-climate mangroves in the world. The total mangrove forest area along the Pakistan coastal line is 86727.86 Ha based on the SPOTXS data (2003).

India has 0.45 million Ha of mangrove. In India, mangroves are found in the States of West Bengal, Orissa, Andhra Pradesh, Tamil Nadu, Andaman and Nicobar Islands, Kerala, Goa, Maharashtra, Karnataka, and Gujarat. Sundarbans in the Gangetic delta of West Bengal is the largest mangrove region in the world and have the largest coverage of mangroves, around 212 million Ha, which consist of 26 plant species. The mangroves cover in Gujarat is about 104,400 Ha (Pandey and Hirose 2013). Pichavram in Tamil Nadu is the second-largest mangrove forest with an area of 1100 Ha, consisting of 12 species (Sundararaju 2019). In Kerala, mangroves are distributed in ten Districts. Among them, Kannur has the highest area of mangrove coverage, up to 755 Ha. Kozhikode and Ernakulam are in second and third positions with coverage of 293 Ha and 260 Ha of mangrove spreads, respectively (Muraleedharan et al. 2009).

The largest continuous mangrove forest in the world, Sundarbans, is located on the border of Bangladesh and India. Mangroves in Bangladesh are located in the Sundarbans, the Chittagong region in the southeast, and the Madhupur tracts in the north-central region, ideally protected in "reserved forests." Mangrove forests are also found in Cox's Bazar and the Noakhali coastal belt. The total mangrove area is estimated to be 599,330 Ha (Islam and Bhuiyan 2018).

China's mangrove forests are mainly spread in areas of Zhejiang, Fujian, Guangdong, Hainan provinces, and Guangxi Zhuang autonomous region. The third national land survey of China demonstrates that the country now has about 27,100 Ha of mangrove forests (Chinadaily 2022).

13.2.2 Africa

East African mangroves are noticed in Mozambique, Tanzania, Kenya, and southern Somalia. The most elaborate mangroves are observed in the Rufiji River Delta in Tanzania and the Zambezi River Delta in Mozambique. There are two general categories of mangroves along the Kenyan and Tanzanian coasts: those found in fringe communities along the open coastline and those found in estuaries and at river mouths. An assessment by Dinerstein et al. (2017) elucidated that 843,000 Ha, or 45%, of the East African mangroves are in protected areas.

West African countries with mangroves include Angola, Benin, Cameroon, Congo, the Democratic Republic of Congo, Equatorial Guinea, Gabon, Gambia, Ghana, Guinea, Guinea Bissau, the Ivory Coast, Liberia, Mauritania, Nigeria, Sao Tome and Principe, Senegal, Sierra Leone, and Togo. Mangroves in West Africa cover more than 2.3 million Ha, which constitutes 13% of mangrove forests worldwide. The most extensive mangrove forests in West Africa are found between Senegal and the south of Sierra Leone; between Ghana and Cameroon; and the Niger Delta (USFS 2014).

The total mangrove cover in South Africa is approximately 1900 Ha (Ward and Steinke 1982; Hoppe-Speer et al. 2013). Mangrove cover starts from Kosi Bay in the north and reaches its southern distributional limit at Nahoon Estuary. The mangroves at Nahoon were once transplanted from Durban Bay in 1969 by Steinke and currently occupy extensive areas on intertidal mudflats in the estuary (Steinke 1999). The largest mangrove forests of South Africa are found in the subtropical areas of St. Lucia and Richards Bay (Naidoo 2016).

13.2.3 American Continents

The Panama Bight Eco-region in the west coast of Central and South America is believed to have one of the best-preserved mangrove ecosystems in the American continent, the widely recognized conservation hotspot. Highly developed mangrove forests are visible along the southern Colombian and northern Ecuadorian Pacific coasts (Castellanos-Galindo et al. 2021). In North America, mangroves are observed from the southern tip of Florida along the Gulf Coast to Texas.

13.2.4 Oceania

Australia owns only 0.9 million Ha of mangrove forest (ABARES, 2019). The mangrove forest is found in all mainland states and the Northern Territory of Australia. They are distributed such that a total of 0.4 million hectares (45%) is found in Queensland, and 0.3 million hectares (39%) is in the Northern Territory.

According to Spalding (2010), New Zealand's mangrove distribution covers about 26,050 Ha. The mangrove trees of New Zealand grow only on the top half of the North Island of New Zealand. Mangroves are found from 34°27′S in the far north of the North Island to 38°05′S at Kawhia Harbour on the west coast and 38°03′S at Ohiwa Harbour on the east coast (Crisp 1990). Planted mangroves have been observed to establish and survive as far south as 41°13′S on the Hutt River, at the southern end of the North Island (de Lange and de Lange 1994; Horstman et al. 2018). Only one species of mangrove is prominent—*Avicennia resinifera,* although in Australia it is called *Avicennia marina*.

13.3 Biodiversity of Mangrove Ecosystem

Mangroves are living treasures of biodiversity. The term mangrove is often used to refer to both the trees and the community, even though trees are the basic and most visible component of mangrove ecosystems. The mangrove community is an assemblage of a wide range of organisms from different systemic groups, including bacteria, fungi, microalgae, invertebrates, birds, and mammals (Holguin et al. 2001).

On a geological time scale, mangroves are relatively recent and ephemeral coastal features. Even though several sorts of mangroves are located on sheltered and sedimented stretches of reefs and islands, the complex mangrove forest is completely achieved only in estuaries and deltas.

13.3.1 Mangrove Flora and Fauna

There are about 110 species of "mangroves" of which only about 54 species in 20 genera from 16 families constitute the "true mangroves," i.e., species that occur almost exclusively in mangrove habitat (Kibria 2013). Mangroves were thought to have evolved in tropical intertidal environments of the early Tethys Sea between Laurentia and Gondwanaland (King et al. 1990). They are a product of the convergent evolution of angiosperms, where plants from different families from the coastal environments have evolved under similar adaptations that enabled them to colonize and reproduce.

The western center with West Africa, Atlantic, and Pacific South America and the eastern center with East Africa to the Western Pacific are considered as the centers of diversity of the mangroves. The first established angiosperm mangrove vegetation type consisted of *Avicennia* sp., *Rhizophora* sp., and *Hibiscus* sp. in both the centers of diversity (Tomlinson 1986).

Nypa sp. was already existing some 63 million years ago during the Cretaceous era, while *Rhizophora* sp. was recorded to be present only 30 million years ago, as revealed by the fossils. Mangrove trees, with some exceptions, do not always need salt to grow but develop some special adaptation mechanism to tolerate high salt concentration. These adaptations are visibly observed in leaves and roots and in reproduction.

Succulent leaves with a thickened epidermis, waxy cuticle on the upper side with white tomentum on the underside like in xerophytes are sometimes observed in mangrove plants. *Rhizophora* sp. and *Sonneratia* species are good examples of this characteristic leaf pattern. Some leaves are covered with pubescence, as in some *Avicennia* species or scales in *Heritiera* species. They tend to have reduced leaf areas, and sunken stomata like in *Rhizophora, Bruguiera, Ceriops, Avicennia, Aegiceras,* and *Lumnitzera.* Mangroves develop superficial rooting systems. This rooting system serves for shallow anchorage, absorbing water, and oxygen in largely anoxic surroundings.

Instead of tap roots, Avicennia sp. and Sonneratia sp. have radial roots. Small anchoring roots are given off, and vertical pneumatophores or breathing roots protrude above the soil surface. These are slender and flexible in *Avicennia* sp., while strong and woody in *Sonneratia* sp. Only a set of branching prop roots are seen in *Rhizophora* sp. from which a succession of long arched roots, halt-hoops are put out radially, which serve as pneumatophores.

Mangroves can reach far upstream from the sea, wherever an increase in the salinity of the surface mud occurs due to a wedge of heavier seawater that can creep over the bottom. Not all the species of mangrove plants are found in any one mangrove community. According to the decrease in salinity and increase in firmness of the soil from the shoreline to inland, the mangrove community's specific plant species usually occur in zonation. Mangrove swamps are divided into various zones with respect to the dominant tree as a means of zoning. Thus, the zonation can be classified into two categories: (1) From a sheltered tidal area to the beach forest area; (2) From the open sea to the beach forest area.

Rog et al. (2016) identified 464 terrestrial vertebrate species to occur in mangrove forests: 320 mammals, 118 reptiles, and 26 amphibians (including 22 subspecies). This is a fivefold increment in the terrestrial vertebrate species previously reported to use mangroves (excluding birds). Following previous reviews were also added representatives of 14 additional families (Kathiresan and Bingham 2001; Nagelkerken et al. 2008; Luther and Greenberg 2009; Hogarth 2015).

The faunal components of the Mangal belong to a large variety of classes when compared to the floral components. About 75% of the fauna found in mangrove forests is not found in any other zone (Frith et al. 1976). The fauna can be majorly divided into three groups: Tree fauna, ground or surface fauna, and burrow fauna. The trunks, leaves, and roots of mangrove trees support a banding of sessile and mobile animals. The most conspicuous of the insect population in Mangals are the mosquitoes. About 125 species of mosquitoes have been recorded from mangrove areas in Sulawesi, Indonesia, of which *Anopheles sundaicus* carries malaria. The larvae of this species can tolerate water salinity of up to 13%. Colonies of weaver ants, *Oecophylla* sp., fierce predators, live in untidy leaf nests made by weaving five or six leaves together with fine silk thread.

Ciliates and foraminifers are numerous in mangroves, but the meiofauna of the sediment does not exhibit any species diversity. The peculiar peanut worm, *Phascolosoma* sp., is able to store oxygen in its coelomic fluid and lives permanently in the soil of the pioneer zone when the tide is out (Göltenboth and Schoppe 2006). The detritus is eaten by a group of small animals such as zooplankton, crustaceans, like penaeid prawns and small crabs, and small fish, particularly fingerlings. The most important litter processors after the crustaceans are isopods, like *Exosperoma* sp., and capitellidae polychaeta, like C*apitellides* sp.

One group of animals that are widely used as indicators of changes in the balance of the mangrove ecosystem is molluscs because of the uniqueness in their distribution. The molluscs, especially class bivalve and gastropod, follow a site-specific distribution pattern that is closely related to the characteristics of their habitat (Vermeij 1973). Molluscs function as predators, detritus eaters, and carcass eaters in the Mangal. They guarantee a balance of energy flow in the ecosystem (Rahardjanto et al. 2020).

The Littorina snails, such as *Littoraria scabra* and *Littoraria carinifera,* reside high in foliage. The tapering, ovoid *Auriculastra* sp*., Vittina* sp*., Cassidula* sp*.,* and *Terebralia* sp. (Fam. Potamididae) are usually found on more muddy parts of the Mangal, whereas the primitive pulmonate snails *Melampus* sp. (Fam. Ellobiidae)*, Nerita* sp. (Fam. Neritidae)*, Heminerita* sp., and *Truncatella* sp. (Fam. Potamididae) are found on more silty sand (Göltenboth and Schoppe 2006).

The distribution of molluscs associated with the trees depends on the water or tidal level. Thus, the zonation pattern is like branches, mid region, root, and mud. Branches and roots of trees near the high water mark carry small acorn barnacles, *Chthamalus* sp*.,* and oysters, *Crassostrea* sp. At mid-tide level, a small estuarine mussel, *Modiolus* sp. or the bivalve *Enigmonia* sp*.,* which lives on leaves and trunks attached by a stout byssus, may be found. A flat bivalve *Isognomon* sp. may be found among the lower roots. Root holes and clefts hollowed by shipworms shelter amphibious Ellobiidae molluscs, crabs, prawns, nereid, and other polychaete worms. The living roots of *Rhizophora* are invaded by wood-drilling *Sphaeroma* sp. The heteroptera bug *Halobates* sp. skims actively over the surface of stagnant water. The bivalve *Geloina ceylonica* lives buried deep in the mud (Göltenboth and Schoppe 2006).

Besides the snails, the crustaceans are always a prominent and diverse component of the mangrove fauna. The red-clawed fast running Grapsidae *Sesarma* sp. and *Metopograpsus* sp. and the slow moving Xanthidae *Epixanthus* sp. often live under boulders and in holes between roots. The most attractive of tropical mudflat shore crabs belonging to the family Ocypodidae are the fiddler crabs (*Uca* sp.). *Dotilla* sp. or the soldier crab that builds an igloo of mud balls around itself are also seen in the mud. Hermit crabs belonging to *Clibanarius* sp., of the family Paguridae and *Coenobita* sp. of the family Coenobitidae, and mud lobster, *Thalassina anomala* of the family Thalassinidae are usually very common in the Mangal. The king or horseshoe crabs, *Carcinoscorpius rotundicauda,* are living fossils. They are the surviving members of Xiphosura and are ancient marine relatives of the spiders and scorpions which inhabited the oceans some 200 million years ago (Göltenboth and Schoppe 2006).

Drainage channels of the Mangal serve as important habitat for many littoral fish species, reef fishes, and fishes from rivers. Juveniles of the families, particularly Mugilidae, Tetraodontidae, and Gobiidae can be seen. The muddy flats are invaded by the genus *Boleophthalmus* and *Periophthalmus* (mudskippers). *Boleophthalmus boddarti* (Boddart's goggle-eyed goby) is usually found at the seaward edge of the mid-tide area, grazing the algae. Carnivorous *Periophthalmodon schlosseri* (Giant mudskipper) and omnivorous *Periophthalmus chrysospilos* (Gold-spotted Mudskipper) occupy the highest part of the swamps. The banded archerfish, *Toxotes jaculator,* can also be observed "shooting down" insects from above the water at high tide (Göltenboth and Schoppe 2006).

Rana cancrivora is atypical among amphibians in being able to live and breed in modest saline water. The tadpoles are more resistant to salt than the adults, and metamorphosis is delayed until considerable dilution of the water occurs (Göltenboth and Schoppe 2006). Another mangrove frog (*Eleutherodactylus caribe*) was reported in Haiti (Luther and Greenberg 2009).

A variety of reptiles inhabiting the saline water, the ground floor, and the trees can also be visualized. A majority of mangrove-restricted terrestrial reptiles tend to have laterally compressed tails, which are presumed to be helpful in aquatic environments. Water monitor (*Varanus salvator*) and Mangrove monitor (*Varanus indicus*) were the reptiles found inhabiting Philippine Islands and Papua New Guinean and Australian mangroves, respectively. Near-threatened Mangrove terrapin (*Malaclemys terrapin*) was reported in Southern Florida and North America (Luther and Greenberg 2009).

Luther and Greenberg (2009) recognized 11 species of mangrove snakes. The common skink, *Mabuya multifasciata,* is found both on the ground and in the lower root system. While *Cerberus rynchops* (dog-faced water snake), *Homalopsis buccata* (puff-faced water snake), and the crab-eating snake, *Fordonia leucobalia,* are found in shallow water, the cattle snake, *Elaphe radiata,* is a ground snake (Göltenboth and Schoppe 2006). Arboreal snakes are the common cat snake, *Boiga dendrophila,* and the reticulated python, *Python reticulatus.*

Mangrove forests are potentially a very attractive bird habitat. Many of the birds are not restricted to mangroves. But there are 48 species of birds that are restricted to mangroves alone. An additional 18 bird species depend on mangroves for feeding, roosting, or nesting during daily or seasonal migrations but are not considered restricted to mangroves (Luther and Greenberg 2009). The abundance of particularly small prey is very attractive to kingfishers, *Halcyon chloris.* The sweet nectar of flowers attracts both nectarivorous birds, like the brown-throated sunbird, *Anthreptes malacensis,* purple-throated sunbird, *Nectarinia sperata,* and insectivorous birds like the mangrove blue flycatcher, *Cyornis rufigastra.* Residential species confined exclusively to mangroves include Javan coucal (*Centropus sinensis*), Pacific swallow (*Hirundo tahitica*), and mangrove swallow (*Tachycineta albilinea*). The most endangered bird species identified in mangrove communities is the Milky Stork or *Mycteria cinerea.* Kutt (2007) recorded a number of mangrove-obligate species (e.g., Collared Kingfisher, Mangrove Robin, Mangrove Gerygone) more abundantly, and a further suite of species that were mangrove-facultative (e.g., Shining Flycatcher, Brown Honeyeater, Dusky Honeyeater, Rufous Fantail, Helmeted Friarbird, Spangled Drongo) in Australian mangroves.

Zonal patterns of the distribution corresponding to the mangrove tree species are exhibited by some birds in different mangroves (Noske 1995, 1996). Prominently exhibited by potentially competing species that occupy largely mutually exclusive zones, such as the seaward fringe, tidal channel, saline flats, or landward fringe. This zonation has been observed in woodpeckers in Malaysia (Noske 1995) and in gerygones and kingfishers in Australia (Noske 1996; Schodde et al. 1982). In Australia the correspondence between plant and bird zonation was more pronounced in the dry season than in the wet season, possibly because of restricted insect richness during the dry season (Noske 1996).

The mangrove forest shares a variety of species of mammals with riverine habitats, including some species of monkeys, like the long-tailed macaque, *Macaca fascicularis,* the Javan lutung, *Semnopithecus auratus;* the Bornean silvered langur, *Presbytis cristata;* and the endemic proboscis monkey, *Nasalis larvatus.* The small-clawed otter, *Aonyx cinerea,* and the fishing cat, *Felis viverrina,* are common residents of the Mangal. Pygmy three-toed sloth (*Bradypus pygmaeus*), Vordermann's pipistrelle (*Pipistrellus vordermanni*), Northern pipistrelle (*Pipistrellus westralis*), Proboscis monkey (*Nasalis larvatus*), Garrido's hutia (*Mysateles garridoi*), and Cabrera's hutia (*Mesocapromys angelcabrerai*) are some of the mangrove-restricted mammalian species (Luther and Greenberg 2009). Fruit bats, particularly the flying fox, *Pteropus vampyrus,* roost in the mangrove forest canopy. Other bats, such as *Eonycteris spelaea,* the cave fruit bat, and *Macroglossus sobrinus,* the long-tongued fruit bat, are very important pollinators of *Sonneratia* sp. (Göltenboth and Schoppe 2006).

Facultative users of mangroves depend for critical stages in their life cycles, using these areas to breed, e.g., the Estuarine Crocodile, *Crocodylus porosus*, and the Sea Krait, *Laticauda colubrina* (Göltenboth and Schoppe 2006). There are also records of species using mangroves to shelter from heat stress, e.g., bat species and kangaroos in Australia (Reef et al. 2014) and to disperse between primary habitats, e.g., the marsh rabbit, *Sylvilagus palustris*, in the United States (Kathiresan and Bingham 2001).

Another unique feature is the existence of swamp tigers in one of the world's famous mangrove forests in India, the Sundarbans. Sundarbans tigers are different from all other Royal Bengal tiger populations in their small, stocky, and muscular frame; coarse and short coats and deep reddish-brown coloration are all adaptations to survive in this hostile habitat. They can swim deceptively fast across a brackish-water channel against a rapidly receding tide (World Atlas 2020). Deer are also regular visitors in some forests, including the Key deer in Florida and the spotted and barking deer in the Sundarbans. Livestock, mainly goats and camels, visit mangroves in many parts of the Middle East, Pakistan, and East Africa. Smaller ones include the hutias of the Greater Antilles (Spalding 2010).

13.3.2 Microbial Diversity

Microscopic investigation of decomposing mangrove leaves reveals a complicated community composed of fungi, bacteria, protozoa, and microalgae (Odum and Heald 1975). In tropical mangroves, bacteria and fungi constitute 91% of the total microbial biomass, whereas algae and protozoa represent only 7% and 2% (Alongi 1988). Microbial communities play crucial roles in mangrove nutrient cycling and plant productivity (Allard et al. 2020). There are only a few studies on the role of microorganisms on the expansion or retraction of mangrove forests linked to sea-level rise (Ward and de Lacerda 2021). Thus, understanding the role of microorganisms and their stability can provide crucial information to protect and restore mangroves in the world of climate change (Alongi and Mukhopadhyay 2015).

The planted mangrove sediment tended to have higher bacterial richness and diversity than the unplanted sediment. Plantation can influence the habitats for microbiota through the unique root exudates of mangroves and oxygen leakage (Tong et al. 2019). The mangrove habitats at geographic sites are unique with factors, like the rate of precipitation, organic carbon, evapotranspiration, and temperature, which could influence bacterial distribution with distinct community structures (Tavares et al. 2021).

Most metagenomic datasets of the core microbiome of mangroves worldwide were dominated by Proteobacteria, mainly by Deltaproteobacteria and Gammaproteobacteria with Planctomycetes, Acidobacteria, Bacteroidetes, and Chloroflexi. Desulfobacterales, which comprise anaerobic members involved in sulfur and carbon cycling as well as in the transformation of methane and nitrogen, is the most abundant order commonly observed in mangrove surface soils (Bashan and Holguin 2002).

Some representatives from non-common phyla, such as Elusimicrobia and Deinococcus-Thermus, as well as Proteobacteria (*Modicisalibacter*) were selected as indicator strains. These genera comprise bacteria capable of reducing nitrate or sulfur compounds, some of them with particular features, such as *Blastocatella* (Elusimicrobia), previously isolated from semi-arid savanna soil; *Truepera* (Deinococcus-Thermus), resistant to ionizing radiation; *Algiphilus* (Proteobacteria), aromatic hydrocarbon degrading; *Thiovulum* (Proteobacteria), rapid swimming bacteria; and *Planktotalea* (Proteobacteria) previously isolated from seawater or marine organisms from cold regions (Parte et al. 2020) and SEEP-SRB1 (sulfate-reducing bacteria cluster).

Even though rare species are non-relevant under a given environmental condition, they may offer a pool of genetic resources under appropriate conditions of climate change or some drastic environmental changes (Jousset et al. 2017). The emergence of novel microbial families Ignavibacteriae (Iino et al. 2010), in Mangalavanam, Kadalundi, and Kallai mangroves (India) and Calditrichaeota (Marshall et al. 2017), and Mucromycota (fungi) in Kadamakkudy mangrove was noticed in a post flood metagenomic analysis of Kerala mangrove sediments (Bindiya and Bhat 2019).

13.3.2.1 Nitrogen-Fixing Bacteria

Nitrogen-fixing bacteria, which constituted members of the genera *Azospirillum*, *Azotobacter*, *Rhizobium*, *Clostridium*, and *Klebsiella,* have been isolated from the sediments rhizosphere and root surfaces of various mangrove species. Several strains of diazotrophic bacteria *Vibrio campbellii*, *Listonella anguillarum*, *V. aestuarianus*, and *Phyllobacterium* sp. were also isolated from the rhizosphere *Rhizophora mangle*, *Avicennia germinans*, and *Laguncularia racemosa* in Mexico. The nitrogen fixing capacity of these bacteria was similar to that of diazotrophic bacteria from the terrestrial environment, such as *Azospirillum* sp. (Bashan and Holguin 2002).

13.3.2.2 Phosphate-Solubilizing Bacteria

In an arid mangrove ecosystem in Mexico, nine strains of phosphate-solubilizing bacteria *Bacillus amyloliquefaciens*, *B. atrophaeus*, *Paenibacillus macerans*, *Xanthobacter agilis, Vibrio proteolyticus, Enterobacter aerogenes*, *E. taylorae*, *E. asburiae*, and *Kluyvera cryocrescens* were isolated from *A. germinans* roots; and three strains *B. licheniformis*, *Chryseomonas luteola*, and *Pseudomonas stutzeri,* from that of *Laguncularia racemosa* (Vazquez et al. 2000). *Penicillium* and *Aspergillus* are very commonly reported as phosphate-solubilizing groups of fungi present in mangroves. *Streptomycetes* is the only known genus of actinomycetes to be identified as a phosphate solubilizer in mangroves (Bashan and Holguin 2002).

13.3.2.3 Sulfate-Reducing Bacteria

In Florida, sulfate-reducing bacteria were the most numerous bacterial group in the rhizosphere of *R. mangle* and *A. germinans* mangroves (Zuberer and Silver 1978). In Goa (India) mangroves, eight species of sulfate-reducing bacteria were isolated which were identified as *Desulfovibrio desulfuricans, Desulfovibrio desulfuricans aestuarii, Desulfovibrio salexigens, Desulfovibrio sapovorans, Desulfotomaculum orientis, Desulfotomaculum acetoxidans, Desulfosarcina variabilis,* and *Desulfococcus multivorans* (Bashan and Holguin 2002).

13.3.2.4 Photosynthetic Anoxygenic Bacteria

Photosynthetic anoxygenic bacteria *Chromatiaceae* (purple Sulfur bacteria) and *Rhodospirillaceae* (purple non-sulfur bacteria) were recovered from Indian mangrove sediments. *Chloronema, Chromatium, Beggiatoa, Thiopedia,* and *Leucothoe* bacteria were the predominant bacterial genera identified in the mangrove ecosystem of Cochin (India). Unidentified species of brown *Chlorobiaceae* were also present (Holguin et al. 2001). Isolates of purple non-sulfur bacteria belonging to ten species, representing four different genera, *Rhodobacter* and *Rhodopseudomonas,* were most common and were identified in mangroves on the coast of the Red Sea in Egypt (Shoreit et al. 1992).

13.3.2.5 Methanogenic Bacteria

A strain of the methanogenic bacterium, *Methanococcoides methylutens* (Mohanraju et al. 1997), and four strains of unidentified thermotolerant methanogenic bacteria have been isolated from the sediment of mangrove forest. Dimethylsulfide-utilizing methylotrophic methanogenic archaeon *Methanosarcina semesiae* was isolated from Tanzanian mangrove sediments (Lyimo et al. 2002). Lyimo et al. (2009) also identified important members from the genus *Methanococcoides* in the mangrove ecosystem both by culture-dependent and culture-independent methods.

13.3.2.6 Fungi

Twenty of the fungal species found in mangrove detritus were identified as ascomycetes (Kohlmeyer et al. 1995) followed by Deuteromycetes and Basidiomycetes. The fungi *Cladosporium herbarum*, *Fusarium moniliforme*, *Cirrenalia basiminuta*, an unidentified hyphomycete, and *Halophytophthora vesicula* were isolated from the dead leaves of *Rhizophora apiculata* (Raghukumar et al. 1994). One of the most notable macroscopic fungi in the mangroves is *Ganoderma* sp. Alias et al. (2010) reported more than 234 species of mangrove and marine fungi prepared as identified and an additional 68 species unidentified.

13.4 Degradation of Mangrove Forest

Anthropogenic pressures due to developmental activities along the coasts, overexploitation and natural calamities have raised concerns about the degradation of mangroves and associated coastal habitats. Major factors which cause the degradation of mangroves around the globe, including land reclamation for agriculture and aquaculture. Increased land-use changes, such as conversion to agriculture, aquaculture, and urban development, have severely degraded the fragile environment of mangroves. Since mangroves are rich in soil nutrients, they are ideally suited for agriculture. Earlier, 90% of mangroves in Kerala were destroyed either for paddy cultivation, coconut orchards, or for land reclamation (Muraleedharan et al. 2009). Mangroves are also being exploited for the production of salt.

13.4.1 Aquaculture

Mangroves are also suited for aquaculture because of their proximity to the sea. Shrimp ponds constructed in the mangroves seriously affect the mangrove ecosystem as the shrimps and other species are fed on specific diets which usually contain certain chemicals. These extra nutrients from food cause eutrophication which decreases the oxygen level and adversely affects the surrounding marine habitats and alters the species distribution. It is reported that shrimp farming alone has caused a loss of 38% of the world's healthy mangroves (Catt et al. 2022). In Kerala massive destruction of mangroves was reported in Kannur district for shrimp farming and Kaippad paddy cultivation (Muraleedharan et al. 2009). In Southeast Asia, 15% of the mangrove areas have been removed for aquaculture.

13.4.2 Coastal Development

Development of the tourism industry, jetties for fisheries landing and mangrove clearance for commercial building and residential areas has severely affected the mangrove population. The introduction of these man-made structures is always associated with the issues of pollution, improper disposal of waste, the emergence of invasive species, altered hydrology, and erosion. Transportation facilities, such as roads and flyovers that have been built within the mangrove areas, forcefully re-routed or blocked the rivers that once flowed through them. This creates the issues of temperature change, salinity, filtration, and sedimentation, which adversely affect the species diversity inside the mangrove ecosystem. In fact, in the past 20 years, more than 700 hectares of mangroves have been cleared for development, yet the current status is still unknown (Catt et al. 2022).

13.4.3 Climate Change

The major impact of climate change along the world's coastlines is sea-level rises and shifting of ocean's chemistry (IPCC 2007; NRC 2011). The rate of these impacts increases at a rate that exceeds the ability of the mangrove ecosystem to adapt to the change. Apart from sea-level rise, increased storminess, altered precipitation regime, and increasing temperature are also threats to the mangrove diversity.

13.4.3.1 Sea-Level Rise

The mangroves are present approximately greater than 1 m above the present low water level. Any increase in sea level may seriously affect the mangroves by altering the hydrological features and related processes. Increase in sea level results in a vertical rise of the water column leading to waterlogging which ultimately kills the mangroves and associated fauna (Ward et al. 2016).

13.4.3.2 Storminess

Frequent storms and hurricanes can significantly influence mangrove productivity. Although some species are resistant to the damage caused by storms, in certain cases, intense storms and cyclones will lead to the uprooting of trees, breakage of branches, and defoliation of the canopy. Extreme storms can also have long-term successional impacts on mangroves by providing a rapid input of non-native sediment, which can increase soil elevation (Ward et al. 2016).

13.4.3.3 Precipitation

The changes in precipitation is often associated with the changes in temperature, which in turn influence the rate of evaporation and transpiration. Changes in rainfall patterns affect the distribution extent and growth rate of mangroves by altering the salinity. When the salinity of the soil gets increased, it will interfere with seedling survival, productivity, and growth of the mangrove system (Ward et al. 2016).

13.4.3.4 Temperature

"Global temperatures are predicted to increase by up to 4.8 °C by 2081–2100 relative to 1986–2005" (IPCC 2013). Alterations in atmospheric temperature substantially influence the composition, phenology, productivity, and finally the pattern of mangrove distribution. Figure 13.2 describes how the temperature is often associated with the ability of CO_2 assimilation in the mangrove ecosystem. Any extreme changes in temperature will collapse the biochemical reactions, which ultimately leads to degradation, vascular embolism and cellular rupture, and the productivity of the mangrove ecosystem will decrease when the temperature exceeds the peak of photosynthesis (Fig. 13.2). The temperature increase is always accompanied with an increased rate of evaporation which ultimately results in increased salinity (Ward et al. 2016).

13.4.4 Deforestation of Mangroves

The emergence of cottage industries in coastline communities' demands for the mangrove timber and charcoal leads to the chopping down of mangroves. Since mangrove wood is suitable as a building material, fencing and fuel, cutting down of

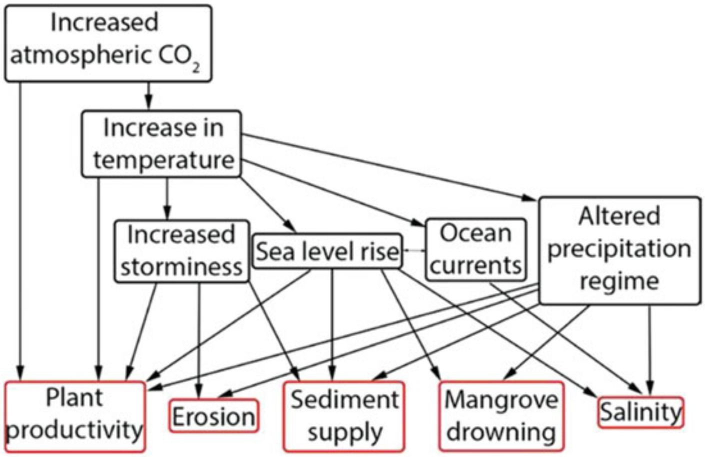

Fig. 13.2 Representation of principal impacting factors of climate change and their influence on mangrove communities

mangroves is proceeding at a higher pace. Many of the coastline communities have turned to charcoal production as their livelihood since mangroves can yield high-quality charcoal (Catt et al. 2022).

13.4.5 Extinction

Approximately 60 species of mangroves have been identified around the world and more than 1 in 6 species of them are under threat. More than 35% of the world's mangrove ecosystems have been destroyed, and 40% of vertebrates endemic to mangroves are threatened with extinction (Catt et al. 2022).

13.5 Conservation of Mangroves: The Need of the Hour

Mangrove ecosystems are considered as the complex ecosystems which form the interface between terrestrial forest and marine ecosystems. From the detailed discussion about the geographical distribution of mangroves (Sect. 13.2) and their biodiversity (Sect. 13.3), we can interpret that along with the structural complexities of mangrove vegetation, it offers a diversified habitat for a wide variety of organisms. Their significant ecological function includes the following:

13.5.1 Stabilization of Shoreline

Mangroves consist of numerous prop roots and other respiratory roots, which form a meshwork under the ground which reduces soil erosion. These complex root systems facilitate the accumulation of debris and prevent the loosening of the soil. Hence, mangroves can be considered as the "coast guards" or "watch dogs" of the shoreline geography and geomorphology (Muraleedharan et al. 2009).

13.5.2 Deep Drainage/Deep Percolation

Mangroves facilitate the movement of surface water into the groundwater flow system which is called the deep drainage or groundwater recharge. Thus, water remains as a part of a shallow water reservoir, which is important for maintaining the water table and influencing the supply of water to surrounding areas. This recharging of groundwater done by mangroves can be considered an environmental service to the community and industries (Muraleedharan et al. 2009).

13.5.3 Regulation of Water Flow

The extensive root system of mangroves can control the excess flow of water entering into them during a flood or heavy rainfall. Mangroves can either store or slow down the flow as it creates several hindrances in the flow path (Muraleedharan et al. 2009).

13.5.4 Sediment Deposition and Nutrient Retention

The structural complexities of mangrove vegetation help slow down the water flow through them, thereby facilitating sediment deposition and nutrient retention. Sediment deposition is always associated with the advantageous removal of toxicants as these molecules are seen attached to the sediment particles. The regulated or controlled flow of water prevents the runoff of nutrients and thus helps in the retention within the system (Muraleedharan et al. 2009).

13.5.5 Carbon Sequestration

The process of capturing carbon dioxide from the atmosphere and its storage is referred to as carbon sequestration. Carbon dioxide is considered a common greenhouse gas that causes global warming, leading to climatic change. Mangroves play a significant role in the biological sequestration of carbon dioxide and are referred to as the "Blue carbon ecosystems". Mangroves are capable of storing three–four times more carbon than terrestrial forests, which are referred to as "Green carbon ecosystems." During the period of growth, mangroves can store and stockpile carbon from 50 metric tons to 220 metric tons per acre. Considering the whole world, mangroves can sequester more than 24 million metric tons of carbon per year (Muraleedharan et al. 2009).

13.5.6 Protection of Habitat and Biodiversity

Mangroves are considered as the most productive marine ecosystems on earth, which provide a unique habitat for many species. They serve as breeding grounds and nursery sites for several species of fish and prawns for spawning and juvenile development (Refer Sect. 13.3) (Muraleedharan et al. 2009).

A diverse range of microbial populations is also found associated with the root system of mangroves. Along with this, fungal endophytes associated with the mesophylls of mangrove leaves are thought to produce novel secondary metabolites of industrial importance.

13.5.7 Gene Bank

Since mangroves are among the most resilient species, they contain more adaptive genes. These genes can be used to modify the genome of crop plants or can be used to impart taste to agricultural products etc. The recombination of salt-tolerant genes of mangroves with crop plants may yield a salt-tolerant plant that can be grown in saline areas and to produce maximum yield (Muraleedharan et al. 2009).

13.5.8 Nutrient Cycling

Different groups of bacteria are usually present in the mangrove ecosystem due to the abundance of carbon and other nutrient contents, where they perform functions, like photosynthesis, nitrogen fixation, and methanogenesis (Das et al. 2007; Holguin et al. 2001). These microbial communities are known to control the chemical environment of the mangrove ecosystem. They stabilize, protect, and nourish coastal water with nutrients and also play a major role in the cycling of nutrients, such as carbon, nitrogen, sulfur, and phosphorus (Alongi 1994). Detritus-supported bacterial biomass routes essential elements through the food web by providing nitrogen and phosphorus to protozoa and metazoa, and eventually to commercially important higher-trophic-level organisms, such as fish and shrimp (Bano et al. 1997).

Mangrove ecosystems are rare and splendid and act as a boundary between land and sea. These ecosystems contribute to the well-being of coastal communities as well as to the environment on a global scale. It acts as a natural coast defense against several natural calamities and disasters.

13.6 Tools for Mangrove Conservation

The mangrove ecosystem is a vital hub of the marine environment because of nutrient fluxes, productivity, and biodiversity of organisms. Despite their importance, mangroves are being degraded at a faster rate because of industrialization, urbanization as well as global climatic change. The conservation of this invaluable treasure of our biodiversity is now considered as the need of the hour. Therefore, the development of effective conservation tools is very much essential to ensure the proper conservation strategies. Although we have well-built conservation policies in legal systems, such as Environmental protection laws and several community efforts and institutional supports, we need to be more practical regarding the conservation. The use of genetic information in mangrove conservation is crucial for its long-term effectiveness. Conservation genetics is an effective tool for highlighting the roles of evolutionary and population genetics for biodiversity conservation (Wee et al. 2019).

13.6.1 Selection of Species to be Conserved

The primary step in the conservation practice is the identification of rare and endangered species of known mangroves which are threatened. Most of the species have a widespread distribution having many congeneric relatives giving them a chance for hybridization and introgression, which leads to perplexes in the proper identification of species to be conserved. Thus, clarification of species identification is important for implementing conservation practices toward priority species and ensuring efficacy. The best example of this is the case study of *Bruguiera hainesii*1 of two critically endangered mangroves, which are a hybrid of *B. gymnorrhiza* and *B. cylindrical*. The International Union for Conservation of Nature (IUCN) prioritizes only the conservation of species, not hybrids (Wee et al. 2019).

13.6.2 Formation of Conservation Units

Since mangroves have a widespread distribution, cross-border conservation is a challenge, especially in implementing protection strategies and enforcing international law. Therefore defining conservation units (CUs) can be helpful for designing reserve networks. The important aspect in defining the CU is genetic connectivity. Genetic connectivity helps identify the geographical regions, metapopulations, and barriers to dispersal.

The identification of CUs based on geographical locations is useful in the genetic evaluation of species present in potential sites. For example, mangroves are present in 274 of over 2000 sites listed under the wetlands of international importance (Ramsar List 2017). The mangrove forest in the Ramsar site has lower rates of deforestation than the global average. The identification of CUs across the borders and prioritizing the region as new Ramsar sites helps conserve the genetic diversity of that particular region. This requires international collaboration and large-scale genotyping (Wee et al. 2019).

13.6.3 Analyzing the Adaptations

Increased anthropogenic activities and global climatic changes have significantly affected the distribution and persistence of mangroves. Because of this, mangroves exhibit differences in the pattern of stress as well as salinity tolerance. Hence, it is essential to understand their molecular mechanisms and physiological responses to environmental stresses and identify the potential evolutionary outcomes under different scenarios. Studies on molecular aspects of adaptive evolution are important in the application of real-time conservation problems. The effective execution of conservation strategies requires the integration of physiological as well as molecular data. With the emergence of NGS, the regulatory mechanisms and phenotypic characteristics for adaptation can be examined through stress tolerance, transcriptome analysis, and epigenetics. By analyzing all this information, managers can potentially identify populations with limited capacity for adaptation and can increase their evolution by providing connectivity to other populations (Wee et al. 2019).

13.6.4 Molecular Tools for Conservation

Molecular techniques used for conservation include different types of markers for the identification of genetic differences between organisms. There are mainly three types of markers, namely, morphological, biochemical, and DNA-based markers (Sahu and Kathiresan 2012).

13.6.4.1 Biochemical Markers and Molecular Markers

Molecular markers can be classified as PCR-based and non-PCR-based markers. Non PCR based markers include; allozymes, Restriction Fragment Length Polymorphism (RFLP) are used to identify genetic diversity within the species. It has been used to study the genomic relationship among 24 mangroves and their associated species.

RAPD is another widely used PCR-based indirect molecular approach for genotypic differentiation and molecular taxonomy among different mangrove species. Mangroves do have inter and intra-generic relations, as proved by RAPD. The RAPD markers alone or along with other molecular markers have widely been used to study genetic variations in mangrove species, including Avicennia, *Excoecaria, Acanthus,* and *Bruguiera*. It is also useful to study the parentage analysis in Rhizophora hybrids (Sahu and Kathiresan 2012). Amplified Polymorphic Length Polymorphism (AFLP) is a PCR-based approach to DNA fingerprinting that provides high levels of resolution to delineate complex genetic structures. AFLP markers have been used to study the genomic relations in three species of Heritiera and the results have shown clear-cut segregation of true mangrove species *H. fomes* from mangrove associate *H. littoralis* and also landrace species *H. macrophylla* (Sahu and Kathiresan 2012). Sreekanth and Anupama (2021) reported the genetic diversity and population structure of *Avicennia marina* from its native distributional range in Kerala, Southern India. Gene diversity within the population is comparatively higher than among the population; the establishment of on-site protection zones for *Avicennia marina* to reduce the impact of human activities would allow its habitats to increase in size through natural regeneration to reach maximum population size. *Avicennia marina* mangrove can be introduced from other populations via appropriate propagation and seedling management to increase the chance of gene exchange and recombination and to improve the level of genetic diversity over time. The comprehensive information on genetic diversity will be baseline data for monitoring the genetic pollution that occurs in response to a particular habitat. The introduction of a species to an ecosystem and the relationship between environmental factors and genetic erosion may not be straightforward. It might be non-linear and site-specific and might involve complex interactions among factors. A more extensive study for conservation and phylogeography of *Avicennia marina* is a high priority. Based on a large number of native distributional areas, population genetic diversity in the entire east coast and west coast of India using genome-wide analysis will be helpful for further predicting the implication of conservation of these species.

Microsatellites, also known as simple sequence repeats (SSRs), are an important class of markers because of their greater abundance and variability. SSRs have been used in population genetic studies in mangroves. Cross-priming studies have shown the polymorphic nature of all the loci in *Kandelia candel* and *Rhizophora stylosa* and proved that the microsatellite markers are ideal for population studies (Sahu and Kathiresan 2012).

13.6.4.2 DNA Barcoding of Mangroves

DNA barcoding is a useful alternative for global biodiversity assessment, providing an accurate identification system for living organisms. DNA barcoding is also considered a powerful method to traditional morphological approaches. The two-locus combination of rbcL + matK has been recommended as the plant barcode and has been approved by the Consortium for the Barcode of Life (CBOL) in 2009 (Sahu and Kathiresan 2012).

13.6.4.2.1 Maturase K (matK) Gene

The matK gene, formerly known as orfK, is considered a valuable gene for studying molecular systematics and the evolution of mangroves. Because of its reasonable size, high substitution rate, evenly distributed codon position variation, low transition and transversion ratio, and the easiness of amplification due to its two flanking coding trnK exons. The 1500 bp matK gene is named according to its possible maturase function and its location within the trnK gene encoding the tRNALys (UUU) (Sahu and Kathiresan 2012).

13.6.4.2.2 Ribulose Bisphosphate Carboxylase Large Subunit (Rbcl) Gene

RbcL gene, located on the chloroplast genome, is an appropriate choice for inference of phylogenetic relationships at a higher taxonomic level. It is a 1350 bp gene which is one of the most widely studied chloroplast DNA genes by means of molecular techniques and is known to exhibit extensive variation above the species level (Sahu and Kathiresan 2012).

13.6.4.2.3 Molecular Phylogenetic Software

Molecular phylogenetics applies a combination of molecular and statistical techniques to infer evolutionary relationships among organisms or genes. Recent advances in sequence analysis methods and computational techniques have revolutionized phylogenetics studies. Mangrove geneticists across the globe routinely employ molecular phylogenetic methods in their research (Sahu and Kathiresan 2012).

13.6.4.3 Next-Generation Sequencing

The development of conservation genomics during the last decades has played a significant role in conservation biology. The emergence of next-generation sequencing technologies made it easier to generate molecular data, which is important in the process of conservation. The next-generation sequencing (NGS)-based data are particularly useful in the areas of species identity, defining CUs, and understanding adaptation (Wee et al. 2019).

13.6.5 In Situ and Ex Situ Conservation Strategies

Increased awareness about the protective, productive, and ecological functions of tropical mangrove ecosystems have highlighted the need to conserve and manage them sustainably. India has taken a great initiative in mangrove forest management. The Sundarbans mangroves of the Bay of Bengal (partly in India and partly in Bangladesh) were the first mangroves in the world brought under scientific management. The area's first management plan was implemented in 1892. The government introduced a scheme for the conservation and protection of mangroves which includes identification of specific mangrove ecosystems for conservation, formulation of a management plan, enhancing research on mangroves, and declaring the participation of state governments, universities, research institutions, and local organizations (Deshmukh and Balaji 1994). The two important strategies adopted for mangrove conservation are as follows:

13.6.5.1 In Situ Conservation of Mangroves

This method helps in the conservation of mangroves within their natural habitat along with the associated animals and plants by creating protected areas such as national parks and wildlife sanctuaries. In situ conservation, which remains as a natural ecosystem, is one of the most recommended methods for conserving forest genetic resources. This involves maintaining the natural areas and executing proper protection measures and maintenance so that the ecosystem is restored in its natural environment itself. In situ conservation not only aims for the conservation of mangroves in their natural habitat but also it provides a site for storing the plant genetic material for future use. In India, 188 permanent preservation plots covering a total area of about 8442 Ha have been established with different forest types. These areas are considered as important "gene sanctuaries," where besides the tree species included, all other associated species can evolve under natural selection pressure (Deshmukh and Balaji 1994).

13.6.5.1.1 Role of Conservation Genomics in Management Actions

Having a clear-cut idea about the genetic variations within a population is crucial for the management of threatened species. The reproductive potential, adaptations, and distribution of a species in a population is directly related to the extent of their genetic diversity within the population. Knowing about this genetic information can be helpful in the decision-making process of conservation, such as prioritization of populations and mixing or excluding certain populations during in situ *and* ex situ management activities (Rossetto et al. 2021).

13.6.5.1.2 Criteria for Sampling

In order to design an effective conservation strategy, certain factors must be considered, which include a well-defined criteria for sampling that can go with the further procedures, like recovery process, analysis, data interpretation, and ultimately the recovery actions. In the case of geographically restricted species, sampling can be done considering a representative species of a population. There are certain special circumstances that we need to consider during sampling. In the case of species that do not have accurate information about evolutionary history and distinctiveness, sampling is needed from closely related taxa or from good quality herbarium specimens collected. The chances for hybridization should also be considered while sampling because it is very crucial for the conservation and management of threatened species. Excluding hybrids from sampling will compromise the purity of the remaining populations and affect the translocation plans (Rossetto et al. 2021).

13.6.5.1.3 Sampling Analysis and Data Interpretation

A perfectly designed sampling procedure can provide data for the analysis of the populations under study and to formulate interpretations which ultimately lead to management approaches. A thoughtful analysis of the sample can lead to productive interpretations. Degradation of the environment can lead to habitat loss, thereby reducing the effective population size. A reduction in population size can lead to stochastic hybridization. When small populations are surrounded by closely related individuals, it leads to interspecific gene flow, which can lead to genetic swamping. Hence, when planning for translocation, understanding the risk of hybridization is very important. Polyploidy also can lead to speciation in plants; it is also important to identify the natural distributions and reproductive boundaries between the species under conservation (Rossetto et al. 2021).

Accelerating genetic diversity through genetic rescue and other mechanisms is an important strategy in the conservation of threatened species recovery. Ideas about the reproductive mechanisms of the species are thus important in taking diversity-related decisions. Small populations which face inbreeding depression and genetic drift are more likely to have less genetic diversity. The less diverse the organism, the more it is prone to extinction. So methods that increase genetic diversity and genetic rescue mechanisms can be used to increase their population size and fitness (Rossetto et al. 2021).

Translocations and other recovery-related methods can be thus adapted according to the kind of species to be conserved. However, conserving a particular species alone can affect the genetic diversity of the entire population.

13.6.5.2 Ex Situ Conservation

This method refers to the conservation of mangroves in the areas outside their natural habitat, such as nurseries and botanical gardens. Ex situ conservation is a protective method applicable for both indigenous species, where in situ conservation is not possible, and for exotic species. In this conservation strategy, genetic diversity cannot be maintained as selected species are being conserved and protected in areas outside their natural habitat. But it can help ensure a fairly good representation of the initial variability. Ex situ conservation of mangroves involved the following:

13.6.5.2.1 Acquisition of Germplasm

Germplasm collection consists of going to the field to search for and collect the genetic variability of the wild species from the natural habitat. The same number should be taken from every plant and in good physical and sanitary conditions. A proper moisture content and temperature should be maintained and controlled to prevent the samples from drying out or rotting (Rahman 2016).

13.6.5.2.2 Storage of Samples

After completing the phytosanitary transactions, the germplasm was taken to the place of conservation, where the samples were checked for sufficient number and viability for conservation. Viable and sufficient samples were collected and stored immediately for raising the nursery. Seedlings selected for plantation should be vigorous and in sufficient numbers to represent the genetic variability, thereby ensuring the continuity of the conserved materials. The seedlings should be planted in such a way that they cannot exchange pollen, thus preventing the populations from losing their original genotype. The exact site where each accession was planted should be recorded on a map. Once germplasm is conditioned and stored in the place of conservation under optimal conditions to ensure its survival, the germplasm has to be managed, starting with characterization and evaluation. Growth and survivability data of planted species should be recorded at regular intervals. Meteorological data were recorded. Data on water salinity, soil salinity, soil pH, sedimentation, soil erosion, and inundation were also recorded. Microsoft Excel programs were used to process all collected data and to prepare tables, charts, and graphs (Rahman 2016).

The Sundarbans mangroves located in the Bay of Bengal were the first mangroves in the world to be put under scientific management. The area's first management plan was implemented in 1892. In 1927, the Indian Forest Act was applied to the mangrove forests of the Sundarbans, which have been declared a reserved area. In Chorao, Goa, 178 ha of the best mangrove area has been declared as a Reserved Forest under the Indian Forest Act, 1927 to protect and conserve the mangrove forests. Subsequently, in 1988, this area was declared a bird sanctuary under the Wildlife (Protection) Act, 1972. Since 1987, the Andaman and Nicobar Administration has banned the extraction of mangrove wood. The plywood industries, power stations, and government steam vessels have since switched over to diesel. Bhitarkanika Wildlife Sanctuary, located at a distance of 120 km from Cuttack in Odisha, is the second-largest mangrove forest in India.

13.7 Conclusion

The insufficiency of proper scientific knowledge in mangrove ecosystems and biodiversity and the ecological functions they are providing basket the efforts to conserve and manage mangroves, which leads to the unscientific and unsustainable exploitation of mangroves. A well-organized team of experts from various disciplines is necessary to sort out the real issues in the degradation and execute proper conservation strategies. This will promote the exchange of valuable ideas regarding the maintenance of mangrove ecosystems.

The lack of knowledge regarding the genetic studies of mangroves is one of the major constraints in the area of conservation. Also a taxonomic study on the species diversity is essential to develop a national database which could be able to monitor the status of species diversity in specific mangrove populations. In order to execute proper management actions, the ecological functions as well as the interdependency of mangroves with other ecosystems should also be considered.

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