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Tropical Forest UPDATE

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A newsletter from the International Tropical Timber Organization to promote the conservation and sustainable development of tropical forests

Mapping mangroves

Mangroves are highly productive, biodiversity-rich forest ecosystems adapted to survive in the harsh interface between land and sea. They provide resources such as timber, firewood, thatching materials and a wide range of other products, they serve as habitat for fisheries, and they help protect coastlines from tsunamis, storm surges and erosion. But they are under threat. An estimated 35 600 km² were lost between 1980 and 2005, and the annual rate of loss between 2000 and 2005 was 0.66%.

Recognizing the importance of mangroves and the peril they face, a consortium of organizations—ITTO, ISME, FAO, UNESCO-MAB, UNEP-WCMC, UNU-INWEH and TNC[1]– worked together to produce the 2010 World Atlas of Mangroves, a follow-up to an Atlas published by ITTO and ISME in 1997 and the most comprehensive worldwide study ever undertaken on mangrove ecosystems. This special edition of the TFU summarizes its main findings.

Special edition summarizing the findings of the 2010 World Atlas of Mangroves

ITTO

Photo: © J.F. Hellio and N. Van Ingen

Contents

ITTO

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Background

The *World Mangrove Atlas,* an initiative of ITTO and ISME, was published in 1997. This highly acclaimed work supported the development of a new global perception of the extent and status of mangrove ecosystems. It contained world and regional mangrove distribution maps, country-by-country assessments, and case studies on the geomorphology, species composition and socioeconomic condition of specific areas.

The aim of the 2010 *World Atlas of Mangroves* was to revise and improve the accuracy of the original *World Mangrove Atlas* through analytical assessments of mangrove forest area and status at the regional and national levels. Published in English in July 2010, the revised Atlas was written by Mark Spalding (TNC), Mami Kainuma (ISME) and Lorna Collins (TNC), with funding from the Government of Japan and the inputs of more than 100 international mangrove researchers and organizations.

The 2010 *World Atlas of Mangroves* constitutes the first truly global assessment of the state of mangroves, providing recent and reliable coverage of nearly 99% of the world's mangroves and a wealth of statistics on biodiversity, habitat area, loss and economic value. It contains 60 full-page maps—including new maps derived from recent satellite imagery for about 59% of the resource—showing locations of the entire world's mangroves. It includes hundreds of photographs and illustrations together with comprehensive country-by-country assessments.

Supporting countries and organizations

The following organizations provided financial or in-kind contributions to the project: Government of Japan (the major funding source of the project); Thailand Environment Institute; Tokio Marine and Nichido Fire Insurance; Tropical Biosphere Research Center of University of the Ryukyus; Wetlands International; the United States Department of State; and the Government of Spain (the latter two provided funding for publishing French and Spanish versions of the Atlas in 2011 and early 2012, respectively).

Contents

Chapters 1 and 2 of the Atlas provide information on mangrove distribution, biogeography, productivity, ecology, human use, economic value, threats and management approaches. Chapter 3 describes the methodology used in the production of the regional, national and subnational mangrove distribution maps presented in Chapters 4–13, which also contain information at the country level on mangrove distribution, ecology and use. Ten case studies written by regional experts provide insights into regional mangrove issues, including ecology, productivity, biodiversity, traditional use and values, and sustainable management.

The Atlas contains three annexes. Annex 1 consists of range maps for 73 mangrove species; Annex 2 provides a listing of country-by-country species; and Annex 3 presents national-level statistics on various mangrove parameters.

This special TFU summarizes chapters 1–13 of the Atlas and also, under 'Management implications', extends it to address some of the efforts that are being made to ensure the sustainability of the world's remaining mangrove ecosystems.

Map production

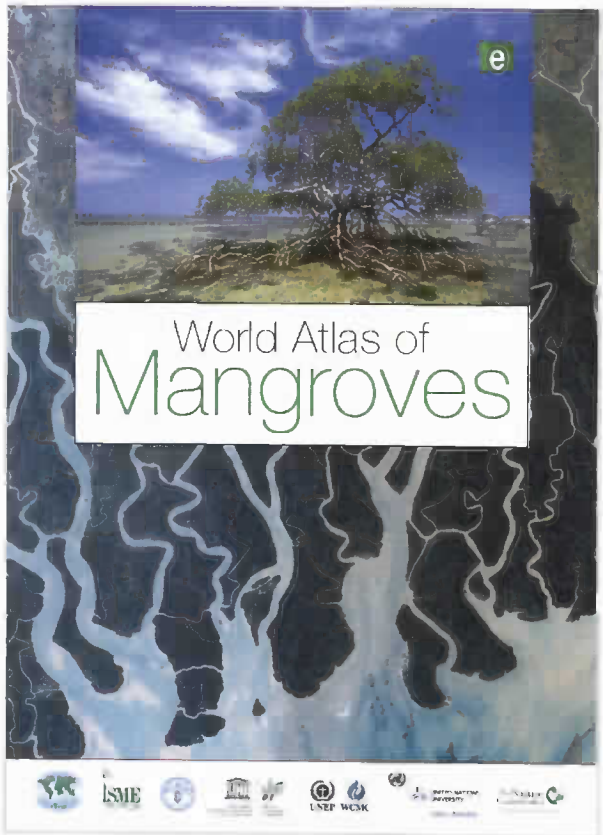
FAO and UNEP-WCMC led the mapping effort. A major element of this work was the creation from Landsat imagery of new maps for part or all of 55 countries and territories (representing 57% of the world's mangroves). In addition, high-resolution mangrove maps for the remaining 43% of the global mangrove resource were obtained from other sources, including the 1997 World Mangrove Atlas. The resulting global map is a major milestone, with data of broadly consistent age and resolution for 98.6% of the total global mangrove area. This dataset enables comparisons over geographic space and provides a critical base for assessing future change over time.

1 *International Tropical Timber Organization, International Society for Mangrove Ecosystems (ISME), Food and Agriculture Organization of the United Nations (FAO), United Nations Educational, Scientific and Cultural Organization–Man and the Biosphere Programme (UNESCO-MAB), United Nations Environment Programme–World Conservation Monitoring Centre (UNEP-WCMC), United Nations University–Institute for Water Environment and Health (UNU-IWEH), and The Nature Conservancy (TNC).*

World Atlas of Mangroves

Publication announcement

This Atlas provides the first truly global assessment of the state of the world's mangroves. Written by Dr. Mark Spalding, a leading expert on mangroves with support from more than 100 top international mangrove researchers and organizations, this full colour Atlas contains 60 full-page maps showing locations of all the world's mangroves, hundreds of photographs and illustrations and comprehensive country-by-country assessments of mangroves. The detailed maps and new mangrove area statistics are derived from recent satellite imagery, comprising, the most comprehensive study ever undertaken of these important ecosystems.



Mangroves are considered both ecologically and from a human perspective. Initial chapters provide a global view, with information on distribution, biogeography, productivity and wider ecology, as well as on human uses, economic values, threats, and approaches for mangrove management. These themes are revisited throughout the regional chapters, where the maps provide a spatial context or starting point for further exploration. The book also presents a wealth of statistics on biodiversity, habitat area, loss and economic value which provide a unique record of mangroves against which future threats and changes can be evaluated. Case studies, written by regional experts provide insights into regional mangrove issues, including ecology, primary and potential productivity, biodiversity, sustainable management and information on present and

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Dr Mami Kainuma is the Project Coordinator and a Senior Researcher for the International Society for Mangrove Ecosystems (ISME), Japan.
Lorna Collins has worked as a research associate for TNC and holds a Masters degree in Marine Biology from the University of Plymouth, UK.

Map preparation was lead by FAO

traditional uses and values.

The World Atlas of Mangroves is the result of a project implemented since 2005 as a joint initiative of the International Tropical Timber Organization (ITTO), the International Society of Mangrove Ecosystems (ISME), the Food and Agriculture Organization of the United Nations (FAO), UNEP-World Conservation Monitoring Centre (UNEP-WCMC), UNESCO-Man and the Biosphere (UNESCO-MAB), UNU-Institute for Water Environment and Health (UNU-INWEH) and The Nature Conservancy (TNC) to revise the World Mangrove Atlas published in 1997 from ITTO and ISME in collaboration with WCMC. The majority of funding was provided by ITTO through a Japanese Government project grant and the project was implemented by ISME.

The Spanish and French translated versions are also published. For further information, please contact the ISME Secretariat at isme@mangrove.or.jp, or visit Routledge at http://www.routledge.com/books/details/9781844076574/ (20% discount code AF20 for the English version).

Contents

Available from Earthscan. 319 pages, 8-1/2 x 11" (A4), over 200 photographs, 50 line illustrations, 129 maps (65 full-page). Hard cover. ISBN: 978-1-84407-657-4.

'The importance of mangroves is well-known, but never has there been such a comprehensive review of these critical ecosystems. This book should change the way we view, and manage, mangroves for the benefit of coastal peoples and biodiversity world-wide.'

Achim Steiner, Executive Director, United Nations Environment Programme (UNEP)

'I am pleased that ITTO, ISME, and the other members of this excellent partnership have produced such a magnificent reference book. The World Atlas of Mangroves details an incredible variety of useful information that will be of considerable value to forest researchers, practitioners, and students to learn more about mangrove ecosystems.'

Professor Don K. Lee, President, International Union of Forest Research Organizations (IUFRO)

'an invaluable sourcebook for any national or international institution concerned or charged with the sustained use and protection of mangroves.'

Professor Eberhard F. Bruenig, International Forestry Review

'a classic masterpiece. ...a must-have publication for every mangrove ecologist, conservation biologist or policy-maker working within or adjacent to mangrove ecosystems.'

Dr. Farid Dahdouh-Guebas, Human Ecology

Mangrove ecosystems

Mangrove plants

Mangrove plants are mostly trees and large shrubs, but also include ferns and a palm species. In the Atlas, a total of 73 species and hybrids are considered to be true mangroves: all have adapted to mangrove environments and are rarely, if ever, found elsewhere. Thirty-eight of these species might be considered 'core species' that typify mangroves and dominate in most locations. The remainder are rarely so abundant or are more typically found on the fringes of mangrove habitats (Table 1).

Table 1 Core mangrove species

Indo-West Pacific			
Family	**Species**	**Family**	**Species**
Avicenniaceae	*Avicennia alba*	Rhizophoraceae (cont.)	*Ceriops australis*
	Avicennia integra		*Ceriops decandra*
	Avicennia marina		*Ceriops tagal*
	Avicennia officinalis		*Kandelia candel*
	Avicennia rumphiana		*Kandelia obovata*
Combretaceae	*Lumnitzera littorea*		*Rhizophora apiculata*
	Lumnitzera racemosa		*Rhizophora mucronata*
			Rhizophora samoensis
Meliaceae	*Xylocarpus granatum*		*Rhizophora stylosa*
	Xylocarpus moluccensis	Sonneratiaceae	*Sonneratia alba*
Rhizophoraceae	*Bruguiera cylindrica*		*Sonneratia apetala*
	Bruguiera exaristata		*Sonneratia caseolaris*
	Bruguiera gymnorhiza		*Sonneratia griffithii*
	Bruguiera hainesii		*Sonneratia lanceolata*
	Bruguiera parviflora		*Sonneratia ovata*
	Bruguiera sexangula		
Atlantic East Pacific			
Family	**Species**	**Family**	**Species**
Avicenniaceae	*Avicennia bicolor*	Pellicieraceae	*Pelliciera rhizophorae*
	Avicennia germinans	Rhizophoraceae	*Rhizophora mangle*
	Avicennia schaueriana		*Rhizophora racemosa*
Combretaceae	*Conocarpus erectus*		
	Laguncularia racemosa		

Note: See Atlas for a list of all 73 mangrove species and hybrids.

The environment in which mangroves grow is harsh, with variable but often high salinity; regular inundation; and with soft, waterlogged and often unstable sediments. To survive, most mangrove plants have developed adaptive strategies in morphology, physiology and/or reproduction. These include:

- Coping with salinity through ultra-filtration at the root endodermis, deposition in bark and roots, disposal through leaf senescence, and secretion via salt glands.
- The development of aerating roots such as stilt roots, pneumatophores, knee roots and buttress roots, which provide important structural support and aid the supply of oxygen to the roots.
- The formation of lenticels in aerial roots to facilitate gaseous exchange.
- The development of vivipary, in which young plants begin to grow within fruits while they are still attached to the parent plant, enabling more rapid establishment and early growth when they settle in the right environment. Vivipary is best developed in species of Rhizophoraceae: the embryo grows out of the seed and then out of the fruit while still attached to the parent plant, so that the propagule that is eventually released is a seedling rather than a seed.

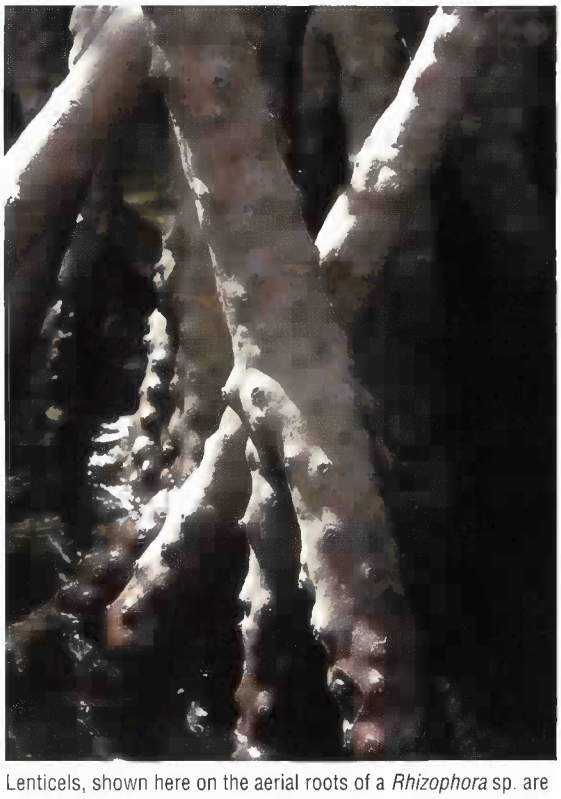
Roots need air and in the waterlogged soils of mangrove forests this can be in short supply. Mangrove species have developed a range of root formations that allow access to the open air at low tide, including the knee roots of *Bruguiera* spp. *Photo: M. Kainuma.*

Mangrove environment

The habitats formed by mangroves are variously termed forests, swamps and communities. The intertidal zone in which mangroves grow is restricted spatially, bound as it is by the sea on one side and terrestrial environments (where competition for space with other plants is fierce) on the other. Aridity and high salinity often further restrict growing space. Although adapted to salinity, mangroves thrive in areas where seawater is diluted by high regular rainfall, groundwater flows or rivers.

Figure 1 Global distribution of mangroves

Where conditions are conducive—typically in deltas, estuaries and coastal lagoons in wetter regions—mangroves form extensive forests, where canopy height may reach 30 m or more. At the other extreme, where conditions are arid or saline, fewer species can survive and trees grow only in dwarf or scrub formations. Mangroves are widely found along open coastlines in places where wave energy is sufficiently low and suitable sediments occur.



Lenticels, shown here on the aerial roots of a *Rhizophora* sp. are small pores that allow gaseous exchange in air but are blocked when the root is submerged. *Photo: M. Spalding*

Mangrove forest morphology

Fringing mangroves are relatively narrow strips tracing shorelines, lagoons or the more steeply shelving part of estuarine or deltaic channels.

Basin mangroves are broader formations, typically occurring in very shallow depressions away from the water's edge. There is no wave action and the mangroves may be inundated only infrequently.

Over-wash mangroves are patches, islands or small promontories that are entirely covered by water at high tides and have little leaf litter accumulation.

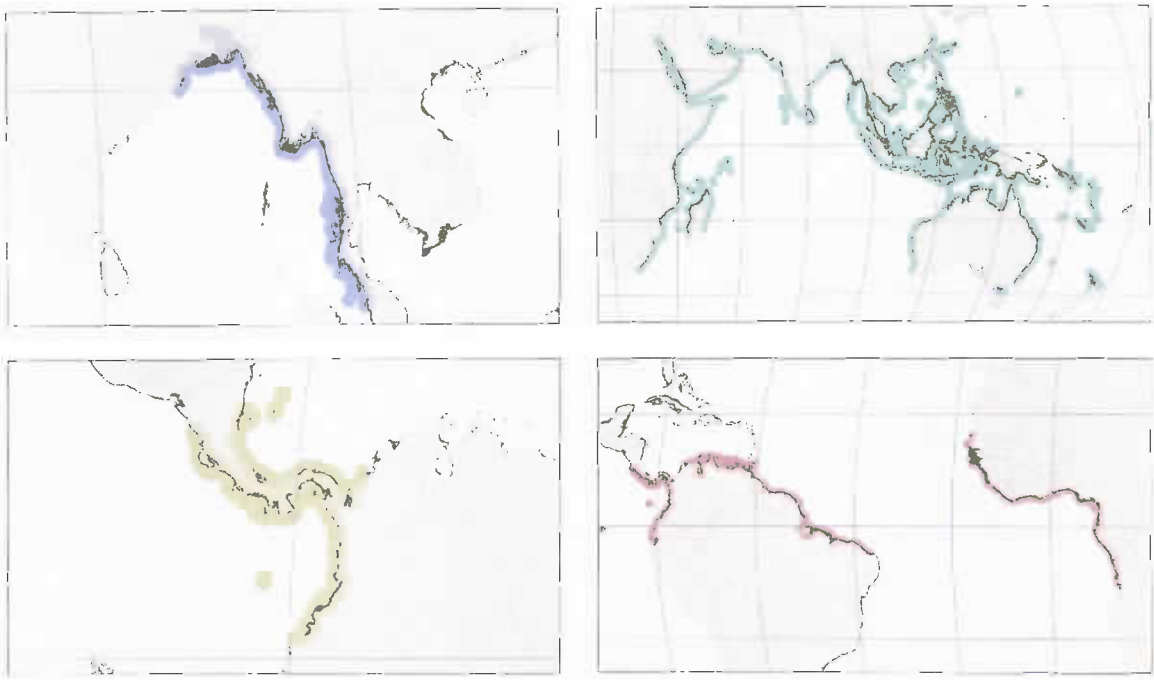
Mangrove distribution

The Atlas includes a new global map derived almost entirely from satellite imagery captured between 1999 and 2003. According to this map, the global mangrove area is 152 360 km², the most accurate estimate ever compiled.[2] Mangroves are found in 123 countries and territories. Despite this broad spread, over two-thirds of the world's mangroves are found in just twelve countries, with Indonesia alone accounting for over 20%.

Figure 1 shows the global distribution of mangroves and their predominantly tropical range. The largest areas are found on the wetter coastlines of South and Central America and West and Central Africa, and from northeast India through Southeast Asia to northern Australia. Although mangroves are still widespread in more arid regions,

2 *Shortly after the 2010 release of the World Atlas of Mangroves, Giri et al. (2010) published an alternative estimate of mangrove area of 137 760 km² (in 118 countries in 2000), also derived from recent satellite imagery. The difference between the two estimates is relatively minor. The authors of the World Atlas of Mangroves have been unable to see the underlying data for the Giri et al. study but point out that it was an unsupervised classification with no ground-truthing. The data generated for the World Atlas of Mangroves, on the other hand, were partially supervised, and some of the large national datasets were fully supervised (ie, the anlaysts had a prior knowledge of the existence of mangroves in the areas being mapped). The World Atlas of Mangroves also involved an extensive review process, with comments and corrections to the maps provided by national and regional experts including some ground-truthing. While it would be valuable to compare the two global maps and perhaps combine them, the authors of the World Atlas of Mangroves are confident that the data in the World Atlas of Mangroves constitute the most reliable global assessment.*

Figure 2 Different mangrove species have remarkably different ranges: e.g. *Heritiera fomes* (top left), *Avicennia marina* (top right), *Pelliciera rhizophorae* (bottom left) and *Rhizophora racemosa* (bottom right)



including subtropical and southern Australia, South Asia, the Middle East and parts of East Africa, the total area in these regions is limited and they are typically dominated by sparse formations (Table 2).

The largest individual tracts of mangroves occur on wet deltaic coasts, where they often extend inland for several tens of kilometres and where mature forests often contain large trees and forest canopies over 20 m in height. The best known of these is the Sundarbans, a vast mangrove forest that straddles the boundary between India and Bangladesh; it covers an area of 6500 km² and extends 85 km inland.

Table 2 Summaries of mangrove areas

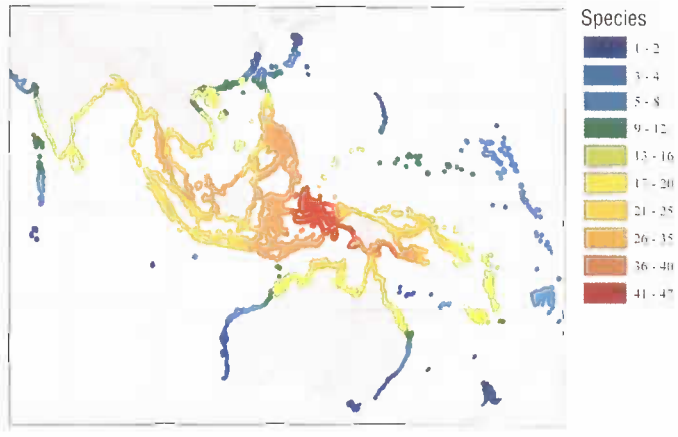
Region	Area (km²)	Proportion of global total
East Africa	7917	5.2%
Middle East	624	0.4%
South Asia	10 344	6.8%
Southeast Asia	51 049	33.5%
East Asia	215	0.1%
Australasia	10 171	6.7%
Pacific Ocean	5717	3.8%
North and Central America	22 402	14.7%
South America	23 882	15.7%
West and Central Africa	20 040	13.2%
Total	**152 361**	

Biogeographic patterns

The Atlas presents the first-ever global compilation of range maps for individual mangrove species, compiled with expert input and support from the International Union for Conservation of Nature (IUCN). These maps show the considerable variation in ranges of different species, as illustrated in Figure 2. By combining the range maps of individual species the Atlas vividly illustrates patterns of mangrove diversity.

The global centre of mangrove biodiversity is in South and Southeast Asia (Figure 3), while there are also diversity centres in the western Indian Ocean and around southern Central America. Diversity decreases away from the tropics.

Figure 3 Asian mangrove diversity



Two distinct floristic realms of mangrove distribution are widely recognized. One is the Indo-West Pacific realm, or eastern group, which extends east from eastern Africa to the islands of the central Pacific. The other is the Atlantic East Pacific realm, or western group, which includes the Americas and West and Central Africa. There is virtually no overlap in species between these realms, with the exception of the fern *Acrostichum aureum*.

The fern *Acrostichum aureum* is found in both the Indo-West Pacific and Atlantic East Pacific regions. *Photo: Chan Hung Tuck*

The Indo-West Pacific floristic realm comprises 62 unique species and hybrids, most of them overlapping with or restricted to a centre of mangrove diversity that extends west of northern Australia and New Guinea through Southeast Asia to the Bay of Bengal. In contrast, the Atlantic East Pacific realm has only twelve species and hybrids, four of which are restricted to the coasts of Central America and Colombia.

The two mangrove realms can be further subdivided into seven subregions: West America; East America; West and Central Africa; East Africa; Indo-Andaman; Southeast Asia; and Australasia.

Mangrove ecology

Mangrove forests are complex ecosystems. Many show patterns of zonation, with different parts of the forest dominated by different species due to variations in the ability of species to cope with salinity, aridity, inundation and sediments. The dynamic nature of coastal environments also means that many forests show a temporal succession, with pioneer species helping to stabilize soils and capture sediments before being replaced by other species.

Under ideal conditions, mangroves are among the world's most productive ecosystems, with typical net primary productivity rates for 10-metre-high forests in the order of 9 tonnes per hectare per year, and considerably higher rates for high-canopy forests. There is considerable interaction—through the movement of species, the supply of nutrients and the modification of environments—between mangroves and other coastal ecosystems such as salt marshes, salt pans, swamp forests, tidal freshwater forests, mud flats, sea grasses and coral reefs (see box for definitions of typical coastal ecosystems).

Coastal ecosystems

Salt marshes are saline wetlands dominated by herbs, grasses and low shrubs. While they predominate and are sometimes considered functionally equivalent to mangroves in temperate regions, they also grow around mangroves in many tropical areas, often surviving in areas of high salinity but in some places also forming pioneer vegetation on new sediments.

Salt pans are areas in the upper tidal zone where aridity and salinity are so high that few plants can survive.

Mud flats are wide, level areas of intertidal soft muddy sediments that typically extend seawards from below the mid-tide level. They are usually devoid of vegetation but are often nutrient-rich and host both algae and numerous burrowing filter-feeders.

Coral reefs are large physical structures built and maintained by the growth of stony corals and other associated species. They often act as breakwaters and provide calm lagoons to landward, enabling mangroves to grow in their lee. They are highly sensitive to sediments and so are not found in some areas where mangroves are abundant. Many reef fish use mangroves as nursery areas.

Swamp forests. The transition to terrestrial vegetation at the upper reaches of mangrove forests can be through saltmarsh or salt-pan communities, but in some areas there is a more subtle change in forest type. This may include a gradation to seasonally or occasionally flooded swamp forest and to tidal freshwater forest.

Mangroves and people

Mangroves offer many important goods and services to human communities. These benefits are often overlooked, however, resulting in the degradation or loss of mangrove forests, at considerable cost to society. Nevertheless, examples are now widespread of the successful management of mangroves, including sustainable silviculture, restoration and protection for conservation purposes.

Ecosystem services

In some traditional societies, people still use and live within mangrove ecosystems. Their impacts are often sustainable and they can be an integral part of the ecology and functioning of the mangroves. In most places, however, commercial and high-intensity uses have changed the nature of the human–mangrove relationship. It is critically important for the future of both mangroves and human societies that the roles and values of mangroves are properly evaluated and understood. The array of benefits derived from mangroves includes timber and other forest products, fisheries, recreation, bio-filtration, coastal protection and carbon sequestration (Table 3).

Timber and forest products

Mangrove wood is dense and resistant to rot and termites. Trees tend to be relatively small compared to lowland forest and hence the wood is rarely sawn. However, the durability of the wood makes it popular as a source of poles used in buildings, boats and fish-traps. Mangrove wood also produces high-value charcoal, while locally it is often used as firewood. In a few places, mangroves have been clearcut for the woodchip and pulp industry, although in many cases this has been unsustainable and has led to major losses of mangrove cover. The leaves of *Nypa* palms are widely used for roofing.

The leaves of *Nypa* palms are widely used for thatching, such as on this house in Viet Nam. *Photo: S. Baba*

Some mangrove bark is rich in tannins and has been used at a commercial scale in the leather tanning industry. Today, artificial tannins are mostly used, but there remains some artisanal use of mangrove bark for tanning leather and increasing the longevity of fishing gear, and as a dye.

The nutritional value of mangroves is relatively limited, although some communities have been known to harvest and eat both fruits and propagules. Perhaps the most widespread use of mangroves is for honey—commercial apiculture is practised in mangrove forests around the world—and for the sugar, associated sweet drinks and

Table 3 Mangrove forest products and services

Product/service	Examples
Timber and forest products	Timber: poles and sawnwood
	Firewood
	Charcoal
	Tannins from bark
	Roofing materials from *Nypa* palms
	Honey, sugar and alcohol from *Nypa*; occasional use of other fruits
	Medicinal uses—widespread in many traditional societies, and there is increasing evidence of bio-active compounds that could lead to commercial applications
	Fodder—low nutritional value but used as a supplement in some arid countries
Fisheries	Within mangroves—important for molluscs, mud crabs and prawns, with some finfish capture in channels
	Offshore fisheries—species use mangroves in early life but captured offshore
	Recreational fisheries—widespread sport fishery in northern Australia and the Caribbean
	Aquaculture—although sometimes leading to mangrove destruction, smaller-scale aquaculture and some cage culture and ranching in mangrove channels are relatively benign and rely on mangroves for seeding, nutrients and water purification
Coastal protection	Storm and extreme events
	Coastal stabilization through sediment capture and erosion reduction
Bio-filtration	Capture and removal of nutrients and some pollutants from the water column
Recreation	Includes tourist provision on boat tours and boardwalks, with specialist activities including bird-watching
Carbon sequestration	Living biomass and soils are major carbon stores due to their high productivity and the incorporation of carbon into anaerobic peaty soils

Fish and fuelwood from mangroves support the livelihoods of many traditional coastal communities. *Photo: E. Corcoran*

alcohol derived from *Nypa* palms. Few vertebrate animals browse mangroves, but in some arid countries mangroves are used opportunistically, or during extreme drought conditions, as a supplementary fodder for camels, goats and cattle.

Many societies use mangrove leaves, bark and propagules in traditional medicine. Although such use is largely in decline, research is revealing that some species have significant medicinal properties, which could lead to their development as modern medicines.

Fisheries

Mangroves are among the most important inter-tidal habitats for marine and coastal fisheries, underpinning the livelihoods of many coastal communities and commercial fisheries. For example, mangrove cockles sustain several thousand small-scale fishers on the Pacific coast of the Americas, while mangroves have been estimated to support 30% of the fish catch and almost 100% of the shrimp catch in Southeast Asia.

Important species include invertebrates such as molluscs (oysters, cockles and mussels); crabs and shrimps; and finfish such as mullet, anchovy and snapper, which are found in channels and adjacent lagoons and estuaries. The role of mangroves in sustaining offshore fisheries is also vitally important. The bulk of the catch of most commercial shrimp fisheries consists of species that depend on or benefit from the presence of mangroves to sustain high productivity.

Recreation

Mangroves offer a rich, diverse and fascinating environment that has opened up to ecotourism only relatively recently. For example, boat tours are popular for viewing proboscis monkeys (Box 7.2 in the Atlas) and, at night, for seeing bioluminescent insects (Box 7.1 in the Atlas) and plankton. Recreational fishing, photography, and bird-watching are additional attractions. Mangrove boardwalks are also widespread: for example, some such boardwalks in China are used by up to 60 000 visitors per year.

Coastal protection

Coastlines, deltas and estuaries are highly dynamic places in which water movement is responsible for the deposition and erosion of vast quantities of sediments. The process can be gradual or dramatic, with major changes possible during a single storm or tsunami. Rising sea levels are also having an effect.

Mangroves can be highly influential in moderating coastal dynamics. Mangrove roots can help to reduce erosion by catching and holding soft sediments. They also affect water movement, reducing wave height—even during major storms—and slowing flows to allow new sediments to settle among the roots. Mangrove trunks and branches also help to reduce flows and can limit debris movement during storms, which is often a major source of injury and damage.

Such benefits are not ubiquitous, but there are growing numbers of examples. Along the western coastline of the Gulf of Thailand, where there is overall net erosion in most areas, localities with mangroves have lower erosion rates and net accretion in some areas. During a super cyclone on the coast of Orissa in India, the presence of mangroves was shown to reduce human deaths compared to areas without such protection.

In Aceh, Indonesia, mangroves offered little protection in the worst-hit areas during the Indian Ocean tsunami in 2004

Mangrove crabs provide valuable income for many people in Brazil. *Photo: T. Tsuji*

(during which waves reached over 24 m in height). On the other hand, a number of studies showed that some coastal areas behind mangroves suffered less damage from the tsunami than adjacent areas without an intermediate mangrove belt (elevation and distance from shore were other important factors, Box 6.1 in the Atlas). Broader reviews of both the tsunami and major storms show that mangroves can and have played important roles in absorbing and attenuating wave energy as well as preventing damage caused by debris movement, although in some areas this protective role may have been overstated.

Bio-filtration

With their complex structure, mangroves are able to constrain water movement and trap sediments. Their high productivity also enables them to extract nutrients from surrounding waters. Mangroves therefore perform a valuable service by holding back sediments and reducing pollutants—notably from sewage and aquaculture—in estuaries and coastal waters.

Reducing carbon emissions

Mangrove forests store very large quantities of carbon in their living structures, with one recent estimate suggesting a global average of almost 250 tonnes dry weight per hectare in above-ground biomass. It also appears that mangroves have a larger proportion of below-ground biomass than most other forest types. These levels of productivity and biomass suggest that mangroves may play an important role in the global carbon cycle and may be worthy of greater attention in discussions on climate-change mitigation. Mangrove forest biomass is comparable to that of terrestrial forests due to their larger proportion of below-ground biomass, while they can be highly productive. In addition, a large proportion—perhaps 10%—of all primary productivity enters the sediments, the anaerobic nature of which means that most deposited carbon becomes slow to decompose peat.

Economic value

Numerous assessments of the direct economic value of mangroves have been undertaken, particularly regarding forest products and fisheries. These values are highly influenced by local social and economic conditions and by variations in biomass and productivity. Thus, the value of mangroves to fisheries alone has been estimated at US$1700 per hectare per year in Matang, Malaysia, where productivity is high. Their value to the crab and mollusc fisheries close to an affluent population in Santa Catarina, Brazil, were valued at over US$10 000 per hectare per year.

Recreational and tourism values can also be very high, although these are often restricted to relatively small areas. Many local communities rate coastal protection as the single most important service provided by mangroves, but the economic value of this has rarely been calculated. There have been only a few efforts to estimate the total economic value of mangroves; in areas where mangroves are being used sustainably, estimates of US$2000–9000 per hectare per year do not seem unreasonable.

Human impacts

The area of mangrove forests has declined in recent decades in almost all countries as a result of human activities. Many remaining mangrove areas are no longer pristine, with most showing some level of degradation as a result of excessive harvesting for fuelwood or fish and shellfish.

Forest conversion

The most substantial loss of the world's mangrove cover has arisen from the direct conversion of mangrove areas to other uses, including urban, industrial, aquacultural and agricultural development. Despite their considerable value for their ecosystem services, mangroves are still often seen as valueless waste lands available for other uses.

Coastal real estate in urban and industrial settings can be of very high value and mangroves are often cleared and in-filled with dredged material to form low-lying, level areas with river or port frontage. Remaining mangroves adjacent to urban areas can rapidly become degraded when they are used as a source of fuel or building material.

Where population pressures are high and space is limited, large areas of mangroves have been converted to agricultural land for the cultivation of cash crops. Despite their level terrain, there are risks: many mangrove soils, if allowed to dry out, become highly acidic and impossible to cultivate. There have also been cases where the new agricultural land lies at or even below sea level. In Guyana, for example, the breaching of sea walls caused flooding and salinization, which led to crop damage, loss of productivity and subsequent abandonment.

One of the strongest drivers of mangrove conversion in recent decades has been the growth of shrimp aquaculture. Mangrove areas are ideally suited for aquaculture because tidal movement facilitates water exchange. Many 'extensive' aquacultural systems rely on natural stocking by shrimp larvae from incoming tides, or are stocked with larvae caught in the wild. Similar ponds are used for rearing finfish such as tilapia. Such extensive aquacultural development has transformed mangroves through Central and South America and Southeast Asia; in many countries it has been the driving force behind the loss of 50% or more of the mangrove estate. Some of the most rapid losses took place in the 1990s, often aided by government incentives. Many extensive aquaculture operations have had a limited lifespan and ponds have been abandoned as a result of disease outbreaks or the build-up of pollutants in pond sediments. Restoring such areas can be costly.

There is now a growing effort to manage aquaculture sustainably. For example, intensive aquacultural systems can be located above high tide, using pumps to create water flows and larvae raised in nurseries. Alternatively, extensive systems are being developed that use mangroves both within ponds (where they provide shade, shelter and food for stocks) and in adjacent areas, where they can play an important role in reducing pollution.

Forest degradation

Many remaining mangrove forests have been degraded in their structure, productivity and the ecosystem services they provide. In the Ayeyarwady Delta in Myanmar, the commercially important timber mangrove species *Heritiera fomes* declined in abundance from 94 trees per hectare in 1924 to nine trees per hectare in 1991, with 98% of those trees having girths of less than 9 cm. Part of the decline was due to a top-dying disease, the causes of which are not fully understood but could be related to increasing salinity due to greater upstream water abstraction as well as sea-level rise.

Large areas of mangroves have been cleared for shrimp ponds in Ecuador. *Photo: T. Tsuji*

In the Niger Delta, chronic oil pollution over many decades, combined with localized smothering of roots by dredge spoils, has caused widespread habitat degradation.

Another source of mangrove degradation is the alteration of water flows. Roads, pipelines and coastal defences through or adjacent to mangroves can cut off tidal flows or prolong inundation. Declining freshwater supply—due to upstream dams and irrigation schemes, for example—can stress or kill mangroves. In the Indus Delta in Pakistan, total freshwater flows have been reduced by 90%, causing considerable losses of mangrove biodiversity and changes in structure and function. Falling levels of sediment input can affect coastal dynamics, reducing the growth of deltas or mud-flats and even leading to net erosion while weakening the resilience

The bare ground on the landward margin of this road in Brazil has lost all its mangroves as a result of changes in water flow. *Photo: S. Baba*

of the coastal system to rising sea levels. Defending such coastlines with bunds and rock reinforcements is costly.

While the effects of over-fishing rarely affect the physical mangrove environment there are many examples of fishers needing to travel further and work harder to maintain their catches as the total number of fishers increases or as a result of diminishing mangrove forests. A hidden consequence of reduced catches is a loss in the perceived value of mangroves to local communities, who may then put less effort into maintaining them.

Mangrove forests can regenerate naturally if degradation pressures are removed, although in some places the formation of a dense cover of mangrove ferns has prevented a succession to mature forests.

Global change

There is little or no evidence that climate change due to increasing atmospheric concentrations of greenhouse gases will have direct negative impacts on mangrove species. Warming temperatures appear to be allowing some mangroves to expand their ranges into more temperate salt-marsh communities, for example in Florida, southern Australia and New Zealand. Increased levels of atmospheric carbon dioxide could have a positive impact on the growth rates of mangrove species, and could improve their water-use efficiency. Future changes in precipitation and changes in water extraction and use in watersheds are hard to predict; they could have positive or negative consequences for water supplies at coastal margins. Mostly likely, the most significant impact of climate change on mangroves will be caused by sea-level rise. Under natural conditions, mangroves can adapt to rising seas through vertical accretion and horizontal, landward, migration. In most areas, however, the current rate of sea-level rise may already be too fast for mangrove soil accretion, and this rate is accelerating. In many places, landward migration is likely to be prevented by active coastal defence. This coastal 'squeeze' could become a significant source of mangrove loss in coming decades.

Estimating forest loss

A number of national and regional studies have estimated changes in mangrove area, but building a global picture is a considerable challenge because it requires consistent and accurate measurement over time. While the Atlas provides the best global estimate of mangrove area to date, is it not strictly comparable with earlier global estimates, as those were obtained using different mapping methods. FAO (2007) probably provides the most reliable global assessment of change in mangrove area over time. It estimates the current area at 152 310 km² (very close to the 152 360 km² estimated here) as well as change over time from 1980 (Table 4). All regions except Australasia experienced dramatic losses in mangroves between 1980 and 2000, including a greater than 20% loss in East Asia, Pacific Islands, Southeast Asia and North and Central America.

Although rates of loss have declined over time (from an average of 1.04% in the 1980s to 0.66% in 2000–2005), they are still three to four times higher than the average global rate of loss of all forests (0.18% per year in 2000–2005). This likely reflects the great pressure for development in coastal areas and is of particular concern given the importance of the ecosystem services mangroves provide and the small overall extent of this forest type globally.

Table 4 Change in mangrove area, by region, 1980–2005*

	Reduction (%)	Annual change (%)
East Asia	33.4	1.3
Pacific Islands	28.8	1.2
Southeast Asia	26.5	1.1
North and Central America	23.3	0.9
Middle East	17.0	0.7
West and Central Africa	16.0	0.6
South Asia	15.5	0.6
South America	11.0	0.4
East Africa	7.9	0.3
Australasia	0.6	0.0
Total	19.0	0.8

* data from FAO (2007)

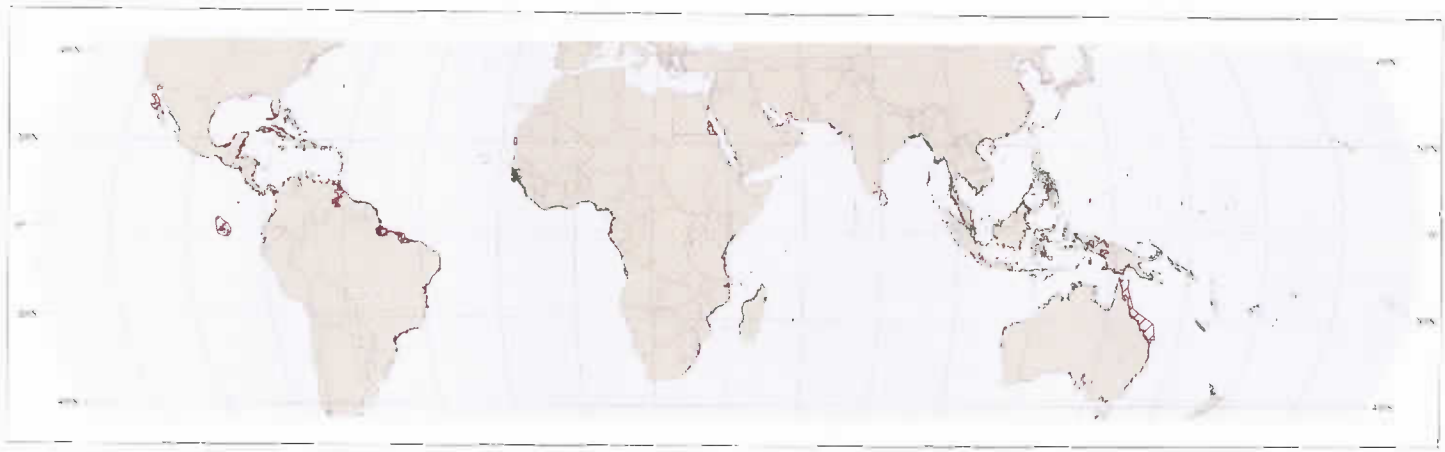
Management of mangroves

Sustainable silviculture

The high value of mangrove timber and charcoal has led to their regular production from managed forests in Asia. Perhaps the most celebrated examples are the Sundarbans in Bangladesh and India, and Matang in Malaysia. In the former, there is evidence of forest management dating back to 1759, with scientific planning established in the late 19th century, while Matang has been sustainably managed since 1902. Such forests are managed on a commercial basis with well-established plantations. Thinning is undertaken to produce a first crop, followed by final felling, after which regeneration can be natural or enhanced through plantation. Such cycles, of 30 years or more, require a large forest area

These plantations of *Rhizophora* spp. in Matang, Malaysia, are managed for a sustainable supply of mangrove timber. *Photo: M. Kainuma*

Figure 4 Location of mangrove protected areas



as well as stable long-term policy and planning. Where managed in an integrated manner with mangrove-associated fisheries and even tourism, the total economic value of such forestry can be substantial.

Restoration and afforestation

Activities to re-establish or rehabilitate mangrove forests (restoration) or to establish them in areas where they previously did not occur (afforestation) are increasing. In many cases, natural regeneration alone can restock large areas following the restoration of tidal flows and the clearance of waste. Afforestation has been encouraged in the Middle East as a form of aesthetic enhancement of coastal areas, while it is being used in various Pacific islands as a form of coastal protection, which is increasingly needed in the face of climate change. Restoration is especially challenging in abandoned aquaculture ponds, where engineering works are often required to restore water flows and to build up intertidal areas.

Protected areas

Large areas of mangroves have been assigned as protected areas for conservation purposes (Figure 4). An estimated 1200 protected areas worldwide contain about 25% of the world's remaining mangroves. The level of protection afforded by these sites is highly variable, but few allow intensive timber harvesting and many protect both plant and animal species. Despite the large global coverage of protected areas, gaps remain, for example in much of the Red Sea, Myanmar, Solomon Islands, Fiji and West and Central Africa. There is an urgent need to fill these gaps to ensure the full representation of mangrove species and ecosystems.

Community involvement

Among the most important lessons learned in recent years is the value of local involvement in the management of natural resources. Local communities are often the main beneficiaries of mangrove goods and services and they often also suffer most from the conversion of mangroves to other uses. Many of the most successful mangrove restoration projects have been undertaken by local communities. In the Philippines, for example, the success rate of mangrove restoration projects is highest in community-led projects.

Similarly, protected areas often have a much greater chance of success if they are planned, designated and managed in collaboration with local communities, and if benefits accrue mainly to those communities.

Reversing the decline

Mangroves should be fully accounted for in policy development, economic decision-making and governance, and their local, subsistence and commercial benefits should be fully accounted for. The ecological, social and financial costs of pollution, lost fisheries and coastal erosion resulting from mangrove degradation or clearance should also be fully assessed. There is an urgent need to communicate more widely the values of mangroves. With greater public awareness of and support for the economic and social values of mangrove ecosystems, it should be possible to halt and reverse their decades-long decline.

Eastern and Southern Africa

Eastern and Southern Africa is an important, geographically distinct mangrove region that is isolated from the rich flora of South and Southeast Asia by the Indian Ocean and the arid coasts of the Middle East. This region includes mangroves along the eastern coast of continental Africa and the western shores of Madagascar, and the patchy distribution of mangroves on the offshore islands (Figure 5). Ten mangrove species have been recorded in the region, none of them endemic. The most extensive and diverse formations are found on the wetter coasts of Tanzania and Mozambique, notably in the large Rufiji and Zambezi river deltas (Table 5).

Mangroves have suffered fewer losses in this region than elsewhere, with only an 8% decline between 1980 and 2005. Even so, use is heavy and in countries such as Kenya and Madagascar an apparent stability in gross area may mask quite significant levels of degradation, with trees becoming more sparsely distributed and often stunted as a result of over-exploitation. The conversion of mangroves to other uses—e.g. rice paddies, salt pans and shrimp ponds—has occurred in a few areas, although not yet to the extent that it has in Asia.

Mangrove protection is variable, but generally quite good. In both Kenya and Tanzania, a degree of at least theoretical protection is provided by general laws governing use and harvesting that date back to the early 19th century. Some small-scale mangrove restoration efforts have been undertaken in Kenya and Tanzania. Quite large areas are also incorporated within protected areas.

Middle East

The Middle East has some of the most arid coastlines in the world. There are few permanent rivers (none at all in the Red Sea area), and even temporary freshwater influxes are limited to a few days per year in most places. Mangroves are typically fringing or lagoonal formations, and are often associated with large alluvial fans at the mouths of intermittent rivers (*wadis*) or found along narrow tidal creeks or inlets, known as *khors*. Although four mangrove species have been recorded, only *Avicennia marina* is widespread, typically growing as a shrub or low tree in small stands, often backing on to salt-marsh communities or sand flats (*sabkhas*).

Despite the low stature and diversity and intermittent occurrence of mangroves, their presence is of considerable ecological importance. Mangrove species are often the only trees in the arid desert landscapes, attracting birds and offering foraging for livestock. Although coastal areas in the region are sparsely populated, nomadic people such as the Bedouin undertake fishing and their goats and camels browse mangroves; in some places, mangroves are used for timber. Such uses are not always sustainable, but some communities apply traditional rules, restricting mangrove use to the dry season or times of extreme drought. More recently, increasing coastal development has had considerable impacts on mangroves, particularly in the oil-rich nations. In some countries, however, mangroves are being planted for their aesthetic value.

Figure 5 Western Indo-Pacific mangroves

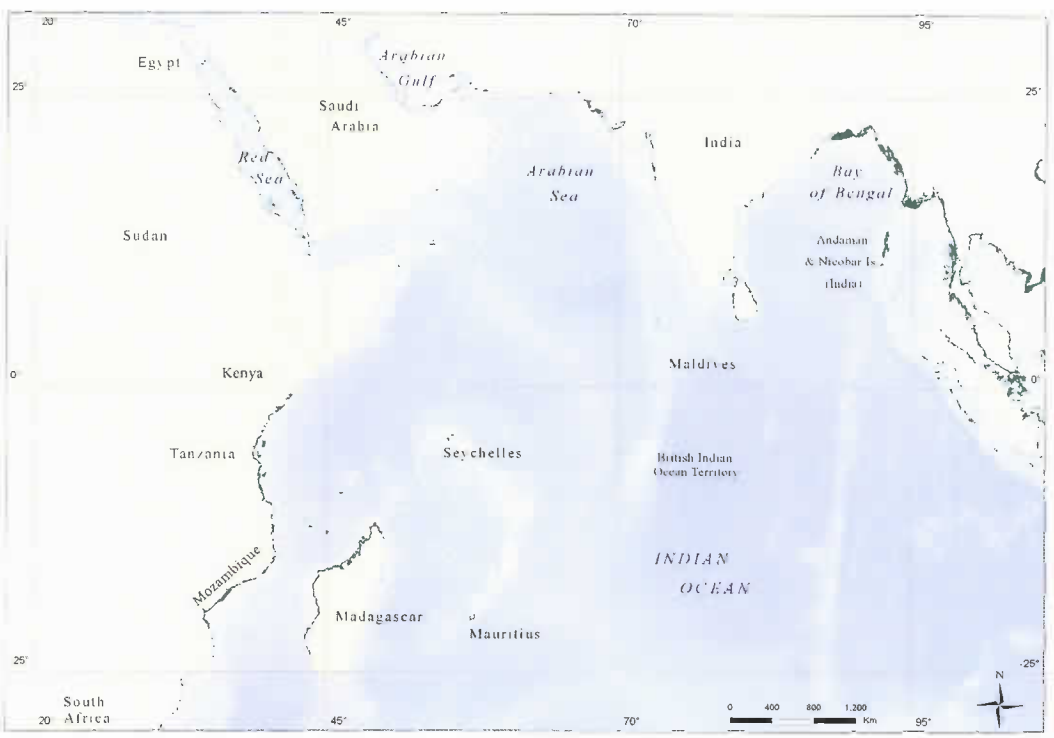


Table 5 Large mangrove extent countries in Eastern and Southern Africa

Country	Mangrove area (km^2)	Number of mangrove species	Number of mangrove protected areas	Number of international protected areas
Madagascar	2990	8	6	1
Mozambique	2910	10	6	1
Tanzania	1290	10	24	1

Arid conditions in the Middle East create hyper-saline salt pans (*sabkhas*). *Photo: R. Spalding*

South Asia

Mangroves are widely distributed, though discontiguous, in South Asia; the largest areas are in India and Bangladesh (Table 6). In Pakistan and northwest India, arid conditions create a harsh environment, and mangroves there have low species diversity and trees are typically stunted. The large Indus Delta once stood out for its large expanses of mangroves, but today this great river has been so heavily used upstream that it only flows to the sea for two months of the year and much of its remaining mangrove resource is degraded. Further south, conditions become more humid and there is more reliable riverine input, although for the most part mangroves are restricted to protected lagoons. Deltaic mangroves become important along the east coast of India and in the Bay of Bengal, where the Sundarbans is one of the world's largest contiguous mangrove forests. Overall, 38 mangrove species have been recorded in the region, with diversity increasing towards the east. The northern Bay of Bengal and Sundarbans (Figure 6) form an important part of the Indo–Andaman biogeographic province, with several regional endemic species.

Almost all mangroves in the region have been influenced by humans, and large areas have been lost through over-exploitation or conversion to aquaculture and agriculture. Concern about mangrove loss is stimulating reforestation: Bangladesh has the world's largest areas of new mangrove plantations, and significant areas have also been planted in Pakistan and India. Many remaining mangrove areas are in protected areas.

Southeast Asia

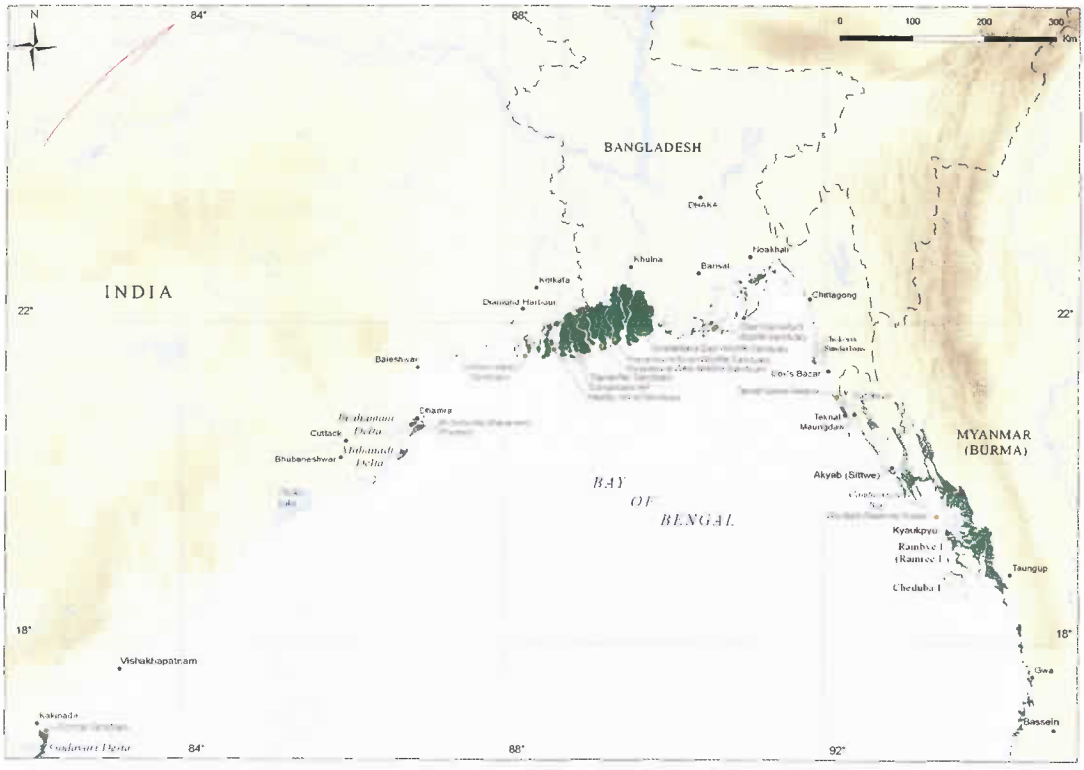
Southeast Asia hosts one-third of the world's mangroves—more than any other region (Table 7, Figure 7). The region is highly conducive to mangrove formation: much of it is humid, with high rainfall, and numerous rivers supply large deltas with freshwater and sediments. These include the Ayeyarwady in Myanmar, the Mekong in Viet Nam, and the extensive deltaic coastline along southern Papua in Indonesia. The region is also the global centre of mangrove diversity, with 51 species, which is 71% of the global total.

Mangroves have long been a source of timber and fisheries in the region; many areas have transitioned to commercial use. Matang Forest in Malaysia has been sustainably managed for timber for over 100 years, while supporting rich fishing industries in channels and adjacent coastal waters. There is a stark contrast between such places and the widespread pattern of mangrove degradation and loss elsewhere in the region. Since the 1970s, aquacultural development has decimated vast areas in the Gulf of Thailand, Viet Nam, Java, Kalimantan and the Philippines. Too often, the benefits of this industry have been short-lived,

Table 6 Large mangrove extent countries in South Asia

Country	Mangrove area (km^2)	Number of mangrove species	Number of mangrove protected areas	Number of international protected areas
Bangladesh	4950	22	5	2
India	4330	37	33	5

Figure 6 The Sundarbans, one of the world's largest contiguous mangrove forests



with ponds abandoned when they become polluted or diseased, leaving behind unproductive saline pools and depleted coastal fisheries.

Large areas of mangrove forest in Manila Bay in the Philippines have been converted to aquaculture and agriculture. *Photo: M. Spalding*

While mangrove deforestation has been high for 25 years, there is growing awareness of the importance of mangroves. Both government-led and community-led efforts are under way to restore and replant mangroves, and to improve legal systems to regulate use. These efforts, combined with a large and growing network of mangrove protected areas in many countries, make it likely that the rate of loss will diminish in the near future.

Table 7 Large mangrove extent countries in Southeast Asia

Country	Mangrove area (km^2)	Number of mangrove species	Number of mangrove protected areas	Number of international protected areas
Indonesia	31 890	45	91	8
Malaysia	7100	40	88	4
Myanmar	5030	32	4	-
Philippines	2570	42	52	5
Thailand	2480	35	23	7
Viet Nam	1060	30	17	5

East Asia

The coasts of southern China, Taiwan Province of China and the southern islands of Japan encompass a transition from tropical to temperate waters. Mangroves in the region are discontiguous in their distribution and are marked by a latitudinal decline in diversity, from 26 species in Hainan Island to a single species (*Kandelia obovata*) on Kyushu Island in Japan.

Figure 7 Central Indo-Pacific mangroves

With the exception of Japan's mangroves, which are well protected, the mangroves of East Asia are among the most altered mangrove ecosystems in the world, due mainly to coastal development. Only a few natural areas remain, although there are growing efforts to protect some of those and to restore mangroves elsewhere.

Australasia

Australia is one of the world's major mangrove nations, with 6.6% (9910 km²) of the total global area, mostly in the wetter north and northeast. Some 40 mangrove species have been recorded, with a rapid diminution in diversity away from the tropics. *Avicennia marina* extends into temperate areas as far south as the state of Victoria. Aborigines and Torres Strait Islanders traditionally use mangroves for food, timber and other products. Mangroves are critically important in sustaining non-traditional fisheries, including offshore prawn fisheries and widespread recreational fishing. Overall, mangrove deforestation has been minimal and localized, usually linked to urban expansion and port and marina development. Increasing efforts are being made to protect mangroves through broad policy and regulatory frameworks and the designation of protected areas.

New Zealand lies close to the southern limit of mangroves and has only one species, *Avicennia marina*. Despite this, mangrove forests are widespread in estuaries and sheltered bays in the north of the North Island, even within the Auckland urban area. Mangroves in northern estuaries can form canopies over 4 m tall; the southernmost mangroves reach only 2 m. The Maori people traditionally fish in mangrove areas for oysters and mullet. Recreational and small-scale commercial fisheries operate in and adjacent to mangrove areas. Overall, New Zealand still maintains a thriving mangrove biota. There is community interest in mangroves, and hiking trails, boardwalks and kayaking offer opportunities to explore these habitats in a number of locations. Significant areas of mangroves are in protected areas.

Figure 8 The Americas

Pacific Islands

The Pacific Islands encompass a great variety of mangrove flora. Papua New Guinea, in the west, has high mangrove diversity, with 43 recorded species and extensive mangrove forests (4270 km^2), particularly along the deltaic Gulf of Papua. Diversity declines rapidly eastwards into the Pacific. The larger mangrove areas occur on the larger islands, such as Solomon Islands, Vanuatu, Fiji and New Caledonia, but mangroves are also found on smaller islands, particularly those with mountainous interiors where rainfall and sediment supply are good. The Pacific's numerous low-lying limestone islands present mangroves with a much more challenging environment, with no surface freshwater and generally poor soils. Even so, they do host mangroves if they have protected lagoons or inland brackish ponds.

In many areas in the Pacific people still make extensive use of mangroves. Fishing is a mainstay, both for subsistence and as a commercial enterprise. Dyes extracted from mangrove bark are still used to color the traditional tapa bark-cloth, which is made across the region. The value of mangroves was not lost to the seafaring peoples who first colonized these islands, and it seems likely that some brought mangroves with them. For example, it is generally accepted that *Rhizophora stylosa* was introduced by early arrivals to French Polynesia and *Bruguiera gymnorhiza* to the Marshall Islands, and *Nypa fruticans* may have been introduced to eastern Micronesia. More recently, mangroves were brought to most of the main islands of Hawaii.

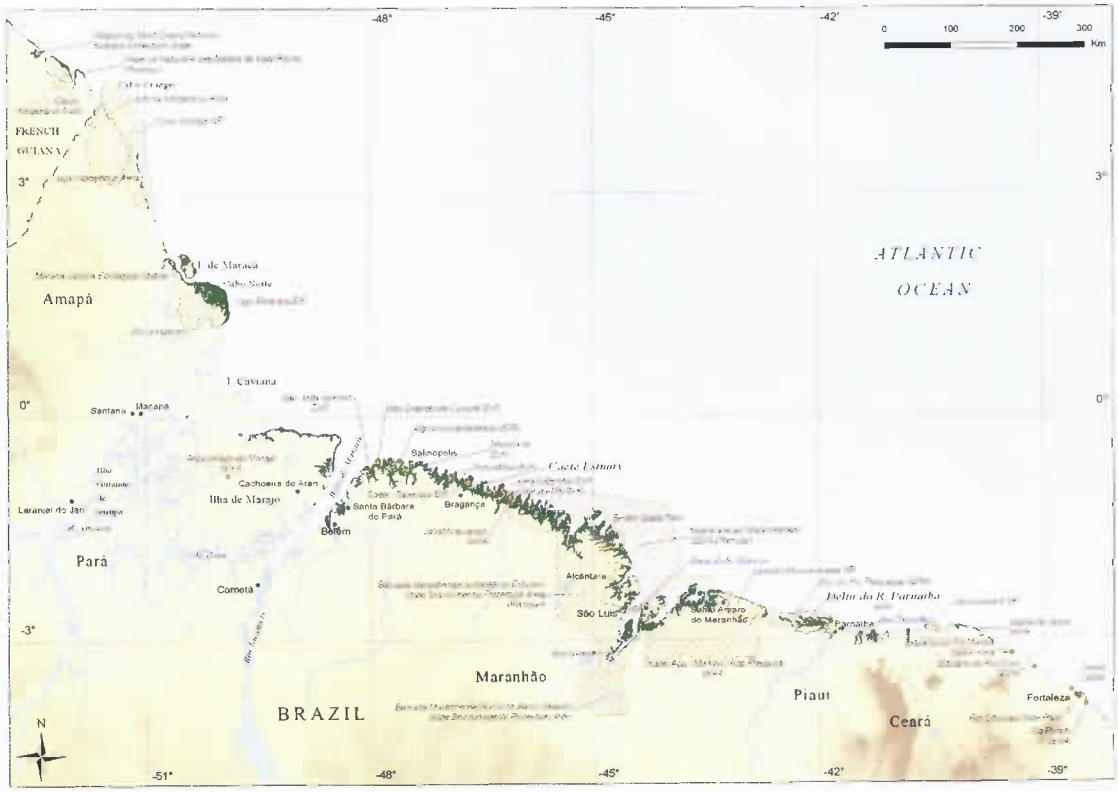
Despite their value, significant mangrove loss has occurred, notably in Papua New Guinea and the Solomon Islands. Both countries are still host to extensive natural mangrove forests, but the situation is changing. Conservation in the region in the form of traditional management practices and some formal legal measures probably covers only a small proportion of the mangrove resource.

North and Central America

The extent and structure of mangrove communities in North and Central America (Figure 8) are strongly influenced by climate. Cool air temperatures limit growth in the northern and central parts of the Gulf of Mexico but in southern Florida, warmer conditions and abundant freshwater flows have enabled the development of large areas of mangrove forest. Mexico has the largest area of mangroves of any country in the region (Table 8), including large tracts along its desert and semi-desert coastlines in the Pacific and the Gulf of Mexico. The climate becomes increasingly humid in Central America, and protected lagoons and estuaries support large areas of high-canopy mangroves. Mangroves are also widespread on many Caribbean islands, notably in fringing and lagoon formations. Aridity restricts the growth of many mangrove forests, from the Bahamas to the Lesser Antilles, but some are found around the larger and more mountainous islands, notably Cuba.

There are eleven mangrove species in the most diverse part of this region, which includes Puerto Rico, but most

Figure 9 Mangroves of northern Brazil



countries typically have only 4–5 species. Across the region, mangroves have considerable importance for fisheries. The use of mangroves for timber and fuelwood is not widespread. Tourism is a major industry in many countries, and while this has contributed to extensive and often damaging coastal development, some nature-based tourism—e.g. boat trips, bird-watching and sport fishing—is providing important economic incentives to protect mangroves.

The greatest drivers of mangrove loss include conversion for urban and tourist development and for agriculture and aquaculture, the latter notably in Mexico and Central America. Hurricanes are a major natural influence on mangroves in the region and can be highly destructive, with natural recovery taking years or decades. Several countries, including the United States, Mexico and Cuba, are now showing considerable interest in mangrove protection.

Table 8 Large mangrove extent countries in North and Central America

Country	Mangrove area (km^2)	Number of mangrove species	Number of mangrove protected areas	Number of international protected areas
Mexico	7700	5	36	51
Cuba	4940	5	27	13
USA	3030	5	47	4
Panama	1740	11	19	7

South America

With long coastlines in the Pacific Ocean, Caribbean Sea and Atlantic Ocean, and with numerous rivers and abundant rainfall, mangrove forests are widespread in South America (Figure 8). The largest areas are found along the wetter coastlines, including the Pacific and western Caribbean coasts of Colombia and an expanse of over 3000 km from the Orinoco Delta in Venezuela to northern Brazil (Figure 9, Table 9). Drier areas, such as the northern coasts of Colombia and Venezuela and the southern coasts of Ecuador and Peru, have fewer mangrove forests, although they are abundant in estuarine and lagoon formations. The southernmost limits of mangroves are probably determined by increasing aridity on the Pacific coast and by cooler temperatures on the Atlantic coast.

Some of the earliest human populations in the Americas lived adjacent to mangroves, and even today some groups, such as the Warao Indians in the Orinoco Delta, maintain close links to these ecosystems. Commonly used mangrove products include shellfish, timber, tannin and fuelwood. Commercial fisheries, both near-shore and offshore, rely on mangroves as breeding and nursery grounds. There is also increasing awareness of the role of mangroves in coastal protection and in helping to stabilize sediments.

While there remain large areas of mangroves in South America, there has also been considerable loss, notably in Ecuador and northern Peru, where shrimp aquaculture has transformed vast areas, and also in eastern Guyana, where mangroves have been converted to agricultural land. The

collapse of shrimp aquaculture through disease and the falling value of shrimp exports have highlighted the risks associated with mangrove clearance. In Guyana, costly ongoing coastal defense is required because of the threat of inundation.

Overall, the region's mangroves remain abundant and the benefits they provide are now appreciated quite widely. Mangroves are subject to increasing levels of protection through legislation and growing public awareness. In Brazil and Venezuela, remaining large areas of mangroves are being incorporated into protected areas.

Table 9 Large mangrove extent countries in South America

Country	Mangrove area (km^2)	Number of mangrove species	Number of mangrove protected areas	Number of international protected areas
Brazil	13 000	8	101	5
Colombia	4080	11	12	4
Venezuela	3570	7	18	5
Ecuador	1580	8	6	6

West and Central Africa

Although mangroves are found all along the eastern Atlantic coast (Figure 10), Nigeria has by far the largest area of any country in the region (Table 10). At their latitudinal extremes, mangrove diversity is low, trees are dwarfed and distribution is limited by aridity and a lack of suitable sheltered sites. In the tropics, one of the most mangrove-rich coastlines in the world, known as *Les Rivières du Sud*, extends from the Saloum Estuary in Senegal to Sherbro Island in Liberia. It comprises 7900 km^2 of mangroves in a series of deltaic and estuarine formations that benefit from lower wave energies and high riverine inputs. To the east, the coast is dominated by high-energy sandy shores and most mangrove formations from Liberia to Nigeria are found in coastal lagoons, separated from the sea by extensive sandbars. Mangroves in the Niger Delta cover an area of over 6600 km^2, and east of there through Cameroon to Gabon are other very large and open estuarine and deltaic formations. In the south, most mangrove formations tend to be narrower estuarine and lagoon formations that become less frequent within increasing aridity along the Angola coast. Despite their large area, the mangroves of West and Central Africa contain only seven plant species and, despite their isolation, there are no regional endemics.

Mangroves are important for fisheries and as a source of timber and fuelwood. Aquaculture remains rare, although in some areas there is brush park or acadja fishing in lagoons and channels. Some mangroves in *Les Rivières du Sud* have been cleared for the development of rice fields.

There has been widespread loss of mangroves associated with conversion to urban and agricultural land and, in more arid areas, the creation of salt pans. In a number of countries, especially in the Niger Delta, oil and gas extraction has caused pollution, damaged fish stocks and contributed to the degradation and loss of mangroves.

Continued bottom of page 20

Figure 10 West and Central Africa

Management implications

Issues in mangrove management

The *ISME Mangrove action plan for the sustainable management of mangroves 2004–2009* (ISME and ITTO 2004) identified the key issues in need of management attention. These are set out below.

Overuse for forestry and fisheries. Many mangroves are subject to the over-extraction of timber and non-timber forest products as well as to unsustainable fishing and wildlife use, often driven by poverty and the meeting of daily needs. Such over-use leads to degradation of the mangrove resource and, in some cases, its complete removal. Even if pressures can be removed, natural regeneration is sometimes poor and rehabilitation can be difficult and costly.

Aquaculture. The conversion of mangroves to aquaculture is widespread, particularly in Southeast Asia and Latin America but also now in East Africa. Poor management of aquaculture operations can lead to pollution and disease, rendering ponds unusable within a few years. Because of the massive disturbance to tidal flows and the coastal profile caused by aquaculture development, restoration, even in abandoned sites, can be challenging and costly.

Pollution. Pollution—derived from single or multiple sources including industry, sewage, dredging, pond effluent and agricultural and urban runoff and involving pollutants such as solid wastes, toxic chemicals, hydrocarbons and persistent organic materials—can lead to the loss of biodiversity, declines in mangrove productivity and, in extreme cases, complete destruction.

Hydrological modifications. Upstream activities such as dam construction, water diversion and deforestation alter the flow regimes of freshwater into mangrove ecosystems, often causing marked reductions, especially in dry seasons and arid environments. This can lead to a build-up of salinity in water and soils and changes in sedimentation patterns that affect coastal configuration and the structure of navigational channels, with the potential to alter physiological processes and cause the loss of mangrove species or their substitution by other communities. Coastal modifications such as the construction of sea walls, ports and dredging can also alter tidal circulation patterns, which in turn can lead to structural and functional changes.

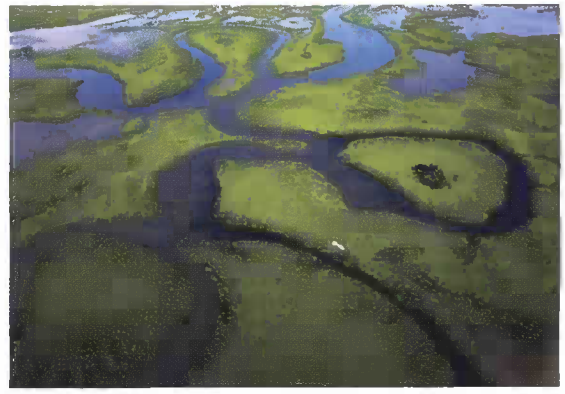
Conversion to other land uses. Conversion due to the development of infrastructure, residential areas and for agriculture, cattle-ranching, salt pans and mining causes the direct, irreversible loss of mangroves. Mangrove soils are often only marginally suitable for agriculture, yet the conversion of mangroves for this purpose is widespread. Conversion in one area can often lead to uncontrolled degradation and elimination in adjacent mangrove ecosystems.

Continued from page 19

Concern about mangrove loss is highly variable, but a few countries—Guinea-Bissau, Cameroon and Gabon—have created networks of protected areas that include mangroves. In some cases considerable effort has been made to involve local communities and garner broad support, and ongoing but sustainable use of mangroves is encouraged. Other countries have paid little attention to the protection of mangroves, and wide areas, including in most of the Niger Delta, remain unprotected.

Table 10 Large mangrove extent countries in West and Central Africa

Country	Mangrove area (km^2)	Number of mangrove species	Number of mangrove protected areas	Number of international protected areas
Nigeria	7360	7	4	1
Guinea-Bissau	2980	6	4	1
Guinea	2030	7	-	5
Cameroon	1960	7	3	-
Gabon	1600	7	7	5
Senegal	1280	7	3	2
Sierra Leone	1050	6	-	1



Les Rivières du Sud, a vast complex of rivers and channels extending from Senegal to Liberia, is one of the largest areas of mangrove forest in the world.
Photo: © J.F. Hellio and N. Van Ingen

Lack of appropriate legislation and enforcement. In the absence of laws on the sustainable management and conservation of mangroves, decisions on mangroves are rarely made in the interest of local communities, tending instead to favor large-scale commercial interests such as oil extraction and shrimp-pond construction. Where they exist, legal and policy instruments for mangroves are often dispersed between institutions dealing with fisheries, forestry, planning, agriculture and the environment. Many laws are either inappropriate or rarely enforced, and little consideration is given to the socioeconomic needs of coastal people. Countries that share mangrove resources rarely coordinate their policies and management regimes.

Shortage of capacity, mangrove specialists, managers and technicians. There is a shortage of mangrove specialists in scientific and management institutions, law enforcement agencies and local communities. There is also a lack of exchange of knowledge and experience between professionals and coastal dwellers.

Inadequate communication, education, public awareness and participation. In most countries there is considerable scope for improving public understanding and appreciation of the value of mangrove resources and the benefits that can be derived from them. This awareness should form part of the formal educational system but should also be offered to the general public, decision-makers and local people.

Climate change and sea-level rise. Climate models predict future rises in temperature and sea levels as well as changes in precipitation and freshwater supply; most also predict changes in storm frequency and intensity. Although mangroves are highly opportunistic and might be expected to migrate landwards with rising seas, in many areas such landward migration is likely to be disrupted by human land-use.

Guides for sustainable mangrove management

Given their considerable value, there is rarely any social or economic justification for the loss and degradation of mangroves; on the contrary there are powerful arguments for mangrove conservation and restoration. A critical challenge for those working in the fields of forestry, fisheries and the environment is to communicate these values and to ensure that public and political bodies are fully informed of the consequences of mangrove loss. In some places these lessons have already been learned and are being worked into legal and policy frameworks to protect and/or sustainably use mangroves and adjacent ecosystems.

A number of guides for the sustainable management of mangroves have been developed with the aim of assisting policymakers and practitioners. The following are authoritative manuals, guidebooks, work and action plans, guiding principles and codes of conduct and practice aimed at promoting the sustainable management and use of mangrove resources (extracts from four other relevant sources are provided in the boxes below):

- *Mangrove action plan for sustainable management of mangroves 2004–2009* (ISME and ITTO 2004)
- *Manual on guidelines for rehabilitation of coastal forests damaged by natural hazards in the Asia-Pacific region* (Chan and Baba 2009, published by ISME and ITTO)
- *Restoration of mangrove ecosystems* (Field 1996, published by ISME)
- *Mangrove guidebook for Southeast Asia* (Giesen et al. 2007, published by FAO and Wetlands International)
- *Coastal forest rehabilitation manual for Aceh Province and North Sumatra* (FAO 2008)
- *Mangrove rehabilitation guidebook* (GNF 2007)
- *After the tsunami: coastal ecosystem restoration: lessons learnt* (UNEP 2007)
- *Study of lessons learned from mangrove and coastal ecosystem restoration efforts in Aceh since the tsunami* (Wibisono and Suryadiputra 2006, published by Wetlands International)
- *Principles for a code of conduct for management and sustainable use of mangrove ecosystems* (The World Bank, ISME and cenTER Aarhus 2005)
- Several other ITTO publications also provide guidance for the sustainable management and conservation of mangroves:
- *ITTO action plan 2008–2011* (ITTO 2008)
- *ITTO/IUCN guidelines for the conservation and sustainable use of biodiversity in tropical timber production forests* (ITTO and IUCN 2009)
- *Revised ITTO criteria and indicators for sustainable management of tropical forests including reporting format* (ITTO 2005)
- *Guidelines for the establishment and sustainable management of planted tropical forests* (ITTO 1993)

ITTO mangrove workplan 2002–2006 (ITTO 2002)

Conservation and sustainable management
- Develop criteria and indicators for sustainable management of mangroves.
- Implement sustainable mangrove management and establish protected mangrove areas, including buffer zones.
- Prepare and implement mangrove management plans.
- Implement trans-boundary conservation and management areas.
- Rehabilitate degraded mangroves.

Mangrove information and awareness
- Maintain, expand and improve access to existing mangrove information databases in collaboration with other organizations.

Socioeconomic aspects
- Assess the contribution of mangroves and impacts of mangrove degradation.
- Document and promote use of traditional mangrove knowledge and management.
- Valuate wood and non-wood goods and services from mangrove areas.

Mangrove ecosystem functions and health
- Improve understanding of mangrove forest structure, growth and function.
- Evaluate the health of mangrove species and their habitat including the effects of climate change and sea-level rise.
- Assess the ecological impacts of wood harvesting and other human actions and develop innovative technologies for reducing such impacts.

Cooperation and capacity-building
- Establish national mangrove committees to coordinate all mangrove activities.
- Increase mangrove management capacity.
- Encourage and support cooperative relations between all stakeholders.

Policies and legislation
- Formulate appropriate laws and policies on mangroves with participation of all stakeholders and ensure their enforcement.
- Analyze existing laws and policies and their impacts on mangrove management.

Charter for mangroves (ISME 1991)

- Utilize mangrove resources so that their natural productivity is preserved.
- Avoid degradation of the mangrove ecosystems.
- Rehabilitate degraded mangrove areas.
- Avoid overexploitation of the natural resources produced by mangrove ecosystems.
- Avoid negative impacts on neighboring ecosystems.
- Recognize the social and economic welfare of indigenous mangrove dwellers.
- Control and restrict non-sustainable uses so that long-term productivity and benefits of the mangrove ecosystems are not lost.
- Introduce regulatory measures for the wise use of mangrove ecosystems.

Mangrove forest management guidelines (FAO 1994)

- Ensure that wood, non-wood and aquatic resources are managed in an integrated way which meets local, national or regional needs.
- Plans must be objective oriented and should achieve maximum benefits for the greatest number of people in the long run.
- The ecological carrying capacity should never be exceeded and resource sustainability should be given high priority.
- The need for conservation of biological diversity and wildlife should be recognized.
- Planning is an ongoing dynamic process and must provide for improvements in data and information accuracy.
- Planning functions and responsibilities should be clearly spelt out and the decision-making process must be visible and equitable.

Southeast Asian Fisheries Development Center's Code of practice for sustainable use of mangroves for aquaculture in Southeast Asia (Bagarinao and Primavera 2005)

- Recognize that mangrove ecosystems provide vital ecological services and valuable goods to coastal areas and communities.
- Protect and conserve mangroves to sustain vital ecological services and goods.
- Improve governance over mangrove conservation and sustainable use.
- Integrate aquaculture and mangrove conservation in coastal zone management.
- Assess and classify existing mangrove ecosystems for proper disposition.
- Retain a greenbelt or buffer zone along coasts and rivers where mangroves naturally occur and where replanting is technically feasible.
- Locate aquaculture farms outside of pristine mangroves.
- Prohibit conversion of pristine mangrove ecosystems into shrimp aquaculture farms.
- Rehabilitate abandoned aquaculture ponds back to mangroves.
- Resolve conflicts between aquaculture and other users of mangrove ecosystems.

Increasing incentives for sustainable use

While there is considerable knowledge on sustainable mangrove management, there is an urgent need to provide financial and social incentives for its implementation.

Building more holistic models for natural resource accounting is one avenue. New approaches are being encouraged through, *for example*, The Economics of Ecosystems and Biodiversity studies (Kumar et al. 2010), which highlight the need for comprehensive and cross-sectoral accounting of ecosystem services.

There may also be opportunities to encourage financial payments for ecosystem services, such as through the REDD+ mechanism being discussed within the United Nations Framework Convention on Climate Change, designed to encourage payments to developing countries for avoided forest loss and degradation (e.g. Pritchard 2009;

Sandbrook et al. 2010). Although the total area of mangroves is small compared to the size of the global forest estate, their importance is considerable, not only as living biomass but for their role in carbon sequestration and long-term storage in soils. This sequestration role has largely been ignored in REDD+ discussions, but it has been highlighted in recent reports on coastal wetlands and 'blue carbon'—the role of coastal ecosystems in carbon storage and sequestration (e.g. Crooks et al. 2011; Laffoley and Grimsditch 2009; Murray et al. 2010).

The role of mangroves in coastal defense deserves more attention in the preparation of climate-change adaptation plans. To date, many such plans have focused on hard engineering structures to prevent damage from sea-level rise. Such approaches are costly, however, and can lead to further losses of coastal ecosystems and other associated ecosystem services. The use of natural coastal protection, including mangrove restoration, should be encouraged, including through adaptation funding mechanisms (Gedan et al. 2011; Hale et al. 2009).

Information and communication

The decisions that are made on mangrove use, conservation, management and restoration in coming years will have a profound effect on millions and possibly billions of people worldwide. They must be made, therefore, on the best available information. The *World Atlas of Mangroves* is one contribution to improving understanding of the importance of mangrove ecosystems, their distribution and the pressures they face. There is no doubt that mangroves are better appreciated today than they have been in the past. But there is no time for complacency: the work of mangrove countries and the partner organizations that produced the Atlas is far from over.

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Partner organizations

ITTO

ISME

FAO

UNEP

WCMC

UNESCO

United Nations Educational, Scientific and Cultural Organization

MaB

Man and the Biosphere Programme

UNITED NATIONS UNIVERSITY

UNU-INWEH

The Nature Conservancy

Protecting nature. Preserving life.™

Supporting countries/ organizations

JAPAN

DEPARTMENT OF STATE UNITED STATES OF AMERICA

GOBIERNO DE ESPAÑA MINISTERIO DE MEDIO AMBIENTE Y MEDIO RURAL Y MARINO

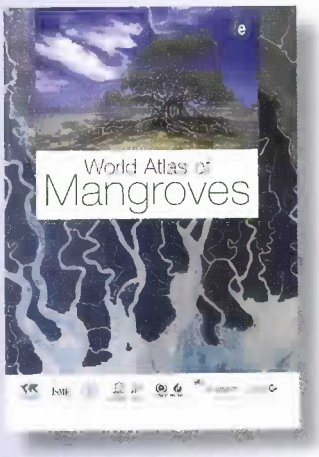
สถาบันสิ่งแวดล้อมไทย
Thailand Environment Institute

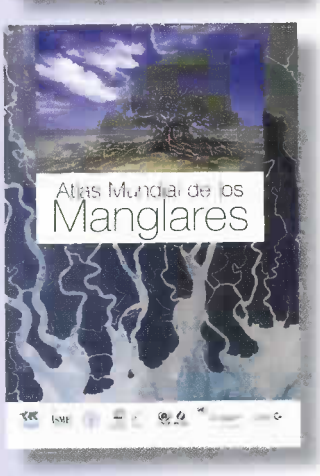
TOKIO MARINE NICHIDO

YL Invest Co.,Ltd.

TBRC

WETLANDS INTERNATIONAL





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