Chapter 13
Sri Lankan Mangroves: Biodiversity, Livelihoods, and Conservation

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Abstract Mangroves in Sri Lanka occur in a patchy distribution along the island's coastline, in areas adjacent to lagoons, estuaries, and river mouths covering an area of 16,017 ha. Twenty-one species of true mangroves and 18 mangrove associates are recorded, while 214 vertebrates comprising of 112 species of ichthyofauna, 2 species of Amphibia, 13 species of Reptilia, 72 species of Avifauna, and 15 mammal species are found in the mangrove forests. Local communities settled near mangrove areas are heavily dependent on mangroves for their livelihood; branches of *Avicennia* spp. are used for brush pile traditional fisheries; tender leaves of *Avicennia marina*, *Sonneratia caseolaris*, *Acrostichum aureum*, and *Suaeda maritima* are used as food. Wood of *Cerbera manghas* is used to carve masks and puppets, while *Nypa fruticans* is used to make alcohol, sugar, and vinegar. Overexploitation of mangrove products, habitat destruction for development, pollution, spreading invasive alien species, climate change, and global warming are some of the threats to the mangrove ecosystem in Sri Lanka. Successful restoration practices are carried out in Kalpitiya, Pambala, and Negombo. Approximately 1000–1200 ha of mangroves have been planted in 23 sites in Sri Lanka. Sri Lanka claims to be the first nation in the world to protect all its mangroves, making it illegal to cut down them anywhere in the island, and the first to open a mangrove museum (in Pambala, Chilaw). Sri Lanka has also been named as a leader for the conservation of mangroves in Commonwealth countries.

Keywords Patchy distribution · Local communities · Traditional fisheries · Restoration · Mangrove museum

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13.1 Introduction

The exact extent of mangroves is yet to be verified formally, but recent investigations carried out by the Department of Forest have revealed an extent of 16,017 ha of mangroves in Sri Lanka (Fig. 13.1). The major mangroves in Sri Lanka are located around Jaffna, Vadamarachchi, Thondaimanaru lagoons (northern coast), Kokkilai, Navarau lagoons, Trinkomalee, Kathiraveli, Valaichenai, Batticaloa, Pottuvil (eastern coast), Weligama, Gintota (southern coast), Balapitiya, Bentota, Negombo and

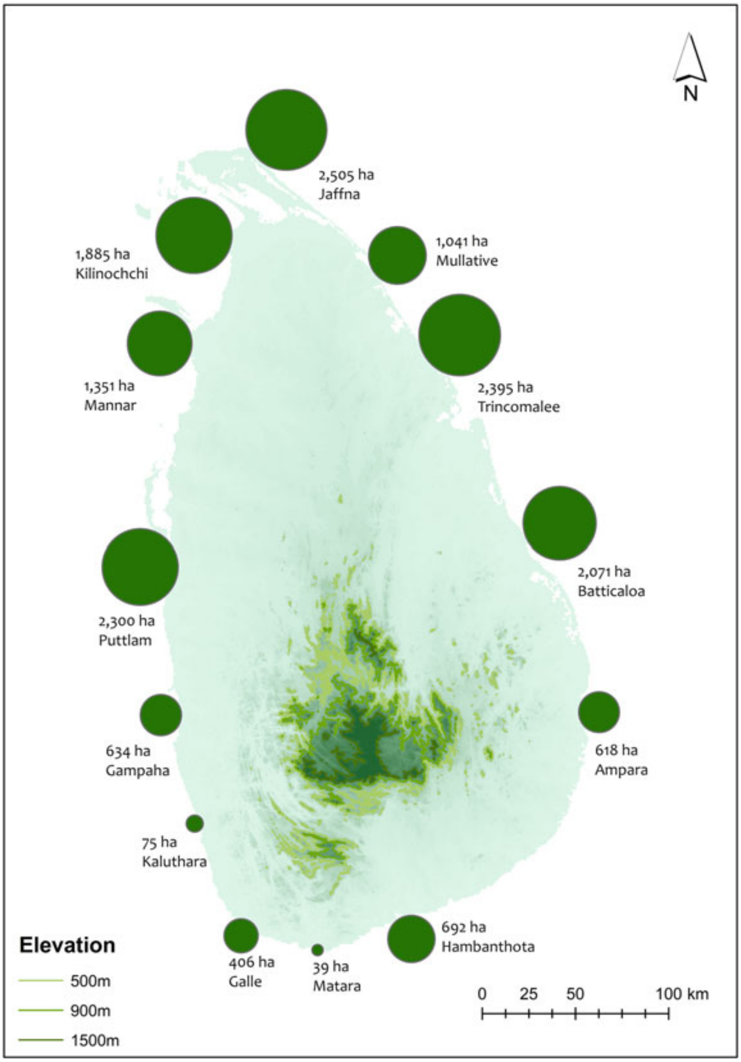

Fig. 13.1 Extent and distribution of mangroves along the coastal region of Sri Lanka

Chilaw lagoons, Puttalam lagoon, and Mannar (western and northwestern coasts) (Ranawana 2017). Most of the mangrove patches are small in extent, disjointed, and disturbed, but a few relatively undisturbed mangrove patches with a considerable extent (>1000 ha) are found in northwestern (Gangewadiya), northern (Vidattaltivu Nature Reserve), and northeastern (Gangi, Upparu in Mahaweli river mouth) coastal belt (MoMD & E 2019).

13.1.1 Dynamics of Physiochemical Characteristics

Five types of mangroves, namely, riverine, fringing, scrub, over wash, and basin, have been identified in the island. This classification was based on the topography, flooding characteristics, and floristic composition (Balasubramaniam 1985). Many factors strongly influence the occurrence and growth of mangroves, and these include geographical latitude, wave action, rainfall, freshwater runoff, erosion/sedimentation rates, acidity, salinity, nutrient inputs, and soil quality (Perera et al. 2013). Research findings of Cooray et al. (Cooray et al. 2021) highlighted that soil pH, salinity, organic matter, K, Mg, Ca, Cu, Ni, Zn, and Mn were identified as fundamental soil chemical properties that preserve and support mangrove vegetation. In return, tree density, tree height, stand basal area, tree biomass, and vegetation complexity sustained the soil as primary forest structural attributes.

Kodikara et al. (2017) highlighted some physicochemical characteristic of mangroves in different climatic zones (Table 13.1), while De Silva and De Silva (1998) reported physicochemical characteristic of some mangroves (Table 13.2). The average air temperatures prevailing in the mangrove forests range from about 30 °C to 35 °C. The relative humidity is very high and ranges from 80% to >90%. The mean surface water temperature of the Negombo Lagoon was within the range of 29.8–30.1 °C, with seasonal temperature difference of 3–6 °C, as reported by Silva and De Silva (1981) and Rajapaksha 1997, respectively.

Table 13.1 Climate data and distribution of true mangroves with respect to different climatic zones (Source: Kodikara et al. 2017)

Climate zone	Mean annual rainfall (mm)	Average annual temperature (°C)	Tidal amplitude (ppt)	True mangrove species
Dry	<1750	31.5	0.4–0.6	11
Wet	>2500	28.5	0.5	10
Intermediate	1750–2500	30.0	0.5	16
Arid	<1250	32.5	0.4–0.6	11

Table 13.2 Some important physicochemical characteristics of water in selected mangrove forests (Source: De Silva and De Silva (1998))

Location	Climatic zone	Mangrove type	Temperature (°C)	pH	DO ppm	Salinity (ppt)
Negombo	WZ	HS/LS	27–31	7.5–8.3	4.6–8.7	18–32
Bentota	WZ	LS	26–30	6.1–7.2	5.1–8.8	0–8
Balapitiya	WZ	LS	26–31	6.4–7.6	4.1–8.1	0–6
Koggala	WZ	LS	27–32	6.6–8.2	4.5–9.2	0–12
Rekawa	WZ	HS	29–34	6.2–7.4	6.3–10.6	18–34
Ranna Oya	WZ	LS	28–32	6.2–7.3	5.2–8.3	3–9
Kalametiya-Lunama	WZ	LS	28–32	7.5–9.2	4.0–8.5	0–6
Menik River	DZ	HS	27–33	7.1–8.3	4.1–7.9	0–26
Kumbukkan Oya	DZ	LS	27–33	7.1–8.2	4.3–8.0	0–18
Batticaloa	DZ	HS	27–34	6.9–8.3	3.9–7.8	6–34
Mannar	DZ	HS	28–42	6.9–7.9	3.1–7.5	2–36
Kalpitiya	DZ	HS	28–41	7.3–8.2	3.1–8.1	21–36
Kala Oya	DZ	HS/LS	27–31	7.1–8.1	3.5–7.4	0–28
Mee Oya	DZ	HS/LS	27–31	6.9–8.1	4.1–8.3	0–25
Mundel	DZ	SC	27–35	7.1–8.4	4.5–9.1	15–45

DO dissolved oxygen, *WZ* wet zone, *DZ* dry zone, *HS* high salinity, *LS* low salinity, *SC* scrub

13.1.1.1 Soil and Sediments

The lagoons and estuaries contain alluvial deposits, and the soil consists mainly of silt and fine clay, although in some areas, sandy soil is found. The soil is waterlogged and consequently poorly aerated; in some locations, there is stagnant water (Perera and Amarasinghe 2019). The density of mangroves affected the granulometry and chemistry of accreting sediment and the belowground biomass of the trees. Sediments with finer textures also usually have higher nutrient concentrations, partly because of their greater ability to bind nutrients onto particle surfaces and within interstitial spaces (Phillips et al. 2017).

13.1.1.2 Salinity

The salinity in mangrove waters could vary from almost nil to more than that of seawater. Salinity depends mainly on the pattern and amount of freshwater discharge from nearby rivers, the tidal amplitude, and the topography and the extent of the estuary or lagoon. The salinity of Negombo Lagoon is strongly related to the monsoon rains (Silva and De Silva 1981; Rajapaksha 1997). The floristic composition and the species distribution of the mangrove depend on the level of salinity. In Kala Oya estuary, the *Avicennia marina* was the most salinity-tolerant species (13.25–23 mg/l) followed by *Rhizophora mucronata*, *Ceriops tagal*, and *Lumnitzera* *racemosa* (8 mg/l). *Excoecaria agallocha* was the least salt-tolerant species in the area (Perera et al. 2013). Further, this study showed that the soil salinity of 13 mg/l supports the highest mangrove species richness in the Kala Oya estuary. This might be the most favorable salinity regime for the majority of mangrove species of this area. Cooray et al. (Cooray et al. 2021) showed unlike other mangrove species recorded in Vidattaltivu, *Avicennia marina* thrived in elevated salinities (4.36–20.16 ppt).

13.1.1.3 Total Organic Carbon (TOC)

Mangroves are supreme agents in building blue carbon pools by capturing atmospheric carbon and storing them in biomass and soil. Anaerobic mangrove soils favor accumulation of partially decomposed organic matter that builds the carbon stocks over time. In the majority of mangrove areas, TOC stocks increased with depth and across the water-land gradient. An estimated magnitude of the carbon pools in Sri Lankan mangrove soils ranges from 316.29 to 580.84 Mg ha^{-1}. Mangrove soils of Rekawa Lagoon, located in the intermediate climatic zone, were found to be the largest soil carbon sink (580.84 Mg ha^{-1}) while that of Batticaloa Lagoon in the dry zone was the smallest (316.29 Mg ha^{-1}). TOC storage in mangrove soils depends on the annual rainfall of the country (Perera and Amarasinghe 2018).

The amount of total organic carbon (TOC) content embedded in plant biomass was calculated to be 158.57 Mg C ha^{-1}, out of which 131.60 Mg C ha^{-1} was in the aboveground and 26.96 Mg C ha^{-1} in the belowground parts of plants. The total standing biomass (298.71 Mg ha^{-1}) of mangrove ecosystems in the Batticaloa Lagoon therefore is greater than that in the Negombo estuary (163.72 Mg ha^{-1}) located in the wet zone (Perera and Amarasinghe 2018) and that in the Rekawa Lagoon (62.4–201.8 Mg ha^{-1}) situated in the intermediate climatic zone (Dayarathne and Kumara 2013).

13.1.1.4 pH and Redox Potential

Soil pH and redox potential were measured in dry, wet, intermediate, and arid zones. Soil pH for the mangrove soils in these zones ranged from 7.1 to 5. Mangrove soil in the wet zone showed significantly lower pH values as compared to the other zones. Redox potential at 30 cm ranged from +6 to −146 mV in all zones and was relatively higher in the intermediate and wet zones than in the dry and arid zones (Kodikara et al. 2017). However, in Vidattaltivu mangrove (dry zone), soil redox potential values ranged between 14.30 mV and − 39.80 mV, and pH values range from 4.64 to 7.29 (Cooray et al. 2021). Cooray et al. (Cooray et al. 2021) showed that the concentrations of most plant micronutrients (except Cu) decreased with increasing soil pH.

13.2 Floral Biodiversity of Mangroves in Sri Lanka

The total extent of mangroves in Sri Lanka was 15,670 ha (Edirisinghe et al. 2012) but has recently been revised to 15,981 ha (Arulnayagam et al. 2021) and 19,726 ha by the Forestry Department (Piyasiri et al. 2017). These mangroves are mostly associated with lagoons and estuaries in the coastal area of the country, and as a result, sparse distribution can be seen (Figs. 13.2 and 13.3). Distribution of mangroves is mostly in Jaffna, Trincomalee, Batticaloa, and Puttalam districts and to a lesser extent in southern coastal districts. In Sri Lanka, mangroves are usually limited to narrow belts because of the low (75 cm) tidal amplitude (Ranawana 2017; Karunathilake 2003).

Mangrove plant species are of two types, "true mangroves," species that are strictly limited to the mangrove environment, and "mangrove associates," species that are mainly distributed in a terrestrial or aquatic habitat but also occur in the mangrove ecosystem (Tomlinson 1994). The exact number of true mangrove species in Sri Lanka is erratic due to conflicting number of species reported in the literature by different authors which ranges from 16 to 29 species (Amarasinghe 1996; Arulchelvam 1968; Jayatissa et al. 2002; Jayatissa 2012). However, 21 true mangrove species (Table 13.3) are widely accepted (Jayatissa 2012). The most common and widely distributed are *Avicennia marina*, *Rhizophora mucronata*, *R. apiculata*, *Bruguiera gymnorhiza*, *B. sexangula*, *Excoecaria agallocha*, *Sonneratia caseolaris*, *Aegiceras corniculatum*, and *Lumnitzera racemosa* whereas *L. littorea*, *Xylocarpus granatum*, and *Scyphiphora hydrophyllacea* have limited distribution.

The exact number of mangrove associate species is also ambiguous due to conflicting reports, for example, Jayatissa et al. (2002) listed 18 mangrove associates which included *Acanthus ilicifolius*, *Acrostichum aureum*, *Cynometra iripa*, and *Xylocarpus rumphii* while some authors considered these species as true mangroves (Amarasinghe 1996; Arulchelvam 1968). Karunathilake (2003) mentioned that more than 25 plant species can be identified as mangrove associates and it depends on the edaphic and climatic factors of the habitat.

Based on the distribution of annual rainfall, Sri Lanka is mainly divided into three different climatic zones, namely, dry, wet, and intermediate. Interestingly, uneven species distribution is recorded by different authors within these climatic zones. For instance, the number of true and associate mangroves in the intermediate zone is 16 and 10, respectively. However, the number of true and associate mangroves in the wet or dry zones is 10–11 and 12–14, respectively (Jayatissa et al. 2002; Kodikara et al. 2017). However, Prasanna et al. (2017) have done a survey completely in the dry zone of the country covering 786 km (76% of the total mangrove area in the country) and reported 18 out of 21 true mangroves with the other three species confined to wet and intermediate zones.

Fig. 13.2 Flowering mangroves in Sri Lanka. (Mangrove associates: *Dolichandrone spathacea*, *Ardisia elliptica*, *Clerodendrum inerme*, *Cynometra iripa*, and *Acanthus ilicifolius*). (Photo courtesy: Gehan Jayasuriya and Malaka Wijayasinghe)

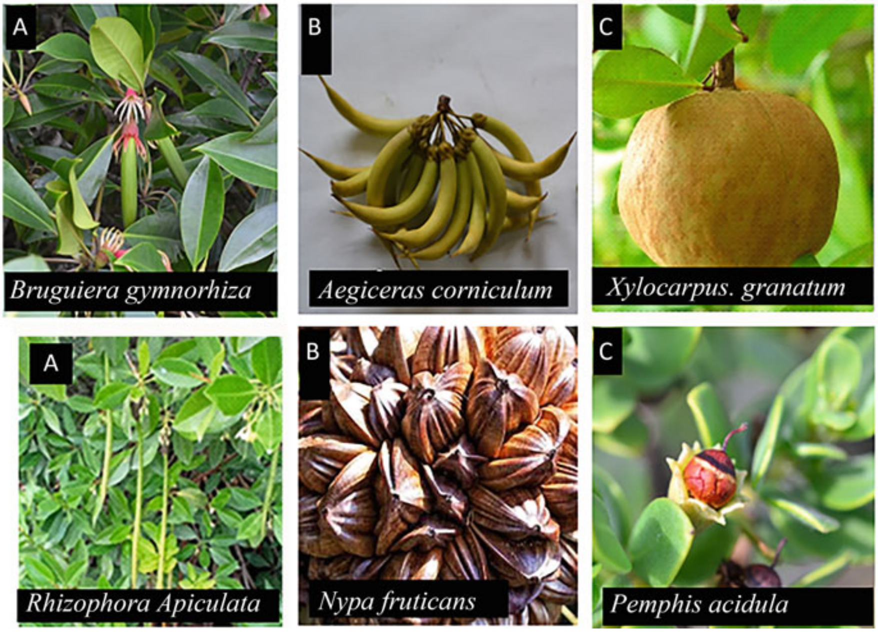

Fig. 13.3 Different types of fruits of true mangrove species in Sri Lanka according to their germination behavior: (**a**) true viviparous, (**b**) crypto-viviparous, and (**c**) non-viviparous (Photo courtesy: Gehan Jayasuriya and Malaka Wijayasinghe)

13.3 Faunal Biodiversity of Mangroves in Sri Lanka

13.3.1 Mangrove Fauna

Mangrove ecosystems are unique as they provide a variety of habitats for both invertebrate and vertebrate groups and provide nesting, breeding, and feeding grounds to a variety of marine and brackish species. The diversity of fauna in Sri Lankan mangroves is immense but is relatively poorly studied (Priyadarshani et al. 2010). However, a total of 99 invertebrates and 214 vertebrates have been reported so far, although most studies have been concentrated on the southwestern coast with Negombo as a hotspot for mangrove research (Arulnayagam et al. 2021).

13.3.1.1 Invertebrate Fauna

The mudflats of the mangrove forests are supporting various types of invertebrates including phylum Nematoda, Annelida, Mollusca, and Arthropoda. A total of 99 invertebrates dominated by 55 species of Arthropoda, and 26 species of Mollusca, with Nematoda ($n = 17$) and Annelids ($n = 26$) species, is also recorded from different mangrove sites in Sri Lanka (Arulnayagam et al. 2021).

Table 13.3 List of true mangrove species in Sri Lanka (Source: Jayatissa 2012) and their viviparity

Family	Species	Viviparity
Avicenniaceae	*Avicennia marina*	Crypto-viviparous
	Avicennia officinalis	Crypto-viviparous
Combretaceae	*Lumnitzera littorea*	Non-viviparous
	Lumnitzera racemosa	Non-viviparous
Euphorbiaceae	*Excoecaria agallocha*	Non-viviparous
	Excoecaria indica	Non-viviparous
Lythraceae	*Pemphis acidula*	Non-viviparous
Meliaceae	*Xylocarpus granatum*	Non-viviparous
Arecaceae	*Nypa fruticans*	Crypto-viviparous
Primulaceae	*Aegiceras corniculatum*	Crypto-viviparous
Rhizophoraceae	*Rhizophora apiculata*	Viviparous
	Rhizophora mucronata	Viviparous
	Bruguiera cylindrica	Viviparous
	Bruguiera gymnorhiza	Viviparous
	Bruguiera sexangula	Viviparous
	Ceriops decandra	Viviparous
	Ceriops tagal	Viviparous
Rubiaceae	*Scyphiphora hydrophyllacea*	Non-viviparous
Sonneratiaceae	*Sonneratia alba*	Non-viviparous
	Sonneratia caseolaris	Non-viviparous
Sterculiaceae	*Heritiera littoralis*	Non-viviparous

13.3.1.2 The Crab Fauna (Crustacea: Brachyura)

Out of 55 species of Arthropoda, crabs (Crustacea: Brachyura) are the dominant macrofaunal group (Table 13.4); 19 crab species from family Ocypodidae, Grapsidae, and Portunidae are recorded common in all large mangrove forests. In the muddy mangrove islets, there are numerous species of terrestrial crabs, commonly called mud crabs belonging to the family Grapsidae, which include *Chiromantes* spp. (mud crab), *Neosarmatium* spp., and *Neoepisesarma* spp. (De Silva and De Silva 1998). Most of the organisms in the mangrove swamp are burrowers, and they help to recycle nutrients, bringing subsoil to the surface, while feeding. *Neosermatium smithi* make complex burrows, but when the burrows are flooded, they build mud turrets reinforced by a stem of a small tree, so that they could maintain the burrow environment above the ground. *Neosermatium malbaricum* make T-shaped burrows, so that they can run into either branch of the burrow to avoid danger. *Chiromantes darwinensis* and *Chiromantes indiarum* often do not make neat burrows but find refuge in the crevices of puddles. The crabs of the family Ocypodidae, the fiddler crabs, occur on mudflats. *Uca dussumieri* and *Uca lacteal* were recorded from several mangrove forests in Sri Lanka. They all disappear into their burrows at the slightest shadow of danger. Another ocypodid, *Macrophthalmus*

Table 13.4 List of crab species recorded from Sri Lankan mangroves

Class	Order	Family	Species name	English name
Malacostraca	Decapoda	Grapsidae/ Sesarmidae	*Episesarma versicolor*	Violet vinegar crab
			Metopograpsus thukuhar	Thukuhar shore crab
			Metopograpsus messor	Tree climber crab
			Perisesarma guttatum	Red-claw man-grove crab
			Neosermatium smithi	Red spider crab
			Neosermatium malbaricum	
			Chiromantes darwinensis Sesarma (Chiromantes) darwinensis	
			Chiromantes indiarum Sesarma (Perisesarma) indiarum	
		Ocypodidae	*Uca [Tubuca] dussumieri*	Dussumier's fid-dler crab
			Uca lactea	Fiddler crab
		Portunidae	*Portunus sanguinolentus*	Three-spot swim-ming crab
			Portunus pelagicus	Blue swimmer crab
		Portunidae	*Scylla serrata*	Mud crab
			Thalamita crenata	Spiny rock crab
		Varunidae	*Pyxidognathus deianira*	
		Thalassinidae	*Thalassina anomala*	Scorpion mud lobster
		Paguridae	*Eupagurus* sp.	Hermit crabs
	Isopoda	Sphaeromatidae	*Spheroma verrucauda*	

Sources: Arulnayagam et al. 2021, Sarachchandra et al. 2018, Jayasingham 2008, De Silva and De Silva 1998

depressus, is also found on these mudflats but prefers to remain submerged, with its long-stalked eyes above water, scanning the environment, as a submarine periscope.

The fiddler crab *Uca* spp. is found in mudflats within as well as outside the mangrove forests (De Silva and De Silva 1998). Males swing their large colorful claw to attract the females, but often females pay little attention. They all disappear into their burrows at the slightest shadow of danger. Hermit crabs *Eupagurus* sp. and *Pagurus* sp. were seen in all mangrove forests. The portunid crab *Scylla serrata*, which is commercially important in Sri Lanka, was found ubiquitously in all lagoons and estuaries examined but is especially common in Kalpitiya lagoon, eastern province, Negombo, and Chilaw (Sarathchandra et al. 2018; Jayasingham 2008; De Silva and De Silva 1998). The Anomuran *Thalassina anomala* (scorpion mud lobster) was seen in Mannar, Kalpitiya, Mi Oya, Kala Oya, and Negombo and Batticaloa mangrove forests.

13.3.1.3 Other Crustaceans

Twelve species of prawns and shrimps have been recorded from mangrove-associated habitat in Sri Lanka. Several species of peneid prawns were seen in lagoons and estuaries, of which the common species of commercial importance were *Penaeus indicus* (Indian banana prawn), *P. semisulcatus* (green tiger prawn), *Metapenaeus dobsoni* (Kadal shrimp), and *P. monodon* (tiger prawn). *Penaeus semisulcatus* is common in Kalpitiya area but is rare in the wet zone. *Macrobrachium* spp. (family Palaemonidae) is common in the estuaries of both dry and wet zones; *Metapenaeus rosenbergii* is the commonest species, but *Metapenaeus scabriculum* is also frequent. Atyid shrimps such as *Atyopsis spinipes*, *Caridina zeylanica*, *Caridina propinqua*, and *Caridina gracilirostris* were also recorded (De Silva and De Silva 1998; Jayasiri and Haputhantri 2015; Jayasingham 2008).

13.3.1.4 Mollusca

The most abundant bivalve families are Mytilidae and Veneridae. The bivalves, *Anadara* spp., *Geloina ceylonica*, and *Gafrarium tumidum*, are common in the mud in the shallow lagoons and estuaries in the dry zone and are found among sea grasses and occasionally within mangrove forests. The oysters, *Crassostrea* spp., are seen attached to the submerged roots of *Rhizophora* spp., etc. and in the shallow regions of all lagoons and estuaries. *Perna* spp., *Marcia* spp., *Pinna bicolor*, and the gastropod *Pleuroploca trapezium* were found in the lagoons and estuaries of the dry zone. *Littorina scabra* and *Nerita polita* are found in both the wet and the dry zone mangrove forests (De Silva and De Silva 1998; Jayasiri and Haputhantri 2015; Jayasingham 2008).

13.3.1.5 Polychetes

Polychetous annelids representing 16 families and 36 species (*Erantia*, 22 spp.; *Sedentaria*, 14 spp.) constituted 40% of the total macrofauna in Negombo Lagoon (Dahanayaka et al. 2008). Families with highest species richness are Nereididae (7 spp.), Peloridiidae (3 spp.), and Spionidae (3 spp.). Pilargidiids and Heterospionids are dominated in most of the areas of the lagoon. Low diversity or absolute absence of polychete was recorded from the mouth region and deeper areas of the middle region of the lagoon.

13.3.1.6 Zooplankton

Copepods and nauplii are common in the zooplankton of all lagoons and estuaries. However, some differences in the zooplankton in the wet zone and dry zone lagoons and estuaries were observed. In dry zone lagoons such as Kalpitiya and Batticaloa, the dominant zooplankton are *Caprella* spp. and *Noctiluca* spp., while *Ceratium* spp., Dinoflagellata, Cladocerans, and rotifers are dominated in the wet zone lagoons such as Negombo Lagoon (De Silva and De Silva 1998; Jayasiri and Haputhantri 2015). Only three locations have been studied so there is a limitation in assessing microfaunal diversity, and the reason for such a drop is still unknown.

13.3.2 Vertebrates

There are 214 vertebrates comprising 112 species of ichthyofauna, 2 species of amphibian, 13 species of reptilian, 72 species of avifauna, and 15 mammal species (Arulnayagam et al. 2021). The vertebrate fauna mainly depends upon the composition of the fauna of the surrounding area as most mangrove forests in Sri Lanka are rather restricted in size.

13.3.2.1 Ichthyofauna

Much of the ichthyofaunal community associated with estuaries are marine, followed by brackish and then freshwater species. Within Sri Lanka, mangroves also act as nursery grounds for marine species that are economically significant to the national fishing industry (Sarathchandra et al. 2018). Mugilids, carangids, cichlids, siganids, centropomids, and gobiids are a few of the common estuarine fish species associated with mangrove forests found in lagoons and estuaries as well as over 150 recorded species within mangrove forest-associated lagoons and estuaries (De Silva and De Silva 1998). Despite the existence of many common species depending on the prevailing salinity, the fish fauna differs somewhat in the wet zone and dry zone estuaries and lagoons. Glass eels and juvenile eels are also seen within the waters among the prop roots of *Rhizophora* spp. Bambaradeniya et al. (Bambaradeniya et al. 2002a) recorded some endemic fish species, namely, Sri Lanka filamented barb (*Dawkinsia singhala*) and near-threatened Sri Lanka walking catfish (*Clarias brachysoma*) and threatened Horadandia (*Horadandia atukorali*), from Maduganga mangrove areas. The mudskipper *Periophthalmus koelreuteri* is a regular occurrence on mudflats and among the prop roots of *Rhizophora* spp. in both the wet and dry zone mangroves (Fig. 13.4).

Fig. 13.4 *Periophthalmus koelreuteri*. (Photo courtesy: Damindu Wijewardana)

Table 13.5 Some common species of reptiles, avifauna, and mammal species recorded from different mangrove forests in Sri Lanka

Taxa	Common species
Class Reptilia	Green garden lizard (*Calotes calotes*), common garden (*Calotes versicolor*), common house gecko (*Hemidactylus frenatus*), python (*Python molurus*), mugger crocodile (*Crocodylus palustris*), saltwater crocodile (*Crocodylus porosus*), monitor (*Varanus salvator*), etc
Class Aves	Whiskered tern (*Chlidonias hybrida*), gray heron (*Ardea cinerea*), Indian pond heron (*Ardeola grayii*), great egret (*Casmerodius albus*), intermediate egret (*Mesophoyx intermedia*), little cormorant (*Phalacrocorax niger*), common myna (*Acridotheres tristis*), barn swallow (*Hirundo rustica*), etc
Class Mammalia	Sri Lanka toque monkey (*Macaca sinica*), gray mongoose (*Herpestes edwardsii*), mouse deer (*Moschiola meminna*), wild boar (*Sus scrofa*), fishing cat (*Prionailurus viverrinus*), otter (*Lutra lutra*), jackal (*Canis aureus*), spotted deer (*Axis axis*), etc

Sources: Jayasingham (Jayasingham 2008); Prakash et al. (2017); Priyashantha (2018); Arulnayagam et al. (2021)

13.3.2.2 Amphibians

The common toad *Bufo melanostictus* and the common frog *Limnonectes limnocharis* are the only species of amphibians observed within the mangrove forests, due to the prevailing saline conditions (Arulnayagam et al. 2021).

13.3.2.3 Reptiles

Water snake (*Xenochrophis piscator)*, python (*Python molurus*), cobra (*Naja naja*), crocodile species, and some lizards were observed within mangrove forests (Table 13.5). There were 13 species recorded from different mangrove forests from Rekawa Lagoon, Madu Ganga Estuary, Chilaw and Puttalam lagoons, and

Mundel Lake, located on the northwest coast of the island (Bambaradeniya et al. Bambaradeniya et al. 2002a, b; Arulnayagam et al. 2021).

13.3.2.4 Avifauna

Detailed studies on birds occupying mangroves and related habitats have been conducted in the Negombo Lagoon and nearby Muthurajawela Wetland Sanctuary (Bambaradeniya et al. 2002b), Rekawa Lagoon, Madu Ganga Estuary, Chilaw and Puttalam lagoons, and Mundel Lake, located on the northwest coast of the island (Katupotha 2012). Avifaunal diversity includes a wide range of cormorants, ducks, egrets, gulls, herons, etc. Mangrove wetlands play an important role in attracting migratory birds at any phase of their life cycle, seeking their food in the creeks and channels and nesting in the trees. Arulnayagam et al. (2021) recorded 72 species of avifauna from the different locations of mangroves, and Table 13.5 shows some common avifaunal species in mangrove forests.

13.3.2.5 Mammals

Mammalian fauna are mostly visitors. Many mammals were observed in forests associating with mangrove associates, but only a few species such as bats or rodents were observed in mangroves. In the mangrove forest of Pomparippu Ara-Kala Oya estuaries (in Wilpattu National Park) as well as in those of Menik River (including Katupila Ara and Agara Ara) and Kumbukkan Oya estuaries (in Ruhuna National Park), tracks and dung/scat piles of many mammal species including the elephant (*Elephas maximus*), water buffalo (*Bubalus bubalis*), sambar (*Cervus unicolor*), leopard (*Panthera pardus*), and sloth bear (*Melursus ursinus*) were seen (Table 13.5).

13.4 Ecosystem Services

Mangroves are one of the vital tropical and subtropical coastal ecosystems with a significant amount of the global biodiversity and provide a wide range of ecosystem services that contribute to human well-being (Polanía and Agudelo 2015). Mangroves are the coastal equivalent of tropical forests and hence of important ecological and environmental significance. Sri Lanka is a tropical island with ~1760 km coastline harboring ~1210 km^2 of highly productive lagoon and estuary ecosystems (Harkes 2015). Mangrove areas in Sri Lanka cover less than 0.01% of the land area, due to the very low tidal amplitude the distribution of mangroves is confined to a narrow intertidal belt having a patchy distribution. However, as the coastline runs through different climatic zones and different geomorphological settings, the diversity of mangrove habitats is remarkably high, and hence the species diversity also in mangroves is comparatively high. Mangroves protect Sri Lanka's coastline from sea erosion, while providing diverse livelihoods to the locals. Despite these important services, mangroves are cleared for development activities that have undesirable effects on the well-being of mangrove-dependent communities and the country's economy. Therefore, prior to the implementation of any development activity, it is vital that the biodiversity, ecosystem services, and conservation status of mangroves are assessed.

Deterioration of mangrove vegetation is considered to be one of the main causes for the reduction in fish harvest (Wickramasinghe 1997), and a reduced yield in fisheries may seriously affect the nutrition of local communities. As an example from the Sri Lankan context, an analysis of the data available from the Pambala-Chilaw lagoon complex shows that the fish catch from the lagoon per unit effort has dropped on average from 4 to 1.5 kg between 1994 and 1997 (Wickramasinghe 1997). Similar situations prevail in a majority of the lagoons in Sri Lanka.

The ecosystem services provided by mangroves include riverbank and shoreline stabilization, flood control, groundwater recharge, and pollution control. They also act as breeding and spawning grounds for commercially important marine life such as finfish and crustaceans. In summary, mangrove communities are economically and ecologically valuable and are one of the most productive ecosystems in the world. Coastal communities depend on the interactions and processes that take place within these ecosystems and the valuable services provided by them. Four main types of services are provided by mangroves which can be categorized as follows.

13.4.1 Provisioning Services

These are the direct goods provided by mangrove habitats which can be used for consumption and sale.

13.4.2 Food

Mangroves serve as nursery grounds for many fish and crustacean species, some of which are harvested on a commercial basis. The closely packed pneumatophores and prop roots do not allow larger predators to enter the mangrove environment, providing a safe nursery ground for juveniles, with sufficient food material. Over 40,000 fisher families depend on fishing in estuaries and lagoons containing mangroves, salt marshes, and sea grass beds as a source of income. Mangroves support shrimp farming and traditional fisheries such as brush pile and fish kraals. The highest dependence of local communities on mangrove fisheries has been recorded from Puttalam lagoon, Mi Oya estuary, Chilaw lagoon, and Negombo Lagoon, respectively.

13.4.3 Timber and Fuelwood

Globally, the timber of mangrove flora is used to make furniture, rafters, fences, bridges, poles, boats, and houses. Unlike the mangroves in Southeast Asia, the low standing stock of timber in Sri Lankan mangroves prevent them being used as timber or charcoal on a large scale. In Sri Lanka, mangrove timber is used sparingly for construction, especially for building of temporary housing for the fishing communities near the sea or lagoon. Mangroves are used as firewood in some northwestern coastal areas where no other vegetation exists substantially to be used for this purpose. Light woods are used for mask carving and puppet production. In Negombo Lagoon, wood of *R. mucronata* and *L. racemosa* are used primarily to construct "brush piles," a widely used traditional fishing technique. *R. mucronata* and *L. racemosa* are the most preferred species for the purpose because of their greater durability (due to the presence of tannin) and profuse branching. Mature branches are cut, and the leaves are shed before taking these branches into the predetermined shallow areas of the lagoon and placed close to each other so as to make a square or circular pile of brush in the water. The brush piles mimic mangrove areas, and they provide food and refuge particularly to the juveniles of finfish and shellfish and therefore serve as fish aggregation centers. After a few weeks, depending on the time of the year, brush parks are surrounded with a net, and the mangrove twigs and branches are removed to catch the fish with a scoop net. Brush parks installed in deeper waters are made out of coconut trunks at the margins in order to prevent the twigs being washed away by the moving water. Brush pile fishery in Negombo Lagoon is an incentive for local fishermen to cultivate mangroves, a traditional practice that has been mastered by indigenous communities. Some of the mangrove woodlots that they cultivate particularly in the mudflats of the northern part of the lagoon, near the sea mouth, are maintained with methods that are on par with modern silvicultural practices (Amarasinghe 2009).

13.4.4 Medicines

About 70 different mangrove plant species are listed as having traditional medicinal uses. *Bruguiera*, *Rhizophora*, and *Lumnitzera* are used for the treatment of various ailments and diseases.

13.4.5 Other Non-timber Forest Products

The leaves of many species such as *Nypa* are used for thatching and weaving. The breathing roots of various *Sonneratia* spp. are used to make corks and fish floats. Mangrove plants are also used as sources of sodium, while the ash produced from burning species such as *Avicennia* is used to make soap. The bark of many species produces resins and tannins which are used for curing leather and fish nets. Beach seine fishermen along the western and southern coasts of Sri Lanka use tannin to enhance the durability of their nets. Tannin that is added to dyes used for dying the sails of traditional crafts is obtained from bark collected from mangrove areas of the Puttalam lagoon (Amarasinghe 2009).

13.5 Regulating Services

These are the benefits obtained from the regulation of ecosystem processes such as climate and flood regulation.

13.5.1 Protecting the Shoreline

Mangroves are able to resist the strong forces of wave and wind energy by providing resistance and drag. They are able to absorb between 70% and 90% of the energy of the waves, thereby reducing the strength of waves and currents, resulting in less damage to coastal areas. This protective function is important in shielding coastal communities during natural disasters such as storm surges and cyclones.

13.5.2 Trapping Pollutants

Mangrove roots help to improve the purity of water by filtering out pollutants that reach the sea from inland waters (Amarasinghe 2009).

13.5.3 Supporting Services

These are ecosystem services that are necessary for the production of all other ecosystem services.

13.5.4 Biodiversity

Mangrove ecosystems carry a unique variety of flora and fauna that is not found in any other ecosystem. Organisms occupy habitats associated with the roots, both above and below water level, mangrove soil, stems, bark, leaves, branches, and canopy. The Maduganga estuary in Southwestern Sri Lanka has 303 species of plants and 248 vertebrate species (70 fish, 12 amphibians, 31 reptiles, 124 birds, 24 mammals) (Amarasinghe 2009).

13.5.5 Sequestering Carbon

Carbon sequestration is the process through which plant life removes CO_2 from the atmosphere and stores it as biomass. Therefore, plants are referred to as carbon sinks. Globally, mangroves are important carbon sinks, and measurements suggest that they can capture as much as 1.5 tons of carbon per hectare per year. They also provide more than 10% of essential dissolved organic carbon (i.e., carbon-based nutrients released into the water due to decomposing plant matter) that is supplied to the global oceans from land (Amarasinghe 2009; Perera and Amarasinghe 2018).

13.5.6 Retention/Detention of Sediments

The wide and tangled root system of mangroves is able to trap sediment and prevent it from washing into the sea. This trapping also protects coral reefs from sedimentation. *Avicennia marina* may be the best land stabilizer because of its quick aerial root production and pneumatophores that increase sediment holding capabilities. The roots function to build up sediment, stabilizing the ground and fixing mud banks, thereby preventing erosion. Communities around estuaries and lagoons plant mangroves to protect their land and properties from erosion. In the Negombo Lagoon, a few rows of *R. mucronata* have been planted along the waterfront to form a fence, which protects the land from erosion caused by turbulent estuarine and lagoon waters (Amarasinghe 2009).

13.5.7 Primary Production

Like all green plants, the mangroves manufacture their own food through the process of photosynthesis. Organic matter which is produced by photosynthesis of mangrove plants is the major source of energy available for organisms in coastal waters. It is decomposed by microorganisms into detritus on which most fish, crustaceans, and mollusks are directly dependent on as a source of food. Decaying organic matter from mangroves is broken down into nutrients that are washed into the sea every time the tide goes out. Annually, this amounts to an estimated 12,500 tons of food for marine life (Amarasinghe 2009). This enriches coastal food webs and coastal fishery production.

13.5.8 Aesthetic Services

People obtain nonmaterial benefits from ecosystems through spiritual enrichment, development of learning, recreation, and aesthetic experience. Mangroves provide a recreational habitat for visitors. Mangrove areas on the southwestern coasts – particularly Bentota, Maduganga, and Kaluwamodera estuaries – are used for ecotourism and recreation. Nature observation, recreational fishing, and canoeing are popular leisure activities among tourists. Unfortunately, heavy use of speed boats in the Bentota River has uprooted mangroves in some areas (Amarasinghe 2009).

13.6 Livelihoods

Many mangrove resources are harvested for subsistence purposes (e.g., fuelwood, edible plants, honey, etc.). Local communities settled near mangrove areas are heavily dependent on mangroves for their livelihood. Satyanarayana et al. (2013) highlighted that branches of *Avicennia* spp. are used for brush pile traditional fisheries. Prop roots from mangrove species like *Rhizophora apiculata* are used as fuelwood. Tender leaves of *Avicennia marina* are used as a vegetable (Katupotha 2012). Wood of *Cerbera manghas* is used by Sri Lankans to carve masks and puppets because of its light weight (Miththapala 2008). Moreover, *Nypa fruticans* is used to make alcohol, sugar, and vinegar though in Sri Lanka, it is minimally practiced at present (Ranawana 2017). Tender leaves of *Sonneratia caseolaris* are traditionally used as a curry, and water from the boiled leaves are used as an anti-poison (Bandaranayake 1999). In addition, fruitsof *S. caseolaris* are used to prepare a soft drink (Ranawana 2017). Leaves of *Acrostichum aureum* and *Suaeda maritima* are also used as vegetables (Priyashantha and Taufikurahma 2020). Pneumatophores of *Sonneratia* spp. are porous and used as bottle stoppers and fishing floats (Katupotha 2012).

Fishing is the most important economic activity in the coastal regions of Sri Lanka (Fig. 13.5), and many communities depend upon it for their livelihood as

Fig. 13.5 Fishing is the most important economic activity in the mangrove ecosystem. (Photo courtesy: Sriyani Wickramasinghe and Damindu Wijewardana)

fishery activities provide income for traditional and marginalized groups (Polanía and Agudelo 2015). Fish also constitutes approximately 65% of the animal protein consumption and 13% of the total protein intake for the population of Sri Lanka (Rajasuriya et al. 1995). It is estimated that two-thirds of the world's fishing communities depend on the existence of mangroves (FAO 2003; Rönnbäck 1999). Mangrove areas provide food and shelter for many commercially important aquatic species, and a positive correlation has been observed between near shore coastal shrimp and fish catches and mangrove area cover (Singh et al. 1994; Baran and Hambrey 1998; de Graaf and Xuan 1998; Rönnbäck 1999).

A community survey was conducted in the Northwestern Sri Lanka enlisting all the products collected from the mangrove ecosystem, the amount of each product obtained and if any of these products are sold rather than just used in the household then any selling-buying procedure, the market price of the product and thus the total family value for the products to understand the community livelihoods, the monthly income of each livelihood and the community living pattern in relation to the mangrove ecosystem.

In the northwest of Sri Lanka, mangrove and offshore fisheries are two of the most important livelihood activities associated with mangroves. Most households reported fish, shrimps, crabs, and bivalves (in order of preference) obtained from this mangrove environment, and the fishing activities were observed all along the lagoon. The fish, crabs, shrimps, and edible bivalves were caught using various fishing gears such as fishing lines, dip nets, cast nets, and fishing traps. Travel cost methodology was not able to be used due to the absence of reliable tourism data and information on the number of guests, room rates, and reasons for visit in any of the study sites.

The head of households were interviewed about their use of mangroves as construction material (for making boats or houses, fishing stakes, etc.), fuelwood, as medicinal and edible plants, and about other non-timber forest products (masks, hats, and ornaments). In the case of fuelwood, questions were asked about their preferences for mangrove wood (including for personal use and for sales), in contrast to wood from non-mangrove trees and/or nonwoody resources such as gas and kerosene. The same methods were used to identify the role of mangroves as suppliers of edible plants (with emphasis on its uses, collection, selling practices, and people's preferences), together with reasons for decreased consumption over time (more details are available on https://www.mdpi.com/1424-2818/10/2/20). In summary, in the northwestern area of Sri Lanka, *Bruguiera*, *Rhizophora*, and *Lumnitzera* are used for the treatment of various ailments and diseases; the highest valuation is obtained from aquatic food, including fish, shrimp, crabs, and mollusks (Sarathchandra et al. 2018).

13.7 Threats

More than a third of the world's mangrove forests have disappeared in the last 50 years due to overexploitation and destruction of mangrove habitats. Globally, the rate of mangrove deforestation is between 2% and 8% per year. Some countries have lost more than 80% of their mangrove forest cover over the last 20 years. Shrimp aquaculture accounts for the loss of 20–50% of mangroves worldwide. It is predicted that developing countries will lose 25% of their remaining mangrove cover by 2050 (Amarasinghe 2009).

Mangroves are the coastal equivalent of tropical forests and hence of important ecological and environmental significance. In Sri Lanka, as in many other countries, conversion of mangrove forests to other uses has resulted in a considerable decline of these ecosystems (Legg and Jewell 1995). Despite their multiple values, mangroves are disappearing at an alarming rate. Less than half the original extent of mangroves remains in the world today, and the rate of loss is highest in the Indo-Malayan region which also has the highest mangrove diversity in the world. In Sri Lanka, with the increasing population in coastal areas, the demand for land has risen. Because of this, there is pressure to use intertidal coastal wetlands for development activities. As a result, the mangroves are among the world's most threatened ecosystems. Some major threats faced by mangroves in Sri Lanka include as follows.

13.7.1 Overexploitation of Mangrove Products

Most of the mangrove habitats are degraded because of overexploitation for fuel-wood and timber. In Puttalam lagoon, mangroves are overused heavily particularly for firewood and tannin (Fig. 13.6b).

Fig. 13.6 Discharge wastewater to the mangrove forest (**a**) and cutting mangroves for domestic use (**b**) (Photo courtesy: Damindu Wijewardana)

13.7.2 Habitat Destruction

Coastal development, land conversion for aquaculture, salt pond (saltern) construction, and agriculture contribute to degradation of mangrove habitats. Mangrove areas are cleared for highway construction, hotel construction, and human settlements. This has resulted in altered hydrology at Mi Oya estuary, loss of prawn species in Chilaw lagoon, and a decline in fishery resources in Mundel Lake. Mangroves are affected seriously by inland freshwater diversion schemes for irrigation. It is estimated that 11% of mangrove habitats are degraded globally because of inland water extraction. In areas such as the Kalametiya Lagoon, diverse mangrove stands have been replaced by monospecific *Sonneratia caseolaris* stands due to the release of excess freshwater into the lagoon.

One of the major factors that have led to their destruction in Sri Lanka is shrimp farming. Valiela et al. (2001) reported that the conversion of mangroves to aquaculture ponds is responsible for about 38% of the total mangrove loss that has occurred in the country. In addition to the direct destruction of mangroves, shrimp farming has also caused the degradation of water quality in lagoons and the loss of biodiversity in the remaining patches of vegetation (De Silva and de Silva 2002; Wolanski 2000). Local political patronage is one of the main causes for this adverse situation despite Sri Lanka being the first tropical country with a centrally managed integrated coastal zone management program (Clark 1996).

In Sri Lanka, shrimp farming did not start until the mid-1980s in the western coastal belt between Kalpitiya and Negombo, but there has been a rapid expansion in shrimp cultivation in recent years (Jayasinghe and De Silva 1993). In 1996, Sri Lanka produced 4000 metric tons of shrimp (*Penaeus monodon* Fabricius) at a value of US$ 540,000 (FAO 1998), and during the period 1985–1992, it contributed between 53% and 73% of the total foreign exchange earnings from the fishery sector (Jayasinghe and Macintoch 1993). As recently as 1997, the director of the Aquaculture Development Division, Ministry of Fisheries and Aquatic Resources in Sri Lanka stated that more areas were to be brought under shrimp farming (Jayasekara 1997).

The mangrove areas of Sri Lanka have been reduced and impoverished in quality under an increasing human pressure (Silva and Balasubramaniam 1984, Balasubramaniam 1985; Jayewardene 1986). In recent years, shrimp farming has emerged as a major threat to mangrove ecosystems in Sri Lanka (Jayasinghe and De Silva 1993). Conversion of such ecosystem to alternate development activities deprives all the beneficial uses of mangrove ecosystems and thus would adversely affect the well-being of mangrove-dependent communities, country's economy, and social welfare. In order to make sound judgments of development activities, it is vital that the uses and values of mangroves to local communities are identified and estimated.

Despite these beneficial uses of mangrove ecosystems, the vast amount of mangrove habitat has been destructed for commercial purposes specially converting to prawn farms. It was estimated that around 3385 ha of mangrove cover along the shores of Puttalam lagoon, Dutch Bay, and Portugal bay complex. A wide destruction has taken place from 1981 to 1992 leaving around 993 ha of mangrove cover in the Puttalam lagoon (Amarasinghe and Perera 1995).

13.7.3 Pollution

Inland farming, housing, and development result in chemical and sewage pollution (Fig. 13.6a), which can overfertilize coastal waters, causing the growth of "tides" of algae which can turn toxic and rapidly reduce productivity by blocking sunlight from reaching below the water surface (Amarasinghe 2009).

13.7.4 Invasive Alien Species (IAS)

IAS does not remain confined to the area into which they were introduced; they become established in natural ecosystems and threaten native species. IAS poses a threat to the provisioning services of mangroves. In Southwestern Sri Lanka, the mangroves are being affected by the spread of pond apple (*Annona glabra*) (Amarasinghe 2009).

13.7.5 Climate Change and Global Warming

In recent decades, global warming and climate change have become prominent threats. Changes in temperature, CO_2 levels, rainfall patterns, and increases in frequency of storms and hurricanes have been observed. Both global warming and climate change are directly linked to anthropogenic activities. Changes in precipitation as a result of climate change will affect growth, productivity, and seedling survival of mangroves. Decreased precipitation and increased salinity and salt water intrusion caused by the rise in sea levels could favor more salt-tolerant species and change species composition. Increased natural disasters will increase physical damage to mangroves.

Sea level rise will result in the loss of land occupied by mangroves. Changing wave climates increase coastal erosion and damage mangrove habitats. Climate change, in short, will have serious impacts on mangroves, which will, in turn, affect their ecosystem services (Amarasinghe 2009).

The climate of Sri Lanka has been fluctuating at an alarming rate during the recent past. These changes are reported to have significant impacts on the livelihoods of the people in the country. The mangrove ecosystem is especially vulnerable to the impacts from climate change because it is already depleting at an alarming rate due to anthropogenic activities (Khaniya et al. 2021) and inhabiting in the intertidal zone, thus more likely to be early indicators of the impact from climate change such as sea level rises (McLeod and Salm 2006; Nitto et al. 2014). Currently, relative sea level rises have been a lesser threat to mangroves when compared to non-climate-related anthropogenic stressors. However, more empirical studies should be conducted to understand the mangrove responses to sea level rises in Sri Lanka. For instance, more studies on the ability of the mangrove forest to migrate to more landward zones, salinity tolerance, seed dispersal, etc. are essential.

Mangrove species composition can strongly affect a mangrove's resilience and resistance to sea level rises. The accurate species composition in Sri Lanka is still uncertain, and the mangrove species present at each mangrove patch also need to be well assessed in a scientific manner in order to support future conservation efforts (Prasanna et al. 2017). Further, restoration practitioners and local authorities should keep pace with the scale changes predicted under most climate change scenarios (Huxham et al. 2010).

13.8 Regeneration of Mangroves/Silviculture

In general, mangroves regenerate naturally when they are in suitable conditions for their dispersal, germination, growth, and establishment. However, due to changes in geomorphological and hydrological conditions caused by anthropogenic activities or natural disasters, the natural regeneration of mangroves is hampered. For example, in 2004, Sri Lankan mangroves were severely damaged by the tsunami in the Indian Ocean; 1200 km of coastline was affected. As a consequence, the natural habitat of the mangroves altered and did not recover well. After 2004, Sri Lanka received international attention for mangrove restoration projects and a significant amount of funding (Kodikara et al. 2017) to aid these projects conducted by many governmental and nongovernmental organizations.

According to a study done by Kodikara et al. (2017), approximately 1000–1200 ha of mangroves have been planted in 23 sites in Sri Lanka, and 20 of them were established after the tsunami catastrophe (2004) (Fig. 13.7). Unfortunately, the study revealed that the current extent of the surviving planted area is only about 200–220 ha, only a 20% success rate. Furthermore, a total of 67 planting attempts were done during a period of 8 years, and 36 of them showed zero survival. Many restoration attempts were unsuccessful in tsunami-affected areas, while the majority of successful restoration sites were in areas unaffected by the tsunami (Kodikara et al. 2017). These restoration failures happen mainly due to lack of awareness or ignorance of the major ecological components of mangrove restoration sites such as hydrology, salinity, and species composition of each habitat. Additionally, involvement of untrained people with lack of expertise in mangrove restoration could worsen these restoration attempts. To overcome these problems, involvement of experts who have experience on mangrove restoration is essential (Elster 2000;

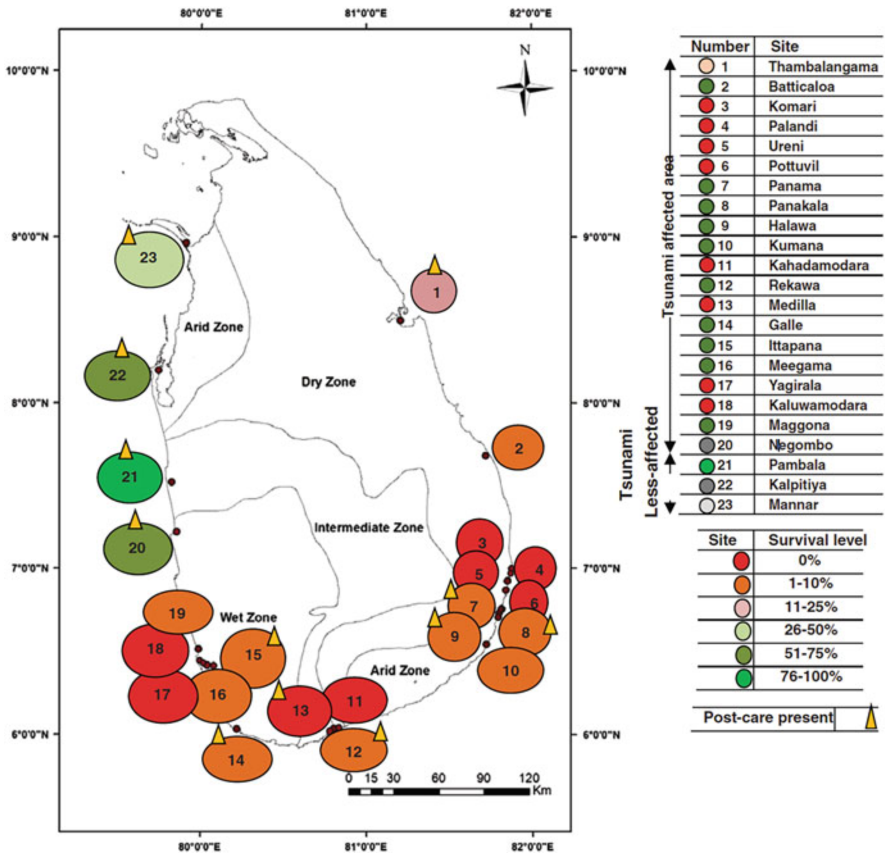

Fig. 13.7 Map showing the restoration project sites along the Sri Lankan coastline with respect to major climate zones. Black circles show the actual locations of restoration project sites. Different colors represent the level of success, and a yellow triangle shows the status of post-care in each site (Source: Kodikara et al. 2017)

Primavera and Esteban 2008; Ahmad 2012). Scientific understanding of the mangrove ecosystem is crucial together with some preliminary research on the particular restoration site. Additionally, proper post development activities should be scrutinized closely by collective efforts from all the pertinent authorities.

Germination behavior is one of the important characters that restoration practitioners should consider prior to restoration efforts. Interestingly, a wide range of germination behavior can be seen in mangrove plants. According to the germination behavior, mangrove species can be classified into two groups, viviparous and non-viviparous species. In viviparous species, germination and subsequent development of the propagule take place while the fruit is still attached to the mother plant (Tomlinson 1994), whereas in non-viviparous species, germination and subsequent development of the seeds/diaspore take place after seed dispersal (Tomlinson 1994; Baskin and Baskin 2014). There are seven true viviparous and four crypto-viviparous mangroves in Sri Lanka (Table 13.3).

The majority of mangrove regeneration efforts in Sri Lanka have been conducted by planting viviparous species such as *Rhizophora* spp. and *Bruguiera* spp., with the use of non-viviparous species (Fig. 13.4) for restoration projects used to a lesser extent (Kodikara et al. 2017). This happens due to many reasons, that is, direct seedling/propagule planting method is more feasible, propagules are easy to find from the wild in large amounts, maintenance in the nurseries is easy, and there is a lack of deep dormancies.

Knowledge on seed germination behavior (dormancy, dormancy-breaking requirements, and germination requirements) is crucial for meaningful conservation efforts of mangroves (Duke et al. 2007; Polidoro et al. 2010; Van Lavieren et al. 2012). Instead of collecting seedlings from the field, seedlings can be raised in nurseries for large-scale restoration activities. However, one of the major constraints faced in practicing this method is the lack of knowledge on seed germination behavior of most of the true mangrove and mangrove-associated species (Field 1998; Ellison 2000; Baskin and Baskin 2014). Seed germination and dormancy studies have been mainly conducted on viviparous mangrove species, while only a few studies have been reported on other mangrove and mangrove-associated species in Sri Lanka (Baskin and Baskin 2014). These seed dormancy studies are important to compare the relative importance of seed dormancy classes in mangrove plants (Baskin and Baskin 2014) and elucidate the dynamics of ecosystems (Skoglund 1992) and crucially in crafting strategies for conservation efforts.

De Silva and Amarasinghe (2021) mentioned that natural regeneration could be observed in some abandoned shrimp ponds around Chilaw lagoon area where there is less salinity relative to other abandoned ponds in other areas. They also mentioned that rehabilitation of abandoned ponds with high salinity has not been attempted yet and to do that, high salt-tolerant plants should be considered to improve the health of the degraded soil. Therefore, more research should be done in order to identify the mangrove species that can be germinated and established under high salt conditions.

Some studies have been conducted in Sri Lanka on the effect of salinity on mangrove seed germination, seedling, and establishment (Wijayasinghe et al. 2019; De Silva and Amarasinghe 2021; Kodikara et al. 2017). De Silva and Amarasinghe (2021) investigated the potential of using mangrove species for rehabilitation of high saline environments by revealing the capacities of species to remove salt from sediment with four viviparous species, namely, *Rhizophora apiculata*, *R. mucronata*, *Ceriops tagal*, and *Avicennia marina*, and they showed that the highest salt tolerance is in *A. marina* and the lowest is in *R. apiculata*. Therefore, *A. marina* appears to be the most suitable mangrove species not only for coastal mangrove restoration but also for rehabilitating salinity-affected landscapes. Kodikara et al. (2017) also studied the growth and survival of *R. apiculata*, *R. mucronata*, *A. marina*, *A. officinalis*, *Bruguiera gymnorrhiza*, and *B. sexangula* seedlings under three contrasting salinity treatments over a 30-week period, and they revealed that the low salinity treatment provided the best conditions for initial establishment and growth of the seedlings of all species until 15–20 weeks of age. However, the same seedlings showed better performance under moderate salinity after 15–20 weeks of age. This information is critical for species selection for restoration and adjusts the conditions when managing a nursery for restoration. However, more studies should be done in order to help restoration efforts be more successful.

13.9 Conservation

The Sri Lankan government has taken many steps in order to protect the valuable mangrove ecosystem including implementing legislations. Sri Lanka claims to be the first nation in the world to protect all its mangroves, making it illegal to cut them down anywhere in the island, and the first to open a mangrove museum (in Pambala, Chilaw). Sri Lanka was also named as a leader for conservation of mangroves in Commonwealth countries (Priyashantha and Taufikurahma 2020).

As the increasing demand for fish protein in the island and for the export market is leading to the overexploitation of fishery resources, it is a timely concern to develop sustainable fishery and aquaculture practices (Jalaldeen and Vinobaba 2010), which will eventually be an alternative to the depletion of a fishery resource and thus amend environmental pressure by becoming a stable source of income for Sri Lankan coastal people. Fishery resources are an asset to Sri Lanka; if managed efficiently and sustainably, it can be a major part of foreign export income. Therefore, it is essential to impose legal barriers prohibiting the use of illegal devices such as nets with a small mesh size that capture immature stages and spawning stages. However, if the people involved are not properly concerned on these issues, legal barriers will not serve any purpose, and ultimately if the lagoon and coastal fishery fail, fishermen will be the ones most affected. Therefore, awareness and education through mass media and extension services will do a great service to safeguard this invaluable resource in Sri Lanka.

Community surveys exploring suggestions from local people for the conservation of the mangrove ecosystems around them have received the following feedback:

- Implement policies and regulations on shrimp farming fairly.
- Provide job opportunities for skilled workers.
- Improve sanitation facilities.
- Introduce proper housing scheme systems.
- Pose strict fines for those who neglect rules and regulations.
- Remove barriers for marine fisheries.
- Construct a proper fishing port.
- Minimize political interventions in shrimp farming.

- Introduce alternative livelihoods.
- Build community-based ecological mangrove rehabilitation.
- Continue conducting more awareness programs but with solutions for the existing conflicts, not just information and what is happening.

Many coastal inhabitants do not understand the true economic value of the ecosystem forgone by destroying it though they have experience on depleting fishery products for the past few years. They are willing to contribute to any programs which will sustain both their livelihoods and ecosystem protection together. Continuing the assessment of the ecosystem status will help in conserving threatened ecosystems and informing government policy makers at what level and how political interventions should be involved, such as effective monitoring of mangrove ecosystems, arrangement of marketing facilities, and professional training on fish catch processing techniques.

Mangroves are great resources which need to be preserved; when dealing with coastal development in the phase of global climate change where rising sea levels are recorded, healthy mangrove forests are the best protectors of the coastline. Losing those means increasing the chances for coastal subsidence, erosion, and storm damage which will come with its own repairing cost. Therefore, mangrove swamps should not be seen as useless areas of vegetation to be cut down indiscriminately for aquaculture, agriculture, housing, and industrial development but as viable resources to be developed in a sustainable manner.

A positive recent development in mangrove conservation in Sri Lanka is that the government agreed to give legal protection to the remaining mangroves of the whole island totaling to a ~8800 ha and to reestablish another 3900 ha of mangroves (Huxham 2015) which hopefully will not be limited to papers and be practically implemented. In 2001, MOFE (Ministry of Finance and Economy), by way of Circular No 2001/5, empowered the Forest Department to manage all the mangrove resources in the country and take necessary action for their protection and development (IUCN 2001). Fourteen mangrove areas, in all, were surveyed and their boundaries demarcated and were declared as conservation forests in 2002 (IUCN 2011). Currently, the ministry of environment has drafted national guidelines, formats, and information for restoration of mangrove ecosystems and propagation of mangroves (MoMD & E 2019).

However, still, not enough attention has been paid to conserve the very rare and endangered mangrove species, and further steps have not been taken even to educate the locals about those species. In addition, any continuous observations or assessments have not been carried out on the conserved mangrove forests (Jayatissa et al. 2002).

13.10 Highlights of the Sri Lankan Mangrove Conservation Project

Highlights of the Sri Lankan Mangrove Conservation Project
Seacology, in collaboration with Sri Lanka-based NGO Sudeesa, is working to make Sri Lanka the world's first nation to protect all of its mangrove forests. The project has managed to replant over 1,200 acres of mangroves, and almost a million mangrove seedlings have been raised in new nurseries—double the project's goal. Business training programs have been conducted for more than 14,000 people, and almost 12,000 of them received microloans to start or improve their businesses. Small groups of women called the Community Beneficiary Organizations (CBOs) have been established in order to manage the process smoothly. Women in the community of Iranawila village, in Puttalam District, have been given three-day training sessions. One project participant opened a retail shop with Rs 10,000 microloan obtained from the microfinance components of the program. They now earn revenue of about Rs 1500 per day with a daily profit of about Rs 150. She is planning to get a second loan after repayment of the first to improve her business further. Another person initiated a tailoring business, which increased the family's income, while another started production of snacks with an Rs 10, 000 microloans.

Seacology Sudeesa established the Sri Lanka Mangrove Museum at Pambala North adjacent to the Chilaw lagoon. This, the key component of Sri Lanka Mangrove Conservation Project, was opened on July 26, 2016. The main objective is to educate locals and visiting eco tourists alike about the ecological and economic importance of mangroves and introduce thousands of guests to conservation and restoration of mangrove ecosystems in Sri Lanka.

The project has received substantial international recognition. The United Nations gave Seacology a UNFCCC Momentum for the Change Lighthouse Activity Award, recognizing the project's work to fight climate change. Further, Sudeesa received the 2019 Presidential Environment Award, presented by former Sri Lankan President, Mr. Maithripala Sirisena (https://www.seacology.org/project/sri-lanka-mangrove-conservation-project/).

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