NEOTROPICAL MANGROVES

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Summary

The last few decades have seen a rapid growth of interest in mangroves. This results from the perception that mangrove ecosystems are valuable resources and provides many environmental services at the local and regional scales, and at a global level in a scenario of climate changes. Mangroves are adapted to the rash conditions of the intertidal frame and therefore are ideal models to the study of different plant physiologies and adaptative mechanisms; also mangroves respond rapidly to global climate change and may be used as proxies to its impacts on the coastal region. Unfortunately, there is an accelerated rate of destruction of mangroves worldwide and nearly all maritime countries in the tropics and subtropics are concerned with the conservation and sustainable management of this natural wealth. Surreptitiously, however, many nations permit the misuse of mangroves for quick monetary returns. The scientific community and decision makers worldwide are now in a state of alert, requesting sound directives for the sustainable use of mangroves. The present chapter is an attempt to present a concise information of the botany, ecology, threats and management of mangrove ecosystems, aiming a rapid and useful source of major facts of interest to decision makers and to all those who see the ecological and economical value of mangroves.

1. Mangroves extension and distribution in the world

Mangroves are the dominant vegetation form colonizing protected coastal areas and estuaries throughout the tropics and sub-tropics. Mangroves are restricted to tidally influenced wetlands. However, they can also occur in areas without a tidal regime e.g. in some choked coastal lagoons and along rivers upstream to the saline intrusion. Some few examples of inland mangroves have been reported for areas where carbonate geology (e.g. some Caribbean islands) allows underground saline waters to penetrate far from the tidal fringe. Generally speaking, mangroves refer to salt-tolerant marine tidal evergreen forests that include trees, shrubs, palms, epiphytes and ferns in most areas in tropical and subtropical latitudes.

Mangroves provide important services and goods, mostly related to coastal protection, conservation of biological diversity and provision of habitat, spawning grounds and nutrients for a variety of fish and shellfish. In certain areas mangroves are significant sources of construction wood, fodder and wood products, as well as charcoal and fuel wood, medicine, honey, tannins, dye and other forest products. Also, mangroves are important carbon sinks in coastal areas, mostly associated with their high standing biomass and the accumulation of carbon-rich sediments, where sub-oxic to anoxic conditions inhibit complete oxidation of organic matter. The high concentration of tannins in mangrove biomass and high sedimentation rates typical of these ecosystems, also favour the rapid burial and slow decomposition of organic matter augmenting their role as long term carbon sink (Lacerda, 2002). Below sectors of the Great Barrier Reef in Australia, large deposits of poorly decomposed mangrove peat has been recently found. This material was buried and eventually covered by more recent coral reef sedimentation following past sea level rise about 9,000 year ago. The degree of preservation of this peat material suggests very slow decomposition confirming the role of long term sink played by mangroves. Notwithstanding their ecological significance, mangrove forests throughout the world are suffering impacts from many anthropogenic activities, which resulted in a steady decrease in their extension in most countries, reaching a world average forest loss of about 20% during the past 25 years (FAO, 2007).

Mangroves occupy about 70% of tropical and subtropical coasts between latitudes 35ºN and 38ºS, although their best development in terms of biomass, productivity and biodiversity occurs between latitude 10ºN and 10ºS, where climate conditions and freshwater supply are most favourable. Global extension of mangrove forests reaches about 16 million hectares, with about 29% in the Americas, including the Caribbean, 20% in Africa and 51% in the Indo-Pacific region.

Region	**Global extension 10^6 ha**	**% of the world total**	**Source**
Neotropical mangroves			
Atlantic coast	2.52		
Pacific coast	1.21		Lacerda (2002)
Caribbean	0.81		
Americas	4.54	28.7	
Africa	3.24	20.4	Spalding *et al*. (1997)
Asia	6.05	38.2	FAO (2007)
Oceania	2.02	12.7	FAO (2007)
Total	**15.85**	**100**	**-**

Table 1. Extension of Neotropical mangroves and the global distribution of mangrove forests area based on the available most recent and reliable estimates obtained by remote sensing mapping.

In the Americas abundant rainfall and extensive fluvial systems favoured the development of extensive and broad forests along coastal plain estuaries of the Pacific coast, from Honduras to northern Ecuador, and also in the Atlantic coast, along what is probably the world's most extensive near-continuous mangrove coastline extending for nearly 3.000 km, including the Orinoco Delta, the entire coastline of the Guyana, Sironame and French Guyana and the coastline of northern Brazil to Maranhão State, which includes the world's largest continuous mangrove stand located along the Maranhão-Pará coast in Northern Brazil covering about 0.7 x 10^6 ha, being considerably larger than the Sundarbans of Bangladesh, the second larger continuous mangrove belt in the world, with about 0.5 x 10^6 ha (Spalding et al., 1997).

Mangrove area in the neotropics is largest along the Atlantic coast (2.52 x 10^6 ha) where nearly optimal environmental conditions (climate and freshwater supply) occur. The Pacific coast with 1.21 x 10^6 ha harbors less than 50% of the total area along the Atlantic Ocean. This more restricted distribution is caused by climatic constrains generated by singular oceanographic conditions resultant from the Humboldt Current suppressing connective activity and creating an arid climate sector southward from 3^{o}30' S of latitude in northern Peru. High soil salinity and nearly no freshwater continental contribution stops mangrove distribution southward to this latitude, at the Tumbes River estuary. The Caribbean region, in particular the larger islands of Cuba, Jamaica and Haiti/Santo Domingo, has about 0.81 x 10^6 ha (Table 1). Countries with largest forests are Brazil with 1.38 x 10^6 ha; followed by Cuba (0.53 x 10^6 ha); Mexico (0.52 x 10^6 ha); Colombia (0.39 x 10^6 ha) Venezuela (0.25 x 10^6 ha) and Honduras (0.23 x 10^6 ha). These seven countries respond for over 72% of the total mangrove area in the American continent (Lacerda, 2002).

2. Mangrove flora and the origin of the Neotropical mangroves

From nearly half a million species of vascular plants only about 70 species and a few hybrids are recognized as true mangrove species, meaning those species with occurrence restricted to mangrove habitats, not to be found anywhere else. Among these only two families Rhizophoraceae and Avicenniaceae present a pan tropical distribution, even extending to higher sub-tropical latitudes such as south Japan and southeast USA, in the northern hemisphere and to south Brazil, Australia and New Zealand in the southern hemisphere (Tomlinson, 1986). Depending on region and costal characteristics within regions, over one hundred additional plant species also occur within mangroves, including epiphytes migrated from landward forests and sea grasses and algae from the seaward edge. At higher latitudes salt marsh floral components are also common.

Most of the true mangrove plant species occurs in the Indo-Pacific region, where plants are believed to have first acquired the mangrove habitat and evolved the physiological and structural adaptations to the brackish water about 100 to 80 million years ago. Through radiate dispersal during the Pliocene, including a littoral drift along the Tethys Sea coastline and what is presently the Mediterranean Sea, mangroves were dispersed through most of the tropics. Mangroves thence crossed through the still opening Atlantic Ocean to the Caribbean by the early Eocene (55-50 million years), also jumping the then flooded Panama isthmus to the Pacific coast of the Americas. About

40 million years ago mangrove pollen from *Nypa*, *Rhizophora*, *Avicennia* and *Pelliciera* were already spread through the Atlantic and Pacific coast of the Americas and the Caribbean.

From the original Indo-Pacific pool, eleven species belonging to five genera presently constitute the true mangrove flora in the neotropics. A twelfth species, the palm *Nypa* is recorded from the fossil record in South America during the Paleocene, but disappeared from the region in more recent periods. Recently it has been introduced in Panama, but as a farmed species for fiber production. Among present day mangrove taxa, the Avicenniaceae is represented by four species: *Avicennia germinans* (L.) Stearn., the one with largest distribution along both American coasts, and *A. schaueriana* Stapft & Leechm., restricted to the Atlantic coast, but occurring from Florida in the USA to south Brazil. The last two species *A. bicolor* Standl. and *A. tonduzii* Moldenke, are restricted to the Central American Caribbean and Pacific coasts.

The Rhizophoraceae, generally dominating the areas facing open water, is represented by four species: *Rhizophora mangle* L., shown in Figure 1 colonizing river bancs in northern Brazil, the widest distributed species, occurring practically along the entire extension of mangroves in the Americas; and the rarer *R. harrisonii* Leechm*.; R. racemosa* G. F. Mayer and *R. samoensis* (Hochr.) Salvosa., restricted to equatorial latitudes. It is possible that the more restricted distributed species of the Avicenniaceae and Rhizophoraceae are varieties and/or hybrids of the wider distributed species and studies on the genetics of these two genera are still required.

Figure 1. A preserved *Rhizophora mangle* riverine forest in northern Brazil. *R. mangle*, known as the red mangrove due to the high tannin content of its bark, is one of the widest distributed mangrove species in the neotropics.

The family Combretaceae has two widely distributed species *Laguncularia racemosa* (L.) Gaertn. and *Conocarpus erectus* L., both occurring along the Pacific and Atlantic coasts. The two species are better developed along higher, lower salinity areas, but individuals have been reported even at the seaward edge of forests. At least one sub-species of *C. eretus*, has been suggested, but again lack of genetic studies hamper its full acceptance.

The last family is the Pellicieraceae, represented by a single species, *Pelliciera rhizophorae* Pl. & Tr., more abundant on the more consolidated sediments, generally occurring higher in the tidal frame. This species once widespread throughout the Caribbean and the equatorial coast of the Pacific of Central America is today extremely restricted to isolated sites in Panama and Costa Rica. However, similar to *Nypa*, it has recently been re-introduced in reforestation experiments along the Caribbean coast of Colombia (Lacerda, 1993).

Among the most abundant and diversified associated flora, i.e. non-obligatory mangrove species, are the fern *Acrosticum aureum*, *Mora megistosperma* and *M. oleifera*, frequently present along the gradation to terrestrial vegetation. These species are so typical of some Neotropical mangroves, which are considered as part of the mangrove formation proper. Still landward and in upstream locations, mostly under humid climate, mangroves typically grade into swamp forests and palm forests dominated by *Symphonia globulifera*, *Pterocarpus officinalis* and palms such as *Euterpe oleracea*. There are also open areas of herbaceous marshes where the mangrove fern *A. aureum* is mixed with salt marsh species (e.g. *Portulaca oleracea*, *Batis maritima*, *Sporbolus* virginicus, *Cyperus* sp. and occasional small shrubby mangroves as well as bare salt pans in many areas dominated by herbaceous succulent communities formed by Aizoaceae, Amaranthaceae, Chenopodiaceae and Portulacaceae. Along the humid Pacific coasts of Ecuador and Colombia and also in south eastern Brazil, mangrove canopy is invaded by a high diversity of epiphytes, particularly from the families Bromeliacea, Orchidacea and Aracea. Interesting to note is the frequent visits to theses epiphytes by local dwelling fauna in particular land and tree crabs, although the plant-animal relationship in these cases are still to be understood (Lacerda, 1993). Along the tectonically passive coast of the Atlantic Ocean, relic sand dunes and sand ridges left by the last changes in sea level during the Holocene may be frequently seem within the coastal plain. In such cases typical coastal forests and dune vegetation may occur mixed with mangrove vegetation, resulting in patchy, highly biodiversity forests.

The sea grasses *Ruppia maritima* L.; *Halodule wrightii* Achers; *Thalassia testudinum* Konig, *Halophila baillonis* and *Syringodium filiforme* are found in the lower intertidal and into the sub-tidal areas along most of the seaward fringe of the Caribbean and Atlantic mangroves. These sea grasses are the preferred fodder for the manatees, which find shelter in mangrove tidal creeks. Apart from sea grasses, benthic seaweeds found in mangroves include over 110 species, mostly from the Rhodophyceae. Diversity is higher in the highly transparent Caribbean waters and lower in continental mangroves receiving large continental contribution. About 50% of the species were recorded growing on roots and trunks, the remnants colonizing rocks, stones and shell fragments (about 30%) or directly growing on sand or mud substrates (about 20%). A few associations of macroalgae are found in most mangroves worldwide; the Bostrichietum, typically colonizing trunks and roots, which is formed by a dozen Rhodophyceae including the genera *Bostrichia*, *Caloglossa* and *Catenella*. Another association, the Rhizoclonietum is formed by over 10 species of the Chlorophyceae, mostly from the genera *Rhizoclonium*, *Enteromorpha* and *Cladophora*. Additionally, about 60 species of fungi belonging to all groups of warm waters infest submersed roots, stems and twigs, only a few, however, are host-specific. This group of organisms plays a central role in biomass decomposition and nutrient cycling within mangroves.

Benthic micro flora is dominated by diatoms of the genera *Auliscus*, *Cyclotella*, *Cocconeis*, *Fragilaria*, *Melosira*, *Navicula*, *Bidulphia*, *Thalassionema*, *Thalassiosira*, *Actynophycus*. These plants are extremely important to the biogeochemical characteristics of mangrove sediments. Biofilms, formed at the sediment-water interface, mostly by micro algae, fungi and bacteria, promotes the rapid formation of bio-mineralized minerals, in particular framboidal pyrites with plays a key role in nutrient and trace element geochemistry in mangrove sediments. Two stages of the formation of biogenic framboidal pyrites are shown in Figure 2. In figure 2A aggregations of pyrite crystals are easily seem forming the typical framboidal structure. In figure 2B fromboids are covered by a clay-organic thin film, helping preserving them into the anoxic sediment. This biomineralization processes is eventually responsible for the capacity of mangroves in immobilizing pollutants, in particular heavy metals of environmental significance, decreasing their bioavailability to mangrove plants and animals. This non-obvious service is of increasing use in developing nations as an alternative to much more expensive pollution mitigation procedures.

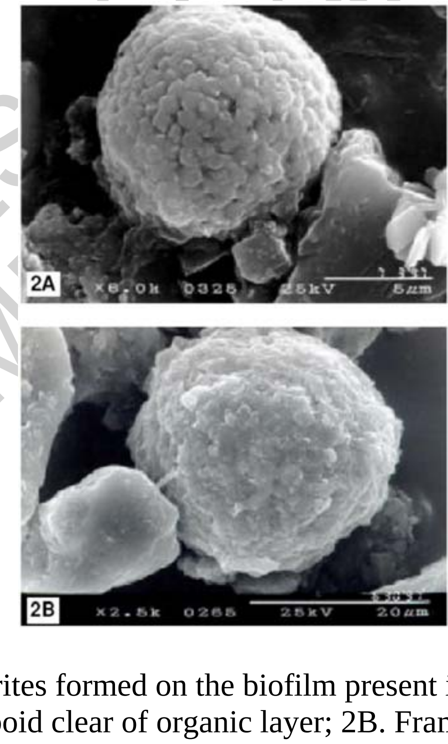

Figure 2. Framboidal pyrites formed on the biofilm present in the surface sediments of mangroves. 2A. Framboid clear of organic layer; 2B. Framboid covered by a clay-organic layer. These structures forms rapidly by the activity of sulfate reducing bacterial and are able to efficiently trap trace elements.

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Biographical Sketch

Professor Luiz Drude de Lacerda has a Graduation in Biology (1977), MSc (1980) and PhD (1983) in Biophysics from the Federal University of Rio de Janeiro. He is a Titular Professor at the Fluminense Federal University, Niteroi, and Head of the Graduate Program in Marine Sciences of the Federal University of Ceará, in northeastern Brazil, and coordinator of the national Institute of Science and Technology on Continent-Ocean Materials Transfer. He has acted as visiting professor at the universities of Hamburg, Germany; Nice and Toulon, France. Professor Lacerda is presently a CNPq senior researcher (1A) and a Scientific Steering Committee member of the IGBP-LOICZ program (International Geosphere-Biosphere Program - Land Ocean Interactions in the Coastal Zone) and of the ISME (International Society for Mangrove Ecosystems). Under these programs he has coordinated several international research projects on mangrove ecology, management and conservation in Asia, Africa and Latin America. Prof. Lacerda has authored over 170 journal papers and 18 books and 68 book chapters, on mangrove subjects and on the biogeochemistry of tropical ecosystems in general, environmental pollution and coastal zone management.