Mangrove Forests: Distribution, Species Diversity, Roles, Threats and Conservation Strategies

Chapter · September 2021

DOI: 10.1002/9781119692621.ch12

14 authors, including:

Ajay Kumar
Central University of Kerala

Anju Thattantavide
Central University of Kerala

Archa Vijay

Sushil Kumar
Indian Institute of Integrative Medicine

12

Mangrove Forests: Distribution, Species Diversity, Roles, Threats and Conservation Strategies

Ajay Kumar[1], Thattantavide Anju[1], Vijay Archa[1], Vidya P. Warrier[1,2], Sushil Kumar[3], Ginkuntla Saikiran Goud[1], Arun Kumar Kashyap[4], Shuchita Singh[5], Komal[6], Pardeep Singh[7], Raj Kumar[8], Sanjeev Sharma[8], Arun M. Radhakrishnan[1], and Nirala Ramchiary[9]

[1] Department of Plant Science, School of Biological Sciences, Central University of Kerala, Kasaragod, Kerala, India
[2] Department of Biotechnology, Indian Institute of Technology, Madras, Chennai, Tamil Nadu, India
[3] Department of Botany, Government Degree College, Ramnagar, Jammu and Kashmir, India
[4] Department of Biotechnology, Government E. Raghavendra Rao PG Science College, Bilaspur, Chhattisgarh, India
[5] Lachoo Memorial College of Science and Technology, Jodhpur, Rajasthan, India
[6] Department of Higher Education, Government Degree College, Bani, Jammu and Kashmir, India
[7] Department of Environmental Studies, PGDAV College, University of Delhi, New Delhi, India
[8] Centre for the Study of Regional Development, School of Social Sciences, Jawaharlal Nehru University, New Delhi, India
[9] School of Life Sciences, Laboratory of Translational and Evolutionary Genomics, Jawaharlal Nehru University, New Delhi, India

12.1 Introduction

Mangroves are a group of trees and shrubs belonging to several families of flowering plants (Santisuk 1983, p. 63; Ricklefs and Latham 1993, p. 215). Owing to a large number of unique and special morphological, physiological, and anatomical modifications such as buttress root system, pneumatophores, root ultrafiltration systems, vivipary, salt secretion system, and cell wall composition, they can tolerate extreme saline coastal conditions and are adapted to narrow zone between the land and sea (Kathiresan and Bingham 2001; Dahdouh-Guebas et al. 2007; Liang et al. 2008). Mangroves are also known as tidal forests, marine forests, marsh forests, or ocean rain forests (Kathiresan and Bingham 2001; Naidoo 2016). The term "mangrove," in general, is used to encompass the unique plants belonging to different families having specialized characters that help them grow in a narrow intertidal zone between land and sea (Macnae 1968; Tomlinson 2016; Bibi et al. 2019). The term "mangal" is used for mangrove forest communities including other biotic components such as microbes and fungi, animals and other mangrove-associated plants (Macnae 1968; Bibi et al. 2019). Mangroves are a

Wetlands Conservation: Current Challenges and Future Strategies, First Edition.
Edited by Sanjeev Sharma and Pardeep Singh.

good source of numerous products such as food, honey, medicines (such as steroids, triterpenes, saponins, flavonoids, alkaloids, and tannin), timber and firewood, and services such as recreation, ecotourism, and aesthetics (Othman 1994, p. 277; Mazda et al. 1997; Kathiresan 2012; Guannel et al. 2016; Macreadie et al. 2017, p. 206; Owuor et al. 2019b). Timber from mangroves is used for constructing houses, furniture, house studs, rafters, joists, telegraph poles, walls, bridges, railway sleepers, fish trap poles, paddles and rafts, boats and paddleboards, and fuel (Bandaranayake 1998). Mangroves help in the protection of seagrasses, coral reefs, and shrimp by collecting riverine runoff sediments (Primavera 1998; Valiela and Cole 2002; Duke and Larkum 2008, p. 156). They are an important component of "coastal blue carbon" as they store and sequester large amounts of carbon (Donato et al. 2011; Lee et al. 2014; Alongi 2015; Estrada and Soares 2017; Kelleway et al. 2017; Rogers et al. 2019). Current studies suggest that mangroves sequester higher carbon than the mature tropical rain forests and most of it is stored below ground, suggesting their important roles in combating climate change posed by global warming (Francisco et al. 2018; Sanderman et al. 2018; National Oceanic and Atmospheric Administration 2020).

As per the IUCN red list of threatened species report, 11 out of 73 mangrove species are near threatened (IUCN 2020b) due to several reasons such as excessive exploitation, habitat destruction, mangrove forest encroachments, human settlements, and road and construction activities (Barbier and Sathirathai 2004; Polidoro et al. 2010; Barbier et al. 2011; Costanza et al. 2014). The rising global sea level due to global warming and changing salinity levels also threaten the existence of the mangroves. Despite being one of the most productive, unique, and important ecosystems, the mangroves face a serious existential crisis. Their narrow zone of existence and the shrinking of the habitat raise serious concerns (Polidoro et al. 2010; IUCN 2010). Increasing concerns about the loss of such important ecosystems of the world have shifted the focus of the global community toward taking actions in saving, conserving, and restoring mangrove ecosystems (Carugati et al. 2018). Therefore, conservation and restoration efforts must be taken to rescue the leftover habitats and the remaining species for their tremendous goods and services to the plants and people (Lefebvre and Poulin 1997; Lewis 2005; Giri et al. 2011). The protection of mangrove ecosystems requires the cooperation of local communities, NGOs, and state and central governments along with the expertise of scientists and academics (Farley et al. 2010, p. 36; Romañach et al. 2018). Concerted efforts from various corners of domains are required to protect the unique ecosystems of the world. This chapter provides an outline of the importance of the unique mangrove ecosystems, their diversity, threats, and conservation challenges.

12.2 Mangrove Species Diversity

Based on several characters, mangroves have been classified as true mangroves or obligate mangroves and mangrove associates or semi-mangroves (Wang et al. 2010, 2011; Tomlinson 2016, p. 29). True mangroves are characterized by their occurrence in mangrove forests and not in terrestrial communities, are major components of the mangrove forests possessing special characters for adaptation/survival in the saline environment and mechanisms for the salt exclusion (Tomlinson 2016, p. 29; Quadros and Zimmer 2017). True mangroves are further grouped into major and minor components of mangrove ecosystems (Spalding et al. 2010; Tomlinson 2016, p. 29; Quadros and Zimmer 2017). Spalding et al. (2010) have published an important updated book titled "Atlas of Mangroves" giving detailed maps of mangroves across the globe. They have enlisted a total of 73 true mangrove species and hybrids (Spalding et al. 2010). Mangrove species are genetically distinct but ecologically related (Bibi et al. 2019) with the common property of inhabiting the intertidal region (Duke et al. 1998). True mangrove species and hybrids including major and minor components are distributed across 28 genera belonging to 18 diverse families of flowering plants (Table 12.1). Rhizophoraceae is one of the most important and diverse families of mangroves comprising four genera, i.e. *Bruguiera* (7 species), *Ceriops* (3), *Kandelia* (2), and *Rhizophora* (10). Combretaceae comprises three genera, i.e. *Conocarpus* (1), *Laguncularia* (1), and *Lumnitzera* (3). Malvaceae, Leguminosae, Bignoniaceae, Lythraceae, and Meliaceae comprise two genera each. Malvaceae is represented by *Camptostemon* (2) and *Heritera* (3), Leguminosae by *Cynometra* (1) and *Mora* (1), Bignoniaceae by *Dolichandrone* (1), and *Tabebuia* (1) and Lythraceae by *Pemphis* (1), and *Sonneratia* (9). The family Meliaceae is represented by *Aglaia* (1) and *Xylocarpus* (2). Rest of the families are represented by one genus each, i.e. Acanthaceae by *Acanthus* (2), Pteridaceae by *Acrostichum* (3), Plumbaginaceae by *Aegialitis* (2), Primulaceae by *Aegiceras* (2), Avicenniaceae by *Avicennia* (8), Ebenaceae by *Diospyros* (1), Euphorbiaceae by *Excoecaria* (2), Arecaceae by *Nypa* (1), Myrtaceae by *Osbornia* (1), Tetrameristaceae by *Pelliciera* (1), and Rubiaceae by *Scyphiphora* (1). Diversity of true mangroves and their threat status are shown in Table 12.1. Of the total 73 species and hybrids, three are critically endangered, three are endangered, and seven are vulnerable whereas five are near threatened (Table 12.1, Figure 12.1). Although the majority of species are least concerned, some of them show a decline in their population and face several threats and need special attention for their conservation (Duke et al. 2007; IUCN 2020b; See Table 12.1).

Table 12.1 Diversity of true mangroves and current threat status as per the IUCN Red List of Threatened Species.

S. No.	Name of the species	IUCN status
Genus: *Acanthus* (2), Family: Acanthaceae		
1.	*A. ilicifolius* L.	LC
2.	*A. ebracteatus* Vahl	LC

(*Continued*)

Table 12.1 (Continued)

S. No.	Name of the species	IUCN status
Acrostichum (3), Pteridaceae		
3.	*A. aureum* Cav.	LC
4.	*A. speciosum* (Fée) C. Presl	LC
5.	*A. danaeifolium* (Fée) C. Presl	LC
Aegialitis (3), Plumbaginaceae		
6.	*A. annulata* Kurz.	LC
7.	*A. rotundifolia* Roxb.	NT
Aegiceras (2), Primulaceae		
8.	*A. corniculatum* (L.) Blanco.	LC
9.	*A. floridum* Roem. & Schult.	NT
Aglaia (1), Meliaceae		
10.	*A. cucullata* (Roxb.) Pellegr.	DD
Avicennia (8), Avicenniaceae		
11.	*A. alba* Blume.	LC
12.	*A. bicolor* Standl.	VU
13.	*A. germinans* (L.) Stearn.	LC
14.	*A. integra* N.C.Duke.	VU
15.	*A. marina* (Forssk.) Vierh.	LC
16.	*A. officinalis* L.	LC
17.	*A. rumphiana* Hallier f.	VU
18.	*A. schaueriana* Stapf & Leechm.	LC

Table 12.1 (Continued)

S. No.	Name of the species	IUCN status
Bruguiera (7), Rhizophoraceae		
19.	*B. cylindrica* (L.) Blume.	LC
20.	*B. exaristata* Ding Hou.	LC
21.	*B. gymnorhhiza* (L.) Lam.	LC
22.	*B. hainesii* C.G.Rogers	CR
23.	*B. parviflora* (Roxb.) Wight & Arn.	LC
24.	*B. rhynchopetala* (W.C.Ko) N.C.Duke & X.J.Ge.	Hybrid taxon
25.	*B. sexangula* (Lour.) Poir.	LC
Camptostemon (2), Malvaceae		
26.	*C. schultzii* Mast.	LC
27.	*C. philippinense* (Vidal) Becc.	EN
Ceriops (3), Rhizophoraceae		
28.	*C. australis* (C.T.White) Ballment.	LC
29.	*C. decandra* Ding Hou.	NT
30.	*C. tagal* (Perr.).	LC
Conocarpus (1), Combretaceae		
31.	*C. erectus* L.	LC
Cynometra (2), Leguminosae		
32.	*C. iripa* Kostel	LC
Dolichandrone (1), Bignoniaceae		
33.	*D. spathacea* (L.f.) Seem.	LC
Diospyros (1), Ebenaceae		
34.	*D. littorea* (R.Br.) Kosterm.	NA

(*Continued*)

Table 12.1 (Continued)

S. No.	Name of the species	IUCN status
Excoecaria (2), Euphorbiaceae		
35.	*E. agallocha* L.	LC
36.	*E. indica* (Willd.) Müll. Arg. (Now synonym of *Shirakiopsis indica (Willd) Esser*)	DD
Heritiera (3), Malvaceae		
37.	*H. fomes* Buch.-Ham.	EN
38.	*H. globosa* Kosterm	EN
39.	*H. littoralis* Aiton.	LC
Kandelia (2), Rhizophoraceae		
40.	*K. candel* (L.) Druce	LC
41.	*K. obovata* Sheue, Liu & Yong.	LC
Laguncularia (1), Combretaceae		
42.	*L. racemosa* Willd.	LC
Lumnitzera (2), Combretaceae		
43.	*L. littorea* (Jack) Voigt.	LC
44.	*L. racemosa* Willd.	LC
45.	*Lumnitzera X rosea*	NA
Mora (1), Leguminosae		
46.	*M. oleifera* (Hemsl.) Ducke	VU
Nypa (1), Arecaceae		
47.	*N. fruticans* Wurmb.	LC
Osbornia (1), Myrtaceae		
48.	*O. octodonta* F.Muell.	LC
Pelliciera (1), Tetrameristaceae		
49.	*P. rhizophorae* Planch. & Triana.	VU

Table 12.1 (Continued)

S. No.	Name of the species	IUCN status
Pemphis (1), Lythraceae		
50.	*P. acidula* J.R. Forst.	LC
Rhizophora (10), Rhizophoraceae		
51.	*R. apiculata* Blume.	LC
52.	*Rhizophora x neocaledonica*	NA
53.	*R. harrisonii* Leechm.	Species name is accepted in the genus *Rhizophora*.
54.	*R. lamarckii* Montrouz.	Species name is accepted in the genus *Rhizophora*.
55.	*R. mangle* Roxb.	LC
56.	*R. mucronata* Poir.	LC
57.	*R. racemosa* G.Mey.	LC
58.	*R. samoensis* (Hochr.) Salvoza.	NT
59.	*R. stylosa* Griff.	LC
60.	*R. selala* (Salvoza) Toml.	Hybrid taxon
Scyphiphora (1), Rubiaceae		
61.	*S. hydrophylacea* C.F. Gaertn.	LC
Sonneratia (9), Lythraceae		
62.	*S. alba* Griff.	LC
63.	*S. apetala* Buch.-Ham.	LC
64.	*S. caseolaris* Druce.	LC
65.	*S. griffithii* Kurz.	CR
66.	*S. gulngai* N.C. Duke.	Hybrid Parentage (*S. alba* × *caseolaris*).
67.	*S. hainanensis* W.C. Ko, E.Y. Chen & W.Y. Chen.	CR

(*Continued*)

Table 12.1 (Continued)

S. No.	Name of the species	IUCN status
68.	*S. lanceolata* Blume.	LC
69.	*S. urama* N.C. Duke	Hybrid taxon (NA on IUCN website)
70.	*S. ovata* Backer.	NT
Tabebuia (1), Bignoniaceae		
71.	*T. palustris* Hemsl.	VU
Xylocarpus (3), Meliaceae		
72.	*X. granatum* J. Koenig.	LC
73.	*X. moluccensis* (Lam.) M. Roem.	LC

Source: From Spalding et al. (2010) and IUCN (2020b). © John Wiley & Sons. Families have changed due to APG IV classification: Primulaceae = Myrsinaceae; Malvaceae = Bombacaceae; Leguminosae = Caesalpiniaceae; Heritiera (3), Malvaceae = Sterculiaceae; Tetrameristaceae = Pellicieraceae; Lythraceae = Sonneratiaceae. 18 families with their respective genera are: 1. Acanthaceae – Acanthus (2), 2. Pteridaceae – Acrostichum (3), 3. Plumbaginaceae – Aegialitis (2), 4. Primulaceae – Aegiceras (2), 5. Meliaceae – Aglaia (1), Xylocarpus (2), 6. Avicenniaceae – Avicennia (8), 7. Rhizophoraceae – Bruguiera (7), Ceriops (3), Kandelia (2), Rhizophora (10), 8. Malvaceae – Camptostemon (2), Heritera (3), 9. Combretaceae – Conocarpus (1), Laguncularia (1), Lumnitzera (3), 10. Leguminosae – Cynometra (1), Mora (1), 11. Bignoniaceae – Dolichandrone (1), Tabebuia (1), 12. Ebenaceae – Diospyros (1), 13. Euphorbiaceae – Excoecaria (2), 14. Arecaceae – Nypa (1), 15. Myrtaceae – Osbornia (1), 16. Tetrameristaceae – Pelliciera (1), 17. Lythraceae – Pemphis (1), Sonneratia (9), 18. Rubiaceae – Scyphiphora (1).

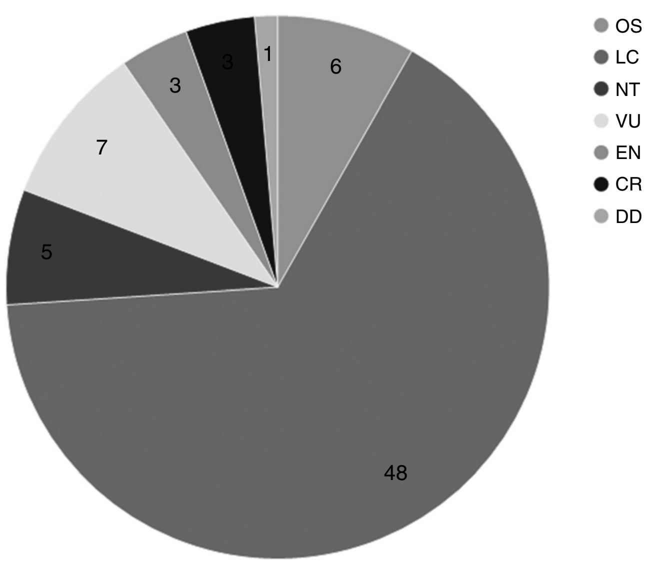

Figure 12.1 Threat status of the 73 true mangrove species and hybrids as per IUCN Red List of threatened species. *Source:* Modified from Spalding et al. (2010). IUCN (2020b). © John Wiley & Sons.

12.3 Geographical Distribution of Mangroves Across the Globe and India

Mangroves are distributed in nearly 118 countries across the globe (Spalding et al. 2010). Continuous efforts are being made to access the distribution of mangroves using various techniques. Giri et al. (2011) have reported an area of 137 760 km^2 under mangrove cover in 118 countries for the year 2000. A more recent estimate shows that mangroves occupy an area of approximately 152 000 km^2 across the world (Yeo 2014). They are present between 30° N and 30° S in the tropical and subtropical areas (Sandilyan and Kathiresan 2012), while the highest percentage of mangroves is available between 5° N and 5° S (Giri et al. 2011). Mangrove distribution is dependent on rainfall, runoff, salinity, and temperature (Jayatissa et al. 2008; Wang et al. 2011; Osland et al. 2017). The higher rainfall and runoff decrease salinity and improve nutrient availability in the estuaries which contribute to increased mangrove growth and productivity (Singh 2020). Several authors suggest that salinity is one of the most important factors determining the distribution of the mangroves (Jayatissa et al. 2008; Wang et al. 2011; Osland et al. 2017). Geographically, mangroves are located in the tropics and subtropics. Among the continents, Asia represents the highest percentage of mangrove area (42%) followed by Africa (21%), North and Central America (15%), and South America (11%). Among the countries having mangrove vegetation, Indonesia represents the highest percentage of land under mangroves (Hamilton and Casey 2016; Yong 2018; Bibi et al. 2019) whereas Southeast Asian countries contribute 33% to global mangroves (Basha 2016, p. 766). Country-wise distribution of the mangroves across the globe is given in Figure 12.2 while Table 12.2 represents the top fifteen countries having the highest mangrove cover.

India accounts for around 3% of the total mangrove cover in South Asia (Forest Survey of India 2019) harboring more than 50% of the world's mangrove species (Ragavan et al. 2016). India represents nearly 46 true mangrove species and hybrids belonging to 14 families and 22 genera, and is distributed along the coastline of nine states and three union territories: Andhra Pradesh, Gujarat, West Bengal, Odisha, Andaman and Nicobar Islands, Daman and Diu, Tamil Nadu, Kerala, Karnataka, Goa, Pondicherry, and Maharashtra (Forest Survey of India 2019; Table 12.3). Mangroves in India span an area of more than 4975 sq km (Forest Survey of India 2019; Ragavan et al. 2019, p. 257; Kumari et al. 2020, p. 1). Of the total mangrove cover in India, 29% occur along the west coast and 58% along the east coast whereas the remaining 13% occur along the Andaman and Nicobar Islands (Kumari et al. 2020, p. 1). State-wise mangrove cover of India is represented in Figure 12.3 and Table 12.3.

12.4 Important Roles of Mangroves

Mangrove forests are one of the most important ecosystems on earth (Sandilyan and Kathiresan 2012; Carugati et al. 2018). Mangroves offer a large number of goods and services to the society in addition to their important ecological roles (Barbier et al. 2011;

Figure 12.2 Extent of the global distribution of mangroves in 118 countries. *Source:* Global Mangrove Alliance Data Portal (2020) and Giri et al. (2011). © John Wiley & Sons.

Table 12.2 Top 15 countries having the maximum extent of mangrove distribution (area in km^2; Giri et al. 2011).

S. No.	Country	Area (km^2)
1.	Ashmore and Cartier Islands	9581.154059
2.	Australia	9581.154059
3.	Bangladesh	4435.329037
4.	Brazil	10521.26464
5.	Burma	5047.38696
6.	Guinea-Bissau	2733.991351
7.	India	3848.495466
8.	Indonesia	27729.48109
9.	Malaysia	5554.206441
10.	Mexico	7260.029787
11.	Mozambique	2941.053557
12.	Nigeria	6224.844022
13.	Papua New Guinea	4715.912505
14.	Philippines	2574.165676
15.	Venezuela	3334.072747

Source: Based on Giri et al. (2011). © John Wiley & Sons.

Table 12.3 State-wise distribution of mangroves in India.

S. No.	State	Area in (km^2)	No. of mangrove species
1.	Andhra Pradesh	404	22
2.	Goa	26	16
3.	Gujarat	1177	15
4.	Karnataka	10	16
5.	Kerala	9	19
6.	Maharashtra	320	22
7.	Odisha	251	34
8.	Tamil Nadu	45	17
9.	West Bengal	2,112	33
10.	A&N Islands	616	38
11.	Daman & Diu	3	4
12.	Puducherry	2	15
Total		**4975**	**46**[a]

[a] Indian mangroves represent 46 true mangrove species (42 species and four natural hybrids) belonging to 14 families and 22 genera (Ragavan et al. 2019)
Source: Forest Survey of India (2019), Ragavan et al. (2019). © John Wiley & Sons.

Figure 12.3 Extent of the area under mangroves in India. The mangroves are distributed in the 12 coastal states and Union Territories of India. *Source:* Forest Survey of India (2019) and Ragavan et al. (2019). © John Wiley & Sons.

Mangroves for the future 2012; IUCN 2020a). Mangroves provide goods such as timber, fuelwood, charcoal, and medicines (Uddin et al. 2013). They provide important services such as protection of coastal communities from natural disasters such as tsunami, floods, hurricanes, erosion, and landslides by serving as bioshields (Kathiresan and Rajendran 2005; Duke et al. 2007; Cheong et al. 2013; Sandilyan and Kathiresan 2015), act as habitats for several organisms including microorganisms and serve as breeding and spawning ground for many marine species such as fish, crabs, mollusks, insects, and birds (Teas 1977; Goforth and Thomas 1980; FAO 1994; Upadhyay et al. 2002; Duke et al. 2007; Giri et al. 2011; Lee et al. 2014; Buelow and Sheaves 2015; Mohd-Azlan (2014)). Unique adaptations in the mangrove communities provide many other direct and indirect benefits to the society (Mitra 2020). For example, some mangroves and even their associated flora can accumulate

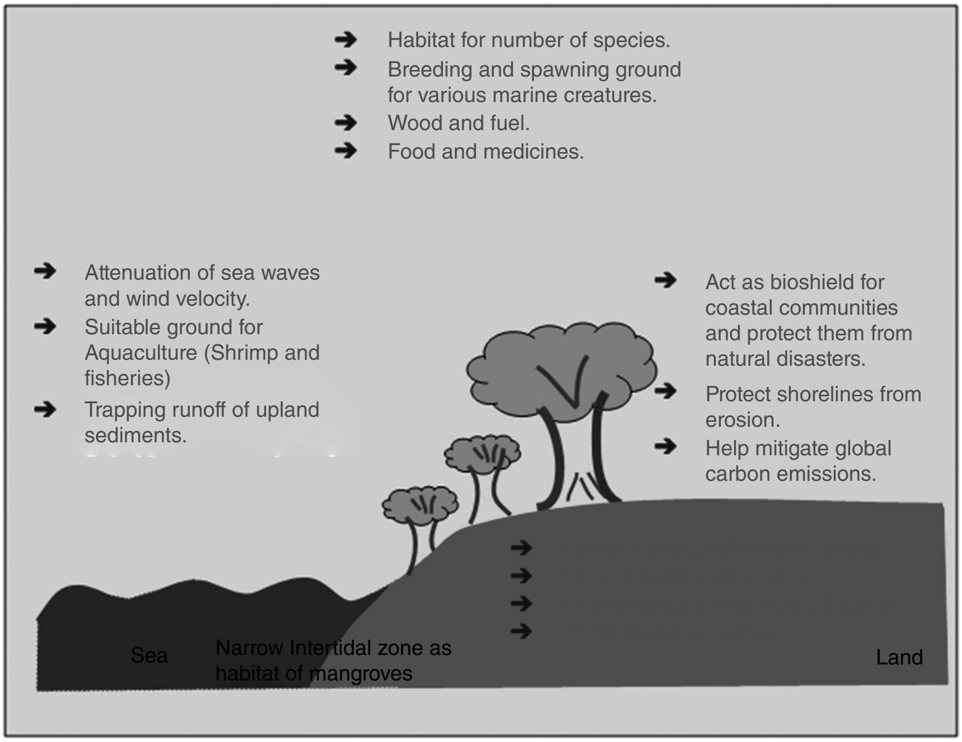

Figure 12.4 Important roles of mangroves. *Source:* Dahdouh-Guebas et al. (2005), Kathiresan and Rajendran (2005), National Parks Board Singapore (2010). Lee et al. (2014), Buelow and Sheaves (2015), Mohd-Azlan (2014). © John Wiley & Sons.

and immobilize heavy metals and other pollutants in their roots (Kumari et al. 2020). Mangrove ecosystems effectively aid in natural bioremediation and pollutant detoxification (Kumari et al. 2020). Mangroves can also absorb runoff water and waste emitted from aquaculture and therefore protect coral reefs, seagrasses, and fish habitats (Gilbert and Janssen 1998; Tam and Wong 1999; Kathiresan and Qasim 2005, p. 537). The mangroves also help in carbon sequestration and thus help combat global climate change (Alongi 2011). Following subheadings briefly explain some of the important roles that mangroves play. Figure 12.4 shows the major important roles played by mangroves and mangrove ecosystems.

12.4.1 Mangrove Forests are the Richest and Most Biodiverse Ecosystems on Earth

The mangrove ecosystem hosts diverse forms of life and therefore are reservoirs of genetic and biological diversity (Kathiresan and Bingham 2001; Sandilyan and Kathiresan 2012). They harbor huge diversity of other organisms including microorganisms, phytoplanktons, fish, crabs, and zooplanktons (Lugo and Snedaker 1974; Mumby et al. 2004; Gaos et al. 2016). A study by Upadhyay et al. (2002) stated that mangroves support a large number of organisms such as crabs, mollusks, and insects. Many termites and ants are also dependent on mangrove species (Adams and Levings 1987, p. 1069; Nielsen 2011, p. 113; Duke and Schmitt 2015, p. 1). Leaves and twigs of mangroves act as important shelters for insects (Macnae 1968). They are also breeding ground for migratory arthropods and birds (Poulin et al. 1992; Noske 1993; Noske 1995; Lefebvre and Poulin 1997; Nagelkerken et al. 2008; Florida Museum 2018; Wood 2019; Arcos et al. 2020). Studies have shown that several vertebrates are endemic to mangrove ecosystems (Rog et al. 2017, p. 221) and nearly half of endemic mangrove vertebrates are globally endangered (Luther and Greenberg 2009; Heimbuch 2011; Virata 2011; IUCN 2017). Some aquatic species thriving in mangrove environments are also facing various degrees of threats (Carugati et al. 2018).

12.4.2 Aquaculture: Shrimp and Fish Cultivation

Mangroves are important to humans as they provide a wide range of ecological services and livelihood opportunities. Of the several important services, aquaculture is an important service provided by mangrove forests. Fish and shrimp cultivation in the estuarine habitat of mangroves provides economic stability to the coastal communities and contribute to the enhancement of their lifestyles (Carrasquilla-Henao et al. 2019). Studies have reported the importance of mangroves for coastal shrimp and fish cultivation (Gunawardena and Rowan 2005; Manson et al. 2005; Primavera 2008; Lee et al. 2014). Studies indicate that increasing mangrove diversity may lead to increased fish production (Aburto-Oropez et al. 2008; Abrantes et al. 2019; Vincentius et al. 2019). However, recent studies show that excessive use of mangrove areas for aquaculture has contributed much to its destruction and is one of the major factors responsible for mangrove losses (Norris and Cargile 1998; Pattanaik and Prasad 2011; Rochmyaningsih 2017). The negative pressure posed by excessive conversion of mangrove habitats into aquaculture indicates that steps must be taken to reverse the losses incurred due to this and new methods for integrated and sustainable fish and shrimp farming must be developed keeping mangroves at the center of all other activities (Ahmed et al. 2018).

12.4.3 Protection from Natural Disasters: Mangroves Act as Natural Bioshields Against Natural Disasters

Mangroves are known as natural bioshields and protect coastal communities and other marine organisms for they act as a barrier to natural disasters such as tsunamis, hurricanes, and cyclones (Dahdouh-Guebas et al. 2005; Kathiresan and Rajendran 2005; del Valle et al. 2019). The aerial root system and the canopy architecture of the mangroves provide protective properties to them (Massel et al. 1999; Mazda et al. 2006; Barbier et al. 2008; Van Lavieren et al. 2012; Horstman et al. 2014; Yeo 2014; Hamilton and Casey 2016; Naidoo 2016). They are known to protect coastal areas from high wind velocity (Das and Crépin 2013) and storm surge (Gurib-Fakim and Brendler 2004; Krauss et al. 2009; Schneider 2011; Zhang et al. 2012; Liu et al. 2013; Gardner 2016). Several studies suggest that during Indian Ocean cyclones, human settlements lacking mangroves face more damages than those shielded by mangrove vegetation (Danielsen et al. 2005; Das and Vincent 2009).

Increased mangrove forest cover can increase the protective effect. Various characteristics of mangroves such as the dominance of the species, age, and size determine the reduction of damage by natural disasters (Patel et al. 2014, p. 29; Asbridge et al. 2018; Dasgupta et al. 2019). A large number of studies explain the important protective roles of mangrove forests. The degree of protection is dependent on the species' composition, tree size, age, and canopy architecture of the mangrove forests. Therefore, it is important to take steps and actions to protect the mangroves for stable coastal communities.

12.4.4 Medicinal Value of Mangroves

Many mangroves have been used by traditional communities based on their ethnobotanical knowledge (Ravindran et al. 2005, p. 409; Bibi et al. 2019). Therefore, like any other terrestrial medicinal plants, several species of mangroves also possess important medicinal properties because of the important metabolites they harbor in their cells (Bandaranayake 1998; Eldeen and Effendy 2013, p. 872; Saranraj and Sujitha 2015). Not only true mangroves but mangrove associates and other associated organisms, such as endophytes, also possess medicinal properties (Nurunnabi et al. 2020). Ethnobotanical studies suggest that mangroves have been used for many diseases/ailments across different countries including India (Bibi et al. 2019). Bibi et al. (2019) suggest that *Bruguiera gymnorrhiza*, *Rhizophora mucronata*, *Acanthus ilicifolius*, and *Heritiera fomes* are medicinally more important than other species. Increasing studies suggest important medicinal roles of the mangroves (Liebezeit and Rau 2006; Nurdiani et al. 2012, p. 27; Seepana et al. 2016). Bibi et al. (2019) has extensively reviewed the current knowledge on medicinal, pharmacological, and phytochemical aspects of various species of mangroves. It will not be impossible to explore new sources of drugs from mangrove ecosystems. However, future studies on the prospecting of mangroves for medicinal plants and drugs must keep in mind the principles of the sustainable development goals.

12.5 Threats to Mangroves

Mangroves, though one of the most important and productive ecosystems, face survival threats (Gilman et al. 2008; Chaudhuri et al. 2015; Makowski and Finkl 2018; Romañach et al. 2018). Large parts of mangrove forests have been converted to non-mangrove activities (Valiela et al. 2001; Thu and Populus 2007, p. 98). Many species of mangroves face varying degrees of threats and some of them are already critically endangered (IUCN 2020b). Mangroves face a large number of threats due to several factors such as human settlements, excessive use of wood, climate change, conversion of mangroves for other developmental activities, and oil spills (Duke et al. 1997; Lamparelli et al. 1997, p. 191; Walters 1997; Goldberg et al. 2020). Loss of mangroves has an indirect effect on the monumental diversity of organisms they support. Loss of mangroves directly means the loss of a large number of other organisms, also endangering the stability and survival of the coastal marine ecosystems. The following subheadings explain various threats that are responsible for the loss of mangroves and if corrective steps are not taken to reverse them, the loss of mangroves will continue putting the coastal communities and other marine biotas at risk. The various threats that mangroves currently face are summarized in Figure 12.5.

12.5.1 Human Settlements and Other Developmental Activities

Increasing population and immigration to the mangrove-rich coastal areas has resulted in the loss of mangrove cover across the globe including India (Walters 1997; Walters 2003; Nguyen et al. 2013; Munji et al. 2014; Saw and Kanzaki 2015; Bhomia et al. 2016; Sarmin et al. 2016; Chowdhury et al. 2017, p. 275; Goldberg et al. 2020). Rideout et al. (2013) have reported an increase in the population in Kenyan mangrove areas between 2000 and 2010 and found its positive correlation with mangrove loss. With immigration and increasing population density, other developmental activities such as roads, buildings, and construction activities also contribute to the loss of mangrove areas (Hirales-Cota et al. 2010, p. 147). Some mangrove regions of the world also face increased industrial development at

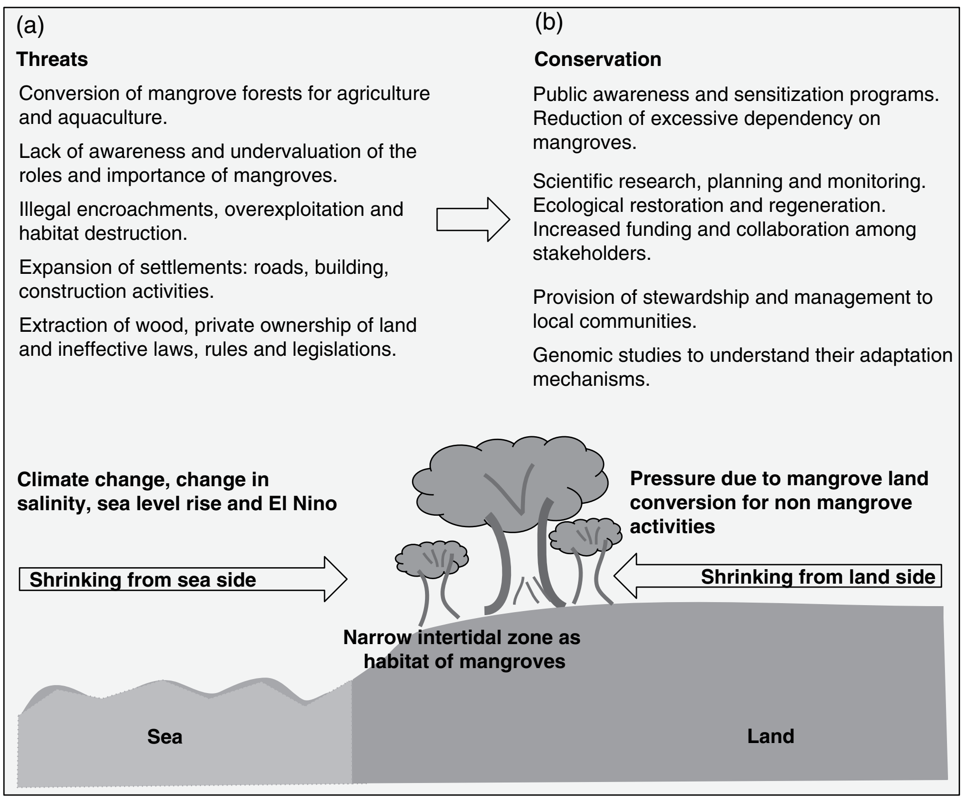

Figure 12.5 Threats to mangroves and conservation efforts. (a) Various threats mangroves facing. *Source*: Sippo et al. (2018), Munji et al. (2014), Hema and Devi (2014), Palacios and Cantera (2017), Islam and Wahab (2005), Badola et al. (2012), Krauss et al. (2014) and Lovelock et al. (2017). © John Wiley & Sons. (b) Strategies for effective mangrove conservation and restoration. *Source*: Based on Islam and Bhuiyan (2018). © John Wiley & Sons.

the cost of precious mangroves (Ferreira and Lacerda 2016). The industries and human settlements also release pollutants that endanger other marine lives in addition to harming the mangroves (Agoramoorthy et al. 2008).

12.5.2 Excessive Extraction of Wood

Timber from mangroves species is used as a construction material for various purposes (Feka and Manzano 2008; Tolangara 2014, p. 54; Palacios and Cantera 2017). Wood harvesting has helped a large number of communities but unsustainable harvesting can lead to the change of mangrove structure and composition (Semesi 1992; Rajkaran et al. 2010; Scales and Friess 2019). Recently, we have seen increased harvesting and overexploitation of the mangrove wood for various purposes (Ajonina and Usongo 2001; Rasquinha and Mishra 2020). Loss of mangroves has resulted in increased erosion of the mangrove areas, which can cause secondary issues to the coastal areas and the communities relying on them (Lara et al. 2002; Goldberg et al. 2020).

12.5.3 Conversion of Mangrove Forests for Farming and Related Activities

To feed the burgeoning population, land resources are insufficient and unsustainable practices are followed by people around the world to clear forest lands for agricultural purposes (FAO 2016; Kumari et al. 2019; Meek 2019). Even the mangrove forests, which are unique and limited, are also not spared from such activities (Alongi 2002; Richards and Friess 2016; Butler 2019). The mangroves have been converted into rice fields and oil palm plantations in several countries (Ong 1995; Ellison and Farnsworth 1996; Ong 2007; Saw and Kanzaki 2015; Kinver 2016; Richards and Friess 2016; Fauzi et al. 2019; Sustainability Times 2020). Increasing studies suggest the threats to mangroves due to excessive and unsustainable strategies adopted by farmers across the globe. There is a global consensus among the people that mangrove forest conversions must be halted by providing alternative livelihood opportunities and finding new innovative solutions to agricultural demand such as soil-less agriculture and indoor hydroponics (Saha 2010, p. 139).

12.5.4 Conversion of Mangrove Forests for Aquaculture

In addition to conversion of the mangrove forests for agriculture, larger portions of them are also converted to aquaculture activities such as shrimp and fish cultivation (De Graaf and Xuan 1998; Hein 2000, p. 48; Barbier and Cox 2004; Ashton 2008; Polidoro et al. 2010; Romañach et al. 2018). Several researchers have reported a decline in mangrove cover due to aquaculture (Dahdouh-Guebas et al. 2002; Islam and Wahab 2005; Giri and Muhlhausen 2008; Feller et al. 2017). Even excessive harvesting of the fish broods from the natural mangrove environment has resulted in disturbances to the food chains and food webs (Ellison 2008). Although aquaculture has been an important source of livelihood for the coastal communities and provides economic stability to them, the unsustainable practices of large-scale mangrove forest conversions may lead to exposure of these communities and will make them more vulnerable to natural disasters.

12.5.5 Global Warming, Climate Change, and Sea Level Rise

Global warming has contributed to global climate change (Dai 2010; McCarthy et al. 2010; Singh and Singh 2012, p. 93). Several studies suggest that global climate change will have extreme impacts on the mangroves (Field 1995, p. 75; Gilman et al. 2008; Krauss et al. 2014; Alongi 2015; Wilson 2017). Global climate change impacts global temperatures, rainfall, sea level, ocean salinity, and CO_2 levels (Najjar et al. 2000; Gilman et al. 2008; Najjar et al. 2010; Ellison and Zouh 2012; Ward et al. 2016). All climate-associated changes may affect mangrove distribution and species' diversity across the globe (Gilman et al. 2008; Record et al. 2013; Alongi 2015; Ward et al. 2016; Osland et al. 2017). Scientists have started understanding and predicting the future impacts of climate change on mangroves. Cavanaugh et al. (2019) suggested that the mangroves might move toward poles because of increasing global temperature. However, their long-term survival may not be possible despite poleward movements as they can be impacted by other climatic constraints (Osland et al. 2017). Climate change-associated changes such as global sea level rise, increased accumulation of sediments, change in salinity and availability of freshwater have started impacting mangroves (Ellison 1994, p. 11; Ellison 2012; Krauss et al. 2014; Alongi 2015; Ellison 2015; Lovelock et al. 2015; Ward et al. 2016). Few authors have studied the loss of mangroves due to sea level rise (Woodroffe and Davies 2009, p. 65; Meeder et al. 2017) and some have projected that sea level rise may result in intolerable levels of root submergence of the mangroves in future (Krauss et al. 2014; Calma 2020). Limited research is available on the impact of such changes on mangroves and future studies must focus on understanding and simulating the effects of such changes on their adaptability, physiology, and biochemistry necessary for their survival (Duke et al. 2007; Gilman et al. 2008; Yáñez-Espinosa and Flores 2011, p. 253; Godoy and de Lacerda 2015; Lovelock et al. 2016, p. 149). Ward et al. (2016) have reviewed region-specific impacts of climate change on mangroves and suggest that varying responses may be required to deal with climate change impacts on mangroves.

12.5.6 Limits to Landward Movement

The sea level rise may push the mangrove habitats landward (Semeniuk 1994, p. 1050; Di Nitto et al. 2014; Peterson and Bell 2015; Ward et al. 2016; Meeder et al. 2017; Osland et al. 2017). However, the landward movement may not be possible because human settlements and other anthropogenic activities have also extended and intruded into the mangrove habitats (Gilman et al. 2008; Di Nitto et al. 2014; IPCC 2019; See Figure 12.5 for illustration). Therefore, mangrove spaces are shrinking from the seaside due to the sea level rise and from landslides due to human activities making them vulnerable to extinction (Godoy and de Lacerda 2015; Schwartzstein 2019; Wongthong 2020). Further, the shrinking of the mangrove habitats can result in irreversible damages to the fragile yet one of the most important ecosystems. Adaptation of mangrove species to the land may not take place at the pace at which landward movement of mangroves is taking place because some of the species may adapt faster whereas others may take time (Gilman et al. 2008; Di Nitto et al. 2014). Therefore, policies should be devised based on the outcomes of the research on the mismatch in the adaptation of mangroves and the landward movement so that further mangrove losses can be prevented that could happen due to this.

12.5.7 El Niño and La Niña Events

Mangroves are also vulnerable to other weather extremes such as El Niño-Southern Oscillation (ENSO) and the La Niña events (Erftemeijer and Hamerlynck 2005, p. 228; López-Medellín et al. 2011; Heras and Soares 2017; Lovelock et al. 2017; Whitfield et al. 2019). The ENSO occurs once in two to seven years and affects global climate patterns (Scaife et al. 2019). ENSO and La Niña both have been known to impact mangrove ecosystems similar to other marine ecosystems (Drexler and Ewel 2001; Alongi 2002; Gilman et al. 2008; Heras and Soares 2017; Riascos et al. 2018). El Niño and La Niña events also result in secondary events such as flooding, excessive rains, or droughts, high temperatures, and may also adversely impact the mangroves (Rosenzweig and Hillel 2008; Cashman and Nagdee 2017, p. 155; Heras and Soares 2017). Few studies have shown several impacts of ENSO and La Niña on the mangroves; however, detailed studies are required to further understand and predict the long-term impacts of El Niño and La Niña on mangrove ecosystems.

12.6 Strategies for the Conservation of Mangroves

12.6.1 Increased and Focused Research on Understanding Mangroves

Mangroves are important components of the planet earth but research on them has picked up only recently. There are fewer studies on mangroves, especially about their distribution and species composition, primarily because many mangrove swamps are inaccessible or difficult to field survey (Giri et al. 2008; Kamal and Phinn 2011; Kuenzer et al. 2011). Recently, remote sensing technology has enabled accessing the area cover under mangroves (Giri et al. 2008, 2011) because remote sensing is an indispensable tool for assessing and monitoring mangrove forests (Abbas et al. 2013). In recent years, we have seen increasing literature for the mangrove distribution, area, species diversity, their roles, and threats (Field and Whittaker 1998; Biswas et al. 2007; Alongi 2008; Nagelkerken et al. 2008; Giri et al. 2011; Goutham-Bharathi et al. 2014; Lee et al. 2014; Giri et al. 2015). However, increased studies are needed with a special focus on region-wise threat status monitoring and taking necessary interventions, the impact of climate change, adaptations in mangroves in response to climate change (Biswas et al. 2007; Grantham et al. 2011; DasGupta and Shaw 2013; Ghosh et al. 2015; Chow 2017; Romañach et al. 2018; Singh et al. 2019), and policy-based studies to evaluate the shortcomings of the legislation and rules framed based on the mangroves (Rogers et al. 2016; Sundar 2018, p. 1). Modern genomics studies can also be carried out to evaluate their genomic basis of adaptations to prepare for the future (Dodd and Rafii 2002; Das and Strasser 2013, p. 53; Xu et al. 2017).

12.6.2 Implementation of Mangrove Conservation-Related Laws, Guidelines, and Other Initiatives

It has been found that of the 75% of mangroves located in 15 top countries, only 6.9% of them are in the protected areas (Thomas et al. 2017; Bibi et al. 2019). Several factors have contributed to the loss of mangrove species and the mangrove ecosystems and to arrest the continuous decline, laws must be reanalyzed and reframed as per the current demands of time (Duke et al. 2007; Friess et al. 2019; Bell-James et al. 2020). Various international agencies, organizations, and governments of the different countries have framed general and specific guidelines and promulgated laws for the protection of mangroves (Duangjai et al. 2013; Lundquist et al. 2017; Udoh 2016, p. 151; Suman 2019, p. 1055). Specific legislations are needed to tackle growing losses to mangroves and these legislations vary from country to country. Many countries like Tonga lack the basic guidelines (MESCAL 2011) whereas countries like Indonesia have certain guidelines for the conservation of mangroves, but are unable to reduce the deterioration of the mangroves due to the overlapping of the laws and illegal logging in these ecosystems (Sunyowati et al. 2016). To fill that gap, FAO (1994) has issued some important mangrove forest management guidelines which have been found to be successful in several countries (Field 1999; Kairo et al. 2001). Various initiatives have been taken worldwide for the conservation of mangroves. The General Conference of UNESCO held in 2015 has adopted "The International Day for the Conservation of the Mangrove Ecosystem" and it is celebrated each year on 26 July globally (UNESCO 2015). The purpose of this is to raise awareness of the importance of mangrove ecosystems as "a unique, special, and vulnerable ecosystem" and to take steps to sustainable management of mangroves (Shunula 2002). The 2030 Agenda for Sustainable Development which includes 17 goals and 169 targets has also given due importance to mangrove conservation and management (Sharrock and Jackson 2016; Neumann et al. 2017; Nagabhatla et al. 2019). The role of mangroves and the need for their conservation is also well acknowledged under the Paris Agreement of the United Nations Framework Convention on Climate Change (UNFCCC) (Burns 2015, p. 415). Save Our Mangroves Now, an initiative of the IUCN and WWF is also contributing to the conservation of the mangroves (IUCN 2018; United Nations Ocean Conference 2019; IUCN 2020a).

In India also, several measures have been taken including statutory mechanisms for the conservation of mangroves (Kumar 2000). Several legislations such as The Environment (Protection) Act of 1986, The Biological Diversity Act of 2002 are directly or indirectly linked to mangrove conservation and management (Ramachandran et al. 2018). Green India Mission which is a subcomponent of the National Action Plan on Climate Change, 2008 has prioritized conservation and restoration of mangroves (Ravindranath and Murthy 2010; DasGupta and Shaw 2013).

In spite of all these efforts, difficulties arise in the proper implementation of laws and various other guidelines and initiatives due to the undervaluation of mangroves and other factors such as fragmented geographical distribution of mangroves and acute shortage of government staff and facilities (Ashokkumar and Irfan 2018). However, to save mangroves, a proper policy and legislative framework is important but its implementation is more challenging and important. Therefore, an implementation must be given more preference and also reformation of some of the archaic legislations must be done. Table 12.4 represents a non-exhaustive and indicative list of various types of initiatives and the organizations/agencies involved in mangrove conservation and management.

Table 12.4 Some of the important global initiatives for the Conservation, Protection, and Regeneration of Mangroves.

S. No	Organization/Initiative	Effective working area	Website/URL
1.	Global Mangrove Alliance	Financing, strengthening policy, building capacity, developing a proof of concept and knowledge sharing.	http://www.mangrovealliance.org/initiatives/
2.	Food and Agriculture Organization	Various activities such mangrove forest management, afforestation and various studies on them, reports, guidelines.	http://www.fao.org/forestry/mangrove/3940/en/
3.	IUCN Mangrove Rehabilitation for Sustainably Managed Healthy Forests Project.	Building capacity and improving the sustainable management of mangroves at local and national level.	https://www.iucn.org/regions/oceania/our-work/nature-based-solutions/water-and-wetlands/pacific-mangroves-initiative/mangrove-rehabilitation-sustainably-managed-healthy-forests-marsh-project
4.	World Wildlife Fund	Protection of mangrove ecosystems using various programs and by collaborating with various organizations and governments.	https://www.wwfca.org/en/species_and_places/mangroves/
5.	The International Blue Carbon Initiative	Emphasize on the importance of the marine resources such as mangroves for their protection and use for carbon sequestration.	https://www.thebluecarboninitiative.org/
6.	International Partnership for Blue Carbon	Protection and conservation of mangroves and other ecosystems that are important for capturing carbon.	https://bluecarbonpartnership.org/
7.	Global Nature Fund	Reforestation of global degraded mangrove areas	https://www.globalnature.org/Mangroves
8.	Mangrove Action Project	US-based nonprofit which collaborates with individuals and organizations to preserve, conserve, and restore mangrove forests.	https://mangroveactionproject.org/
9.	Global Mangrove Watch	Online platform that provides the remote sensing data and tools for monitoring mangroves.	https://www.globalmangrovewatch.org/?
10.	Mangrove Science	Monitoring and modeling mangroves with remote sensing.	https://mangrovescience.org/

(*Continued*)

Table 12.4 (Continued)

S. No	Organization/Initiative	Effective working area	Website/URL
11.	The Mangrove Alliance	Community-led stewardship of mangrove forest ecosystems and restoration of mangrove ecosystems.	https://ecoviva.org/mangrove-alliance/#
12.	International Society for Mangrove Ecosystems	Knowledge, training for mangrove conservation.	http://www.mangrove.or.jp/isme/english/index.htm
13.	Turing Foundation	Mangrove rehabilitation projects.	http://www.turingfoundation.org/kw_mangrove_uk.html
14.	BirdLife International	Protection of mangroves by involving communities.	http://www.birdlife.org on 21/09/2020
14.	ZSL Institute of Zoology	Conservation and monitoring of mangrove forests.	https://www.zsl.org/science/research/mangroves
15.	International Tropical Timber Organization	It is involved in conservation and sustainable management of mangroves.	https://www.itto.int/sustainable_forest_management/mangroves/
16.	Nature Environment and Wildlife Society	Conserve ecology and environment, wildlife, natural resources.	https://naturewildlife.org/
17.	Mission Mangroves	Aims to restore Mumbai's depleted mangrove cover	https://www.unitedwaymumbai.org/mission-mangroves
18.	Australian Mangrove and Saltmarsh Network	An Australian independent informal network for protection of mangroves.	https://www.amsn.net.au/
19.	Mangroves for the Future	Promotes mangrove conservation by partnerships with organizations and communities.	https://www.mangrovesforthefuture.org/

12.6.3 Strengthening Conservation Mechanisms

Conservation and/or restoration of mangroves and degraded mangrove ecosystems must be based on the evidence-based conservation/restoration approaches (Le 2008). Ideally, conservation and restoration practices should be based on natural regeneration systems (Kairo et al. 2001; IUCN 2011; Mchenga and Ali 2014, p. 334; Romañach et al. 2018; Lee et al. 2019). For example, monocultures of one type of mangrove species to increase mangrove forest cover may not yield the desirable results but holistic approaches must be taken to recover the mangrove ecosystems along with other organisms of the ecosystem (Primavera et al. 2016; Romañach et al. 2018). Therefore, conservation activities must be revisited and holistic elements must be added to the mangrove conservation and regeneration programs (Kairo and Mwita 2020). Moreover, the focus should also be placed on high-priority species which are at high risk of extinction in the near future (Macintosh and Ashton 2002, p. 338) (See Table 12.1 for varying degrees of threats mangrove species face). Evidence-based sustainable conservation mechanisms must be strengthened to obtain desirable outcomes (Farley et al. 2010, p. 39).

12.6.4 Targeting Land Ownership-Related Issues

In several regions, mangroves exist on privately owned lands, which creates hurdles in the implementation of mangrove-related laws (Hema and Devi 2014: Suman 2019, p. 1055). In one of the Indian states, i.e. Kerala alone, about 80% of the mangrove land is under private ownership (Muraleedharan et al. 2009; Vidyasagaran and Madhusoodanan 2014, p. 38). A similar issue exists in other states of India and other countries of the world also such as Srilanka, the Philippines, and Ghana (Farley et al. 2010; Adger et al. 1997; Asante et al. 2017). Because of the ineffective imposition of the laws to private properties, mangrove forests are being converted to personal private activities such as aquaculture, agriculture and settlement purposes (Ron and Padilla, 1999, p. 297; Farley et al. 2010; Asante et al. 2017; Sathirathai and Barbier 2007; Srivastava and Mehta 2017). Several countries have allowed the conservation of plants on private lands also by sufficiently rewarding the people involved (McNeely 1993, p. 144; Spiteri and Nepalz 2006, p. 1; Pascual and Perrings 2007, p. 256; Kamal et al. 2015, p. 576). Some successful examples of mangrove conservation on private land are available. For example, in Southeast Asia, payment for ecosystem services approach through landowners ensured sustainable livelihoods and mangrove conservation (Friess et al. 2016). Therefore, a similar practice of promotion of conservation on private land can be taken up wherever this issue exists.

12.6.5 Involvement of Local Communities

Involvement of local communities is important for the effective implementation of the projects aimed at the conservation of the mangroves because in several parts of the country and globe, mangroves are located in the private lands of the people. Engagement of local communities can improve the conservation success rates (Mangora 2011). Badola et al. (2012) studied the attitudes of local communities toward the conservation of mangroves in the East Coast of India and found that many participants provided positive feedback and agreed to participate in mangrove conservation programs. A similar study by Roy (2016) from Bangladesh suggests that more than 50% of the people agreed to participate in mangrove conservation programs. Studies also suggest that the unavailability of alternative employment opportunities also push people toward illegal harvesting of mangrove resources (Badola et al. 2012; Roy 2016). Local coastal communities are connected to the mangrove forests and somehow know the values of mangrove–human connections and their ecological and economic importance (Hussain and Badola 2010; Kusmana and Sukristijiono 2016). Spreading more awareness and sensitizing them about the roles and importance of mangroves can yield positive results in the participatory management of the mangroves (Shunula 2002). Since mangroves provide a large number of economic benefits to the communities associated with them, excessive usage and overexploitation of mangrove resources can result in loss of jobs and lead to poverty among the coastal communities relying on them (Hoanh et al. 2006; Aye et al. 2019). It has been suggested that educating coastal communities about sustainable consumption and production and harvesting practices can help in effective management and sustainable exploitation of mangrove and associated resources (Glaser 2003; Ramirez and Townsend 2006). The bottom-up approaches to conservation and management of mangroves involving the local communities have been successful so far (Owuor et al. 2019a). Therefore, policies should be designed keeping both mangroves as well as local communities relying on them at the center in which locals also derive economic and livelihood benefits and mangroves are also sustainably managed (Badola et al. 2012). Alternatively, policies can be designed to provide alternative sources of income to the locals by reducing their overdependency on mangroves (Mitra et al. 2006; Sathirathai and Barbier 2007; Leal Filho et al. 2019). However, excessive restrictions on the locals and prohibiting them from using mangroves do not yield positive results without providing alternative income and livelihood resources (Mitra et al. 2006). A very successful model of sustainable conservation involving local communities is often cited from the two coastal sites in the Philippines, i.e. Bais Bay and Banacon Island (Walters 2003, 2004). The local communities in these two islands started participating in the conservation and restoration of mangroves using local knowledge even before the participation of governments and non-governmental organizations (Walters 2003, 2004). Several other studies have also indicated the important roles of local community knowledge in the sustainable management of mangroves (Kumar 2000, p. 41; Zorini et al. 2004; Iftekhar 2008; Badola et al. 2012; Datta et al. 2012; Roy and Alam 2012; Febryano et al. 2014; Lee et al. 2019).

12.7 Conclusion

This chapter explored various important aspects of mangroves such as species diversity, global distribution, threats, challenges, and the recent conservation initiatives. The chapter also discussed various goods and services provided by the mangroves that contribute toward the overall prosperity of mankind. It is well established that they provide numerous ecological services that could be harnessed to mitigate the effects of global climate change. For example, they are one of the most important storehouses of carbon sequestration and storage. Some species of mangroves face serious survival threats.

Various threats and the conservation challenges that impede conservation and restoration efforts have been discussed in detail. The chapter will be an important and useful material for the students and researchers who wish to start their research in the diverse areas of mangroves. It will also act as an awareness material for people from nonscientific and nontechnical backgrounds.

Acknowledgments

Ajay Kumar acknowledges the funding support provided by Science and Engineering Research Board (SERB), Department of Science and Technology (DST) vide Sanction order File No. EEQ/2019/000441 dated 2 December 2019 and Central University of Kerala for extending other facilities.

References

Abbas, S., Qamer, F.M., Ali, G. et al. (2013). An assessment of status and distribution of mangrove forest cover in Pakistan. *Journal of Biodiversity and Environmental Sciences* 3 (6): 64–78.

Abrantes, K.G., Sheaves, M., and Fries, J. (2019). Estimating the value of tropical coastal wetland habitats to fisheries: Caveats and assumptions. *PLoS One* 14: 1–23. https://doi.org/10.1371/journal.pone.0215350.

Aburto-Oropez, O., Ezcurra, E., Danemann, G. et al. (2008). Mangroves in the Gulf of California increase fishery yields. *Proceedings of the National Academy of Sciences of the United States of America* 105: 10456–10459. https://doi.org/10.1073/pnas.0804601105.

Adams, E.S. and Levings, S.C. (1987). Territory size and population limits in mangrove termites. *Journal of Animal Ecology* 56 (3): 1069–1081.

Adger, W.N., Kelly, M., Ninh, N.H. et al. (1997). Property rights and the social incidence of mangrove conversion in Vietnam. CSERGE Working Paper GEC 97-21.

Agoramoorthy, G., Chen, F.A., and Hsu, M.J. (2008). Threat of heavy metal pollution in halophytic and mangrove plants of Tamil Nadu, India. *Environmental Pollution* 155: 320–326. https://doi.org/10.1016/j.envpol.2007.11.011.

Ahmed, N., Thompson, S., and Glaser, M. (2018). Integrated mangrove-shrimp cultivation: potential for blue carbon sequestration. *Ambio: A Journal of the Human Environment* 47: 441–452. https://doi.org/10.1007/s13280-017-0946-2.

Ajonina, G. and Usongo, L. (2001). Preliminary quantitative impact assessment of wood extraction on the mangroves of Douala-Edea Forest Reserve, Cameroon. *Tropical Biodiversity* 7 (2-3): 137–149.

Alongi, D.M. (2002). Present state and future of the world's mangrove forests. *Environmental Conservation* 29: 331–349. https://doi.org/10.1017/s0376892902000231.

Alongi, D.M. (2008). Mangrove forests: Resilience, protection from tsunamis, and responses to global climate change. *Estuarine, Coastal and Shelf Science* 76: 1–13. https://doi.org/10.1016/j.ecss.2007.08.024.

Alongi, D.M. (2011). Carbon payments for mangrove conservation: ecosystem constraints and uncertainties of sequestration potential. *Environmental Science & Policy* 14: 462–470. https://doi.org/10.1016/j.envsci.2011.02.004.

Alongi, D.M. (2015). The impact of climate change on mangrove forests. *Current Climate Change Reports* 1: 30–39. https://doi.org/10.1007/s40641-015-0002-x.

Arcos, C.D., Badillo-Alemán, M., Arceo-Carranza, D. et al. (2020). Feeding ecology of the waterbirds in a tropical mangrove in the southeast Gulf of Mexico. *Studies on Neotropical Fauna and Environment* 55: 1–9. https://doi.org/10.1080/01650521.2019.1682232.

Asante, W.A., Acheampong, E., Boateng, K. et al. (2017). The implications of land tenure and ownership regimes on sustainable mangrove management and conservation in two Ramsar sites in Ghana. *Forest Policy and Economics* 85: 65–75. https://doi.org/10.1016/j.forpol.2017.08.018.

Asbridge, E., Lucas, R., Rogers, K. et al. (2018). The extent of mangrove change and potential for recovery following severe Tropical Cyclone Yasi, Hinchinbrook Island, Queensland, Australia. *Ecology and Evolution* 8: 10416–10434. https://doi.org/10.1002/ece3.4485.

Ashokkumar, S. and Irfan, Z.B. (2018). Current status of mangroves in India: benefits, rising threats policy and suggestions for the way forward. Madras School of Economics Working Paper- 174/2018. http://www.mse.ac.in/wp-content/uploads/2018/08/Working-Paper-174.pdf.

Ashton, E.C. (2008). The impact of shrimp farming on mangrove ecosystems. *CAB Reviews: Perspectives in Agriculture, Veterinary Science, Nutrition and Natural Resources* 3: 1–12. https://doi.org/10.1079/PAVSNNR20083003.

Aye, W.N., Yali, W., Marin, K. et al. (2019). Contribution of mangrove forest to the livelihood of local communities in Ayeyarwaddy Region, Myanmar. *Forests* 10: 1–12. https://doi.org/10.3390/f10050414.

Badola, R., Barthwal, S., and Hussain, S.A. (2012). Attitudes of local communities towards conservation of mangrove forests: a case study from the east coast of India. *Estuarine, Coastal and Shelf Science* 96: 188–196. https://doi.org/10.1016/j.ecss.2011.11.016.

Bandaranayake, W.M. (1998). Traditional and medicinal uses of mangroves. *Mangroves and Salt Marshes* 2: 133–148. https://doi.org/10.1023/a:1009988607044.

Barbier, E. and Sathirathai, S. (2004). *Shrimp Farming and Mangrove Loss in Thailand*. Cheltenham: Edward Elgar Publishing.

Barbier, E.B. and Cox, M. (2004). An economic analysis of shrimp farm expansion and mangrove conversion in Thailand. *Land Economics* 80: 389–407. https://doi.org/10.2307/3654728.

Barbier, E.B., Hacker, S.D., Kennedy, C. et al. (2011). The value of estuarine and coastal ecosystem services. *Ecological Monographs* 81: 169–193. https://doi.org/10.1890/10-1510.1.

Barbier, E.B., Koch, E.W., Silliman, B.R. et al. (2008). Coastal ecosystem-based management with nonlinear ecological functions and values. *Science* 319: 321–323. https://doi.org/10.1126/science.1150349.

Basha, C.S.K. (2016). An overview on global mangrove distribution. *Indian Journal of Geo-marine Sciences* 47 (4): 766–772.

Bell-James, J., Boardman, T., and Foster, R. (2020). Can't see the (mangrove) forest for the trees: Trends in the legal and policy recognition of mangrove and coastal wetland ecosystem services in Australia. *Ecosystem Services* 45: 1–12. https://doi.org/10.1016/j.ecoser.2020.101148.

Bhomia, R.K., MacKenzie, R.A., Murdiyarso, D. et al. (2016). Impacts of land use on Indian mangrove forest carbon stocks: Implications for conservation and management. *Ecological Applications* 26: 1396–1408. https://doi.org/10.1890/15-2143.

Bibi, N.S., Fawzi, M.M., Gokhan, Z. et al. (2019). Ethnopharmacology, phytochemistry, and global distribution of mangroves- a comprehensive review. *Marine Drugs* 17: 1–82. https://doi.org/10.3390/md17040231.

Biswas, S.R., Choudhury, J.K., Nishat, A. et al. (2007). Do invasive plants threaten the Sundarbans mangrove forest of Bangladesh? *Forest Ecology and Management* 245: 1–9. https://doi.org/10.1016/j.foreco.2007.02.011.

Buelow, C. and Sheaves, M. (2015). A birds-eye view of biological connectivity in mangrove systems. *Estuarine, Coastal and Shelf Science* 152: 33–43. https://doi.org/10.1016/j.ecss.2014.10.014.

Burns, W. (2015). Loss and damage and the 21st Conference of the Parties to the United Nations Framework Convention on Climate Change. *International Law Students Association Journal of International and Comparative Law* 22: 415–433.

Butler (2019). Mongabay. https://rainforests.mongabay.com/08-deforestation.html (accessed 29 October 2020).

Calma, J. (2020). Rising sea levels could wipe out mangroves by 2050. https://www.theverge.com/2020/6/4/21280580/sea-level-rise-mangroves-climate-change-2050 (accessed 29 October 2020)

Carrasquilla-Henao, M., Ban, N., Rueda, M. et al. (2019). The mangrove-fishery relationship: a local ecological knowledge perspective. *Marine Policy* 108: 1–11. https://doi.org/10.1016/j.marpol.2019.103656.

Carugati, L., Gatto, B., Rastelli, E. et al. (2018). Impact of mangrove forests degradation on biodiversity and ecosystem functioning. *Scientific Reports* 8: 1–11. https://doi.org/10.1038/s41598-018-31683-0.

Cashman, A. and Nagdee, M.R. (2017). Impacts of climate change on settlements and infrastructure in the coastal and marine environments of Caribbean small island developing states (SIDS). *Science Review*: 155–173.

Cavanaugh, K.C., Dangremond, E.M., Doughty, C.L. et al. (2019). Climate-driven regime shifts in a mangrove–salt marsh ecotone over the past 250 years. *Proceedings of the National Academy of Sciences* 116: 21602–21608. https://doi.org/10.1073/pnas.1902181116.

Cheong, S.M., Silliman, B., Wong, P.P. et al. (2013). Coastal adaptation with ecological engineering. *Nature Climate Change* 3: 787–791. https://doi.org/10.1038/nclimate1854.

Chow, J. (2017). Mangrove management for climate change adaptation and sustainable development in coastal zones. *Journal of Sustainable Forestry* 37: 139–156. https://doi.org/10.1080/10549811.2017.1339615.

Chaudhuri, P., Ghosh, S., Bakshi, M. et al. (2015). A review of threats and vulnerabilities to mangrove habitats: with special emphasis on east coast of India. *Journal of Earth Science and Climatic Change* 6: 1–9. https://doi.org/10.4172/2157-7617.1000270.

Chowdhury, R.R., Uchida, E., Chen, L. et al. (2017). Anthropogenic drivers of mangrove loss: geographic patterns and implications for livelihoods. In: *Mangrove Ecosystems: A Global Biogeographic Perspective* (eds. V.H. Rivera-Monroy et al.), 275–300. New York: Springer.

Costanza, R., de Groot, R., Sutton, P. et al. (2014). Changes in the global value of ecosystem services. *Global Environmental Change* 26: 152–158. https://doi.org/10.1016/j.gloenvcha.2014.04.002.

Dahdouh-Guebas, F., Jayatissa, L.P., Di Nitto, D. et al. (2005). How effective were mangroves as a defence against the recent tsunami? *Current Biology* 15: 443–447. https://doi.org/10.1016/j.cub.2005.06.008.

Dahdouh-Guebas, F., Kairo, J.G., De Bondt, R. et al. (2007). Pneumatophore height and density in relation to micro-topography in the grey mangrove *Avicennia marina*. *Belgian Journal of Botany* 140: 213–221. https://doi.org/10.2307/20794640.

Dahdouh-Guebas, F., Zetterström, T., Rönnbäck, P. et al. (2002). Recent changes in land-use in the Pambala–Chilaw lagoon complex (Sri Lanka) investigated using remote sensing and GIS: conservation of mangroves vs. development of shrimp farming. *Environment, Development and Sustainability* 4: 185–200. https://doi.org/10.1023/A:1020854413866.

Dai, A. (2010). Drought under global warming: a review. *Wiley Interdisciplinary Reviews: Climate Change* 2: 45–65. https://doi.org/10.1002/wcc.81.

Danielsen, F., Sørensen, M.K., Olwig, M.F. et al. (2005). The Asian tsunami: a protective role for coastal vegetation. *Science* 310: 643–643. https://doi.org/10.1126/science.1118387.

Das, A.B. and Strasser, R.J. (2013). Salinity-induced genes and molecular basis of salt-tolerant strategies in mangroves. In: *Molecular Stress Physiology of Plants* (eds. R. Rout and A.B. Das), 53–86. New Delhi, India: Springer.

Das, S. and Crépin, A.-S. (2013). Mangroves can provide protection against wind damage during storms. *Estuarine, Coastal and Shelf Science* 134: 98–107. https://doi.org/10.1016/j.ecss.2013.09.021.

Das, S. and Vincent, J.R. (2009). Mangroves protected villages and reduced death toll during Indian super cyclones. *Proceedings of the National Academy of Sciences* 106: 7357–7360. https://doi.org/10.1073/pnas.0810440106.

DasGupta, R. and Shaw, R. (2013). Changing perspectives of mangrove management in India–an analytical overview. *Ocean and Coastal Management* 80: 107–118. https://doi.org/10.1016/j.ocecoaman.2013.04.010.

DasGupta, S., Islam, M.S., Huq, M. et al. (2019). Quantifying the protective capacity of mangroves from storm surges in coastal Bangladesh. *PLoS One* 14: 1–14. https://doi.org/10.1371/journal.pone.0214079.

Datta, D., Chattopadhyay, R.N., and Guha, P. (2012). Community based mangrove management: a review on status and sustainability. *Journal of Environmental Management* 107: 84–95. https://doi.org/10.1016/j.jenvman.2012.04.013.

De Graaf, G.J. and Xuan, T.T. (1998). Extensive shrimp farming, mangrove clearance and marine fisheries in the southern provinces of Vietnam. *Mangroves and Salt Marshes* 2: 159–166. https://doi.org/10.1023/A:1009975210487.

del Valle, A., Eriksson, M., Ishizawa, O.A. et al. (2019). Mangroves protect coastal economic activity from hurricanes. *Proceedings of the National Academy of Sciences* 117: 265–270. https://doi.org/10.1073/pnas.1911617116.

Di Nitto, D., Neukermans, G., Koedam, N. et al. (2014). Mangroves facing climate change: landward migration potential in response to projected scenarios of sea level rise. *Biogeosciences* 11: 857–871. https://doi.org/10.5194/bg-11-857-2014.

Dodd, R.S. and Rafii, Z.A. (2002). Evolutionary genetics of mangroves: continental drift to recent climate change. *Trees* 16: 80–86. https://doi.org/10.1007/s00468-001-0142-6.

Donato, D.C., Kauffman, J.B., Murdiyarso, D. et al. (2011). Mangroves among the most carbon-rich forests in the tropics. *Nature Geoscience* 4: 293–297. https://doi.org/10.1038/ngeo1123.

Drexler, J.Z. and Ewel, K.C. (2001). Effect of the 1997–1998 ENSO-related drought on hydrology and salinity in a Micronesian wetland complex. *Estuaries* 24: 347–356. https://doi.org/10.2307/1353237.

Duangjai, W., Ngamniyom, A. et al. (2013). The guideline development for sustainable livelihood indicators of village marginal mangrove forest in the Satun Province, Thailand. *Asian Social Science* 9 (9): 123–130.

Duke, N.C., Pinzon, Z.S., and Prada, M.C.T. (1997). Large-scale damage to Mangrove forests following two large oil spills in Panama. *Biotropica* 29: 2–14. https://doi.org/10.1111/j.1744-7429.1997.tb00001.x.

Duke, N.C., Meynecke, J.O., Dittmann, S. et al. (2007). A world without mangroves? *Science* 317: 41–43. https://doi.org/10.1126/science.317.5834.41b.

Duke, N., Ball, M., and Ellison, J. (1998). Factors influencing biodiversity and distributional gradients in mangroves. *Global Ecology and Biogeography Letters* 7: 27–47. https://doi.org/10.1111/j.1466-8238.1998.00269.x.

Duke, N.C. and Larkum, A.W.D. (2008). Mangroves and seagrasses. In: *The Great Barrier Reef: Biology, Environment and Management* (eds. P.A. Hutchings, M. Kingsford and O. Hoegh-Guldberg), 156–170. Clayton: CSIRO Publishing.

Duke, N.C. and Schmitt, K. (2015). Mangroves: unusual forests at the seas edge. In: *Tropical Forestry Handbook* (eds. L. Pancel and M. Kohl), 1–24. New York: Springer.

Eldeen, I.M. and Effendy, M.A. (2013). Antimicrobial agents from mangrove plants and their endophytes. In: *Microbial Pathogens and Strategies for Combating Them: Science, Technology and Education*, 9e (ed. A. Méndez-Vilas), 872–882. Spain: Formatex Research Center.

Ellison, A.M. (2008). Managing mangroves with benthic biodiversity in mind: moving beyond roving banditry. *Journal of Sea Research* 59: 2–15. https://doi.org/10.1016/j.seares.2007.05.003.

Ellison, A.M. and Farnsworth, E.J. (1996). Anthropogenic disturbance of Caribbean Mangrove ecosystems: past impacts, present trends, and future predictions. *Biotropica* 28: 549–565. https://doi.org/10.2307/2389096.

Ellison, J.C. (1994). Climate change and sea level rise impacts on mangrove ecosystems. *Impacts of climate change on ecosystems and species*, A marine conservation and development report, 11-30. Gland: IUCN.

Ellison, J.C. (2012). Climate change vulnerability assessment and adaptation planning for mangrove systems, 5–36. Washington, DC: World Wildlife Fund (WWF). ISBN 978-92-990069-0-0

Ellison, J.C. (2015). Vulnerability assessment of mangroves to climate change and sea-level rise impacts. *Wetlands Ecology and Management* 23: 115–137. https://doi.org/10.1007/s11273-014-9397-8.

Ellison, J.C. and Zouh, I. (2012). Vulnerability to climate change of mangroves: assessment from Cameroon, Central Africa. *Biology* 1: 617–638. https://doi.org/10.3390/biology1030617.

Erftemeijer, P.L.A. and Hamerlynck, O. (2005). Die-Back of the mangrove *Heritiera littoralis* Dryand, in the Rufiji Delta (Tanzania) following El Niño floods. *Journal of Coastal Research* 42: 228–235.

Estrada, G.C.D. and Soares, M.L.G. (2017). Global patterns of aboveground carbon stock and sequestration in mangroves. *Anais da Academia Brasileira de Ciências* 89: 973–989. https://doi.org/10.1590/0001-3765201720160357.

FAO (1994). Mangrove forests management guidelines, 169-191. http://www.fao.org/3/ap428e/ap428e00.pdf (accessed 21 August 2019).

FAO (2016). State of the World's Forests. http://www.fao.org/3/a-i5588e.pdf (accessed 29 October 2020)

Farley, J., Batker, D., de la Torre, I. et al. (2010). Conserving Mangrove ecosystems in the Philippines: transcending disciplinary and institutional borders. *Environmental Management* 45 (1): 39–51.

Fauzi, S., Sakti, A., Yayusman, L. et al. (2019). Contextualizing mangrove forest deforestation in Southeast Asia using environmental and socio-economic data products. *Forests* 10: 1–18. https://doi.org/10.3390/f10110952.

Febryano, I.G., Suharjito, D., Darusman, D. et al. (2014). The roles and sustainability of local institutions of mangrove management in Pahawang island. *Jurnal Manajemen Hutan Tropika*: 69–76. https://doi.org/10.7226/jtfm.20.2.69.

Feka, N.Z. and Manzano, M.G. (2008). The implications of wood exploitation for fish smoking on mangrove ecosystem conservation in the South West Province, Cameroon. *Tropical Conservation Science* 1: 222–241. https://doi.org/10.1177/194008290800100305.

Feller, I.C., Friess, D.A., Krauss, K.W. et al. (2017). The state of the world's mangroves in the 21st century under climate change. *Hydrobiologia* 803: 1–12. https://doi.org/10.1007/s10750-017-3331-z.

Ferreira, A.C. and Lacerda, L.D. (2016). Degradation and conservation of Brazilian mangroves, status and perspectives. *Ocean and Coastal Management* 125: 38–46. https://doi.org/10.1016/j.ocecoaman.2016.03.011.

Field, C.B. and Whittaker, R.J. (1998). Biodiversity and function of mangrove ecosystems. *Global Ecology and Biogeography Letters (United Kingdom)* 7: 3–14. https://doi.org/10.1111/j.1466-8238.1998.00278.x.

Field, C.D. (1999). Rehabilitation of mangrove ecosystems: an overview. *Marine Pollution Bulletin* 37: 383–392. https://doi.org/10.1016/s0025-326x(99)00106-x.

Field, C.D. (1995). Impact of expected climate change on mangroves. In: *Asia-Pacific Symposium on Mangrove Ecosystems* (eds. Y.S. Wong and N.F.Y. Tam), 75–81. New York: Springer.

Florida Museum (2018). https://www.floridamuseum.ufl.edu/southflorida/habitats/mangroves/mangrove-life/

Forest Survey of India (2019). India State Of Forest Report. *Ministry of Environment, Environment, Forests & Climate Change Government of India*, India

Francisco, P.M., Mori, G.M., Alves, F.M. et al. (2018). Population genetic structure, introgression, and hybridization in the genus Rhizophora along the Brazilian coast. *Ecology and Evolution* 8: 3491–3504. https://doi.org/10.1002/ece3.3900.

Friess, D.A., Rogers, K., Lovelock, C.E. et al. (2019). The state of the world's mangrove forests: past, present, and future. *Annual Review of Environment and Resources* 44: 89–115. https://doi.org/10.1146/annurev-environ-101718-033302.

Friess, D.A., Thompson, B.S., Brown, B. et al. (2016). Policy challenges and approaches for the conservation of mangrove forests in Southeast Asia. *Conservation Biology* 30 (5): 933–949.

Gaos, A.R., Lewison, R.L., Liles, M.J. et al. (2016). Hawksbill turtle terra incognita: conservation genetics of eastern Pacific rookeries. *Ecology and Evolution* 6: 1251–1264. https://doi.org/10.1002/ece3.1897.

Gardner, C.J. (2016). Use of mangroves by lemurs. *International Journal of Primatology* 37: 317–332. https://doi.org/10.1007/s10764-016-9905-1.

Ghosh, S., Bakshi, M., Bhattacharyya, S. et al. (2015). A review of threats and vulnerabilities to mangrove habitats: with special emphasis on East Coast of India. *Journal of Earth Science & Climatic Change* 6: 1–9. https://doi.org/10.4172/2157-7617.1000270.

Gilbert, A.J. and Janssen, R. (1998). Use of environmental functions to communicate the values of a mangrove ecosystem under different management regimes. *Ecological Economics* 25: 323–346. https://doi.org/10.1016/s0921-8009(97)00064-5.

Gilman, E.L., Ellison, J., Duke, N.C. et al. (2008). Threats to mangroves from climate change and adaptation options: a review. *Aquatic Botany* 89: 237–250. https://doi.org/10.1016/j.aquabot.2007.12.009.

Giri, C. and Muhlhausen, J. (2008). Mangrove forest distributions and dynamics in Madagascar (1975–2005). *Sensors* 8: 2104–2117. https://doi.org/10.3390/s8042104.

Giri, C., Zhu, Z., Tieszen, L.L. et al. (2008). Mangrove forest distributions and dynamics (1975–2005) of the tsunami-affected region of Asia. *Journal of Biogeography* 35: 519–528. https://doi.org/10.1111/j.1365-2699.2007.01806.x.

Giri, C., Ochieng, E., Tieszen, L.L. et al. (2011). Status and distribution of mangrove forests of the world using earth observation satellite data. *Global Ecology and Biogeography* 20: 154–159. https://doi.org/10.1111/j.1466-8238.2010.00584.x.

Giri, C., Long, J., Abbas, S. et al. (2015). Distribution and dynamics of mangrove forests of South Asia. *Journal of Environmental Management* 148: 101–111. https://doi.org/10.1016/j.jenvman.2014.01.020.

Glaser, M. (2003). Interrelations between mangrove ecosystem, local economy and social sustainability in Caeté Estuary, North Brazil. *Wetlands Ecology and Management* 11: 265–272. https://doi.org/10.1023/A:1025015600125.

Global Mangrove Alliance Data Portal (2020). https://gma-panda.opendata.arcgis.com/ (accessed on 30 October 2020)

Godoy, M.D.P. and de Lacerda, L.D. (2015). Mangroves response to climate change: a review of recent findings on mangrove extension and distribution. *Anais da Academia Brasileira de Ciências* 87: 651–667. https://doi.org/10.1590/0001-3765201520150055.

Goforth Jr, H.W. and Thomas, J.R. (1980). Plantings of red Mangroves (*Rhizophora mangle* L.) for stabilization of Marl shorelines in the Florida keys (No. NOSC/TR-506). NAVAL OCEAN SYSTEMS CENTER SAN DIEGO CA.

Goldberg, L., Lagomasino, D., Thomas, T. et al. (2020). Global declines in human-driven mangrove loss. *Global Change Biology* 26: 5844–5855. https://doi.org/10.1111/gcb.15275.

Goutham-Bharathi, M.P., Roy, S.D., Krishnan, P. et al. (2014). Species diversity and distribution of mangroves in Andaman and Nicobar Islands, India. *Botanica Marina* 57: 421–432. https://doi.org/10.1515/bot-2014-0033.

Grantham, H.S., McLeod, E., Brooks, A. et al. (2011). Ecosystem-based adaptation in marine ecosystems of tropical Oceania in response to climate change. *Pacific Conservation Biology* 17: 241–258. https://doi.org/10.1071/pc110241.

Guannel, G., Arkema, K., Ruggiero, P. et al. (2016). The power of three: Coral reefs, seagrasses and mangroves protect coastal regions and increase their resilience. *PLoS One* 11: 1–22. https://doi.org/10.1371/journal.pone.0158094.

Gunawardena, M. and Rowan, J.S. (2005). Economic valuation of a mangrove ecosystem threatened by shrimp aquaculture in Sri Lanka. *Environmental Management* 36: 535–550. https://doi.org/10.1007/s00267-003-0286-9.

Gurib-Fakim, A. and Brendler, T. (2004). *Medicinal and Aromatic Plants of Indian Ocean Islands: Madagascar, Comoros, Seychelles and Mascarenes*. Stuttgart, Germany: Medpharm GmbH Scientific Publishers.

Hamilton, S.E. and Casey, D. (2016). Creation of a high spatio-temporal resolution global database of continuous mangrove forest cover for the 21st century (CGMFC-21). *Global Ecology and Biogeography* 25: 729–738. https://doi.org/10.1111/geb.12449.

Heimbuch, J. (2011). Hawksbill sea turtles discovered living in mangroves. Climate action. http://www.climateaction.org/news/endangered_hawksbill_turtles_living_in_mangroves.

Hein, L. (2000). Impact of shrimp farming on mangroves along India's East Coast. *Unasylva* 51: 48–55.

Hema, M. and Devi, I.P. (2014). Factors of mangrove destruction and management of mangrove ecosystem of Kerala, India. *Journal of Aquatic Biology and Fisheries* 2: 184–196.

Heras, S.R. and Soares, M.O. (2017). Effects of El niño on the coastal ecosystems and their related services. *Mercator* 16: 1–16. https://doi.org/10.4215/rm2017.e16030.

Hirales-Cota, M., Espinoza-Avalos, J., Schmook, B. et al. (2010). Drivers of mangrove deforestation in Mahahual-Xcalak, Quintana Roo, southeast Mexico. *Ciencias Marinas* 36 (2): 147–159.

Hoanh, C.T., Tuong, T.P., Gowing, J.W. et al. (2006). *Environment and Livelihoods in Tropical Coastal Zones*. UK: CAB International.

Horstman, E.M., Dohmen-Janssen, C.M., Narra, P.M.F. et al. (2014). Wave attenuation in mangroves: a quantitative approach to field observations. *Coastal Engineering* 94: 47–62. https://doi.org/10.1016/j.coastaleng.2014.08.005.

Hussain, S.A. and Badola, R. (2010). Valuing mangrove benefits: contribution of mangrove forests to local livelihoods in Bhitarkanika Conservation Area, East Coast of India. *Wetlands Ecology and Management* 18 (3): 321–331. https://doi.org/10.1007/s11273-009-9173-3.

Iftekhar, M.S. (2008). An overview of mangrove management strategies in three South Asian countries: Bangladesh, India and Sri Lanka. *International Forestry Review* 10: 38–51. https://doi.org/10.1505/ifor.10.1.38.

IPCC (2019). Sea level rise and implications for low lying islands, coasts and communities. https://www.ipcc.ch/srocc/chapter/chapter-4-sea-level-rise-and-implications-for-low-lying-islands-coasts-and-communities/ (accessed 29 October 2020).

Islam, M.S. and Wahab, M.A. (2005). A review on the present status and management of mangrove wetland habitat resources in Bangladesh with emphasis on mangrove fisheries and aquaculture. *Hydrobiologia* 542: 165–190. https://doi.org/10.1007/s10750-004-0756-y.

Islam, S.M.D.U. and Bhuiyan, M.A.H. (2018). Sundarbans mangrove forest of Bangladesh: causes of degradation and sustainable management options. *Environmental Sustainability* 1: 113–131. https://doi.org/10.1007/s42398-018-0018-y.

IUCN (2010). Mangrove forests in worldwide decline. https://www.iucn.org/content/mangrove-forests-worldwide-decline (accessed 29 October 2020)

IUCN (2011). Mangroves to receive huge boost from new carbon credit rules. https://www.iucn.org/content/mangroves-receive-huge-boost-new-carbon-credit-rules-0.

IUCN (2017). Mangroves: nurseries for the world's seafood supply. www.iucn.org/news/forests/201708/mangroves-nurseries-world%E2%80%99s-seafood-supply (accessed 27 October 2020).

IUCN (2018). Save Our Mangroves Now! https://www.iucn.org/news/environmental-law/201811/iucn-and-wwf-unite-enhance-implementation-legal-tools-protecting-mangroves (accessed 31 October 2020).

IUCN (2020a). Mangroves and coastal ecosystems. https://www.iucn.org/theme/marine-and-polar/our-work/climate-change-and-ocean/mangroves-and-coastal-ecosystems (accessed 29 October 2020)

IUCN (2020b). IUCN Red List of Threatened Species. www.iucnredlist.org/en (accessed 24 October 2020).

Jayatissa, L.P., Wickramasinghe, W.A.A.D.L., Dahdouh-Guebas, F. et al. (2008). Interspecific variations in responses of mangrove seedlings to two contrasting salinities. *International Review of Hydrobiology* 93: 700–710. https://doi.org/10.1002/iroh.200711017.

Kairo, J.G. and Mwita, M.M. (2020). Western Indian Ocean Mangrove Network, and Western Indian Ocean Marine Science Association. *Guidelines on Mangrove Ecosystem Restoration for the Western Indian Ocean Region-Western Indian Ocean Ecosystem Guidelines and Toolkits*. https://www.nairobiconvention.org/CHM%20Documents/WIOSAP/guidelines/GuidelinesonMangroveRestorationForTheWIO.pdf. (accessed 29 October 2020).

Kairo, J.G., Dahdouh-Guebas, F., Bosire, J. et al. (2001). Restoration and management of mangrove systems – a lesson for and from the East African region. *South African Journal of Botany* 67: 383–389. https://doi.org/10.1016/s0254-6299(15)31153-4.

Kamal, M. and Phinn, S. (2011). Hyperspectral data for mangrove species mapping: a comparison of pixel- based and object-based approach. *Remote Sensing* 3: 2222–2242. https://doi.org/10.3390/rs3102222.

Kamal, S., Grodzińska-Jurczak, M., and Brown, G. (2015). Conservation on private land: a review of global strategies with a proposed classification system. *Journal of Environmental Planning and Management* 58 (4): 576–597.

Kathiresan, K. (2012). Importance of mangrove ecosystem. *International Journal of Marine Science* 2: 70–89. https://doi.org/10.5376/ijms.2012.02.0010.

Kathiresan, K. and Bingham, B.L. (2001). Biology of mangroves and mangrove ecosystems. *Advances in Marine Biology* 40: 81–251. https://doi.org/10.1016/S0065-2881(01)40003-4.

Kathiresan, K. and Qasim, S.Z. (2005). *Biodiversity of Mangrove Ecosystems*, 537–539. New Delhi: Hindustan Publication Corporation.

Kathiresan, K. and Rajendran, N. (2005). Coastal mangrove forests mitigates tsunami. *Estuarine, Coastal and Shelf Science* 65: 601–606. https://doi.org/10.1016/j.ecss.2005.06.022.

Kelleway, J.J., Cavanaugh, K., Rogers, K. et al. (2017). Review of the ecosystem service implications of mangrove encroachment into salt marshes. *Global Change Biology* 23 (10): 3967–3983. https://doi.org/10.1111/gcb.13727.

Kinver, M. (2016). Rice and palm oil risk to mangroves. *BBC News* (4 January).

Krauss, K.W., Doyle, T.W., Doyle, T.J. et al. (2009). Water level observations in mangrove swamps during two hurricanes in Florida. *Wetlands* 29: 142–149. https://doi.org/10.1672/07-232.1.

Krauss, K.W., McKee, K.L., Lovelock, C.E. et al. (2014). How mangrove forests adjust to rising sea level. *New Phytologist* 202: 19–34. https://doi.org/10.1111/nph.12605.

Kuenzer, C., Bluemel, A., Gebhardt, S. et al. (2011). Remote sensing of mangrove ecosystems: a review. *Remote Sensing* 3: 878–928. https://doi.org/10.3390/rs3050878.

Kumar, R. (2000). Conservation and management of mangroves in India, with special reference to the State of Goa and the Middle Andaman Islands. *Unasylva* 51 (203): 41–46.

Kumari, P., Singh, J.K., and Pathak, B. (2020). Potential contribution of multifunctional mangrove resources and its conservation. In: *Biotechnological Utilization of Mangrove Resources* (ed. J.K. Patra), 1–26. London: Academic Press.

Kumari, R., Banerjee, A., Kumar, R. et al. (2019). Deforestation in India: Consequences and sustainable solutions. In: *Deforestation Around the World* (ed. P. Moutinho), 1–18. United Kingdom: IntechOpen.

Kusmana, C. and Sukristijiono, S. (2016). Mangrove resource uses by local community in Indonesia. *Jurnal Pengelolaan Sumberdaya Alam dan Lingkungan* 6 (2) https://doi.org/10.19081/jpsl.2016.6.2.217.

Lamparelli, C.C., Rodrigues, F.O., and Moura, D.O. (1997). Long-term assessment of an oil-spill in a mangrove forest in Sao Paulo, Brazil. In: *Mangrove Ecosystem Studies in Latin America and Africa* (eds. B. Kjerfve et al.), 191–203. Paris: UNESCO.

Lara, R., Szlafsztein, C., Cohen, M. et al. (2002). Implications of mangrove dynamics for private land use in Bragança, North Brazil: a case study. *Journal of Coastal Conservation* 8: 97–102. https://doi.org/10.1007/BF02806589.

Leal Filho, W., Barbir, J., and Preziosi, R. (2019). *Handbook of Climate Change and Biodiversity*. New York: Springer.

Lee, S.Y., Hamilton, S., Barbier, E.B. et al. (2019). Better restoration policies are needed to conserve mangrove ecosystems. *Nature Ecology & Evolution* 3: 870–872. https://doi.org/10.1038/s41559-019-0861-y.

Lee, S.Y., Primavera, J.H., Dahdouh-Guebas, F. et al. (2014). Ecological role and services of tropical mangrove ecosystems: a reassessment. *Global Ecology and Biogeography* 23: 726–743. https://doi.org/10.1111/geb.12155.

Lefebvre, G. and Poulin, B. (1997). Bird communities in Panamanian black mangroves: potential effects of physical and biotic factors. *Journal of Tropical Ecology* 13: 97–113. https://doi.org/10.1017/S0266467400010282.

Le, H. (2008). Economic reforms and mangrove forests in central Vietnam. *Society and Natural Resources* 21: 106–119. https://doi.org/10.1080/08941920701617775.

Lewis, R.R. III (2005). Ecological engineering for successful management and restoration of mangrove forests. *Ecological Engineering* 24: 403–418. https://doi.org/10.1016/j.ecoleng.2004.10.003.

Liang, S., Zhou, R., Dong, S. et al. (2008). Adaptation to salinity in mangroves: Implication on the evolution of salt-tolerance. *Chinese Science Bulletin* 53: 1708–1715. https://doi.org/10.1007/s11434-008-0221-9.

Liebezeit, G. and Rau, M.T. (2006). New Guinean mangroves-Traditional usage and chemistry of natural products. *Senckenbergiana Maritima* 36: 1–10. https://doi.org/10.1007/bf03043698.

Liu, H., Zhang, K., Li, Y. et al. (2013). Numerical study of the sensitivity of mangroves in reducing storm surge and flooding to hurricane characteristics in southern Florida. *Continental Shelf Research* 64: 51–65. https://doi.org/10.1016/j.csr.2013.05.015.

Lovelock, C., Cahoon, D., Friess, D. et al. (2015). The vulnerability of Indo-Pacific mangrove forests to sea-level rise. *Nature* 526: 559–563. https://doi.org/10.1038/nature15538.

Lovelock, C.E., Feller, I.C., Reef, R. et al. (2017). Mangrove dieback during fluctuating sea levels. *Scientific Reports* 7: 1–8. https://doi.org/10.1038/s41598-017-01927-6.

Lovelock, C.E., Krauss, K.W., Osland, M.J. et al. (2016). The physiology of mangrove trees with changing climate. In: *Tropical Tree Physiology* (eds. G. Goldstein and L.S. Santiago), 149–179. New York: Springer.

Lugo, A.E. and Snedaker, S.C. (1974). The ecology of mangroves. *Annual Review of Ecology and Systematics* 5: 39–64. https://doi.org/10.1146/annurev.es.05.110174.000351.

Lundquist, C., Carter, K., Hailes, S.F. et al. (2017). *Guidelines for managing mangrove (Mānawa) expansion in New Zealand*. National Institute of Water & Atmospheric Research Ltd. http://www.niwa.co.nz/managingmangroveguide (accessed 31 October 2020).

Luther, D.A. and Greenberg, R. (2009). Mangroves: a global perspective on the evolution and conservation of their terrestrial vertebrates. *BioScience* 59: 602–612. https://doi.org/10.1525/bio.2009.59.7.11.

López-Medellín, X., Ezcurra, E., González-Abraham, C. et al. (2011). Oceanographic anomalies and sea-level rise drive mangroves inland in the Pacific coast of Mexico. *Journal of Vegetarian Science* 22: 143–151. https://doi.org/10.1111/j.1654-1103.2010.01232.x.

Macintosh, D.J. and Ashton, E.C. (2002). A review of mangrove biodiversity conservation and management. *Centre for Tropical Ecosystems Research* 2 (11): 338–341.

Macnae, W. (1968). A general account of the fauna and flora of mangrove swamps and forests in the Indo-West-Pacific region. *Advances in Marine Biology* 6: 73–270. https://doi.org/10.1016/S0065-2881(08)60438-1.

Macreadie, P.I., Nielsen, D.A., Kelleway, J.J. et al. (2017). Can we manage coastal ecosystems to sequester more blue carbon? *Frontiers in Ecology and the Environment* 15 (4): 206–213.

Makowski, C. and Finkl, C.W. (2018). *Threats to Mangrove Forests: Hazards, Vulnerability, and Management*. New York: Springer.

Mangora, M.M. (2011). Poverty and institutional management stand-off: a restoration and conservation dilemma for mangrove forests of Tanzania. *Wetlands Ecology and Management* 19: 533–543. https://doi.org/10.1007/s11273-011-9234-2.

Mangroves for the future (2012). India. http://www.mangrovesforthefuture.org/countries/members/india/ (accessed 29 October 2020)

Manson, F.J., Loneragan, N.R., Harch, B.D. et al. (2005). A broad-scale analysis of links between coastal fisheries production and mangrove extent: a case-study for northeastern Australia. *Fisheries Research* 74: 69–85. https://doi.org/10.1016/j.fishres.2005.04.001.

Massel, S.R., Furukawa, K., and Brinkman, R.M. (1999). Surface wave propagation in mangrove forests. *Fluid Dynamics Research* 24: 219–249. https://doi.org/10.1016/s0169-5983(98)00024-0.

Mazda, Y., Magi, M., Ikeda, Y. et al. (2006). Wave reduction in a mangrove forest dominated by *Sonneratia* sp. *Wetlands Ecology and Management* 14: 365–378. https://doi.org/10.1007/s11273-005-5388-0.

Mazda, Y., Magi, M., Kogo, M. et al. (1997). Mangroves as a coastal protection from waves in the Tong King delta, Vietnam. *Mangroves and Salt Marshes* 1: 127–135. https://doi.org/10.1023/A:1009928003700.

McCarthy, M.P., Best, M.J., and Betts, R.A. (2010). Climate change in cities due to global warming and urban effects. *Geophysical Research Letters* 37: 1–5. https://doi.org/10.1029/2010gl042845.

Mchenga, I.S.S. and Ali, A.I. (2014). Natural regeneration of mangroves in a degraded and non-degraded tropical forest of Zanzibar island. *Journal of Global Biosciences* 3 (1): 334–344.

McNeely, J.A. (1993). Economic incentives for conserving biodiversity: lessons for Africa. *Ambio* 22: 144–150.

Meeder, J.F., Parkinson, R.W., Ruiz, P.L. et al. (2017). Saltwater encroachment and prediction of future ecosystem response to the Anthropocene Marine Transgression, Southeast Saline Everglades, Florida. *Hydrobiologia* 803: 29–48. https://doi.org/10.1007/s10750-017-3359-0.

Meek (2019). Effects of Deforestation: How Does Agriculture Cause Deforestation? https://sentientmedia.org/how-does-agriculture-cause-deforestation/ (accessed 29 October 2020).

MESCAL (2011). Review of Policy and Legislation Relating to Mangroves, the Use and Management of Mangroves in Tonga. https://www.iucn.org/sites/dev/files/content/documents/tonga_policy_and_legislative_review_report.pdf (accessed 31 October 2020).

Mitra, A. (2020). *Mangrove Forests in India*. New York: Springer.

Mitra, R., Bhattacharya, R.N., Hazra, S. et al. (2006). Mangrove conservation efforts and the local economy: a case study. *Economic and Political Weekly* 41: 3612–3616. https://doi.org/10.2307/4418592.

Mohd-Azlan, J., Noske, R.A. and Lawes, M.J. (2014). Resource Partitioning by Mangrove Bird Communities in North Australia. Biotropica, 46: 331–340. https://doi.org/10.1111/btp.12108

Mumby, P.J., Edwards, A.J., Arias-González, J.E. et al. (2004). Mangroves enhance the biomass of coral reef fish communities in the Caribbean. *Nature* 427: 533–536. https://doi.org/10.1038/nature02286.

Munji, C.A., Bele, M.Y., Idinoba, M.E. et al. (2014). Floods and mangrove forests, friends or foes? Perceptions of relationships and risks in Cameroon coastal mangroves. *Estuarine, Coastal and Shelf Science* 140: 67–75. https://doi.org/10.1016/j.ecss.2013.11.017.

Muraleedharan, P.K., Swarupanandan, K., Anitha, V. et al. (2009). The conservation of mangroves in Kerala: economic and ecological linkages. Division of Forestry and Human Dimension, Kerala Forest Research Institute. Peechi: 24.

Nagelkerken, I., Blaber, S.J.M., Bouillon, S. et al. (2008). The habitat function of mangroves for terrestrial and marine fauna: a review. *Aquatic Botany* 89: 155–185. https://doi.org/10.1016/j.aquabot.2007.12.007.

Naidoo, G. (2016). The mangroves of South Africa: an ecophysiological review. *South African Journal of Botany* 107: 101–113. https://doi.org/10.1016/j.sajb.2016.04.014.

Najjar, R., Walker, H., Anderson, P. et al. (2000). The potential impacts of climate change on the mid-Atlantic coastal region. *Climate Research* 14: 219–233. https://doi.org/10.3354/cr014219.

Najjar, R.G., Pyke, C.R., Adams, M.B. et al. (2010). Potential climate-change impacts on the Chesapeake Bay. *Estuarine, Coastal and Shelf Science* 86: 1–20. https://doi.org/10.1016/j.ecss.2009.09.026.

National Oceanic and Atmospheric Administration (2020). Coastal Blue Carbon. https://oceanservice.noaa.gov/ecosystems/coastal-blue-carbon/ (accessed 06 October 2020).

National Parks Board Singapore (2010). 4th National Report to the Convention on Biological Diversity. https://www.cbd.int/doc/world/sg/sg-nr-04-en.pdf (accessed 18 October 2020).

Neumann, B., Ott, K. et al. (2017). Strong sustainability in coastal areas: a conceptual interpretation of SDG 14. *Sustainability Science* 12 (6): 1019–1035.

Nagabhatla, N., Hung, N.T., Tuyen, L.T. et al. (2019). Ecosystem-based approach for planning research and capacity development for integrated coastal zone management in Southeast Asia. *Archives of Psychiatric Nursing* 9 (1): 3–9.

Nguyen, H.H., McAlpine, C., Pullar, D. et al. (2013). The relationship of spatial–temporal changes in fringe mangrove extent and adjacent land-use: case study of Kien Giang coast, Vietnam. *Ocean and Coastal Management* 76: 12–22. https://doi.org/10.1016/j.ocecoaman.2013.01.003.

Nielsen, M.G. (2011). Ants (Hymenoptera: Formicidae) of mangrove and other regularly inundated habitats: life in physiological extreme. *Myrmecological News* 14: 113–121.

Norris, R. and Cargile, M. (1998). Aquaculture and mangrove destruction. http://darwin.bio.uci.edu/~sustain/issueguides/mangrove/. (accessed 29 October 2020).

Noske, R.A. (1993). *Bruguiera hainesii*: another bird-pollinated mangrove? *Biotropica 25*: 481–483. https://doi.org/10.2307/2388873.

Noske, R.A. (1995). The ecology of mangrove forest birds in Peninsular Malaysia. *International Journal of Avian Science* 137: 250–263. https://doi.org/10.1111/j.1474-919X.1995.tb03247.x.

Nurdiani, R., Firdaus, M., and Prihanto, A.A. (2012). Phytochemical screening and antibacterial activity of methanol extract of mangrove plant (*Rhizophora mucronata*) from Porong river estuary. *Journal of Basic Science and Technology* 1 (2): 27–29.

Nurunnabi, T.R., Sabrin, F., Sharif, D.I. et al. (2020). Antimicrobial activity of endophytic fungi isolated from the mangrove plant *Sonneratia apetala* (Buch.-Ham) from the Sundarbans mangrove forest. *Advances in Traditional Medicine* 20: 419–425. https://doi.org/10.1007/s13596-019-00422-9.

Ong, J.E. (1995). The ecology of Mangrove conservation and management. *Hydrobiologia* 295: 343–351.

Ong, J.E. (2007). Food and Agriculture Organization of the United Nations regional office for Asia and the Pacific. http://www.fao.org/tempref/docrep/fao/010/ag124e/ag124e_full.pdf#page=142.

Osland, M.J., Feher, L.C., Griffith, K.T. et al. (2017). Climatic controls on the global distribution, abundance, and species richness of mangrove forests. *Ecological Monographs* 87: 341–359. https://doi.org/10.1002/ecm.1248.

Othman, M.A. (1994). Value of mangroves in coastal protection. *Hydrobiologia* 285: 277–282.

Owuor, M.A., Icely, J., and Newton, A. (2019a). Community perceptions of the status and threats facing mangroves of Mida Creek, Kenya: implications for community based management. *Ocean and Coastal Management* 175: 172–179. https://doi.org/10.1016/j.ocecoaman.2019.03.027.

Owuor, M.A., Mulwa, R., Otieno, P. et al. (2019b). Valuing Mangrove biodiversity and ecosystem services: a deliberative choice experiment in Mida Creek, Kenya. *Ecosystem Services* 40: 1–12. https://doi.org/10.1016/j.ecoser.2019.101040.

Palacios, M.L. and Cantera, J.R. (2017). Mangrove timber use as an ecosystem service in the Colombian Pacific. *Hydrobiologia* 803: 345–358. https://doi.org/10.1007/s10750-017-3309-x.

Pascual, U. and Perrings, C. (2007). Developing incentives and economic mechanisms for in situ biodiversity conservation in agricultural landscapes. *Agriculture, Ecosystems & Environment* 121 (3): 256–268.

Patel, D.M., Patel, V.M., Katriya, B. et al. (2014). Performance of mangrove in tsunami resistance. *International Journal of Emerging Technology and Research* 1 (3): 29–32.

Pattanaik, C. and Prasad, N.S. (2011). Assessment of aquaculture impact on mangroves of Mahanadi delta (Orissa), East coast of India using remote sensing and GIS. *Ocean and Coastal Management* 54: 789–795. https://doi.org/10.1016/j.ocecoaman.2011.07.013.

Peterson, J.M. and Bell, S.S. (2015). Saltmarsh boundary modulates dispersal of mangrove propagules: implications for mangrove migration with sea-level rise. *PLoS One* 10: 1–15. https://doi.org/10.1371/journal.pone.0119128.

Polidoro, B.A., Carpenter, K.E., Collins, L. et al. (2010). The loss of species: mangrove extinction risk and geographic areas of global concern. *PLoS One* 5: 1–10. https://doi.org/10.1371/journal.pone.0010095.

Poulin, B., Lefebvre, G., and McNeil, R. (1992). Tropical avian phenology in relation to abundance and exploitation of food resources. *Ecology* 73: 2295–2309. https://doi.org/10.2307/1941476.

Primavera, J.H. (1998). Mangroves as nurseries: shrimp populations in Mangrove and non-mangrove habitats. *Estuarine, Coastal and Shelf Science* 46: 457–464. https://doi.org/10.1006/ecss.1997.0275.

Primavera, J.H. (2008). Socio-economic impacts of shrimp culture. *Aquaculture Research* 28: 815–827. https://doi.org/10.1046/j.1365-2109.1997.00946.x.

Primavera, J.H., dela Cruz, M., Montilijao, C. et al. (2016). Preliminary assessment of post-Haiyan mangrove damage and short-term recovery in Eastern Samar, central Philippines. *Marine Pollution Bulletin* 109: 744–750. https://doi.org/10.1016/j.marpolbul.2016.05.050.

Quadros, A.F. and Zimmer, M. (2017). Dataset of “true mangroves” plant species traits. *Biodiversity Data Journal* 5: 1–21. https://doi.org/10.3897/BDJ.5.e22089.

Ragavan, P., Dubey, S.K., Dagar, J.C. et al. (2019). Current understanding of the mangrove forests of India. In: *Research Developments in Saline Agriculture* (ed. J.C. Dagar), 257–304. New York: Springer nature.

Ragavan, P., Saxena, A., Jayaraj, R.S.C. et al. (2016). A review of the mangrove floristics of India. *Taiwania* 61: 224–242. https://doi.org/10.6165/tai.2016.61.224.

Rajkaran, A., Adams, J.B., and du Preez, D.R. (2010). A method for monitoring mangrove harvesting at the Mngazana estuary, South Africa. *African Journal of Aquatic Science* 29: 57–65. https://doi.org/10.2989/16085910409503792.

Ramachandran, R., Banerjee, K., Paneer Selvam, A. et al. (2018). Legislation and policy options for conservation and management of seagrass ecosystems in India. *Ocean and Coastal Management* 159: 46–50. https://doi.org/10.1016/j.ocecoaman.2017.12.025.

Ramirez, D.R. and Townsend, W. (2006). Seaweed and mangroves: improving environmental practices in coastal communities to secure sustainable livelihoods. In: *Coastal Resource Management in the Wider Caribbean: Resilience, Adaptation, and Community Diversity* (eds. Y. Breton, D. Brown, B. Davy, et al.), 172–190. Jamaica: Ian Randle Publishers.

Rasquinha, D.N. and Mishra, D.R. (2020). Impact of wood harvesting on mangrove forest structure, composition and biomass dynamics in India. *Estuarine, Coastal and Shelf Science* 106974 https://doi.org/10.1016/j.ecss.2020.106974.

Ravindran, K.C., Venkatesan, K., Balakrishnan, V. et al. (2005). Ethnomedicinal studies of Pichavaram mangroves of East coast, Tamil nadu. *Indian Journal of Traditional Knowledge* 4 (4): 409–411.

Ravindranath, N.H. and Murthy, I.K. (2010). Greening India Mission. *Current Science* 99 (4): 444–449.

Record, S., Charney, N.D., Zakaria, R.M. et al. (2013). Projecting global mangrove species and community distributions under climate change. *Ecosphere* 4 (3): 1–23.

Riascos, J.M., Cantera, J.R., and Blanco-Libreros, J.F. (2018). Growth and mortality of mangrove seedlings in the wettest neotropical mangrove forests during ENSO: implications for vulnerability to climate change. *Aquatic Botany* 147: 34–42. https://doi.org/10.1016/j.aquabot.2018.03.002.

Richards, D.R. and Friess, D.A. (2016). Rates and drivers of mangrove deforestation in Southeast Asia, 2000–2012. *Proceedings of the National Academy of Sciences* 113: 344–349. https://doi.org/10.1073/pnas.1510272113.

Ricklefs, R.E. and Latham, R.E. (1993). Global patterns of diversity in mangrove floras. In: *Species Diversity in Ecological Communities: Historical and Geographical Perspectives* (eds. R.E. Ricklefs and D. Schluter), 215–229. Chicago: University of Chicago Press.

Rideout, A.J.R., Joshi, N.P., Viergever, K.M. et al. (2013). Making predictions of mangrove deforestation: a comparison of two methods in Kenya. *Global Change Biology* 19: 3493–3501. https://doi.org/10.1111/gcb.12176.

Rochmyaningsih, D. (2017). Aquaculture is main driver of mangrove losses. https://www.eco-business.com/news/aquaculture-is-main-driver-of-mangrove-losses/ (accessed 29 October 2020).

Rog, S.M., Clarke, R.H., and Cook, C.N. (2017). More than marine: revealing the critical importance of mangrove ecosystems for terrestrial vertebrates. *Diversity and Distributions* 23 (2): 221–230.

Rogers, K., Boon, P.I., Branigan, S. et al. (2016). The state of legislation and policy protecting Australia's mangrove and salt marsh and their ecosystem services. *Marine Policy* 72: 139–155. https://doi.org/10.1016/j.marpol.2016.06.025.

Rogers, K., Saintilan, N., Mazumder, D. et al. (2019). Mangrove dynamics and blue carbon sequestration. *Biology Letters* 15 (3): 1–5. https://doi.org/10.1098/rsbl.2018.0471.

Romañach, S.S., DeAngelis, D.L., Koh, H.L. et al. (2018). Conservation and restoration of mangroves: global status, perspectives, and prognosis. *Ocean and Coastal Management* 154: 72–82. https://doi.org/10.1016/j.ocecoaman.2018.01.009.

Ron, J. and Padilla, J.E. (1999). Preservation or conversion? Valuation and evaluation of a mangrove forest in the Philippines. *Environmental and Resource Economics* 14 (3): 297–331.

Rosenzweig, C. and Hillel, D. (2008). *Climate Variability and the Global Harvest: Impacts of El Niño and other Oscillations on Agro-ecosystems*. United Kingdom: Oxford University Press.

Roy, A.K.D. (2016). Local community attitudes towards mangrove forest conservation: lessons from Bangladesh. *Marine Policy* 74: 186–194. https://doi.org/10.1016/j.marpol.2016.09.021.

Roy, A.K.D. and Alam, K. (2012). Participatory forest management for the sustainable management of the Sundarbans mangrove forest. *American Journal of Environmental Sciences* 8: 549–555. https://doi.org/10.3844/ajessp.2012.549.555.

Saha, S.K. (2010). Soilless cultivation for landless people: an alternative livelihood practice through indigenous hydroponic agriculture in flood-prone Bangladesh. *Ritsumeikan Asia Pacific University* 27: 139–151.

Sanderman, J., Hengl, T., Fiske, G. et al. (2018). A global map of mangrove forest soil carbon at 30 m spatial resolution. *Environmental Research Letters* 13: 1–12. https://doi.org/10.1088/1748-9326/aabe1c.

Sandilyan, S. and Kathiresan, K. (2012). Mangrove conservation: a global perspective. *Biodiversity and Conservation* 21: 3523–3542. https://doi.org/10.1007/s10531-012-0388-x.

Sandilyan, S. and Kathiresan, K. (2015). Mangroves as bioshield: an indisputable fact. *Ocean and Coastal Management* 103: 94–96. https://doi.org/10.1016/j.ocecoaman.2014.11.011.

Santisuk, T. (1983). Taxonomy and distribution of terrestrial trees and shrubs in the mangrove formations in Thailand. *Natural History Bulletin of the Siam Society* 31 (1): 63–91.

Saranraj, P. and Sujitha, D. (2015). Mangrove medicinal plants: a review. *American-Eurasian Journal of Toxicological Sciences* 7: 146–156. https://doi.org/10.5829/idosi.aejts.2015.7.3.94150.

Sarmin, N.S., Hasmadi, I.M., Pakhriazad, H.Z. et al. (2016). The DPSIR framework for causes analysis of mangrove deforestation in Johor, Malaysia. *Environmental Nanotechnology Monitoring & Management* 6: 214–218. https://doi.org/10.1016/j.enmm.2016.11.002.

Sathirathai, S. and Barbier, E.B. (2007). Valuing mangrove conservation in southern Thailand. *Contemporary Economic Policy* 19: 109–122. https://doi.org/10.1111/j.1465-7287.2001.tb00054.x.

Saw, A.A. and Kanzaki, M. (2015). Local livelihoods and encroachment into a mangrove forest reserve: a case study of the Wunbaik reserved mangrove forest, Myanmar. *Procedia Environmental Sciences* 28: 483–492. https://doi.org/10.1016/j.proenv.2015.07.058.

Scaife, A., Guilyardi, E., Cain, M. et al. (2019). What is the El Niño–Southern oscillation? *Weather* 74: 250–251. https://doi.org/10.1002/wea.3404.

Scales, I.R. and Friess, D.A. (2019). Patterns of mangrove forest disturbance and biomass removal due to small-scale harvesting in southwestern Madagascar. *Wetlands Ecology and Management* 27: 609–625. https://doi.org/10.1007/s11273-019-09680-5.

Schneider, P. (2011). The discovery of tropical mangroves in graeco-roman antiquity: science and wonder. *The Journal of the Hakluyt Society*: 1–16. https://www.hakluyt.com/downloadable_files/Journal/mangroves1.pdf.

Schwartzstein, P. (2019). This vanishing forest protects the coasts – and lives – of two countries. https://www.nationalgeographic.com/magazine/2019/07/sundarbans-mangrove-forest-in-bangladesh-india-threatened-by-rising-waters-illegal-logging/ (accessed 30 October 2020).

Seepana, R., Perumal, K., Kada, N.M. et al. (2016). Evaluation of antimicrobial properties from the mangrove *Rhizophora apiculata* and *Bruguiera gymnorrhiza* of Burmanallah coast, South Andaman, India. *Journal of coastal life medicine* 4: 475–478. https://doi.org/10.12980/jclm.4.2016J6-52.

Semeniuk, V. (1994). Predicting the effect of sea-level rise on mangroves in northwestern Australia. *Journal of Coastal Research* 10 (4): 1050–1076.

Semesi, A.K. (1992). Developing management plans for the mangrove forest reserves of mainland Tanzania. *Hydrobiologia* 247: 1–10. https://doi.org/10.1007/BF00008199.

Sharrock, S. and Jackson, P.W. (2016). Plant Conservation and the Sustainable Development Goals. 1-19. *Conference of the Global Partnership for Plant Conservation on the theme 'Plant Conservation and the Sustainable Development Goals (SDGs)'*, Missouri Botanical Garden, St Louis, U.S.A. (28–29 June 2016).

Shunula, J. (2002). Public awareness, key to mangrove management and conservation: the case of Zanzibar. *Trees* 16: 209–212. https://doi.org/10.1007/s00468-001-0147-1.

Singh, B.R. and Singh, O. (2012). Study of impacts of global warming on climate change: eise in sea level and disaster frequency. In: *Global Warming – Impacts and Future Perspectives* (ed. B.R. Singh), 93–118. United Kingdom: IntechOpen.

Singh, J.K. (2020). Structural characteristics of mangrove forest in different coastal habitats of Gulf of Khambhat arid region of Gujarat, west coast of India. *Heliyon* 6: 1–7. https://doi.org/10.1016/j.heliyon.2020.e04685.

Singh, P.K., Papageorgiou, K., Chudasama, H. et al. (2019). Evaluating the effectiveness of climate change adaptations in the world's largest Mangrove ecosystem. *Sustainability* 11: 1–17. https://doi.org/10.3390/su11236655.

Sippo, J.Z., Lovelock, C.E., Santos, I.R. et al. (2018). Mangrove mortality in a changing climate: an overview. *Estuarine, Coastal and Shelf Science* 215: 241–249. https://doi.org/10.1016/j.ecss.2018.10.011.

Spalding, M., Kainuma, M., and Collins, L. (2010). *World Atlas of Mangroves*. London: Earthscan.

Spiteri, A. and Nepalz, S.K. (2006). Incentive-based conservation programs in developing countries: a review of some key issues and suggestions for improvements. *Environmental Management* 37 (1): 1–14.

Srivastava, S. and Mehta, L. (2017). The social life of Mangroves: Resource complexes and contestations on the industrial coastline of Kutch, India. STEPS Working Paper 99, Brighton: STEPS Centre.

Suman, D.O. (2019). Mangrove management: challenges and guidelines. In: *Coastal Wetlands* (eds. G. Perillo et al.), 1055–1079. Netherlands: Elsevier.

Sundar, I. (2018). Environmental conservation policies, programmes and legislations in India. *International Journal of Management, IT & Engineering* 8 (9): 1–11.

Sunyowati, D., Hastuti, L., and Butar, F.B. (2016). The regulation of sustainable mangroves and coastal zones management in Indonesia. *Journal of Civil & Legal Sciences* 6 (1) https://doi.org/10.4172/2169-0170.1000220.

Sustainability Times (2020). Myanmar's mangrove forests are in grave peril. https://www.sustainability-times.com/environmental-protection/myanmars-mangrove-forests-are-in-grave-peril/ (accessed 29 October 2020).

Tam, N.F.Y. and Wong, Y.S. (1999). Mangroves soils in removing pollutants from municipal waste water of different salinities. *Journal of Environmental Quality* 28 (2): 556–564.

Teas, H.J. (1977). Ecology and restoration of mangrove shorelines in Florida. *Environmental Conservation* 4: 51–58. https://doi.org/10.1017/S0376892900025042.

Thomas, N., Lucas, R., Bunting, P. et al. (2017). Distribution and drivers of global mangrove forest change, 1996–2010. *PLoS One* 12: 1–14. https://doi.org/10.1371/journal.pone.0179302.

Thu, P.M. and Populus, J. (2007). Status and changes of mangrove forest in Mekong Delta: case study in Tra Vinh, Vietnam. *Estuarine, Coastal and Shelf Science* 71 (1-2): 98–109.

Tolangara, A.R. (2014). Forest destruction, wood utilization and mangrove area in district Jailolo, West Halmahera Regency, province of North Mollucas and the conservation education. *International Journal of Engineering Research and Development* 10 (1): 54–60.

Tomlinson, P.B. (2016). Floristics. In: *The Botany of Mangroves*, 29–42. Cambridge, UK: Cambridge University Press.

Udoh, J.P. (2016). Sustainable nondestructive mangrove-friendly aquaculture in Nigeria II: models, best practices and policy frame work. *Aquaculture, Aquarium, Conservation & Legislation* 9 (1): 151–173.

Uddin, M.S., van Steveninck, E.D.R., Stuip, M. et al. (2013). Economic valuation of provisioning and cultural services of a protected mangrove ecosystem: a case study on Sundarbans Reserve Forest, Bangladesh. *Ecosystem Services* 5: 88–93. https://doi.org/10.1016/j.ecoser.2013.07.002.

UNESCO (2015). Proclamation of the International day for the conservation of the mangrove ecosystem. 38th general Conference. https://unesdoc.unesco.org/ark:/48223/pf0000235350. (accessed on 31 October 2020).

United Nations Ocean Conference (2019). Save our mangroves now! by Germany, Federal Ministry for Economic Cooperation and Development (BMZ) (Government). https://oceanconference.un.org/commitments/?id=27534.

Upadhyay, V.P., Ranjan, R., and Singh, J.S. (2002). Human-mangrove conflicts: the way out. *Current Science* 83: 1328–1336.

Valiela, I. and Cole, M.L. (2002). Comparative evidence that salt marshes and mangroves may protect seagrass meadows from land-derived nitrogen loads. *Ecosystems* 5: 92–102. https://doi.org/10.1007/s10021-001-0058-4.

Valiela, I., Bowen, J.L., and York, J.K. (2001). Mangrove Forests: one of the world's threatened major tropical environments. *BioScience* 51: 807–815.

Van Lavieren, H., Spalding, M., Alongi, D.M. et al. (2012). *Securing the Future of Mangroves*. Hamilton, ON, Canada: United Nations University, Institute for Water, Environment and Health.

Vidyasagaran, K. and Madhusoodanan, V.K. (2014). Distribution and plant diversity of mangroves in the west coast of Kerala, India. *Journal of Biodiversity and Environmental Sciences* 4 (5): 38–45.

Vincentius, A., Nessa, M.N., Jompa, J. et al. (2019). Complex relationship between mangrove ecosystem variables and fish assemblages at Maumere Bay, Indonesia. *IOP Conference Series: Earth and Environmental Science* 253: 1–10. https://doi.org/10.1088/1755-1315/253/1/012035.

Virata, J.B. (2011). Hawksbill sea turtles found foraging and living in mangrove estuaries. https://www.reptilesmagazine.com/hawksbill-sea-turtles-found-foraging-and-living-in-mangrove-estuaries/#:~:text=Gaos%20says%20it%20is%20still,rock%20outcrops%20within%20the%20estuaries.

Walters, B.B. (1997). Human ecological questions for tropical restoration: experiences from planting native upland trees and mangroves in the Philippines. *Forest Ecology and Management* 99: 275–290. https://doi.org/10.1016/S0378-1127(97)00211-9.

Walters, B.B. (2003). People and mangroves in the Philippines: fifty years of coastal environmental change. *Environmental Conservation* 30: 293–303. https://doi.org/10.1017/S0376892903000298.

Walters, B.B. (2004). Local management of mangrove forests in the Philippines: successful conservation or efficient resource exploitation? *Human Ecology* 32: 177–195. https://doi.org/10.1023/b:huec.0000019762.36361.48.

Wang, L., Mu, M., Li, X. et al. (2010). Differentiation between true mangroves and mangrove associates based on leaf traits and salt contents. *Journal of Plant Ecology* 4: 292–301. https://doi.org/10.1093/jpe/rtq008.

Wang, W., Yan, Z., You, S. et al. (2011). Mangroves: obligate or facultative halophytes? A review. *Trees* 25: 953–963. https://doi.org/10.1007/s00468-011-0570-x.

Ward, R.D., Friess, D.A., Day, R.H. et al. (2016). Impacts of climate change on mangrove ecosystems: a region by region overview. *Ecosystem Health and Sustainability* 2: 1–25. https://doi.org/10.1002/ehs2.1211.

Whitefield, P., Beauchamp, E., Boyd, D.S. et al. (2019). Exploring temporality in socio-ecological resilience through experiences of the 2015–16 El Niño across the Tropics. *Global Environmental Change* 55: 1–14. https://doi.org/10.1016/j.gloenvcha.2019.01.004.

Wilson, R. (2017). Impacts of climate change on mangrove ecosystems in the coastal and marine environments of Caribbean small island developing states (SIDS). *Caribbean Climate Change Report Card: Science Review*, (pp. 60–82).

Wongthong, P. (2020). Potential impacts of sea level rise on mangroves. http://www.coastalwiki.org/wiki/Potential_Impacts_of_Sea_Level_Rise_on_Mangroves (accessed 30 October 2020).

Wood, J. (2019). World Economic Forum. https://www.weforum.org/agenda/2019/02/5-reasons-to-protect-mangrove-forests-for-the-future/ (accessed 29 October 2020).

Woodroffe, C.D. and Davies, G. (2009). The morphology and development of Coastal wetlands in the Tropics. In: *Coastal Wetlands: An Integrated Ecosystem Approach* (eds. G.M.E. Perello et al.), 65–88. Netherlands: Elsevier.

Xu, S., He, Z., Zhang, Z. et al. (2017). The origin, diversification and adaptation of a major mangrove clade (Rhizophoreae) revealed by whole genome sequencing. *National Science Review* https://doi.org/10.1093/nsr/nwx065.

Yeo, S (2014). Save mangroves for people, planet and the economy, says UN. https://www.climatechangenews.com/2014/09/30/save-mangroves-for-people-planet-and-the-economy-says-un/ (accessed 02 August 2018).

Yong, J. (2018). Origin of mangroves & mangrove diversity. https://mangroveactionproject.org/origin-of-mangrove-mangrove-diversity/ (accessed 02 May 2018)

Yáñez-Espinosa, L. and Flores, J. (2011). A review of sea-level rise effect on mangrove forest species: anatomical and morphological modifications. In: *Global Warming Impacts: Case Study on the Economy, Human Health and on Urban and Natural Environments* (ed. S. Casalegno), 253–276. United Kingdom: IntechOpen.

Zhang, K., Liu, H., Li, Y. et al. (2012). The role of mangroves in attenuating storm surges. *Estuarine, Coastal and Shelf Science* 102: 11–23. https://doi.org/10.1016/j.ecss.2012.02.021.

Zorini, L.O., Contini, C., Jiddawi, N. et al. (2004). Participatory appraisal for potential community-based mangrove management in East Africa. *Wetlands Ecology and Management* 12 (2): 87–102. https://doi.org/10.1023/b:wetl.0000021672.15252.54.