place between it settling through the CCD and reaching the seafloor, and enough probably gets sedimented to extend the depth of diagenetic nodule formation to well below the CCD under high productivity waters where there is limited siliceous sediment accumulation.

In the North Pacific, the trends in nodule composition in relation to the equatorial zone are the mirror image of those in the south. Thus in both the Central Pacific Basin and the Clarion–Clipperton Zone the highest nodule grades occur in diagenetic nodules on the northern flanks of the high productivity area and decline both to the north and south. The general model erected to explain the Penrhyn Basin nodule variability thus probably applies, at least in part, to these areas also.

The model also has some applicability in the Indian Ocean but less in the Atlantic. In the Indian Ocean, diagenetic nodules associated with sediments containing moderate amounts of organic carbon occur resting on siliceous ooze to the south of the equatorial zone in the Central Indian Ocean Basin. Farther to the south these nodules give way to hydrogenous varieties resting on pelagic clay. However, in the north the changes in nodule composition that might be expected under higher productivity waters do not occur, probably because terrigenous sedimentation becomes important in those areas which in turn reduces the Mn, Ni, and Cu content of nodules. In the Atlantic, the influence of equatorial high productivity on nodule composition that is evident in the Pacific is not seen, mainly because the seafloor in the equatorial area is largely above the CCD. Where diagenetic nodules do occur, as in the Angola, Cape and East Georgia Basins, productivity is also elevated, but the seafloor is near or below the CCD leading to reduced sedimentation rates.

Conclusions

Manganese nodules, although not being mined today, are a considerable resource for the future. They consist of ferromanganese oxides variably enriched in Ni, Cu, and other metals. They generally accumulate around a nucleus and exhibit internal layering on both a macro- and microscale. Growth rates are generally slow. The most potentially economic varieties of the deposits occur in the subequatorial Pacific under the flanks of the equatorial zone of high biological productivity, at depths near the CCD. Similar nodules occur in the Indian Ocean under similar conditions.

See also

Authigenic Deposits. Hydrothermal Vent Fluids, Chemistry of. Hydrothermal Vent Biota. Hydrothermal Vent Ecology.

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MANGROVES

M. D. Spalding, UNEP World Conservation Monitoring Centre and Cambridge Coastal Research Unit, Cambridge, UK

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Definition

The term mangrove is used to define both a group of plants and also a community or habitat type in the coastal zone. Mangrove plants live in or adjacent to the intertidal zone. Mangrove communities are those in which these plants predominate. Other terms for these communities include coastal woodland, intertidal forest, tidal forest, mangrove forest, mangrove swamp and mangal. The word mangrove can be clearly traced to the Portugese word ‘mangue’ and the Spanish word ‘mangle’, both of which are actually used in the description of the habitats, rather than the plants themselves, but still have been joined to the English word ‘grove’ to give the word ‘mangrove.’ It has been suggested that the original Portugese word has been adapted from a similar word used locally by the people of Senegal, however an alternative derivation may be the word ‘manggi-manggi’, which is still used in parts of eastern Indonesia to describe one genus (*Avicennia*).

Mangrove Species

Mangrove plants are not a simple taxonomic group, but are largely defined by the ecological niche where they live. The simplest definition describes a shrub or tree which normally grows in or adjacent to the intertidal zone and which has developed special adaptations in order to survive in this environment. Using such a definition a broad range of species can be identified, coming from a number of different families. Although there is no consensus as to which species are, or are not, true mangroves, there is a core group of some 30–40 species which are agreed by most authors. Furthermore, these ‘core’ species are the most important, both numerically and structurally, in almost all mangrove communities. **Table 1** lists a large range of mangrove species (of tree, shrub, fern, and palm), and highlights those which might be regarded as core species.

All of these plants have adapted to a harsh environment, with regular inundation of the soil and highly varied salinities, often approaching hypersaline conditions. Soils may be shallow, but even where they are deep they are usually anaerobic within a few millimeters of the soil surface. Many

Table 1 List of mangrove species: species in bold typeface are those which are considered ‘core’ species

Family	*Species*	*Family*	*Species*
Pteridaceae	*Acrostichum aureum*		***Bruguiera parviflora***
	Acrostichum danaeifolium		***Bruguiera sexangula***
	Acrostichum speciosum		***Ceriops australis***
Plumbaginaceae	*Aegialitis annulata*		***Ceriops decandra***
	Aegialitis rotundifolia		***Ceriops tagal***
Pellicieraceae	***Pelliciera rhizophorae***		***Kandelia candel***
Bombacaceae	*Camptostemon philippensis*		***Rhizophora apiculata***
	Camptostemon schultzii		***Rhizophora harrisonii***
Sterculiaceae	*Heritiera fomes*		***Rhizophora mangle***
	Heritiera globosa		***Rhizophora mucronata***
	Heritiera littoralis		***Rhizophora racemosa***
Ebenaceae	*Diospyros ferrea*		***Rhizophora samoensis***
Myrsinaceae	*Aegiceras corniculatum*		***Rhizophora stylosa***
	Aegiceras floridum		*Rhizophora* × *lamarckii*
Caesalpiniaceae	*Cynometra iripa*		*Rhizophora* × *selala*
	Mora oleifera	Euphorbiaceae	*Excoecaria agallocha*
Combretaceae	***Conocarpus erectus***		*Excoecaria indica*
	Laguncularia racemosa	Meliaceae	*Aglaia cucullata*
	Lumnitzera littorea		***Xylocarpus granatum***
	Lumnitzera racemosa		***Xylocarpus mekongensis***
	Lumnitzera* × *rosea	Avicenniaceae	***Avicennia alba***
Lythraceae	*Pemphis acidula*		***Avicennia bicolor***
Myrtaceae	*Osbornia octodonta*		***Avicennia germinans***
Sonneratiaceae	***Sonneratia alba***		***Avicennia integra***
	Sonneratia apetala		***Avicennia marina***
	Sonneratia caseolaris		***Avicennia officinalis***
	Sonneratia griffithii		***Avicennia rumphiana***
	Sonneratia lanceolata		***Avicennia schaueriana***
	Sonneratia ovata	Acanthaceae	*Acanthus ebracteatus*
	Sonneratia × *gulngai*		*Acanthus ilicifolius*
	Sonneratia × *urama*	Bignoniaceae	*Dolichandrone spathacea*
Rhizophoraceae	***Bruguiera cylindrica***		*Tabebuia palustris*
	Bruguiera exaristata	Rubiaceae	*Scyphiphora hydrophyllacea*
	Bruguiera gymnorrhiza	Arecaceae	***Nypa fruticans***
	Bruguiera hainesii		

mangrove species show one or more of a range of physiological, morphological or life-history adaptations in order to cope with these conditions.

Coping with Salt

All mangroves are able to exclude most of the salt in sea water from their xylem. The exact mechanisms for this remain unclear, but it would appear to be an ultrafiltration process operating at the endodermis of the roots. One group, which includes *Bruguiera, Lumnitzera, Rhizophora* and *Sonneratia*, is highly efficient in this initial salt exclusion and shows only minor further mechanisms for salt secretion. A second group, which includes *Aegialitis, Aegiceras* and *Avicennia* appear to be less efficient at this initial salt exclusion and hence also need to actively secrete salt from their leaves. This is done metabolically, using special salt glands on the leaf surface. The salt evaporates, leaving crystals which may be washed or blown off the leaf surface. In these latter species such exuded salt is often visible on the leaf surface (**Figure 1**).

Anaerobic Soils

The morphological feature for which mangroves are best known is the development of aerial roots. These have developed in most mangrove species in order to cope with the need for atmospheric oxygen at the absorbing surfaces and the impossibility of obtaining such oxygen in an anaerobic and regularly inundated environment. Various types of roots are illustrated in **Figure 1**.

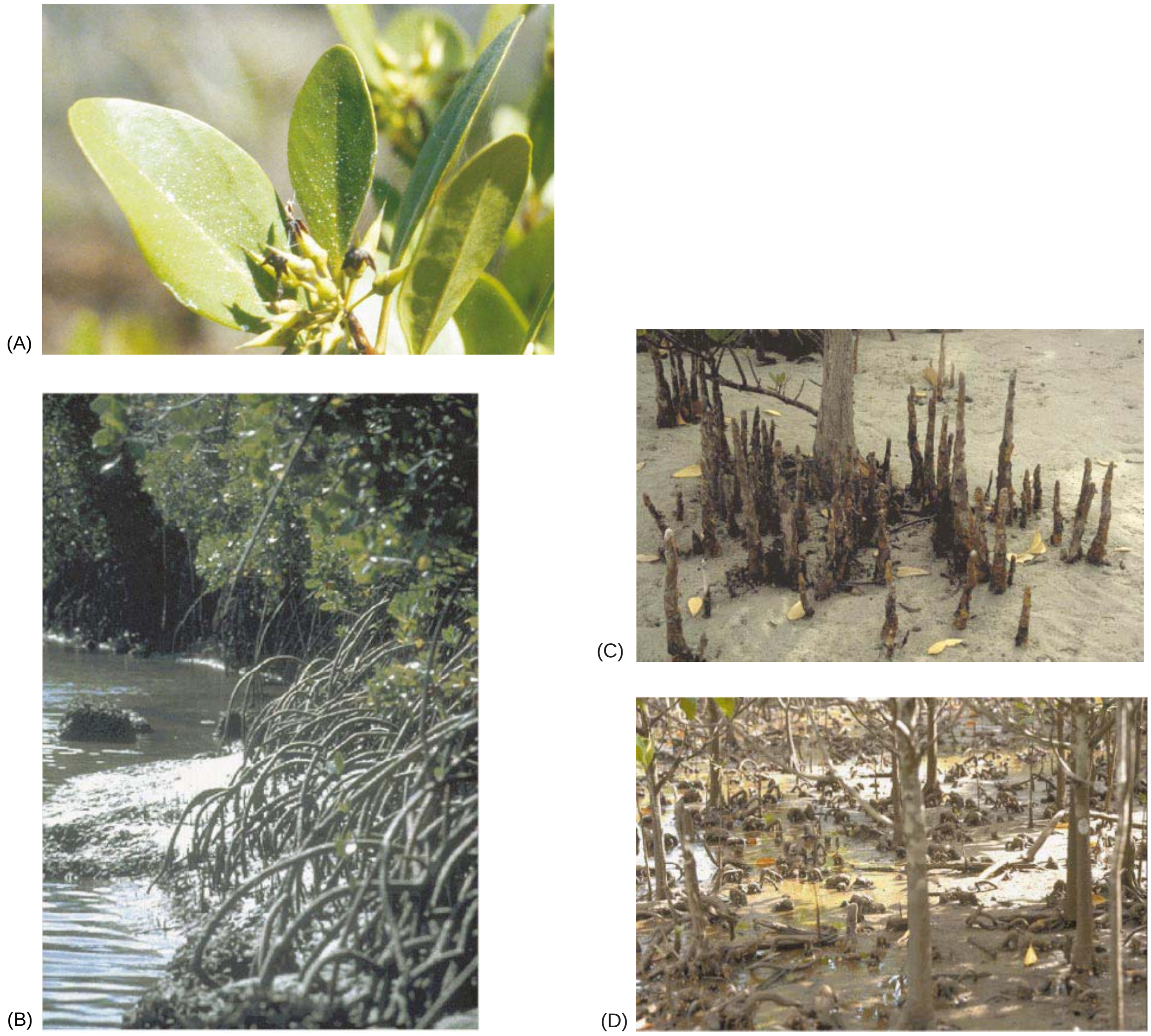

Figure 1 Mangrove adaptations: (A) salt crystals secreted onto the surface of a leaf, *Avicennia*; (B) stilt roots of *Rhizophora*; (C) pneumatophores in *Sonneratia*; (D) root knees in *Bruguiera*; (E) plank roots in *Xylocarpus*; (F) *Rhizophora* propagule.

(E)

(F)

Figure 1 *Continued*

The stilt root, exemplified by *Rhizophora* (**Figure 1B**) consists of long branching structures which arch out away from the tree and may loop down to the soil and up again. Such stilt roots also occur in *Bruguiera* and *Ceriops* although in older specimens they fuse to the trunk as buttresses. They also occur sporadically in other species, including *Avicennia*.

A number of unrelated groups have developed structures known as pneumatophores which are simple upward extensions from the horizontal root into the air above. These are best developed in *Avicennia* and *Sonneratia* (**Figure 1C**), the former typically having narrow, pencil-like pneumatophores, the latter with secondary thickening so that they can become quite tall and conical.

One adaptation on the theme of pneumatophores is that of root knees where more rounded knobs are observed to extend upwards from the roots. In *Xylocarpus mekongensis* these are simply the result of localized secondary cambial growth, but in *Bruguiera* (**Figure 1D**) and *Ceriops* they are the result of a primary looping growth. In these species branching may also occur on these root knees.

Buttress roots are a common adaptation of many tropical trees, but in *Xylocarpus granatum* (**Figure 1E**) and to some degree in *Heritiera* such flange-like extensions of the trunk continue into plank roots which are vertically extended roots with a sinuous plank-like form extending above the soil.

The surfaces of the aerial roots are amply covered with porous lenticels to enable gaseous exchange, and the internal structure of the roots is highly adapted, with large internal gas spaces, making up around 40% of the total root volume in some species. It is further widely accepted that there must be some form of ventilatory mechanism to aid gaseous exchange. A system of tidal suction is the probable mechanism in most species: during high tides, oxygen is used by the plant, while carbon dioxide is readily absorbed in the sea water, leading to reduced pressure within the roots. As the tide recedes and the lenticels open, water is then sucked into the roots.

Seeds and Seedlings

Establishment of new mangrove plants in the unstable substrates and regular tidal washing of the mangrove environment presents a particular evolutionary challenge. All mangroves are dispersed by water and particular structures in the seed or the fruit are adapted to support flotation. In a number of groups a degree of vivipary is observed which is unusual in most nonmangroves. The Rhizophoraceae have developed this to its fullest extent and here the embryo grows out of the seed coat and then out of the fruit while still attached to the parent plant, so that the propagule which is eventually released is actually a seedling rather than a seed (**Figure 1F**). In a number of other groups, including *Aegiceras, Avicennia, Nypa* and *Pelliciera* cryptovivipary exists in which the embryo emerges from the seed coat, but not the fruit, prior to abcission.

Longevity of seedlings is clearly important for many species. Most species are able to survive (float and remain viable) for over a month, whereas some *Avicennia* propagules have been shown to remain viable for over a year while in salt water.

Distribution and Biogeography

As a result of their restriction to intertidal areas, mangroves are limited in global extent (**Figure 2**), and are, in fact, one of the most globally restricted of all forest types. **Figure 2** clearly shows the absolute limits to mangrove distribution. Mangroves are largely confined to the regions between 30° north and south of the equator, with notable extensions beyond this to the north in Bermuda (32°20′N) and Japan (31°22′N), and to the south in Australia (38°45′S), New Zealand (38°03′S) and South Africa (32°59′S). Within these confines they are widely distributed, although their latitudinal development is restricted along the western coasts of the Americas and Africa. In the Pacific Ocean natural mangrove communities are limited to western areas, and they are absent from many Pacific islands.

In all, an estimated 114 countries and territories have mangroves, however for many nations the total area is very small indeed, and the total global area of these forests is only 181 000 km^2. **Table 2** provides a summary of total mangrove areas by region.

Although these statistics suggest a relatively wide distribution, the distribution of individual species within these areas is clearly far more restricted, and **Figure 3** provides a plot of mangrove biodiversity patterns. A number of points of particular interest are clearly illustrated.

1. There is a distinct region of very high mangrove diversity, sometimes referred to as the ‘diversity anomaly’, centered over south-east Asia.
2. Away from this high diversity region mangroves generally show relatively even levels of low diversity, although there is smaller peak of diversity around southern Central America.
3. There is a wide area of the central and western Pacific Ocean from 120 to 160°W where mangroves do not occur.
4. Even in the area of highest mangrove diversity there is a very rapid latitudinal decline in species numbers away from the tropics.

Table 2 Total mangrove area by region

Region	*Area (km^2)*	*Proportion of global total*
South and south-east Asia	75 173	41.5%
Australasia	18 789	10.4%
The Americas	49 096	27.1%
West Africa	27 995	15.5%
East Africa and the Middle East	10 024	5.5%
Total area	181 077	

Data calculated from best available national sources in Spalding *et al.* (1997).

One further observation, which is not fully illustrated in the figures, concerns the division of the global mangrove flora into two highly distinct subregions. An eastern group (sometimes known as the Indo-West Pacific) forms one vast and contiguous block stretching from the Red Sea and East Africa to the central Pacific. This group has a totally different species composition from the western group (the Atlantic–East Pacific or Atlantic–Caribbean–East Pacific), which includes both Pacific and Atlantic shores of the Americas, the Caribbean and the shores of West Africa. A number of these patterns are explored more fully, below.

Latitudinal Patterns

Mangroves limits are closely correlated to minimum temperature requirements. There is only one genus (*Avicennia*) which survives in environments where frosts may occur, but many species appear to have their latitudinal limits set by less extreme cold temperatures; air temperatures of 5°C appear inimical to most mangrove species. Sea-surface temperatures may be more important than air temperatures for some species. The 24°C mean annual isotherm appears to be the minimum water temperature tolerated by mangroves in most areas, although this minimum is closer to 27°C on the north Atlantic coasts of America and Africa, and may be much lower in areas such as southern Japan. The relatively low-latitude limits to mangrove in Peru and Angola are probably related to the cold water currents which affect these coastlines.

Eastern and Western Floras

The division of mangroves into two distinct floras is almost complete at the species level. Of the species listed in **Table 1**, three genera, but only one species, are shared between the two regions. In addition to having distinctive floras, the overall niche-space occupied by the two floras differs, with western mangroves restricted to higher intertidal and downstream estuarine locations than those of the eastern group.

None of these differences can be related to contemporary ecology, and they are clearly of historical origin. Mangroves have a considerable known history, with the oldest of the modern taxa, *Nypa*, being recorded from the Cretaceous (69 million years BP) and *Pellicera* and *Rhizophora* dating back to the Eocene (30 million years BP). Information on

Figure 2 The global distribution of mangrove forests (data kindly provided by the UNEP World Conservation Monitoring Centre).

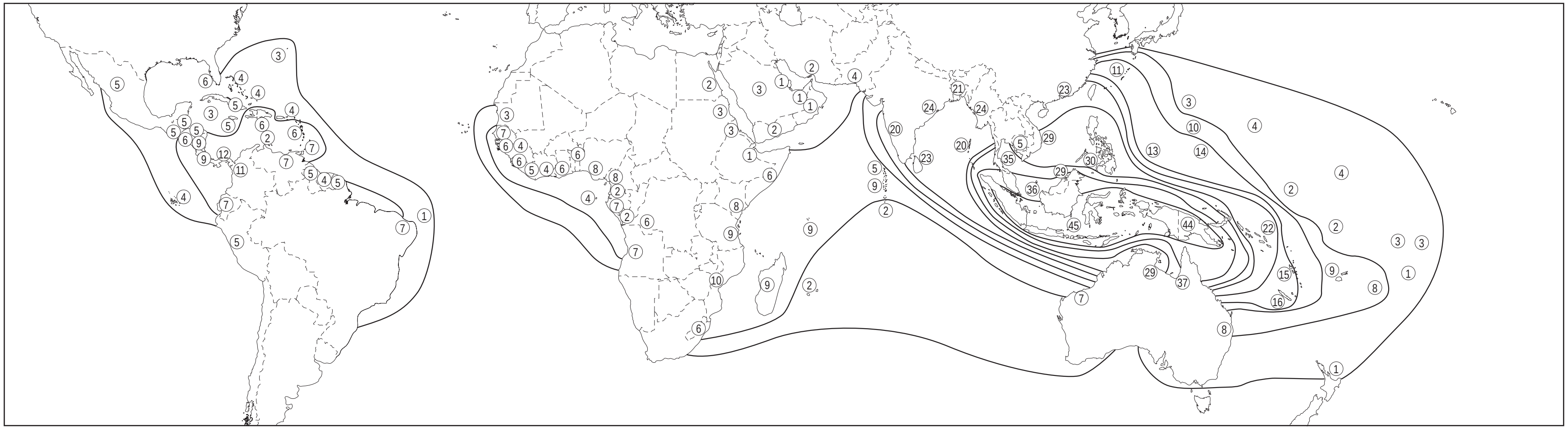

Figure 3 A global map of mangrove diversity plotting contours of equal diversity (1–5 species, 6–10, 11–15, 16–20, 21–25, 26–30, 31–35, 36–40, and 41–45). (Reproduced with permission from: Spalding (1998).)

the centers of origin and subsequent distribution patterns of mangroves is still unclear, and it is likely, given their disparate taxonomic origins, that mangroves evolved independently in a number of localities. Despite this, a number of authors have suggested that the majority of mangrove species have an eastern Tethys Sea origin with dispersal north and westwards (through a proto-Mediterranean) into the Atlantic and then via the Panama gap into the eastern Pacific. Whatever mechanisms may have operated, the climatic conditions, which were once suitable for a pan-Tethyan flora, changed. With the cooling and closure of the Mediterranean from the Tethys Sea the mangrove floras were separated. Divergence of the two communities then occurred through one or more of a number of mechanisms, including natural process of genetic drift and separation, possible extinction and radiation. It is clear that the Atlantic Ocean and the isthmus of Panama now represent insurmountable barriers to mangrove dispersal, however the closeness of the floras on either side of these barriers reflect the relatively short geological period over which these barriers have been in place.

The Diversity Anomaly

Apart from having quite distinctive faunas, the eastern mangroves have a much greater diversity than the western group. Of the species listed in **Table 1**, only 13 are found in the western group, whereas 59 are found in the eastern group. This 'diversity anomaly' is reflected not only in regional statistics, but also at local scales, with individual sites in the west typically having lower species counts than equivalent sites in the east. A number of theories have been propounded to explain this. It has been suggested, for example, that if most mangroves had originated in the eastern Tethys Sea the western flora may be depauperate simply as a result of being an immigrant flora. Alternatively the harsh environmental conditions during the Pleistocene, with significant temperature and sea-level fluctuation may have driven the extinction of a number of western mangroves. By contrast the Indo-West Pacific with its long and complex coastline is known to have had at least pockets of benign climatic conditions over geological timescales. These refugia may have allowed for further allopatric speciation events during periods of isolation from other areas, followed by periods of recombination with other areas as conditions ameliorated.

The relatively rapid tailing off of diversity westwards from Southeast Asia has been related to the relatively harsh climatic conditions which still prevail over much of this area, and the very large distances between more suitable localities for mangroves preventing recolonization. Similarly the absence of mangroves from the central and eastern Pacific is related to the very long distances between areas of suitable habitat. There is some evidence that mangroves may once have been more widespread in the Pacific, but, if this is the case, their disappearance from certain islands is probably explained by the climatic and eustatic changes of the Pleistocene.

Given the good dispersal ability of many mangrove species, distances must be very large indeed to prevent colonization, but it has been suggested, given the relatively short time since the beginning of the last interglacial, that mangrove communities may currently be in a state of expansion.

Biodiversity Patterns at Finer Resolutions: Zonation and Succession

Numerous localized ecological factors influence the occurrence and growth-patterns of mangroves. In addition to factors which affect the majority of plant species, such as water, nutrients, drainage, and soil-type, significant further influence is produced by salinity and tidal influence. Considerable efforts have been made to define patterns of zonation in mangrove communities, and although such patterns do occur in many communities, the enormous variation in local conditions makes the preparation of simple summaries of 'typical' zonation patterns very difficult.

In many tidal areas the regular drying out of the soil, often coupled with patterns of restricted water circulation, or high rates of evaporation, serves to increase salinities to considerably higher levels than the surrounding sea water. This is particularly the case in areas of back mangrove where tidal flushing is less frequent and water circulation may be more restricted. It is further exacerbated in arid regions. In many areas this leads to the development of wide areas of stunted mangroves, or even bare salt-pans where mangroves cannot grow. This situation is diminished, or even reversed in areas where the freshwater input is more considerable, either from high rainfall or terrestrial runoff, or in some estuarine environments.

The tides also exert influences in other ways, most notably through inundation, but also through their influence on soils. Different mangrove species show quite different tolerances to inundation. Species such as *Avicennia* and *Rhizophora*, which are relatively tolerant of frequent and quite high tidal waters, typically form the most seaward zone of the mangrove system. Tides also influence the soil through the delivery or removal of nutrients, and also the re-sorting of sediments. Typically finer sediments are found at higher locations in the tidal frame, whereas coarser sediments tend to be deposited or re-distributed lower down. Once again, the complexity of interactions is highly varied between localities.

In many cases mangrove communities may follow a succession and this has been linked to the process of terrestrial advancement (coastal progradation). The patterns shown in zonation often provide a spatial model for such a temporal succession, starting with the more inundation and salt-tolerant species. These are able to bind nutrients and sediments, gradually raising their position in the tidal frame such that they are then replaced by those species requiring slightly less saline and inundated conditions, and then by mangrove associates and then nonmangrove species. Such successional processes occur in many areas; in parts of Southeast Asia where there is a high input of allochthonous material, rates of coastal advancement have been recorded at 120–200 m year^{-1}. In other areas, however, the notion of mangroves 'creating land' is clearly not valid and mangroves show a range of responses to differing impacts of waves, climate, and sediments. In the Florida Everglades there is considerable evidence for the movement of mangrove communities both landwards and seawards, depending on sea-level changes and it may be more accurate to regard mangroves in these areas as opportunistic followers of sedimentation and substrate or elevation changes.

Humans and Mangroves

Humans have lived in close contact with mangrove communities for millennia and in many cases have made considerable use of this association. Archaeological sites have been located which demonstrate human presence in mangrove areas in Venezuela dating back 5000–6000 years, and there is an Egyptian inscription dating back to the time of King Assa (3580–3536 BC) which mentions mangroves. Countries of the Middle East began a vigorous trade in mangrove timber from about the ninth century, largely for boat-building, exporting from outposts along the shores of East Africa. The European nations became involved in the utilization of mangrove bark as a source of tannins, particularly from the Americas from the sixteenth century.

The earliest record of mangrove protection dates to an edict from the King of Portugal in 1760 who restricted the cutting of mangroves for timber in Brazil unless their bark was also used for tannins. Despite such early concerns, the overexploitation of mangroves began in earnest towards the middle of the twentieth century and is continuing, and in many areas accelerating at the present time.

In many areas mangroves are highly productive and their location on the coastline places them in a zone where many other human activities have, until recently, been somewhat restricted. At the same time they often exist in close proximity to centers of human population, and can be relatively easily approached by sea or land. This makes their utilization inevitable in many areas, although the degree of sustainability of such use is highly variable.

Utilization of Mangroves

Timber and wood products One of the commonest uses of mangroves is as a source of wood. Mangrove wood is often used for fuel either directly or after conversion into charcoal. The former is widespread among artisanal communities worldwide, the latter often for commercial purposes. Mangrove wood is also used for timber; the relatively small size of mangrove trees in many areas has meant that the primary usage of timber is the preparation of timber poles for fencing, housing construction, making of fish-traps and other activities. Larger trees can be utilized for preparation of planking, and indeed some species have a very high value associated with their dense wood and resistance to rot, which is important for construction of houses and boats (both for local and commercial use). Further industrial use of mangrove wood is in the production of wood-pulp for the paper industry, and chipboard.

Fisheries Mangroves and the associated channels which run between them, are important areas of fish productivity. Numerous species inhabit mangrove areas and form the basis of artisanal and commercial fisheries, including crab, prawn, and mollusk fisheries. Mangrove areas are also widely used by a number of offshore fish species which are of commercial importance. These species, which include some highly profitable shrimp species, use mangrove areas for spawning or as a nursery ground and loss of mangrove areas has severe negative impacts on fishery productivity. Cage-based fisheries have been established in many of the wider channels, and mangrove areas are widely used for the capture of juvenile prawns for transfer to aquaculture ponds. In recent years, wide areas of mangrove forest have been cut down in the development of intertidal aquaculture ponds, particularly in south-east Asia. Although this is a highly profitable industry, poor planning has led to the rapid and virtually irrevocable degradation of many of these ponds after only a few years. Rehabilitation of these lands is rarely undertaken with the result that local communities lose a source of valuable natural resources, and the shrimp pond developers move on to new areas.

Coastal protection The important role which mangroves play in the stabilization of coastal sediments and the reduction of coastal erosion has already been mentioned. This role is frequently overlooked until such time as the mangroves are removed and major storm events hit coastlines. The massive and devastating cyclones which regularly impact the coastline of the Bay of Bengal have drawn particular attention to these issues and in a number of localities around the globe there are now efforts to establish mangrove plantations precisely to stabilize sediments and reduce the impact of storm surges.

Alongside these three key areas of human importance, mangroves are regularly utilized for other purposes, a number of which are outlined in **Table 3**. It is highly difficult to place values on many of these uses and functions of mangroves. Apart from direct utilization of wood products, the link between particular products or functions and the mangrove communities which provide them is rarely made. Furthermore, for numerous communities the value in economic terms is greatly enhanced by the social value, providing a source of employment, protein and protection for some of the world's poorest communities.

Table 3 Minor or regionally restriced uses of mangroves

Honey production	An important economic activity in some countries
Fodder	For cattle, camels and goats, notably in India and Pakistan
Recreation	Walkways, boat-based tours and other visiting facilities have been established for tourists and local communities in some areas, notably Trinidad, Bangladesh, and Australia
Thatch and matting	Primarily from the leaves of the mangrove palm *Nypa fruticans* in south-east Asia and from introduced populations in West Africa
Tannin extraction	Formerly widespread, this activity has become less significant as synthetic products have become available
Traditional medicine	Still widespread in many traditional communities
Food	*Nypa fruticians* is widely used for the production of sugar, alcohol and vinegar. Fruits of *Avicennia*, *Kandelia* and *Bruguiera* are used as a source of food in some countries

Overexploitation and Loss

Mention has already been made of the widespread loss of mangrove communities worldwide. Apart from conversion into aquaculture ponds, much of this is related to land reclamation activities for agriculture and for urban and industrial development, and large areas have also been severely degraded or removed by commercial timber companies or through overexploitation by local communities. Some further degradation or loss has been related to human-induced changes to the water regime (including upstream dams leading to reductions in sedimentation at river mouths), pollution (mangroves are particularly sensitive to oil spills), and conversion into salt pans for industrial salt production. To date there is no globally available figure for total mangrove loss, however national loss statistics are available for a number of countries. In south-east Asia, for example, the loss figures for four countries are: Malaysia, 12% from 1980 to 1990; the Philippines, a 60% loss from 4000 km^2 originally to 1600 km^2 today; Thailand, a 55% loss from 5500 km^2 in 1961 to 2470 km^2 in 1986; and Vietnam, a 37% loss from 4000 km^2 originally to 2525 today. These figures alone suggest a total of some 7445 km^2 of mangrove loss, representing over 4% of the current global total. The four countries concerned have certainly suffered significant mangrove loss, but they are not alone.

Sea-level rise associated with global climate change must also be considered as a significant threat to mangrove ecosystems. It is important to note that the impacts of proposed changes (most models predict rises in sea-level of 30–100 cm by 2100) are relatively insignificant in some areas where high levels of sediment movement and deposition will counter such rises, or where other eustatic changes, such as those associated with tectonic movements, will remove or further enhance changing sea-level effects. Furthermore, mangrove species and communities are highly opportunistic and will colonize new areas with some rapidity. Sea-level rise remains a problem, however, as mangrove communities in many areas may become squeezed out as sea-level rise forces mangrove communities landwards, but human use prevents landward migration.

Protection and Plantation

Despite the massive losses which mangrove communities have gone through in the past decades there have also been concerted efforts to protect them in some areas, and the growing realization of their value has led to widespread efforts to utilize mangroves in a more sustainable manner, and in some places large areas of mangrove plantations have now been established.

Worldwide, there are currently an estimated 850 protected areas with mangroves spread between 75 countries, which are managed for conservation purposes. These cover over 16 000 km^2 of mangrove, or 9% of the global total. Although this is a far higher proportion than for many other forest types, active protection is absent from many of these areas, and the remaining unprotected sites are probably more threatened than many other forest types because of their vulnerability to human exploitation.

Increasing recognition of the various values of mangrove forests is leading to widescale mangrove plantation in some areas, for coastal defence, as a source of fuel, or for fisheries enhancement. Plantations in Bangladesh, Vietnam, and Pakistan now cover over 1700 km^2, and Cuba is reported to have planted some 257 km^2 of mangroves. Overall, however, when weighed against the statistics of mangrove loss, the area of such plantations remains insignificant.

Active management of these and other existing mangrove areas for economic production is increasing. The Matang Mangrove Reserve in Malaysia is perhaps the best-known example. Studies have shown combined benefits arising from timber and fuelwood products (notably charcoal), but even more importantly from a large nearshore fishery (directly or indirectly providing employment for over 4000 people), from aquaculture on the mud flats below the mangroves, and from tourism. It is rare that such holistic studies have been carried out. Often the human benefits provided by mangrove fall between several sectors of the economy, fisheries, forestry, tourism, and coastal protection, and their combined benefits are not realized. A better perception of these benefits would undoubtedly lead to much wider-scale protection for mangroves globally.

See also

Coastal Topography, Human Impact on. Coastal Zone Management. Crustacean Fisheries. Fisheries Overview. Reef Fisheries. Sea Level Change.

Further Reading

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MANNED SUBMERSIBLES, DEEP WATER

H. Hotta, H. Momma and S. Takagawa,
Japan Marine Science & Technology Center, Japan

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Introduction

Deep-ocean underwater investigations are much more difficult to carry out than investigations on land or in outer space. This is because electromagnetic waves, such as light and radio waves, do not penetrate deep into sea water, and they cannot be used for remote sensing and data transmission.

Moreover, deep-sea underwater environments are physically and physiologically too severe for humans to endure the high pressures and low temperatures. First of all, pressure increases by 1 atmosphere for every 10 meters depth because the density of water is 1000 times greater than that of air. Furthermore, as we have no gills we can not breathe under water. Water temperature decreases to 1°C or less in the deep sea and there is almost no ambient light at depth because sunlight can not penetrate through more than a few hundred meters of sea water. These