The Mangrove Swamp— An Ecosystem in Danger

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All over the tropics, pressures from rising populations are seriously jeopardizing the coastal mangrove ecosystems. Since mangrove swamps serve as a nursery for many commercially valuable marine species, stabilize the coastal areas and provide raw materials for many purposes, their destruction will mean a long-term loss far exceeding any immediate gain. The authors explain the function and evolution of this fertile ecosystem, and describe how and why the mangroves are being destroyed.

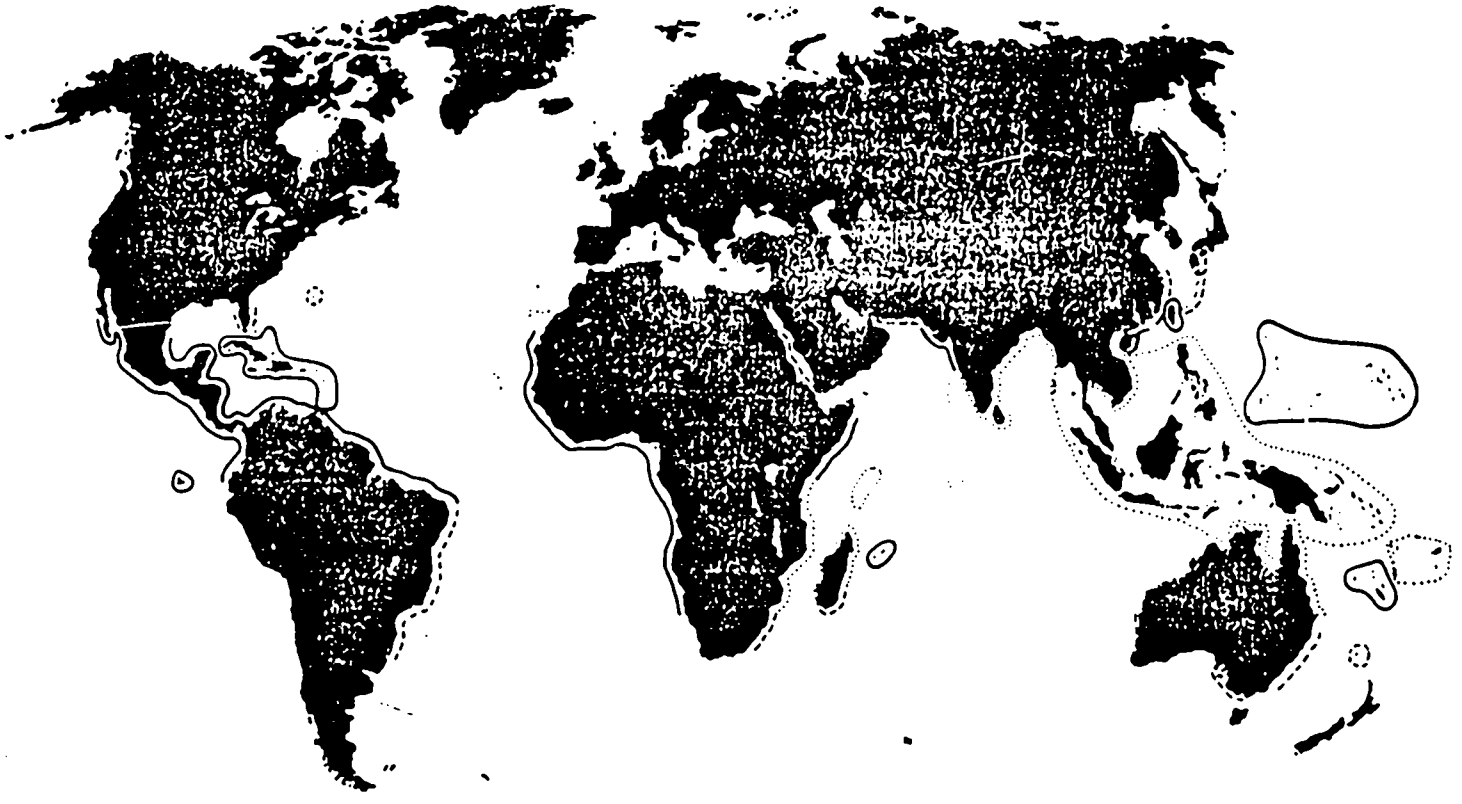

Figure 1. World distribution of mangroves modified after Chapman (6). Coastlines where ——— less than five species occur ——— with five to twenty species and ..... with more than 20 species

Many countries in tropical Asia, Africa and Latin America have populations that can be expected to triple or quadruple between 1950 and 2000. In these countries the population centers are often located along the coasts or on navigable rivers. Population expansion in these areas is even more pronounced due to immigration from surrounding rural areas. For example, the population of urban Calcutta, India, increases by at least 1000 persons per day due to immigration.

The rapid expansion of the coastal cities in tropical countries inevitably places a number of stresses on the surrounding coastal environment. Such stresses are also increasing outside the urban areas. Of the existing coastal ecosystems the mangrove areas appear to be particularly exposed to human impact. The destruction of mangrove forests in developing countries threatens the existence of millions of people who are directly or indirectly dependent on mangroves for their livelihood. In Bangladesh, for

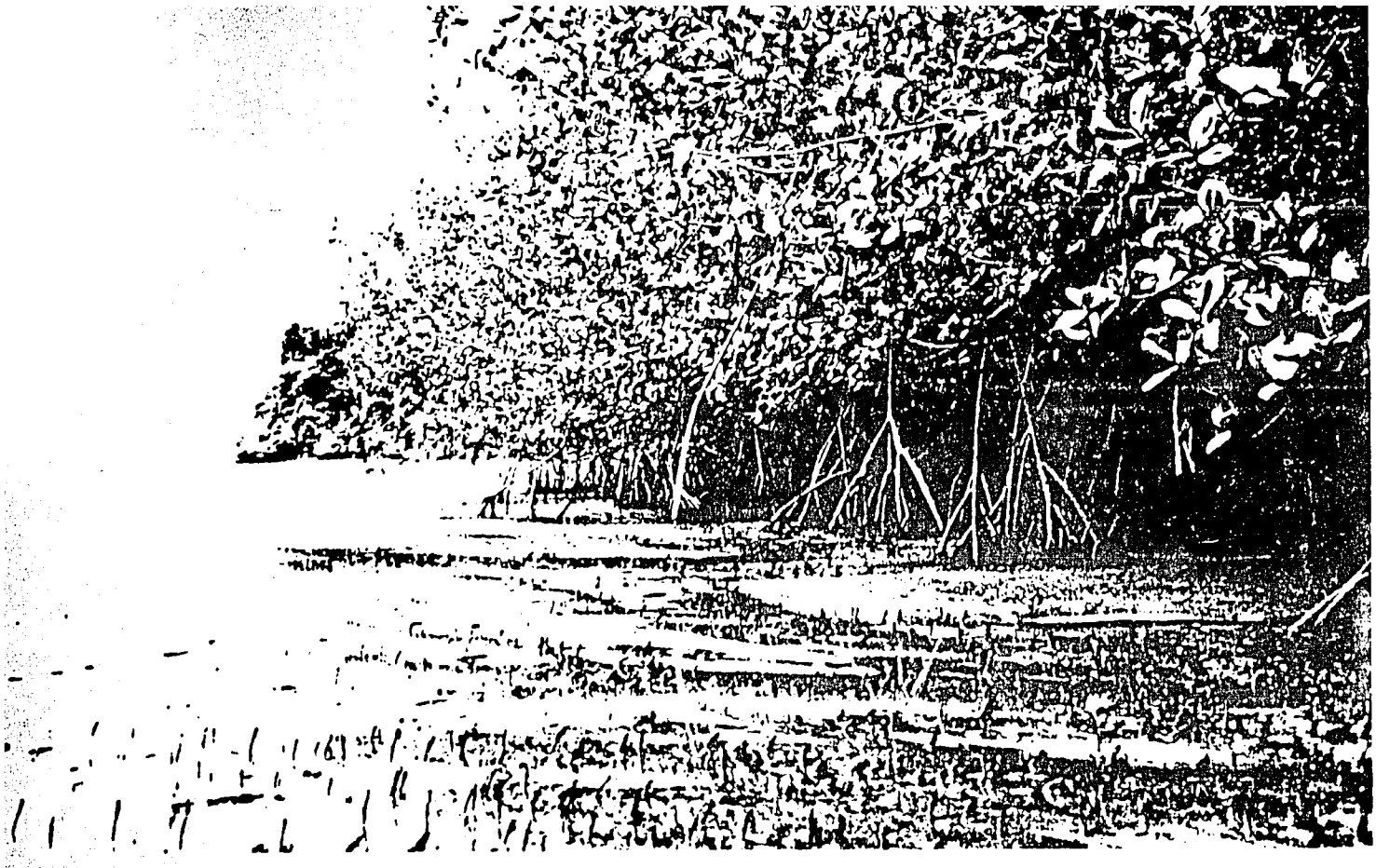

Figure 2. A black mangrove forest (*Avicennia*) along the ocean at Tumaco, Colombia (Lat 2°N).

example, about one-eigth of the country is covered by mangroves, but it is estimated that around one-third of the population is dependent on these mangroves for their income (1).

Human exploitation of the mangroves involves both direct utilization of the vegetation as fuel *etc* and the reclamation of the land for housing, industries or agriculture. Mangroves also suffer indirect stresses from human activity outside the ecosystem.

MANGROVE ECOSYSTEMS

Mangrove ecosystems exist in tropical areas on all continents (Figure 1), and extend to subtropical areas in Asia, North America, subequatorial Africa, Australia, and New Zealand. Mangroves are typically found on flat land between the high and the low tide marks in a geographical zone with high precipitation all year round. Mangroves thus often form the borderline between the oceans and tropical rainforests. However mangrove forests can also be found in arid areas of the world, *eg* in the Middle East, along the coast of the Arabian peninsula.

Mangroves constitute a group of halophytic species of 12 genera belonging to 8 families (2). The genera are: *Avicennia*, *Suaeda*, *Laguncularia*, *Lumnitzera*, *Conocarpus*, *Xylocarpus*, *Aegiceras*, *Aegialitis*, *Rhizophora*, *Bruguiera*, *Ceriops*, and *Sonneratia*. The term "mangrove" also refers to a complex plant community below the high tide mark on sheltered tropical shores. Frequently *tidal forest* is used as a synonym for "mangrove" or mangrove swamps.

Physical and Biological Characteristics

Regarding species distribution, two distinct areas can be recognized. The most luxuriant mangrove forests occur in Southeast Asia (3). A total of 36 species exist around the West Pacific and Indian Oceans, while in the West Africa –America region there are fewer than 10 species (4). The width of the zone covered by mangroves varies from a few meters to an extreme of 75–80 km in Bangladesh and 20–30 km along the west coast of peninsular Malaysia or along the Yucatan shoreline.

In addition to varying salinity, high temperature and high annual precipitation, mangrove habitats are frequently characterized by a thick layer of very loose organic soil, which is anaerobic from a few centimeters below the sediment surface. This soil is partly created by the mangroves themselves, since their tangled roots have an excellent ability to hold both locally produced detritus and particles carried in from the continent or the sea.

Biologically, mangroves are characterized by the various adaptations to their specific habitat. Two types of adaptations have developed to handle the salinity problem. Some species have a salt excretion mechanism with salt glands in the epidermal layer of the leaves (*eg*

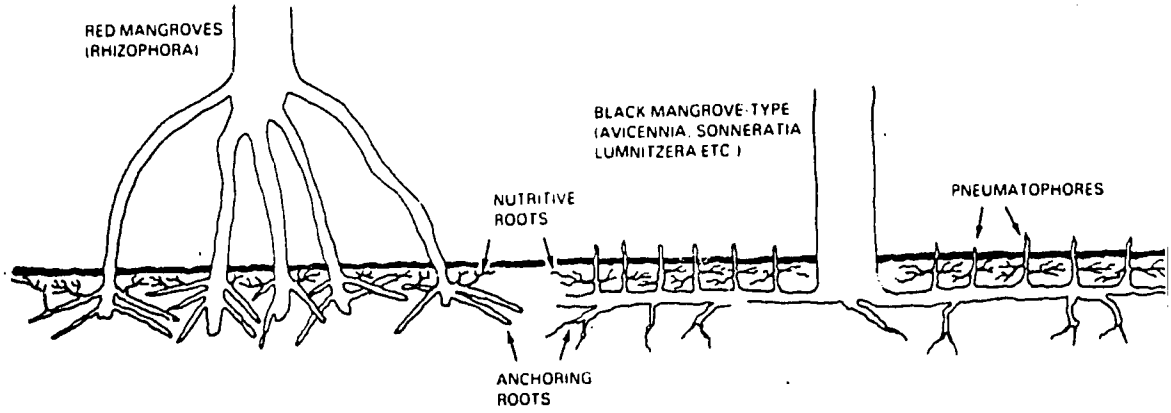

Figure 3. Schematic diagram of the rooting systems of the two major types of mangrove.

Aegialitis annulata, A corniculatum, Avicennia marina). Other species lacking salt glands prevent salt from entering by the roots (*eg Rhizophora, Laguncularia* and *Sonneratia*). The plants have adapted to anaerobic soil by developing air canals within the roots and complex aeration systems, either in the form of aerial roots that arise from the main trunk and lower branches (*Rhizophora*) or in the form of pneumatophores (submerged or exposed roots functioning as respiratory organs) from cable roots (*Avicennia, Sonneratia*) (see Figures 2 and 3).

Mangroves in general have very shallow and widespread root systems. This is an adaptation to the loose substrate in which they generally grow, and it also makes mangrove swamps very effective sedimentation basins (Figure 4).

A characteristic property of mangroves is also the viviparous seed, which can be regarded as both an adaptation to the loose, partly anaerobic soil and as an evolutionary adaptation to high chloride content in the water. Vivparity in this context means that when the zygote is formed it develops through its embryonic stage into a seedling without any dormancy period. Viviparity is found in *eg Rhizophora* (Figure 5) and *Avicennia*, but not in *Sonneratia* and *Xylocarpus*.

Besides high salinity in the wood of mangrove species that have salt glands in the leaves, mangroves in general contain very high concentrations of tannin. As a consequence, wood from mangroves is not vulnerable to termite attacks (4).

Because of their highly specialized ability to cope with their environment, mangroves experience little competition in their habitat. The dominating species are few—in West Africa and America there are frequently only about 5 species and in the West Pacific and Indian Ocean regions around 20. Compared to tropical rain forests the species diversity is very low.

Mangroves as Land Builders

Traditionally mangrove swamps were regarded as wasteland because they are dense and full of mosquitoes, and therefore difficult to explore or live in. After the first studies of sedimentation rates in certain mangroves, however, the view changed drastically and mangroves were ascribed an important role in geological evolution because of their ability to colonize the seashore, accumulate washed-in silt and their own production of detritus, and gradually raise the ground level to form land. In this model, mangroves were seen as the pioneering species, moving further and further out, converting sea to land and as proper land has been formed, "handing over" the area to other species (5, 6).

Subsequent more detailed studies have given evidence both of areas where mangroves do contribute to a rapid land formation, such as the deltas of the rivers Ganges, Brahmaputra and Meghna, in southern Bangladesh (7), and of areas where there is little movement of frontiers over the decades (8). In some areas a gradual retreat of mangroves has been reported. The deciding factors are of course sediment transport via rivers into the mangroves versus erosion by currents and wave action at the water front.

A vast literature has been published on the succession of mangroves, *ie* the zonation from the marine front to the edge of the rain forest or other ecosystems above the high tide mark (9).

The pattern of distribution of mangrove species is determined by several factors, some of which are interdependent. Among the more important are frequency and duration of flooding, salinity, rate of siltation, strength of eroding forces and firmness of soil.

A characteristic feature of a mangrove swamp is the canals, the open waterways through which tidal water passes up and down and rivers or rainwater flow towards the sea.

Associated Flora and Fauna

Mangroves, like any other type of vegetation, have an associated fauna and flora. From the point of view of these associates, several different subsystems exist within the mangroves:

1) The canopy, which consists of the upper branches, twigs, leaves, flowers and fruits. This is essentially a terrestrial environment having minimal contact with the

Figure 4.
Red mangrove (*Rhizophora*) swamp at Tumaco, Colombia.

surface water. Few special studies of this habitat seem to have been made. A personal, general impression of the authors is that the main groups of epiphytes, orchids and others, ressemble those of the rain forest but that there seems to be fewer species. An abundance of small ants is often a striking characteristic. Many species of birds can be found and there are often large aggregates of nesting birds in higher stands of mangrove trees, but feeding, for instance, in bordering marine systems.

2) The soil, which is periodically submerged by tidal action. Organisms living here show a variety of adaptations. Some fish and crabs adapt to terrestrial life by moving up the branches of the trees when the area is flooded. Others like some crabs and ants burrow in holes which they close with a plug of soil when the tide rises, living in an air bubble while the ground is submerged. Large numbers of snails, frequently tiny species, live on the soil and on branches of the trees.

3) A freshwater environment in root holes and in clefts between branches. Here a large number of insect larvae live, especially mosquitoes.

4) Permanent or semipermanent pools containing a variety of fish, shrimps, crabs, snails and frogs that are normally found in the river branches and canals, in the mangrove swamp or in the marine environment.

5) Branches and aerial roots of mangroves at the seafront which are frequently submerged in brackish or marine water. The fauna here is dominated by filtrators such as oysters and barnacles. Here extremely high biomass has been reported (10). In general it can be said that the epifauna seems to have difficulty adapting to frequent drying out and varying salinity, and therefore is generally more diverse and rich in areas nearer the low tide mark.

Productivity

Studies of the primary production of mangroves have given figures as high as 10 g of carbon per m^2 per day, with 2 g C/m^2/day as a representative net figure (11). Comparatively small variations have been reported for different species of mangroves at different sites. Compared to other tropical systems, the primary productivity of the mangroves is low. The generation time for the species is also long—25 to 40 years (4).

The fall of dead leaves and other litter is fairly even over the year and provides food for a variety of organisms. Since many of these organisms are larval stages of fish and shrimp, the mangrove production is important for adjacent marine and freshwater systems. Thus, in Indonesia, a direct correlation between the area covered by mangroves and the abundance of shrimp in the adjacent sea has been demonstrated (12).

MAN'S USE OF MANGROVES

Mangroves are of benefit to man both directly by supplying wood for various purposes, and indirectly via their contribution to the productivity of coastal waters and their erosion-preventing properties.

Wood Production

For thousands of years man has cut mangroves to use the wood. Today the main use of mangrove wood is for fuel wood and charcoal, although it is also an important source of timber for posts, poles and railroad ties in the tropics. Some species contain resins which are used as plywood adhesives, and the bark of other species contains tannin and dyes. Because of their many uses and their relatively slow growth, mangroves have been virtually exterminated in parts of Southeast Asia. Therefore, silviculture of mangroves is practiced in India (13), Thailand and Malaysia (4). In other parts of the world exploitation has

ıally been on a smaller scale, with selective felling in tural stands.

Mangrove wood is heavy and will not float in water. It is sily destroyed by shipworms, but its high tannin content ıkes it resistant to termite attacks. Mangrove poles are ;refore used as building timber in many areas in Africa d have for example been used for supporting structures some taller buildings in many Arabian towns (4). ›wever, the high tannin and salt content also means that ›n nails will rapidly corrode. The red and white man- ›ves are preferred for production of charcoal though ıer species of mangroves are often used.

Due to the high tannin content of the bark, certain ecies of mangroves (*Rhizophora:* 25 percent) are some- ıes used for tanning purposes. Other tropical trees, wever, are more exploited for this purpose than man- ›ves.

angrove Ecosystems and Coastal Productivity

angrove communities contribute significantly to the oduction of food in coastal areas of the tropics. The ationship between the primary production of mangrove ıves and algae and the production of valuable fish and ellfish is described for south Florida by Odum (14) and lum and Heald (15) and by Macnae (16) for Indonesia.

Numerous species of tropical fish and shellfish depend ›on the mangrove environment for food. Thus, Hegerl d Davie (17) report that 52 species of fish, including lyfish (*Elopidae*), mullet (*Mugilidae*), leatherjacket *arangidae*), snapper (*Lutjanidae*) and mojarras (*Ger- lae*) were found in the mangrove forests of Cairns, ›rth Australia. Idyll *et al* (18) report that the mangrove bitat in south Florida supports such valuable marine ecies as gray snapper, red drum, sea trout (*Scianidae*) d mullet. On our own studies in the south Caribbean ıngrove communities, we found 65 fish species in con- ction with the mangroves (19). Many of these were ›mmercially quite important. The clams and crabs (*eg llinectes*) occurring in mangrove swamps are also the ›st important source of protein for a considerable group low-income people in many tropical countries, such as. ose in Central America (20).

The most important groups of organisms, however, both value and weight are those which are dependent upon angroves for shelter and food during the larval and venile stages of their development. Most species of the ›neid shrimps, which are subjected to intensive fishery l over the tropics, belong to this group. These shrimps ›awn in near-shore waters, and the newly hatched larvae e transported to the mangrove swamps along the coasts here they stay until they reach juvenile sta. and migrate fshore (Figure 6). The commercial shrimp production ıs been related directly to the surface areas of mangroves ong the coasts thus showing that a reduction of the angrove swamps causes a decrease in shrimp yield (12). number of fish species such as mullet, leatherjacket, ıapper, menhaden (genus *Brevoortia*), drumfish and sea out in their early stage of life are also dependent on the ›od and shelter offered by mangroves.

Figure 5. Seedling of the viviparous red mangrove (*Rhizophora*).

However, the mangrove ecosystems form the nursery grounds not only for marine species of fish and shellfish. Freshwater forms are also dependent on this environment for this purpose. One example is the prawn genus *Macrobrachium*, over 100 species of which inhabit the tropics. Here, the pregnant females migrate from freshwater rivers and lakes to the mangrove swamps along the coast, where the eggs hatch into free-swimming larvae. After completion of the pelagic larval stage, the larvae metamorphose to a benthic stage and crawl back upstream to freshwater.

Shoreline Protection

A mangrove swamp can be used to protect land against erosion and flooding both actively, by planting mangroves along waterfronts, and passively by leaving intact seaward fringes of mangroves when clearing land for development.

Planting seedlings or transplanting established plants for protection of causeways, railroads, embankments *etc* is common practice in several areas, for example in southern Florida, Hawaii, Sri Lanka and Southeast Asia (4, 21).

prevent erosion by waves (22). Mangroves have been used for centuries to stabilize the banks of fish ponds in various parts of Southeast Asia—notably Java, southern Sumatra, the Philippines and Taiwan (4). In Hawaii mangroves have been introduced to reduce beach erosion, with obvious success (23).

It has been shown that the black and white mangrove (*Avicennia, Languncularia*) give better protection and are more resistant to erosion than the red mangrove (*Rhizophora*). This is due to the profusion of pneumatophores on the black and white mangroves (see Figure 2), which increase their soil holding capacity.

Macnae (4) reports that culture ponds for fish and prawns are being created by clearing mangrove swamps along the coast of Java. Between the ponds and the sea, however, the mangroves are left intact to protect the ponds from destruction by waves. In South America, notably along the Pacific coasts of Colombia and Ecuador, protected waterways run along the coastline behind a natural barrier of mangroves on the sea side. These channels are kept open by man, and are excellent fareways, always protected from strong waves.

THREATS TO THE MANGROVES

Certain natural phenomena constitute a threat to the mangroves. Storms or hurricanes have occasionally caused destruction of mangroves (see *eg* 5). According to Craighead (24), considerable mangrove areas within the Everglades National Park in southern Florida have been destroyed by hurricanes. Heinsohn and Spain (25) report that a tropical cyclone hitting mangrove forests in north Queensland, Australia, stripped off most of the leaves and caused extensive breakage of small branches. Few trees were, however, uprooted (25). Secondary effects of mangroves have been killed as a result of alteration of the water level induced by clogging of tidal canals from sand shifted by tropical storms. Mangroves cannot tolerate inundation, and if the pneumatophores and proproots are submerged or covered by silt or mud the plants will soon die.

Attacks by the burrowing isopod *Sphaeroma terebraus* are also considered a serious threat to mangroves (26, 27). The root system of the red mangrove seems to be heavily attacked by this pest. As a result mangroves are unable to establish themselves in some areas and trees can become so weakened by numerous burrows in the proproots that they topple over (26). However, the wholly negative effect of *S terebraus* on mangroves is not indisputable (28). Reports are also available of attacks by shipworms below the water and by a number of creatures above the water including an array of insects, some crabs and monkeys.

Threats Introduced By Man

Mangroves have long been subjected to stresses caused by various human activities and there is no doubt that the human destruction of mangrove swamps is far greater than that caused by occasional meteorological phenomena or the nibbling of some animals. Until quite recently, mangrove swamps were considered wasteland and were widely used for dumping junk, ballast *etc*. Since they are located close to the sea they were also areas which attracted development for housing. Thus land reclamation for the expansion of housing areas, roads, harbors *etc*, has destroyed large areas of mangrove swamp (see Figure 7); for example in the Biscayne and Tampa Bay systems in Florida (21). In Venezuela, Canestri and Ruiz (29) report on extensive clearing of mangroves to make room for summer homes on pilings. According to Macnae (4) many

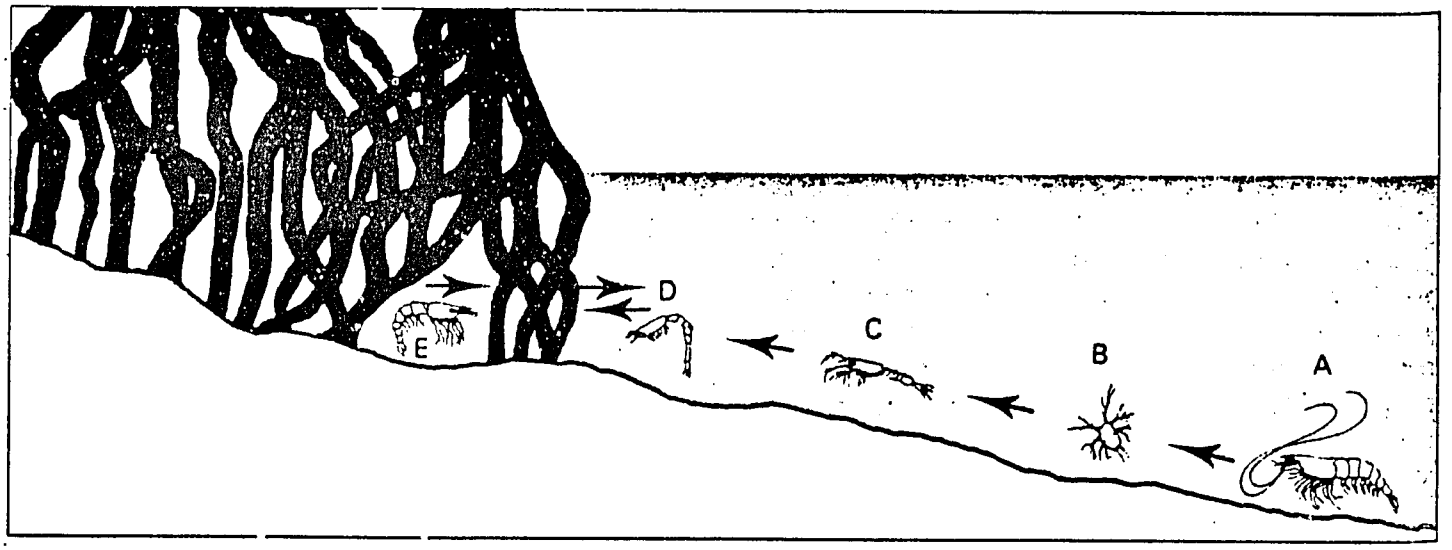

Figure 6. Schematic illustration of the life history of the peneid shrimps (*Penaeus*) in relation to the mangroves.

A = Mature shrimp
B = Nauplius larvae
C = Mysis
D = Postmysis
E = Juvenile shrimp

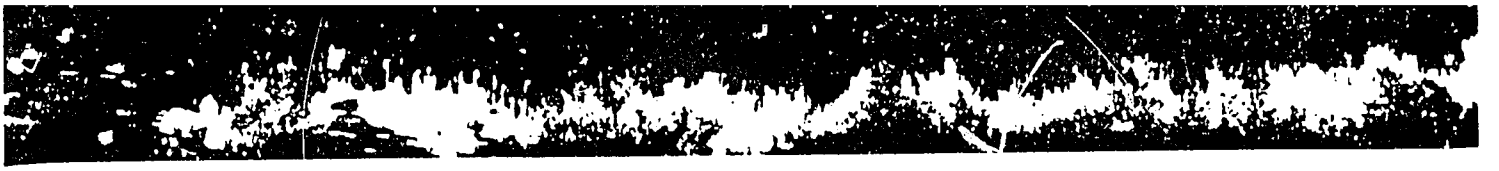

Figure 7. Reclamation of mangrove areas for housing around the city of Bombay, India.

of the low-lying coconut groves in Sri Lanka and Mozambique are reclaimed mangrove swamps. In most of the coastal states of India mangrove areas have been reclaimed for agricultural purposes. In West Bengal and Maharashtra the rate of reclamation is maximum (13). In West Bengal alone 768 km^2 of mangrove forest have been reclaimed since 1959 (13). In some areas, however, the process has not been successful and the clear-cut mangrove swamps are now non-vegetated saline areas. Such areas may be seen along the shores of the Gulf of Thailand (4). In El Salvador clear-cut mangrove swamps are now dry and unproductive due to increased evaporation (20).

Oil Pollution

Mangroves occupy the coastal zone between high and low tide marks, a particularly exposed position in the case of oil contamination. Oil pollution of mangrove swamps has been reported on several occasions (30–37).

Chan (36) reports that oil pollution in the mangroves of the Florida Keys resulted in the death of red mangrove seedlings sustaining greater than 50 percent oiling on their leaves. Black mangroves with greater than 50 percent oiling of pneumatophores also died, as did some where the substrate remained oiled one year later. A number of animals associated with the mangroves migrated away (*Uca* crabs, *Melampus* gastropods) and some mortality was observed among oysters and fish (36). The black coat of oil had a secondary effect of increasing absorption of solar energy and thus elevating the temperature above the lethal limits for many invertebrates and mangrove plants.

Defoliation and mortality among mangroves were observed by Nadeau and Bergquist (35) during three years following an oil spill affecting the mangrove swamps in southern Puerto Rico. The mangrove "proproot communities" revealed sparse and impoverished fauna, and mortality was observed among several major fauna groups. Observations of a very similar nature are reported by Rützler and Sterrer (32) following an oil spill in the mangroves along the Atlantic coast of Panama. Seedlings of red mangroves were killed together with the inter-tidal invertebrates, birds and turtles.

In observing an oil spill in mangrove communities along the Pacific coast of Columbia-Ecuador, the authors noted that partial defoliation of mangroves was common, but that few of the plants died (34). An oil spill in Tartut Bay, Saudi Arabia, had similar effects (33).

There is no doubt that oil contamination can have several serious consequences in mangrove communities. The damage is caused mainly by the direct smothering of pneumatophores or lenticels in the proproots, resulting in oxygen starvation. Harmful effects may also be produced by a number of fractions in oils, particularly the aromatics, which are phytotoxic. Furthermore the dark oil film may dangerously elevate temperatures by absorbing solar radiation. However, some factors do tend to alleviate the damage. Thus, high temperatures generally result in a rapid loss of acute toxic fractions through vaporization. It appears also that tidal action can rather rapidly wash off much of the oil deposited on roots and trunks of mangroves.

Herbicides

Mangroves are extremely susceptible to herbicides (38, 39), which in some parts of Africa have been used in mangrove control for 25 years. Phenoxy acids (2, 4-D and 2,4,5,-T) have been found most effective. Mangroves appear to be 5–10 times more sensitive than forest species.

At the tissue level, the symptoms of herbicide poisoning are dessication of leaves, plugging of vessel elements and destruction of root cortex. Destruction of root cortex impairs the seedlings ability to regulate their balance of water and salt (39).

More than 100 000 ha were defoliated. The assault resulted in large-scale destruction of the ecosystem (40). Considering the size of the affected areas and the effects of erosion and insolation on the land now unprotected by mangrove trees, the recovery time is expected to be very long (41, 42).

Thermal Pollution

The impact of coolant water, mainly from power plants, on mangroves and mangrove communities, has been studied by some authors. Kolehmainen *et al* (43) reported that species diversity and biomass of sessile organisms living on the proproots were not affected at slightly elevated temperatures. Biomass increased and was highest at 6° to 7°C above normal temperature and the number of species declined as the temperature rose above 35°C. Lugo and Snedaker (11) reported increased proproot densities, and also that the leaves of the red mangrove become smaller at elevated ambient water temperature.

Although the available reports on the effects of elevated temperatures on mangroves are few, it seems that mangrove trees themselves are more tolerant than some of the organisms living on the proproots.

However, the impact of thermal pollution is largely unknown. The phenomenon should be studied with particular care, since in true tropical waters the normal water temperature may be close to the upper thermal limits of many organisms.

CONCLUSION

The mangrove swamp is a seriously endangered ecosystem in most of the tropics. The immediate threat comes from overexploitation, *ie* clear cutting and land reclamation. In certain areas, pollution can cause serious destruction. When considering the rapid growth of human populations together with the key role of the mangroves in the preservation of coastal and offshore fish and shellfish stocks, and the shore protecting properties of the ecosystem, the preservation and sensible management of mangrove swamps would seem to be obvious. It is also a fact that the main part of the population subsisting on the mangrove environment are the rural poor. Any change will therefore affect them first. For example, the extensive destruction of the once huge mangrove coasts of Southeast Asia, notably in Bangladesh, may be the main reason for the repeated catastrophic floodings in these areas during the last decade.

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