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Impact on Mangroves

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Abstract

Within the region, there are approximately 3,230,000 hectares of coastal shoreline dominated by mangrove vegetation which represents some 15% of the world inventory of mangroves. Unlike some parts of Asia, the mangroves of the region are not utilized in a sustainable manner although there are a variety of local uses, such as for timber, fuel and charcoal. In less populated areas, mangrove vegetation persists in a relatively undisturbed state. In populated areas, however, the habitat is used for the disposal of wastes, cleared for development projects, or exploited for other purposes, such as shrimp mariculture, all of which are incompatible with the sustainability of nearshore fisheries and environmental quality. In the context of global change, mangroves are more likely to be affected by changes in regional precipitation rather than by rising temperature and sea level. Specifically, mangrove areas that receive substantial precipitation and fresh-water runoff are likely to persist, whereas mangrove areas exposed to full-strength seawater may be overstepped and lost. Because of the importance of intertidal mangroves in shoreline protection, fisheries support and water quality, efforts should be taken by the appropriate authorities and organizations to curb abuses and protect the resource for both ecological and economic purposes.

1 Introduction

Although salt-tolerant mangroves form the dominant shoreline vegetation within the region, the majority of the region-specific data and information on their distribution and current status is sketchy and anecdotal. Any of the data and information obtained for this report are derived from the experience of the author in the region, from a variety of grey literature sources, and from communications with a number of regional correspondents. The resulting report focuses on the characteristics and distribution of mangroves within the region, their current status, and their ability, or not, to cope with and survive global change. The latter includes comments on certain man-related activities that take place in mangrove habitats.

2 The Mangroves of the Region

The ecological grouping of the halophytic spermatophytes known as mangroves occurs throughout the region, and includes *Avicennia germinans* L. Stearn, *Conocarpus erectus* L., *Laguncularia racemosa* L., *Gaertn.* f., *Pelliciera rhizophorae* Triana and Planchon, and *Rhizophora mangle* L. These species

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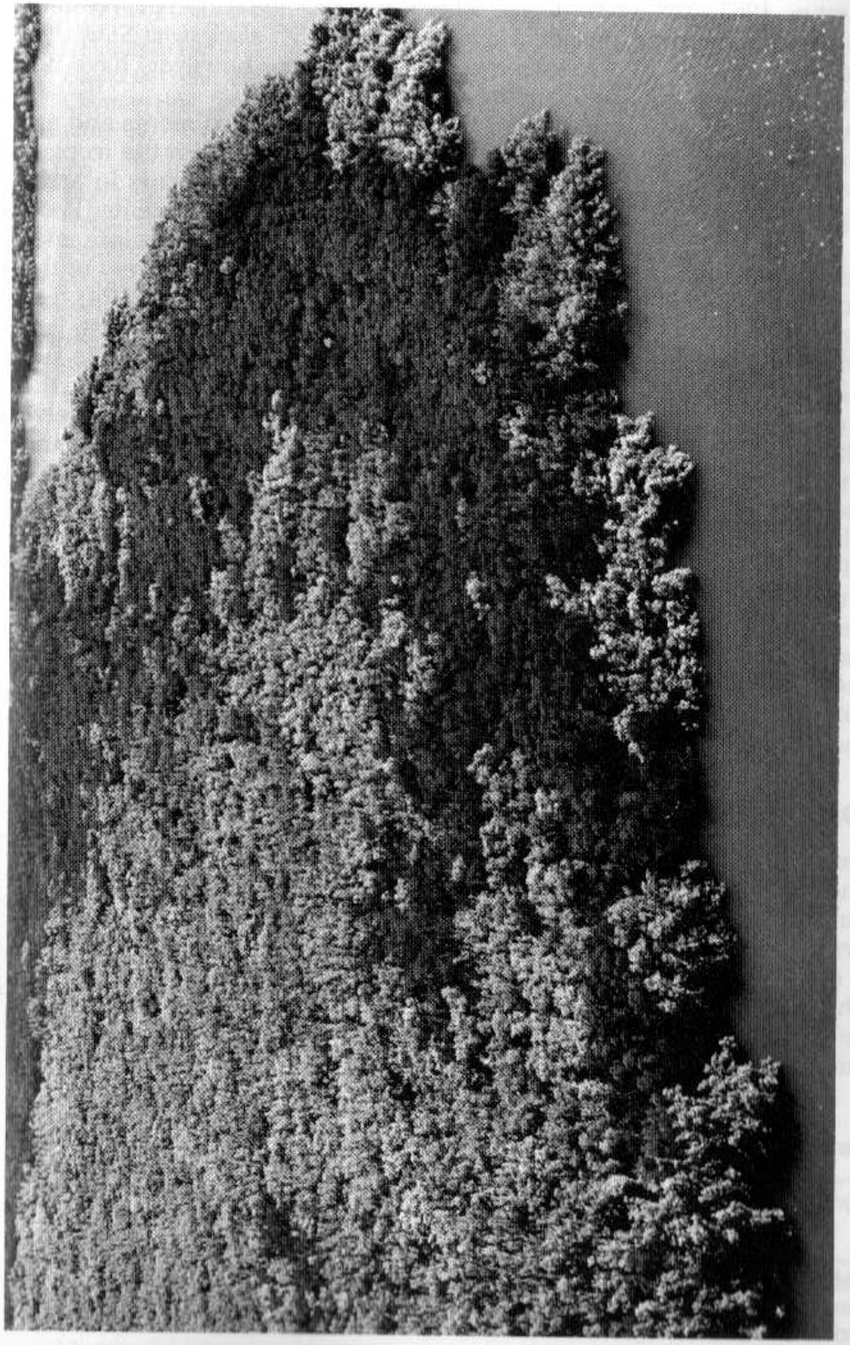

Fig. 12.1 The structural complexity and development of mangrove forests are greatest in coastal areas that receive fresh-water runoff from inland catchments. The input of nutrients in the runoff as well as the reduction in salinity result in high rates of primary productivity. See colour plates between pages 210 and 211.

are ubiquitous throughout the Gulf of Mexico and Caribbean Sea, except for *P. rhizophorae* which appears to be restricted to the coasts of Colombia (Calderon, 1983, 1984) and Costa Rica (Jimenez, 1984). Other Western Hemisphere mangrove species (*A. bicolor Standl.*, *A. shaueriana Stapf.*, *R. harrisonii* Leechman, and *R. racemosa* G.F.W. Meyer), however, have not been verifiably reported as occurring in the region.

Whereas mangroves are adapted to saline anaerobic sediments and are commonly found along protected intertidal shorelines within the tropical latitudes (Chapman, 1976), their maximum development occurs in areas of high precipitation or fresh-water runoff from inland catchments (Pool, *et al.*, 1975; see Fig. 12.1). This phenomenon is attributed to the influence of fresh water in maintaining low-salinity regimes, and the delivery of the products of bedrock and soil weathering (Lugo and Snedaker, 1974). For this general reason, some of the largest areas of mangroves forests are associated with large river drainages (e.g., the Orinoco in Venezuela and the Grijalva-Usumacinta in Mexico), high-rainfall environments (e.g., the Boca del Toros region of Panama and parts of Cuba) and areas that receive substantial sheetflow runoff (e.g., the Atlantic coast of Nicaragua and south Florida).

Elsewhere, for example, on many of the islands, mangrove-forest development is limited by aridity, hypersalinity, and the absence of significant areas of protected intertidal shorelines. In these restrictive settings, mangrove vegetation typically consists of a relatively narrow fringe of short- to moderate-sized trees dominated almost exclusively by *R. mangle* in frost-free regions. In more temperate latitudes, (e.g., around the northern coastline of the Gulf of Mexico) winter frosts and freezes allow the existence of only *A. germinans* which has the capacity to regenerate following severe freeze damage (*cf.* Lugo and Patterson-Zucca, 1977).

3 DISTRIBUTION OF MANGROVE VEGETATION

There are a paucity of data concerning the area of the region dominated by mangrove vegetation. However, based on a variety of published and unpublished reports, and personal communications with knowledgeable individuals within the region, a partial land-area inventory has been assembled (Table 12.1); note that the coverage is incomplete, and that the data are heavily caveated. The tabular total of 3,230,000 hectares represents some 15% of a conservatively estimated total world area of mangroves of 22 million hectares (Fig. 12.2).

Table 12.1 Mangrove forest area*.

Geographic region	*Mangrove forest area (hectares)*	*Notes*
Caribbean		
Bahama Islands	233,200	(1)
Andros Island	155,500	(1)
Grand Bahama Island	51,800	(1)
Inagua Island	26,000	(1)
Barbados	12	(2)
Graeme Hall Swamp, Christ Church	8	(2)
Chancery Lane Swamp, Christ Church	<1	(2)
Cayman Islands	11,655	(3)
Grand Cayman Island	10,878	(3)
Cayman Brac Island	100	(3)
Little Cayman Island	677	(3)
Cuba	626,000	(4)
North coast	131,000	(4)
North coast islands and archipelagos	114,000	(4)
South coast	318,000	(4)
South coast islands	38,000	(4)
South coast archipelagos and Isla de Piños	25,000	(4)
Dominican Republic	23,500	(5)
Rio Yuma	6500	(6)
Bahia de San Lorenzo	2100	(6)
Lake Enriquillo	1600	(6)
remaining area	13,300	(6)
Grand Terre	4320	(7)
Guadeloupe	5700	(8)
Haiti	18,000	(9)
Jamaica	20,200	(10)
Black River	7300	(10)
Negru (Negril)	2000	(10)
Martinique	2,200	(11)
Fort de France Parish	200	(11)
Lamentin Parish	500	(11)
Ducos Parish	300	(11)
Riviere Salee	400	(11)
South Martinique (small parcels)	800	(11)
Monserrat	7	(12)
St. Anthony Parish	6	(12)
St. Georges Parish	1	(12)
St. Peter Parish	<1	(12)
Netherlands Antilles	1500	(13)
Aruba	100	(13)
Bonaire	1000	(13)
Curacao	300	(13)
St. Martin	100	(13)
Puerto Rico	6497	(14)
North central coast	475	(14)
Northeast coast	2021	(14)
East coast	1285	(14)
South central coast	937	(14)
Southwest coast	988	(14)
West coast	207	(14)
Northwest coast	48	(14)
Metropolitan San Juan	274	(14)
Culebra Island	26	(14)

Vieques Island	227	(14)
Mona Island	1	(14)
St. Kitts	20	(15)
Trinidad-Tobago	9000	(16)
Northwest	6000	(16)
Caroni Swamp	3500	(16)
Northeast	1000	(16)
Southwest	1500	(17)
Southeast	400	(16)
Tobago	100	(16)
Virgin Islands	310	(18)
Central America		
Belize	75,000	(19)
Costa Rica	35,000	(20)
Caribbean coast	400	(12)
Guatemala	16,000	(22)
Caribbean coast	8500	(23)
Honduras	145,000	(24)
Pacific coast, Bahia de Fonseca	28,000	(25)
El Salvador border to Rio Nacaome	7500	(25)
Rio Nacaome to San Lorenzo outlet	8000	(25)
Rio San Lorenzo to Rio Choluteca	6000	(25)
Rio Choluteca to Nicaragua border	6500	(25)
Caribbean coast	117,000	(26)
Nicaragua	60,000	(27)
Caribbean coast	25,000	(28)
Panama	297,532	(29)
Caribbean coast		
Bocas del Toro Province	64,010	(30)
Pacific coast		
Cocle	25,125	(30)
Chiriqui	66,645	(30)
Darien	28,225	(30)
Herrera	8450	(30)
Los Santos	8800	(30)
Panama	122,925	(30)
North America		
United States	280,594	(31)
Alabama	25	(32)
California	150	(33)
Florida	274,857	(34)
East coast	47,370	(35)
Biscayne Bay	7877	(36)
West coast	15,917	(37)
Florida Bay	14,938	(37)
Whitewater Bay	30,760	(37)
Charlotte Harbor	9504	(37)
Tampa/Hillsborough Bay	7091	(38)
Louisiana	2956	(39)
Mississippi	250	(40)
Texas	2506	(41)
Aransas County	12	(41)
Calhoun County	1500	(41)
Cameron County	400	(41)
Kenedy County	8	(41)
Kleberg County	8	(41)
Nueces County	570	(41)
Willacy County	8	(41)
Mexico	1,420,200	(42)
Caribbean coast	700,000	(43)
Laguna de Mecoacan (Tabasco)	4000	(44)
Laguna de Terminos (Campeche)	250,000	(45)
South America		
Colombia	501,300	(46)
Caribbean coast	50,000	(46)
	73,975	(47)
Islas del Rosario	297	(48)
Canal del Dique Delta	12,000	(49)
Bahia de Cartagena	30	(50)
Cienaga Grande - Magdalena Delta	46,000	(51)
French Guiana	55,000	(52)
Guyana	80,000	(53)
County of Berbice	30,000	(53)
County of Demerara	10,000	(53)
County of Essequibo	40,000	(53)
Venezuela	673,569	(54)
Western region	15,468	(54)
Central-western region	15,616	(54)
Central region	6608	(54)
Central-eastern region	138,377	(54)
Orinoco Delta	495,200	(54)
Margarita island	2300	(54)
Surinam	115,000	(55)

*See Appendix, pp 295–299, for notes and references.

4 MAJOR REGIONAL PROBLEMS

To a large extent, the types of problems affecting the mangrove resources are not unique from a global perspective. However, because both island land areas and mangrove habitats are limited, present and potential impacts tend to be accentuated. Two major groupings of problems affecting mangroves are identified and discussed below in sections 4.1 and 4.2.

4.1 Economic Exploitation and Direct Conversion to Other Uses

4.1.1 Non-sustainable logging

In part due to the rising global concern over the continuing loss of tropical rain forests (*cf.* Repetto, 1990), high-volume mangrove forests are increasingly being viewed as alternate wood sources, particularly for wood chips used in the pulp and paper industry, and as a source of cellulose. Up

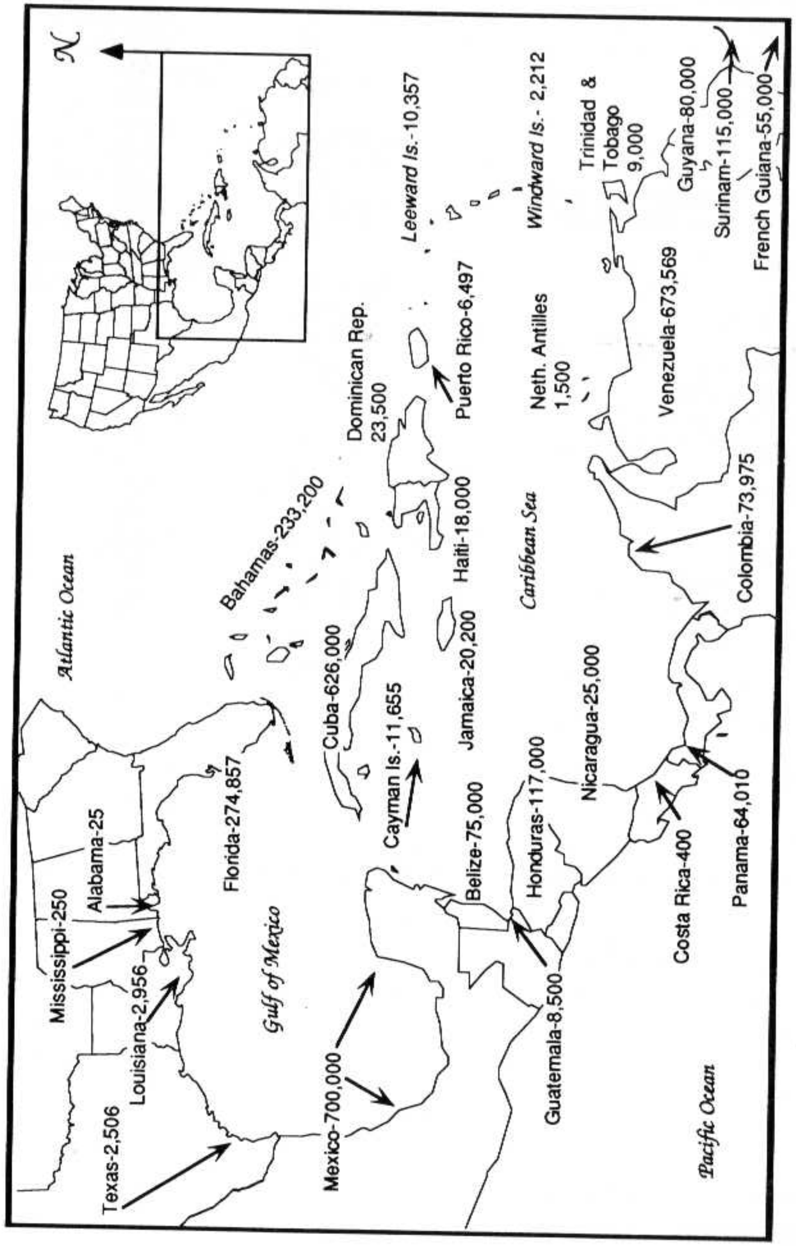

Fig. 12.2 Estimates of mangrove forest area (hectares). For the Leeward Island group, estimates are available for Guadeloupe (5700), Grand Terre (4320), Virgin Islands (310), St. Kitts (20) and Montserrat (7). For the Windward Islands, estimates are available for Martinique (2200) and Barbados (12). For Mexico, and the Central and South American countries with mangrove forest on both oceanic coasts, estimates are reported for the Caribbean coast only. Refer to text and Table 12.1 for details on origin or derivation of estimates.

to now there has been no major clear-felling of mangrove forests except in two areas: (1) In Venezuela, supposedly selective extraction of tall *R. mangle* occurs in the Orinoco Delta for use as utility poles elsewhere in Venezuela (Hamilton and Snedaker, 1984). It is reported that the decision to exploit this resource reportedly was based on the quick economic gain from what had been considered a worthless forest (Saenger *et al.*, 1983). (2) In Colombia, a large *R. mangle* forest in the Canal del Dique Delta was clear-felled by a pulp and paper company. Later, after the concession was completed, the original mangrove species did not recolonize due to the invasion of *Acrostichum* (a salt-tolerant fern). However, in adjacent areas, some regrowth of *L. racemosa* has been observed (Araujo and Polania, 1985).

With the exception of some possible high-volume areas in Cuba, Mexico and Nicaragua, the only other identified potential site for potential clear-felling is in the Boca del Toros province of Panama. That area has received attention because, in addition to the mangrove species, there is also a large contiguous forest dominated by cativo (*Prioria copaifera*) and orey (*Campnosperma panamensis*).

At the present, the harvesting of mangrove wood within the region is pursued mainly for small-scale domestic and industrial use for charcoal, firewood, lumber, poles and posts. Woodcutting is a widespread practice in the mangrove forests along the Caribbean Sea coast of Colombia. In some areas (e.g., Cienaga de La Caimanera) the extraction rate is lower than the natural regrowth of trees, and thus may be considered to be a sustained-yield practice. In that situation *R. mangle* poles and sawtimber are harvested and transported to local markets in Cartagena (Laverde *et al.*, 1987). However, in most other areas of Colombia (e.g., Bahia de Cartagena, Golfo de Morrosquillo, Canal del Dique, Bahia de Barbacoas), the extraction rates exceed the annual regrowth, and the forests are being rapidly depleted and degraded.

4.1.2 Mariculture

The continuing high world demand for seafood and the apparent success of the shrimp mariculture industry in Ecuador have encouraged both governments and private entrepreneurs to pursue coastal mariculture in mangrove areas. In spite of the potential for hard-currency earnings and employment opportunities, shrimp mariculture in mangrove areas is a high-risk venture, and the incidence of failure is remarkably high due mainly to inadequate investment financing. As a result, a low-risk approach is frequently taken based on exploiting low yields in very large pond areas, as opposed to intensively managing high-yield shrimp crops in small pond areas (Snedaker *et al.*, 1986). Notwithstanding the problems and frequent failures, a bilateral US lending agency, for example, is encouraging the conversion of mangrove areas in Honduras to shrimp grow-out ponds by citing the Ecuadorean 'miracle' (Enrique Lahmann, pers. comm., IUCN/CATIE, Turrialba, Costa Rica).

4.1.3 Coastal development

A common threat to mangroves in some more-populated parts of the region is the conversion of mangrove and related coastal habitats to developments serving primarily the tourist industry, but also for upscale residential sales. In addition to the direct loss of mangroves, coastal development represents a non-point source of pollution that affects water quality and other coastal habitats, such as coral reefs, which depend on superior water quality. The principal sources of pollution result from solid-waste dumps, marinas, golf courses and the improper handling and treatment of domestic waste-water treatment (Snedaker, 1990). In spite of laws protecting mangroves, coastal development continues to be a problem around the Gulf coast of the US and in the Virgin Islands and Puerto Rico as specific examples.

In the State of Quintana Roo, Mexico, coastal development proponents call foreign tourism the 'smokeless industry', and have undertaken large coastal development projects which, like the development at Puerta Aventuras, have not been economically successful. In an attempt to control questionable coastal development practices in Quintana Roo, the Fideicomiso Caleta de Xel-ha y del Caribe has mapped all coastal habitats and identified specific areas to be protected versus those that could be developed minimally or intensively (Jorge Lopez Portillo, pers. comm., Instituto de Ecologia, Mexico). Although the government has accepted the plan in principal, strong opposing political opposition and economic pressure suggest that this first attempt at a coastal management plan for Quintana Roo may not be successful (Jorge Lopez Portillo, *op. cit.*).

4.2 Pollution

In 1989, the Caribbean Islands Directorate of the US Man and Biosphere Program sponsored a workshop on land-based sources of pollution and published a consensus statement on the major point and non-point sources. Because mangroves represent the interface between land and ocean, they frequently are exposed to more kinds of pollutants from both land and water than even most fresh-water wetland habitats. In addition to the ocean disposal of sewage and stormwater runoff, which the workshop identified as the most widespread source, other significant point sources included: on-shore refineries and petrochemical plants; sugar factories and rum distilleries; breweries, soft-drink plants and canneries; abattoirs and meat canneries; tanneries; metal and electroplating plants; textile dying industries; edible-oil production plants; cooling and scale-removal activities at powerplants; and banana washing and packing activities. The same workshop concluded that the major non-point sources of marine pollution included: agriculture and forestry; construction works; urban runoff; atmospheric fall-out; groundwater seepage; oil and other chemical spills and disposal; solid-waste disposal and its leachates; subsurface disposal of sewage and other wastes; and mining operations.

4.2.1 Sewage and stormwater runoff

With few exceptions, suitable sewage collection and treatment systems are lacking throughout the region, including parts of the United States and in such popular tourist destinations as Cancun, Mexico. In Cancun, for example, sewage is collected and partially treated, but then discharged into the adjacent mangrove-bordered lagoon (S. Campos, pers. comm., Grupo Ecologista del Mayab a.c., Cancun). Together with uncontrolled stormwater runoff in the same lagoon system, it has now become one of the most polluted mangrove lagoons in the western Caribbean Sea.

Mangrove productivity can be stimulated significantly by exposure to nutrient-rich sewage and the low salinity of the wastewater. As a case in point, one of the more luxuriant stands of mangroves in semi-arid Curaçao is located in a small bay that receives partially treated domestic-waste effluent. Whereas the trees can take up and concentrate potentially toxic materials commonly found in sanitary sewage and domestic liquid wastes, heavy metals, for example, can accumulate in leaves at levels several times above those found in the water-sediment environment (Mathis, 1973; Lindberg and Harriss, 1974; Snedaker and Brown, 1981). Because leaf detritus forms a basis for many nearshore marine foodwebs, this enrichment mechanism represents a possible direct input of pollutants into seafood consumed by man.

Largely because mangroves still carry the perception of a 'wasteland', the use of mangrove habitats as sites for unregulated dumping and solid-waste landfills is a common practice throughout the region, particularly where other options are limited. This problem also occurs in south Florida where it is otherwise illegal to even horticulturally prune mangrove branches. In addition to the permanent loss of habitat, leachates from solid-waste landfill accumulations tend to be highly enriched in toxic ammonia, and may contain a variety of other toxic materials that appear in surface runoff or that enter the groundwater, ultimately affecting the local marine life (Geohegan *et al.*, 1984). Also where there are limited alternatives, or where proper waste-disposal enforcement is lacking, landfills including those in mangrove areas are frequently used for the improper disposal of toxic industrial chemicals and infectious medical wastes. As discussed above, the ability of mangroves to take up and accumulate certain types of pollutants in leaf tissues suggests that the recycling of pollutants into nearshore fisheries may be significant problem in areas of waste dumps.

According to Towle (1982), island systems tend to have lower tolerances to excessive and recurring waste discharges. However, Saenger *et al.* (1983) note that solid-waste accumulations have increased steadily in recent years around coastal urban areas, tourist resort destinations and industrial sites. In Puerto Rico, open dump sites have been sited in mangrove areas where periodic floods and winds spread over and disperse the wastes. Solid-waste dumps also have subsided into the soft underlying substrate, and have aggravated flooding in nearby areas by acting as dikes. Spontaneous combustion and subterranean fires also occur at dump sites, particularly in dry environments (Saenger *et al.*, 1983). In urban areas, mangrove dump-site fires have sparked public controversy at the Munisport toxic dump site in north Miami in early 1990.

Elsewhere, for example, solid wastes in Venezuela are dumped at the edge of the Rio Limon mangroves, north of Maracaibo, and in many other areas along the coast (Taylor, 1988). Solid-waste disposal in uncovered dumps is also recognized as the source of environmental impacts around urbanizing areas in the Dominican Republic. In spite of the Dominican's emphasis on the development of a tourism industry, no effective mechanisms exist to control waste disposal and the ensuing environmental problems (Hartshorn, 1981). In this regard, Port of Spain, Trinidad, may be a classic example. There, a solid-waste dump and sewage-holding ponds have been constructed at the edge of the mangrove area forming the Caroni National Park (Taylor, 1988) which is visited by large numbers of local and international tourists.

A principal concern over the use of low-lying coastal areas for waste dumps is that different aspects of global change can lead to a variety of problems. For example, with increased aridity the probability of spontaneous combustion increases. Conversely, with increasing sea level and/or increased precipitation, the dispersal of solids and leaching would be accelerated. Although there are environmentally suitable techniques available for the 'management' of waste dumps (e.g., subsurface impermeable liners, surface capping, venting of volatile gases, collection and treatment of leachates, etc.), their use is extremely rare.

5 Mangroves and Sea-Level Rise

The current conventional wisdom consists of at least two primary scenarios as to how coastal mangrove wetlands might respond to sea-level rise. These are based mainly on sea-level-rise-induced changing salinity gradients with no major consideration given to other climatic-change phenomena such as warming, shifts in regional precipitation patterns and alterations in the frequency or intensity of cyclonic weather disturbances (e.g., tropical storms, hurricanes, etc.). Temperature alone can be expected to have a minimal effect except for northern range extensions around the Gulf of Mexico and Atlantic coast of the US. Precipitation, however, in terms of its influence on the intertidal seawater/fresh-water balance, is likely to have much greater importance than a simple rise in the open water elevation. Accordingly, a third scenario is proposed that incorporates precipitation and catchment area fresh-water runoff.

5.1 Mangroves Responses to Relative Slow Sea-Level Rise

The most parsimonious of the two scenarios is that mangroves would retreat progressively inland along a sea-level-rise-induced changing salinity gradient, assuming the absence of any inland barrier. Evidence for salinity-induced retreat consists mainly of reports of mangroves that have recently colonized along gradients of increasing salinity. For example, Egler (1952) discussed the historical encroachment of mangroves into fresh-water wetlands and hammocks in southeast Florida following the construction of a railroad that blocked fresh-water runoff. As the affected area became increasingly saline, the glycophytic vegetation gave way to halophytes dominated by the mangrove species. The same general phenomenon has been described elsewhere in southeast Florida, and attributed to a lowering of the water table through drainage along with related actions that promoted inland salinization (*cf.* Reark, 1975). As a conceptual model, this first scenario might apply to relatively slow rates of sea-level rise affecting low-elevation coastal plains that grade into fresh-water habitats.

With accelerated sea-level rise, the second major scenario, two other co-related factors would assume increasing importance, specifically the ability of mangrove propagules to take root and become established in intertidal areas subjected to a higher mean sea level, and the rate of sedimentation relative to the rate of sea-level rise. With respect to propagules, the research of Rabinowitz (1978a,b,c) and Jimenez (1988) in the region documents the differential survivability and establishment of propagules under varying flood levels. In general, the large propagule species (e.g., *Rhizophora* spp.; Fig. 12.3) can become established in significantly deeper water than can the smaller propagule species (e.g., *Avicennia* spp. and *Laguncularia* spp.). Based simply on propagule size, three variants of the scenario can be defined: (1) the larger propagule species become increasingly dominant in habitats occupied by the smaller propagule species; (2) the smaller propagule species retreat to, and become dominant in, any newly formed saline, shallow intertidal areas; and (3) the large propagule mangrove vegetation at the shoreline eventually disappears as a result of the failure of propagule establishment and forest regeneration. This scenario, however, is highly dependent on the rate of sedimentation. A relatively high rate of sedimentation would lead to a lower apparent rate of sea-level rise, whereas reduced sedimentation would result in a higher apparent rate of rise; based on propagule size, the species responses would vary accordingly.

Based principally on basic mangrove ecology together with supporting evidence from the Holocene stratigraphic record, it would appear that these two scenarios and their variants would largely account for mangrove responses to rising sea level. However, based on the argument below, these scenarios probably only apply to non-peat-forming mangrove forest environments. In those mangrove environments characterized by the production and accumulation of subsurface peat, a much different scenario involving precipitation and surface-water runoff must be invoked. Thus, as argued in the third scenario, any speculative projections of mangrove responses to SLR must necessarily incorporate rainfall and fresh-water runoff as principal factors.

5.1.1 *Organic peat responses to changing salinity regimes*

Along the Florida east coast, many mangrove forest areas are impounded by dikes and flooded with estuarine water to prevent mosquitos ovipositing on otherwise moist sediments. As long as the flooding level is relatively low (e.g., several centimetres), metabolic gas exchange can proceed normally without deleteriously affecting the mangroves (Lahmann, 1988). In effect, this periodic flooding every year mimics an apparent rise in the mean sea level over a relatively short period of time. The major problem with this practice (Jim David, St. Lucie Mosquito Control District, pers. comm.) is that mangrove productivity and net peat accumulation are accelerated to the point that ground elevations rise above practical flooding levels, thus thwarting effective mosquito control. Also, the responsible peat-building red mangrove (*R. mangle* L.) eventually dominates to the exclusion of the other woody and herbaceous halophytes. Similar vegetation changes have been reported for impounded mangroves in Puerto Rico (Vazquez, 1983).

This well-documented phenomenon in east Florida implies that red-mangrove habitats can easily keep pace with sea-level rise and not be totally overstepped and abandoned. Superficially, at least, it also explains the existing presence of extensive areas of *Rhizophora* peat, for example, around parts of the shoreline of south Florida which are exposed to abundant fresh-water runoff. However, if these observations are indeed

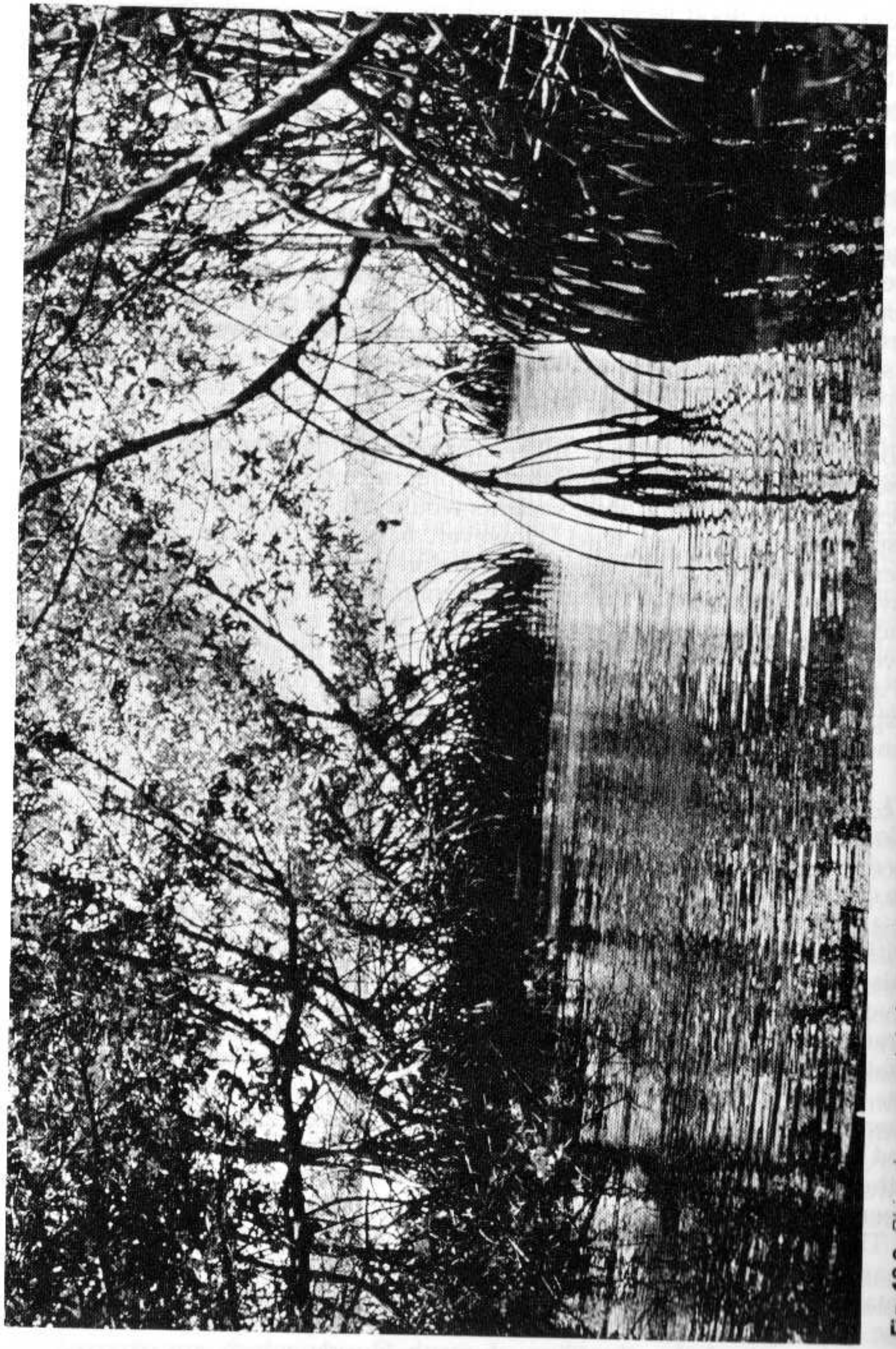

Fig. 12.3 *Rhizophora mangle* is frequently dominant along shorelines that are inundated on all high tides. In areas of moderate salinity, this species is also capable of high rates of root production which accumulates as peat. See colour plates between pages 210 and 211.

correct, then why are large strata or blocks of mangrove peat not recorded in the Holocene stratigraphic record of nearshore sediments on continental shelves? Some authors interpret the discrepancy as evidence that extensive areas of coastal mangrove forests were not present early in the Holocene, and only appeared over extensive areas as the rate of sea-level rise diminished later in the Holocene (*cf.* Ellison, 1990). To explain this discrepancy, it is necessary to examine the processes that result in the balance between mangrove peat production/accumulation and peat decomposition/remineralization, and therefore changes in total peat mass.

5.1.2 *Peat production and accumulation*

Although mangroves are ecologically restricted to saline intertidal environments, mangrove productivity in general increases proportionally with the availability of fresh water principally in the form of terrigenous runoff (Pool *et al.*, 1977). The main causal factors are the reduced salinity stress on the vegetation and availability of mineral nutrients in the surficial runoff. This author has likewise observed in many parts of the Caribbean Sea and elsewhere that the production and accumulation of *Rhizophora* peat also appears to be greatest in areas that receive upland fresh-water drainage during most of the year. To a limited extent, this observation is supported by the work of Lahmann (1988) who linked the low salinity of flooded mangrove impoundments with high mangrove production and the greatest abundance of mangrove peat.

5.1.3 *Peat decomposition and loss*

Rhizophora peat results primarily from root mortality, and the preservation of the organic remains under strongly reducing, or anoxic, conditions. Although anaerobic decomposition and remineralization are continually taking place (as well as aerobic decomposition of surface organic debris), the longer-term rates of loss tend to balance the continual subsurface production of peat-forming roots. Thus, as long as the balance is maintained, the volume and mass of the peat body remain relatively constant. In terms of sea-level rise, as long as there is sufficient fresh-water runoff to maintain the optimum salinity, there should be a proportional net accumulation of peat, and accordingly the mangrove zone would not retreat, be overstepped or abandoned. Conversely, however, if fresh-water runoff ceased or diminished to the point that the mangrove habitat was continually exposed to full or close to full-strength seawater, then organic production would decline. At the same time, the increased availability of sulphate (SO_4, present in seawater at ~2.7 g/kg) to suffuse subsurface peat would necessarily lead to increased anaerobic decomposition by sulphur-reducing microorganisms, and thus a loss of peat mass. Theoretically, the sulphate in 1 litre of seawater is capable of causing the anaerobic decomposition and breakdown of approximately 1.9 g of organic matter.

In this regard, the apparent sea-level rise observed in temperate coastal marshes of the US has been attributed to the biological decomposition of sediment organic matter (Courtney Hackney, pers. comm., University of North Carolina, Wilmington). Although the causal factor (a fungal process) is not necessarily related to the seawater/fresh-water balance, and therefore the presence of SO_4, the rapid rate of subsidence illustrates just how quickly intertidal habitats can be degraded and lost by the loss of sediment organic matter. In addition to the habitat loss, the induced anaerobic conversion of large areas of coastal organic substrates would contribute to the total atmospheric loading of greenhouse gases, notably carbon dioxide (CO_2) and methane (CH_4). (Note, however, that methanogenesis is inhibited in the presence of sulphides such as H_2S which is produced during the sulphate-reduction process.) Although there are no reports, either published or anecdotal, of mangroves being lost to this type of subsidence, the specific spatial pattern of 'browning' and mortality of mangrove areas in southern Florida (Snedaker, unpublished observations) is similar to that described in the temperate marshes.

5.2 Research Initiatives

Because solid-waste dumps are so prevalent throughout the region, and because most are sited within or contiguous with intertidal mangrove habitats, multidisciplinary research should be initiated to determine their contribution to nearshore pollution, both directly and via recycling through mangrove detritus. Furthermore, because the physical characteristics of the underlying substrate have a substantial influence on the quantity and quality of leachates, the research should be undertaken on a comparative basis. For example, one site might be identified in a carbonate/karst environment such as in south Florida, the Bahamas or the Yucatan Peninsula, with a comparative site located in alluvial coastal plains as are found on mountainous islands such as Puerto Rico. The actual selection of study sites would necessarily depend on the local availability of qualified and interested scientists. Local access to qualified analytical laboratories, however, is not required because with proper sample handling and preservation, samples can be air-shipped and analysed at distant locations.

The research protocol should be based on a surrounding network of cased and screened monitoring wells (6-inch [15 cm] bentonite-sealed boreholes) that are suitable for measuring the rate and direction of groundwater flow, and the collection of liquid and gaseous samples for laboratory analyses. Local commercial well drillers can be employed to prepare the boreholes; the well monitoring and sampling equipment are stock items availability from a number of research equipment suppliers. The subsequent analyses should minimally include the heavy metals, organophosphates, chlorinated hydrocarbons and polycyclic aromatic hydrocarbons.

5.2.1 *Sea-level rise*

Based on the question relating to the spatial stability and survival of mangroves in response to sea-level rise, a combined laboratory-field research project is proposed. The laboratory protocol should have the objective of determining the rate of anaerobic/anoxic decomposition and breakdown of organic peat exposed to fresh water and seawater with varying concentrations of SO_4. The field protocol should have a dual objective. The first would be to determine whether or not the browning and mortality of non-shoreline mangroves is associated with topographic subsidence as a result of the loss of sediment organic mass by sulphate reducers or some other related process (*cf.* Padgett, *et al.*, 1986; Hackney, 1987). The second part would be to construct a field experiment in which a series of impounded mangrove forests were subjected to surficial flooding of waters of varying salinities and sulphate concentrations. Alternatively, existing and operational mosquito-control impoundments could be monitored following flooding to test the hypothesis that whereas salinity would remain relatively stable, there would be a rapid drawdown of SO_4 and a corresponding increase in H_2S.

6 CONCLUSIONS

The dominant vegetation of the intertidal zones consists of six species of salt-tolerant mangroves that collectively occupy some 3,230,000 ha. The largest and most productive expanses occur in regions of high rainfall and fresh-water runoff as compared to arid and semi-arid regions where mangroves are largely absent. Although mangroves have a number of documented ecological roles (e.g., coastal protection, fisheries maintenance, water quality, etc.) and a variety of potential economic uses (e.g., timber, fuel, charcoal, etc.), these values are poorly recognized throughout most of the region. As a result, coastal mangrove habitats are: clearcut for their quick-cash timber value, converted for coastal development and shrimp mariculture ponds, used as *ad hoc* sites for solid and liquid waste disposal, and subjected to uncontrolled exploitation for fuel wood and charcoal. Of these, the most insidious abuse is the disposal of polluting wastes, most of which do not significantly harm mangrove trees but which render the water habitat unsuitable for most forms of marine life. As population pressures increase, and land area and natural resources become more limiting, the present trend of mangrove abuse and degradation is certain to accelerate.

With respect to global change, mangrove forests are more likely to be affected by regional changes in precipitation patterns than by the more conventionally perceived consequences of temperature increase and sea-level rise. Because mangroves require substantial quantities of fresh water (via rainfall and surface runoff) to attain their maximum growth potential, a decrease in precipitation would necessarily reduce their productive potential as well as lead to increased exposure to full-strength seawater. In this event, peat substrates would subside as the result of anaerobic decomposition by sulphate-reducing microorganisms, and mangroves would eventually be eliminated at the affected sites.

To curb the current abuse and degradation of mangroves, and to plan for coastal protection in the event of accelerated sea-level rise, three explicit recommendations are made: (1) The appropriate authorities should prohibit intertidal mangrove areas from being utilized as convenient places for the disposal of wastes, particularly waste materials containing potentially toxic or harmful pollutants. (2) Under the leadership of international organizations, such as the Inter-American Development Bank, the Organization of American States, and bilateral donor agencies, research and development efforts should be organized to identify ecologically sustainable economic uses and protocols for mangroves and associated plant and animal life. (3) Because of the importance of fresh water in sustaining high rates of mangrove primary productivity and in the production and accumulation of organic peat, water management authorities should block surface-water drainage canals and divert surplus fresh water discharges into mangrove areas based on a delivery schedule that promotes mangrove productivity.

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9 APPENDIX

Table 12.1 – notes and references

The following notes for Table 12.1 include the sources of the mangrove area data, and the units in which the data were reported originally. For comparative and summary purposes, all area data were converted to hectares (ha). In cases where there are several estimates for the same geographic area, the lowest estimate is reported in the absence of justification for a larger estimate. For this reason, the sum of the individual entries for a country may not equal the total area derived from an independent source(s). Revised data records for South America supercede earlier estimates in Snedaker (1986).

Caribbean

Bahamas

1) Data (in square miles) provided by Roderick Attrill (Bahamas National Trust, Nassau). Although estimates for the larger mangrove areas are reported, the total for the Bahama Island group (including Turks and

Caicos Islands) may be underestimated by as much as 50%.

Barbados

2) Data (in acres) provided by Deborah Riven-Ramsey (University of the West Indies, Bridgetown).

Cayman Islands

3) Data (in hectares) provided by the late Marco E. C. Giglioli (Mosquito Research and Control Unit, Grand Cayman). The estimates for Cayman Brac and Little Cayman are approximations.

Cuba

4) Estimates of mangrove area were extracted using an electronic planimeter by Melvin S. Brown (Law Environmental, Inc., Kennesaw, Georgia) from a private copy of the *'Atlas Nacional de Cuba'*, dated 1970. Areas include salinas which may have led to overestimates for the various areas. FAO/PNUMA (1981) estimated the mangrove coverage to be 400,000 ha, based on a 1961 survey; however, that 1961 estimate includes only the larger tracts of mangroves.

Dominican Republic

5) Data (in hectares) provided by Gilberto Cintron (Department of Natural Resources, San Juan, Puerto Rico), and are based on the manual planimetry of a 1:250,000 map (unidentified).

6) Data (in hectares) obtained from FAO/UNDP (1973) and Gilberto Cintron (pers. comm.).

Grand Terre

7) Data (in hectares) obtained from Stehle (1945) reported in Chapman (1976).

Guadeloupe

8) Data (in hectares) provided by Jean Luc Toffart (Ecole Practique des Hautes Etudes, Paris, France). Renard (1975) estimated the mangrove forest area to be 9000 ha. The lower estimate is believed to be reasonable.

Haiti

9) Estimate of area (in hectares) obtained from FAO/PNUMA (1981).

Jamaica

10) Data (in acres) provided by Barry Wade (General Manager, Petroleum Corporation of Jamaica), and are based on a range of 50,000 to 75,000 acres for all wetlands (mangrove and marsh); values are therefore questionable. FAO/PNUMA (1981) reported a mangrove forest area for Jamaica of 7000 ha, but the basis of the estimate, or its accuracy, is not known.

Martinique

11) Data (in hectares) provided by Joseph Poupon (Office National des Forets, Fort de France).

Montserrat

12) Data (in acres) provided by Jay Blankenship (Department of Agriculture, Plymouth).

Netherlands Antilles

13) Data (in hectares) provided by Ingvar Kristensen (Caribbean Marine Biological Institute, Curacao). There are no mangroves on Saba and St. Eustatius.

Puerto Rico

Data (in hectares) obtained from Carrera and Lugo (1978).

St. Kitts

15) Data (in acres) provided by A. I. George (Ministry of Agriculture, Basseterre).

Trinidad-Tobago

16) Data (in hectares) provided by Ronald Bickram (Ministry of Agriculture, Lands and Food Production, St. James). Other estimates range from a low of 5000 ha to a high of 11,000 ha (Eugene Ramcharan and Clement Lewsey, Institute of Marine Affairs, Port of Spain, and Sheriff Faizool, Forestry Division, Port of Spain). FAO/PNUMA (1981) estimated the area of mangroves to be 4000 ha. Beard (1946) stated there were 12,670 acres (5130 ha) of mangroves on Crown Lands and in forest reserves in 1938.

17) Data (in hectares) obtained from the Management and Development Plan for the Caroni Swamp National Park and were provided by Eugene Ramcharan (Institute of Marine Affairs, Port of Spain).

Virgin Islands

18) Data (in square kilometres) obtained from the Island Resources Foundation, St. Thomas.

Central America

Belize

19) Data (in acres) provided by Janet Gibson (Fisheries Unit Laboratory, Belize City) and are in agreement with the estimates of FAO/PNUMA (1981). Other estimates range from a low of 100,000 ha (Klaus Ruetzler, Smithsonian Institution, Washington) to a high of 591,360 acres (Oscar Rosado, Ministry of Natural Resources, Belmopan).

Costa Rica

20) Estimate provided by Luis Fernando Gonzales Lopez (Direccion General Forestal, San Jose). Other estimates included a value of 45,000 ha (Ludwig Naegle, Morovia) and a value of 50,000 ha extracted from a letter to V. J. Chapman (dated 15 January 1975) from Ing. Oscar Pacheco Jimenez, Jefe, Departamento Secretaria Technica, Ministerio de Agricultura Y Ganaderia, San Jose. FAO/PNUMA (1981) gives an estimate of 39,000 ha.

21) Estimate provided by Enrique J. Lahmann (IUCN/CATIE, Turrialba).

Guatemala

22) Estimate (in hectares) provided by Enrique J. Lahmann (IUCN/CATIE, Turrialba). FAO/PNUMA (1981) gives an estimate of 50,000 ha, but is considered to be too high.

23) Estimate provided by Enrique J. Lahmann (IUCN/CATIE, Turrialba).

Honduras

24) Data (in hectares) obtained from FAO/PNUMA (1981).

25) Data (in hectares) cited from Prats-Llaurado (1958) by Gilberto Cintron (pers. comm.).

26) Estimate provided by Enrique J. Lahmann (IUCN/CATIE, Turrialba).

Nicaragua

27) Data (in hectares) obtained from FAO/PNUMA (1981).

28) Estimate provided by Enrique J. Lahmann (IUCN/CATIE, Turrialba).

Panama

29) Data (in hectares) obtained from the Ministerio de Desarrollo

Agropecuario, Direccion Nacional de Recursos Naturales Renovables (RENARE). FAO/PNUMA (1981) estimates the total area at 486,000 ha whereas PNUD/FAO (1972) gives a total mangrove area for Panama of 409,210 ha. One possible reason for the wide variation in estimates may depend on whether or not contiguous lowland forests, such as dominated by cativo (*Prioria copaifera*) and orey (*Campnosperma panamensis*) are included in the estimates. The range of estimates for Panama are: 33,700 ha (Anonymous, 1978), 104,000 ha (Donaldson, 1963), 199,000 ha (FAO, 1978a), 297,532 ha (RENARE, see below), 505,600 ha (FAO, 1978b)

30) The estimate for the Caribbean coast is based on the provincial distribution (in hectares) obtained from personnel (Thomas A. Vasquez U. and Cristina Garibaldi de Jaen) in the Ministerio de Desarrollo Agropecuario, Direccion Nacional de Recursos Naturales Renovables. They are probably representative of the relative distribution among the provinces.

Panama	*hectares*	*acres*
Caribbean coast		
Bocas del Toro	*64,010*	*15,800*
Pacific coast		
Cocle	*25,125*	*62,060*
Chiriqui	*66,645*	*164,610*
Darien	*28,225*	*69,715*
Herrara	*8450*	*20,870*
Los Santos	*8800*	*21,735*
Panama	*122,925*	*303,625*
Total	*297,532*	*734,900*

North America

United States

31) Summary total for the United States (Atlantic coast and Gulf of Mexico) obtained by summing state totals (in hectares).

32) Estimate (in hectares) made by the author.

33) Estimate is based on earlier information provided by V. J. Chapman (pers. comm.).

34) Data (in acres) obtained from Browder, Littlejohn and Young (1976), and were modified based on personal knowledge and a variety of unpublished and anecdotal information. Other estimates include 479,180 acres (Eric Heald, Heald and Associates, Miami), 500,000 acres (Lewis *et al*. 1986), and 503,700 acres (Joseph D. Carroll, US Fish and Wildlife Service, Vero Beach).

35) Data (in acres) obtained from Spinner (1969).

36) Data (in acres) obtained from Teas (1974). Metropolitan Dade County (1979), citing other sources, states that in 1972 there were 10,500 acres in the Biscayne Bay area north of Turkey Point.

37) Data (in acres) obtained from McNulty, Lindall and Anthony (1970) and McNulty, Lindall and Sykes (1972).

38) Roy R. Lewis (pers. comm.) provided a lower estimate (5630 ha) which is presumed to apply only to Tampa Bay, rather than both bays.

39) Data (in acres) from Chabreck (1972) and Wicker *et al*. (1980).

40) Estimate (in hectares) made by the author.

41) Data (in acres) provided by C. Lee Sherrod (University of Texas, Austin). Estimates were given as suggested ranges, and only the lowest value is used.

Mexico

42) Data (in square kilometres) provided by Jorge Lopez Portillo (Institute of Ecology, Mexico, DF) and Gilberto Cintron (pers. comm.). One other estimate (1,570,000 ha) was provided by Alejandro Yanez-Arancibia (Universidad Nacional Autonoma de Mexico, Mexico DF).

43) There is no reliable information concerning the portion of the total area along the eastern coastline of Mexico. For estimation purposes, one-half of total inventory is assigned to the Caribbean coast.

44) Data (in square kilometres) provided by Jorge Lopez Portillo.

45) Data (in square kilometres) provided by John W. Day, Jr (Louisiana State University, Baton Rouge).

South America

Colombia

46) Data (in hectares) provided by Jorge Hernan Torres Romero (Universidad Nacional, Bogota), and are in general agreement with the majority of other estimates for Colombia, including a report by Omar-Guauque V. (ed.) and the *Mapa General de Bosques* (1967). These sources give an estimate of 50,000 ha for the Caribbean coast. FAO/PNUMA (1981) reported a lower value of 450,000 ha of which 287,000 are located on the Pacific coast and 163,000 ha on the Caribbean coast.

47) Data (in hectares) obtained from INDERENA/IGAC/CIAF (1984).

48) Data (in hectares) obtained from INDERENA/IGAC/CIAF (1984).

49) Data (in hectares) obtained from de las Salas and Hildebrand (1980).

50) Data (in hectares) obtained from FAO/IVL (1978).

51) Data (in hectares) obtained from Botero (1988).

French Guiana

52) Data (in hectares) obtained from FAO/PNUMA (1981).

Guyana

53) Data (in hectares) provided by (C.A. Persaud, Guyana Forestry Commission, Georgetown, and Reuben Charles, Fisheries Division, Ministry of Agriculture, Georgetown). FAO/PNUMA (1981) has given an estimate of 150,000 ha, but the more conservative estimate is used in this report.

Venezuela

54) Data (in hectares) provided by Federico Pannier (Universidad Central, Caracas). FAO/PNUMA (1981) gives a total area for Venezuela of 260,000 ha, but it is believed to reflect only the larger areas of potentially commercial forest.

Surinam

55) Data (in hectares) obtained from FAO/PNUMA (1981).