



The mangroves of Belize Part 1. distribution, composition and classification

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Abstract

Between the late 1980s and early 1990s, significant sections of the Belizean coast came under escalating pressure from development. The resulting habitat loss highlighted the need for a comprehensive assessment of the extent, characteristics and use of the country's remaining mangrove.

This paper reports on the resulting study, and confirms the presence of three true mangroves—*Rhizophora mangle*, *Avicennia germinans* and *Laguncularia racemosa*, plus one mangrove associate—*Conocarpus erectus*. Twenty different sub-communities are distinguished on the basis of physiographic setting, vegetation structure and species composition. Of these, *Rhizophora* scrub is the most widespread, accounting for over 60% of the country's mangrove habitats. True forest sub-communities account for only 10%, the remainder comprises thickets or hypersaline supra-tidal savannas.

GIS analysis of 1990 remote sensing data reveals that Belize's mangroves covers 78,511 ha, equivalent to 3.4% of the country's land area and approximately 2% of the mangrove remaining in the Americas. Through the examination of early aerial photos, historical records and ground conditions, it is estimated that about 98% of Belize's original mangrove cover (80,016 ha) remained at this time. However, more recent mapping for the Belize City area, using 1992 aerial photos, reveals that a further 519 ha has been cleared, a 0.7% reduction in the national total in just two years.

The main geographical factors controlling the distribution of mangroves in Belize are the presence of the barrier reef, the coastline's shallow gradient and the narrow tidal range. Mangrove distribution is further influenced by local subsidence, geomorphology, drainage, hinterland soils and past hurricane tracks. How much mangrove cover Belize may support in the future is thought to largely depend on two factors—hurricane activity and human influence.

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1. Introduction

Belize (formerly British Honduras) forms part of the Yucatan peninsula on the Atlantic coast of Central America. One of the smallest countries in the region, it is locally unusual because much of its 386 km

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coastline retains a fringe of mangrove. This is due at least in part, to the present low population (ca. 250,000 people).

Previous examinations of Belize's mangroves at a national level have been confined to brief accounts in forestry and agricultural assessments of the country's resources (Hooper, 1886; Hummel, 1925; Oliphant, 1928; OFI, 1989; Wright et al., 1959; Jenkin et al., 1976; King et al., 1986, 1989, 1992). Early botanical inventories (e.g. Standley and Record, 1936) added further detail but comprehensive national information on Belize's mangrove remained absent. Despite an increasing number of ad hoc site-specific mangrove studies (e.g. Heymann et al., 1995; Ellison and Farnsworth, 1993; Feller, 1996; Jenkin et al., 1976; Johnson and Chaffey, 1974; Meerman and Boomsma, 1993; Murray, 1995; Murray et al., 1999; West, 1977; Woodroffe, 1995) Belize still lacked comprehensive information about its mangrove resource. This hindered embryonic attempts to introduce coastal zone management (ODI 1989). Therefore, following preliminary assessments (Furley and Ratter, 1992; Furley and Munro, 1993) this study was undertaken as part of the *Tropical Forestry Action Plan* for Belize.

Its aims were to:

1. Map and quantify the extent of mangroves in Belize, using remote sensing, field observations and GIS;
2. Derive a robust classification of mangrove sub-communities, based on the observed floristic composition and physiographic setting;
3. Explain the present pattern of mangrove distribution in Belize.

2. Materials and methods

2.1. Study site

This study examines the mangroves of Belize, Central America (shown in Fig. 1). Occupying part of the Atlantic coastline of the Yucatan Peninsula, Belize has a total land area of 22,700 km². The mainland is generally very low-lying, with over half the land under 200 m above sea level. The most significant areas of relief are the Maya Mountains and Mountain Pine Ridge, created by igneous intrusion and uplift.

The remainder of the country is composed of carbonates and alluvium, fringed by extensive coastal plains, a mix of Quaternary age carbonates and clays. Off the coast lies the barrier reef, three atolls and 1065 islands. Locally known as cays, these islands cover 689 km² (3% of the country's land area). Like other Caribbean countries, Belize experiences a very small tidal range—the mean recorded tidal variation is only 0.3 m (Kjerfve et al., 1982).

Climatically, the country lies in the transition from subtropical to tropical conditions. Northern Belize experiences a tropical monsoon climate (Köppen's Am class), whilst the south of Belize is exposed to tropical rainforest conditions (Af). The only exception to this latitudinal gradient is the Maya Mountains, which are classified as humid subtropical (Cf). The country has a seasonal climate: the dry season runs from December to April, the wet season from May to November, with a mini-dry in late July and August. Rainfall shows a marked north-south distribution, much drier and irregular in the north, wetter in the south. Temperature varies markedly with altitude. Along the coast maximum mean monthly temperature peaks in July at 31 °C, dropping to a minimum of 19 °C in January (Belize Meteorological Service). Temperatures are lower inland, but rarely drop <10 °C even at night. Humidity levels can be very high along the coast. Belize lies in the Atlantic hurricane belt, most recently having been hit by Hurricane Iris (2001) and Hurricane Keith (2000).

Mangroves can be found in a variety of settings in Belize—as a coastal fringe, along some rivers, by inland lagoons and on most of the cays. Seven rivers have significant mangrove areas along their banks (Rio Hondo, the New River, Belize River, Sittee River, Mango Creek, Manatee and Bar Rivers). Most important is the Belize River, which forms the only major delta in the country. Prior to clearance, it was the location of the majority of Belize's mangrove forest.

2.2. Mapping mangrove distribution in Belize

Given the range of mangrove habitats and the small-scale of many clearances in Belize, a multi-platform approach was adopted for mapping. For this study, Landsat TM (thematic mapper) imagery provided the data for extensive mangrove areas or isolated patches not undergoing any alteration. Techniques

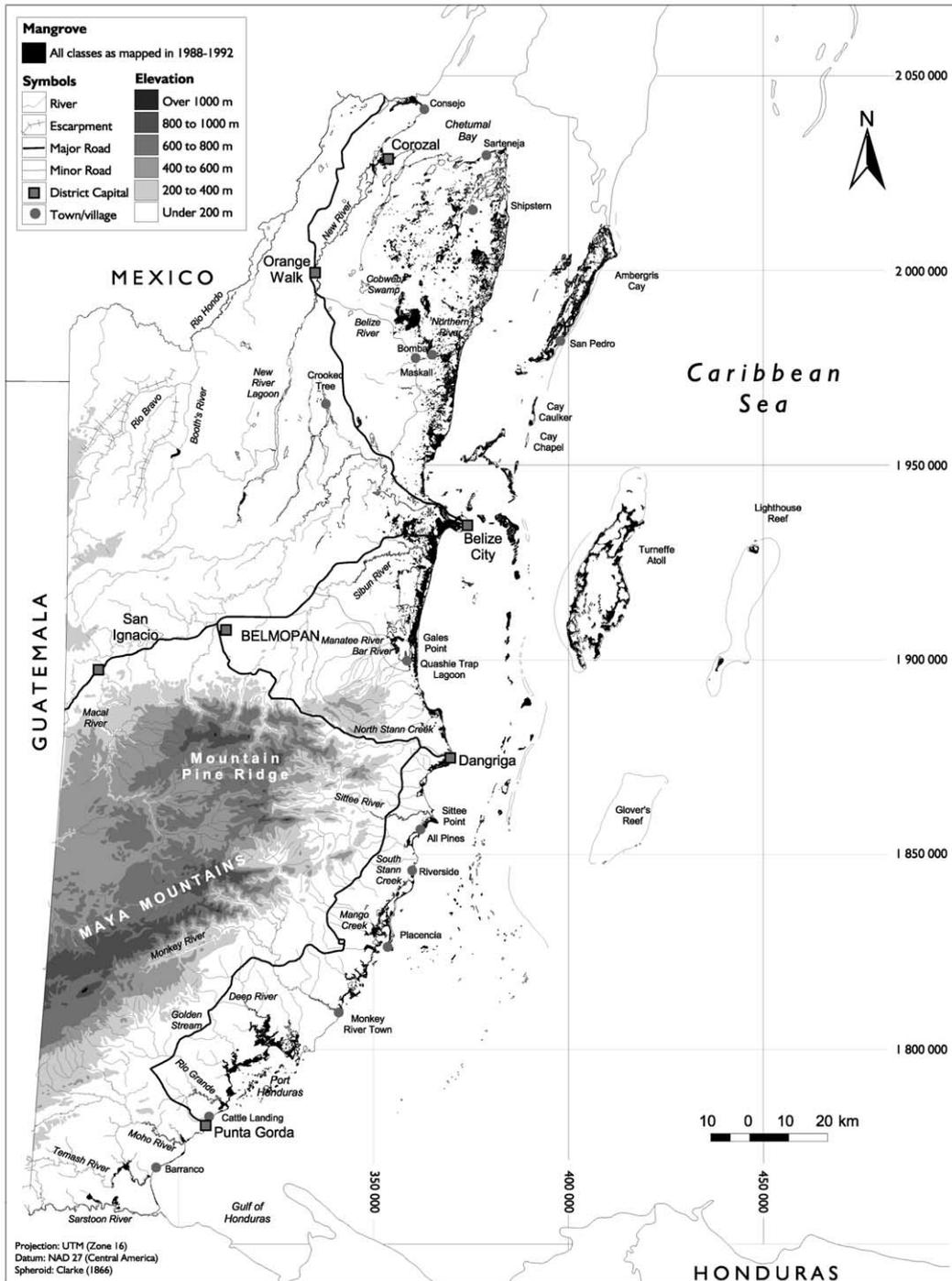


Fig. 1. Distribution of mangroves in Belize.

for mangrove mapping using Landsat TM are well established (FAO, 1994). Automated unsupervised processing was applied to Bands 3, 4, and 5 of the image (WRS Path 19 Rows 47 and 48, acquisition date 4 January 1987) using the ERDAS Image Processing System (Version 7.4). Two band ratios were used to maximise the contrast between mangrove and non-mangrove vegetation and to highlight differences within mangroves (see Zisman, 1998 for further details). The unsupervised classification used the Iterative Self-organising Data Analysis Technique. Output classes were assigned to mangrove and non-mangrove types based on knowledge of mangrove distribution gained from fieldwork. Non-mangroves were then dropped from the data set and a second classification was run on the remaining data. The resulting classes were then assigned to either tall (approximately >7 m tall), medium (approximately 3–8 m tall), dwarf (<3 m tall) or mangrove savanna categories. The division into four classes was considered most appropriate given the detectability of structural variation in mangroves and the requirements of agencies involved in mangrove management. The resulting raster map was transferred onto Arc/Info GIS, with each polygon assigned to one of the four mangrove classes. Finally, the resulting map was geo-corrected using over 100 control points (from the 1:50,000 National Map Series).

For smaller patches (notably, on the cays) and mangroves subjected to exploitation, 1:44,000 scale black and white aerial photographs were the most appropriate data source. The most up-to-date and comprehensive coverage available was flown in March 1990, the only exception being Ambergris Cay, where the most recent photos available dated from 1988.

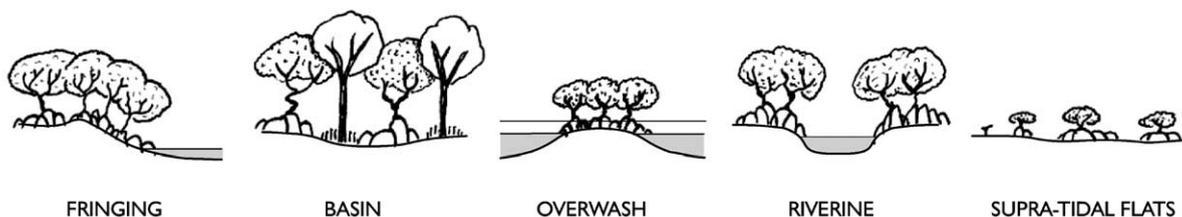
Despite the air photography's different dates, the consistency of the final mangrove map is not compromised because no major clearance took place on Ambergris Cay between 1988 and 1990. Finally, as 1:8000 March 1992 colour aerial photo enlargements were available for the important area in and around Belize City, these were also used.

This finer scale mapping was carried out by manual aerial photo interpretation using a mirror stereoscope. The distribution of natural and altered mangroves was transferred onto acetate and then onto the 1:50,000 National Map Series. Polygons were digitised and then incorporated with the Landsat-derived raster data already on the GIS. As air photo interpretation allowed more detailed land cover mapping (providing information about the causes of mangrove loss) a more diverse classification for the polygons in these areas was used in tandem with the four class system used for the rest of the country.

To verify interpretation of satellite imagery and air photos, a series of overflights of coastal areas was undertaken (12 h flying at heights between 50 and 400 m) and ground truthing at 60 sample sites. Having completed the mapping process, GIS software was used to quantify the extent of the different mangrove classes.

2.3. Mangrove community classification

In order to develop an understanding of the mangrove communities present, structural and species characteristics were studied during fieldwork using a combination of ground survey methods. Where time allowed, point-centred quarter surveys were carried out (following the methods of Cottam and Curtis,



Source: After Lugo and Snedaker (1974). Their scrub category has been dropped as it is just a variant of the basin one. Similarly, the hammock category has been dropped as it is considered only to be a minor variant within basin environments.

Fig. 2. Physiographic environments in which mangroves occur in Belize.

1955; Snedaker and Snedaker, 1984). Measurements of tree species, height and diameter were made at 20 or more sampling points located randomly along a transect line. By measuring the distance from each sample point to the four nearest trees, one in each quarter, it is possible to derive measures of mean basal area, relative density, dominance and frequency. These last three can be summed to generate Curtis' Importance Value (Curtis, 1959), which reaches 300 in monospecific stands. Elsewhere, qualitative descriptions were derived for vegetation structure, species composition and zonation, accompanied by field sketches. In all, over 60 sites were examined, covering the full variety of mangrove environments occurring in Belize.

An attempt was then made to classify the full range of mangrove sub-communities encountered, using a logical and ecologically meaningful schema. This was achieved by integrating species composition with the physiographic divisions of Lugo and Snedaker (1974) (shown in Fig. 2) and structural categories from the UNESCO-adopted protocol of Mueller-Dombois and Ellenberg (1974).

3. Results

3.1. Biogeographical context of Belize's mangroves

Field surveys confirmed the presence of three true mangroves and one mangrove associate in Belize (see Table 1). This assemblage has a wide distribution in the Americas and is found in the Gulf of Mexico, the central Caribbean, the Pacific coast north of El Salvador and on the Galapagos Islands.

In terms of structure, the ground survey shows that mangroves can be found at a range of heights, from dwarf forms (less than a metre tall in some inland areas and in saline flats on inner portions of the cays) to 18 or 20 m tall trees along rivers, particularly in the wetter south. Typically, several mangrove species were found together, zoned according to flood depth, duration and salinity. *Rhizophora mangle* is the most common, particularly in basin environments along river banks and the coast. *Avicennia germinans* tend to dominate sites further inland, where the soil salinity is increased through evaporation. *Laguncularia racemosa* is the least common of the three true mangroves found in Belize and is absent from many sites. The mangrove associate, *Conocarpus erectus* is found on some inland fringes of mangrove areas, particularly in northern Belize. Quantitative data from selected sub-community types are detailed in Table 2.

3.2. Mangrove mapping

The results of the national mangrove mapping (shown combined in Fig. 1) are given in Tables 3 and 4. Fig. 3 shows the mangrove distribution split into the four classes. Fig. 4 shows in more detail the distribution of the remaining mangrove around Belize City.

Table 3 shows that whilst the majority of the mangrove occur on the mainland, over a quarter lies offshore. The inner cays and Turneffe Atoll in particular, contain significant mangrove areas. From mangrove mapping, overflights and fieldwork, it is estimated that mangroves are present in considerable amounts on between 60 and 80% of Belize's cays.

Table 1
Nomenclature of Belizean mangroves and their associates

Family	Scientific name	English name	Mayan name	Spanish name
True mangroves				
Rhizophoraceae	<i>Rhizophora mangle</i> L.	Red mangrove	Tapche	Mangle colorado
Avicenniaceae	<i>Avicennia germinans</i> L. (formerly <i>A. nitida</i> Jacq.)	Black mangrove	(none)	Mangle negro
Combretaceae	<i>Laguncularia racemosa</i> (L.) Gaertn.	White mangrove	Zacalcom	Mangle blanco
Mangrove associates				
Combretaceae	<i>Conocarpus erectus</i> L.	Buttonwood	Kanche	Botoncillo
Polypodiaceae	<i>Acrostichum aureum</i>	Swamp fern	No record	No record

Source: Standley and Record (1936), Wright et al. (1959), Woods et al. (1988) and verified in the field.

Table 2
Point-centred quarter data from selected mangrove forests in Belize

Site	TBA	AD	Species	<i>n</i>	BA	IV
Bar River 1			<i>A. germinans</i>	39	9.5 ± 8.3	155
Basin mixed mangrove forest	16.9	807	<i>L. racemosa</i>	40	7.2 ± 4.3	140
Canopy 13–16 m tall			<i>C. erectus</i>	1	0.2	5
Bar River 2			<i>A. germinans</i>	45	14.9 ± 7.2	179
Basin mixed mangrove forest	19.1	736	<i>R. mangle</i>	23	2.1 ± 1.6	77
Canopy 16–19 m tall			<i>L. racemosa</i>	12	2.1 ± 1.0	44
Bar River 3			<i>A. germinans</i>	–	–	–
Transition: basin mixed, to riverine red mangrove forest	24.3	1190	<i>R. mangle</i>	28	17.8 ± 9.3	208
Canopy 13–16 m tall			<i>L. racemosa</i>	12	6.5 ± 2.2	98
Quashie Trap Lagoon			<i>A. germinans</i>	38	13.0 ± 6.2	277
Basin mixed mangrove forest	13.3	1531	<i>R. mangle</i>	–	–	–
Canopy up to 8 m tall			<i>L. racemosa</i>	2	0.3 ± 0.9	24
Sittee River			<i>A. germinans</i>	31	22.2 ± 30.2	147
Basin mixed mangrove forest	32.1	667	<i>R. mangle</i>	37	5.8 ± 4.1	103
Canopy 16–20 m tall			<i>L. racemosa</i>	12	4.1 ± 4.0	50
Barranco			<i>A. germinans</i>	–	–	–
Transition: basin mixed, to fringing red mangrove forest	22.3	523	<i>R. mangle</i>	37	21.6 ± 8.6	272
Canopy up to 20 m tall			<i>L. racemosa</i>	3	0.7 ± 1.0	28

TBA: total basal area ($\text{m}^2 \text{ha}^{-1}$); AD: absolute density (trees ha^{-1}); BA: basal area ($\text{m}^2 \text{ha}^{-1}$). Values are expressed as the mean ± 1 S.D., except where $n = 1$; IV: importance value. Note: for trees to be measured along the transect, the qualifying diameter at breast height (dbh) was 10 cm.

Table 4 breaks down the mangroves by class. Dwarf mangrove (trees typically <3 m tall) is the most extensive, found both along the coast and at inland sites. Many of the smaller cays are almost exclusively dwarf mangrove. Medium mangroves (approximately 3–8 m tall) are most common along rivers in the north of Belize, with a large expanse on

the Belize River north west of Bomba. Medium mangrove is also relatively common on sheltered cays along the inner reef. Areas of tall mangrove (over approximately 7 m) tend to be on the mainland, inland of the coastal fringe. The largest expanse is behind the delta at the mouth of the Belize River (i.e. immediately west and south of Belize City). Other concentrations occur at headlands to the south, such as Sittee Point and along the lower reaches of the Temash River.

Two classes, mangrove savanna (areas of hypersaline grassland with scattered mangroves) and mangroves growing in open water (shallow, in-filling water bodies such as Shipstern Lagoon) are restricted to the mainland and Ambergris Cay (a large peninsula). Mangrove savanna is most common in the dry north-eastern part of the country. Mixed forest containing mangroves only occurs on the mainland, typically next to inland wetlands on the fringe of palmetto groves or gallery forest, such as east of New River Lagoon.

Table 3
Distribution of mangrove habitat in Belize (1990)

Region	Area (ha)	Percent
Mainland	57109	72.7
Cays		
Ambergris Cay	5764	7.3
Turneffe Atoll	7420	9.4
Lighthouse Reef Atoll	451	0.6
Glover's Reef Atoll	3	>0.1
Other cays (including the barrier reef)	7765	9.9
Total	78512	100

Table 4
Breakdown of distribution by mangrove type (ha)

Region	Dwarf	Medium	Tall	Savanna	Open water	Mixed forest	Total
Mainland	31402	9067	3747	12824	20	49	57109
Ambergris Cay	3575	1417	577	86	109		5764
Turneffe Atoll	3875	3355	190				7420
Lighthouse Reef Atoll	411	40					451
Glover's Reef Atoll	3						3
Other cays	3789	3540	373	63			7765
Total	43055	17419	4887	12973	129	49	78512

Note: the mangrove classes used match those of the final mangrove map and are defined in the text.

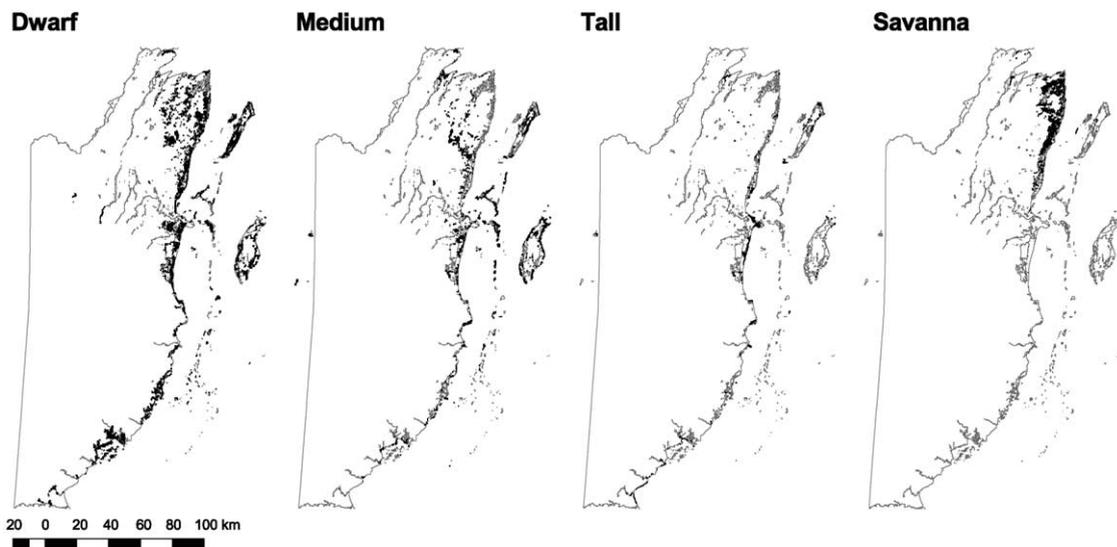


Fig. 3. Maps of the four major mangrove classes

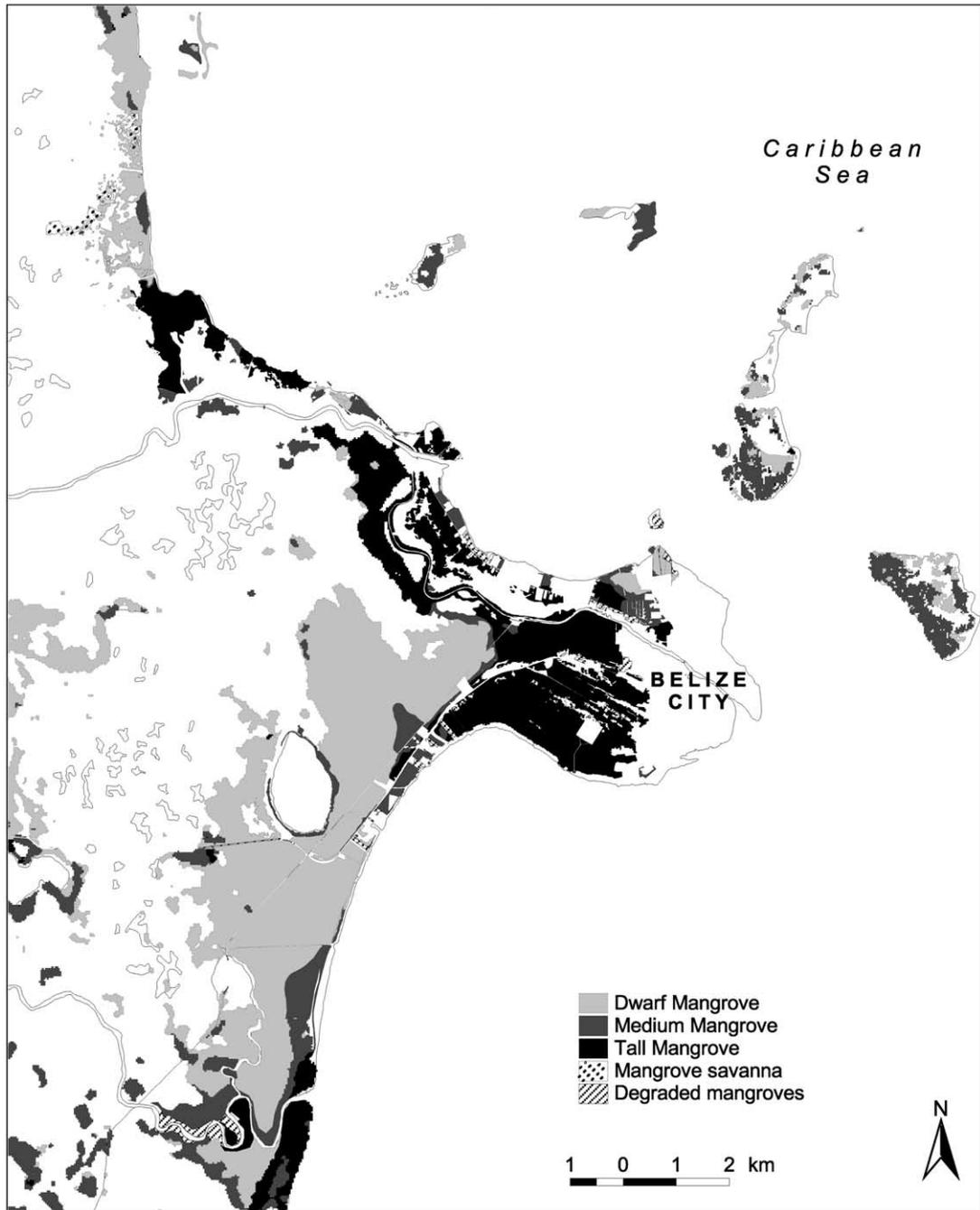
3.3. Classification of Belize's mangroves

Work to classify Belize's mangrove sub-communities resulted in the development a three level hierarchy (shown in Fig. 5). The first level separates sites by physiographic divisions. The second level is divided according to vegetation structure. The final level is based on the sub-communities' species composition encountered in the field. The division was such that each type of mangrove sub-community encountered fell within one of the 20 classes.

4. Discussion

4.1. Species present

This study confirms the findings of other work in Atlantic parts of Central America and the Caribbean, in that only three true mangrove species (*R. mangle*, *A. germinans* and *L. racemosa*) are present in Belize. This is far lower than areas such as south-east Asia, and reflects the depauperate mangrove flora of the wider Americas region—only 10 species in all from four genera, namely three *Rhizophora*, three *Avicennia*, one



This map is an extract from the complete National Mangrove Map. It shows the extent of mangroves around the ex-capital, Belize City. This is one of the most heavily cleared areas in Belize.

Fig. 4. The distribution of remaining mangroves around Belize City (1992).

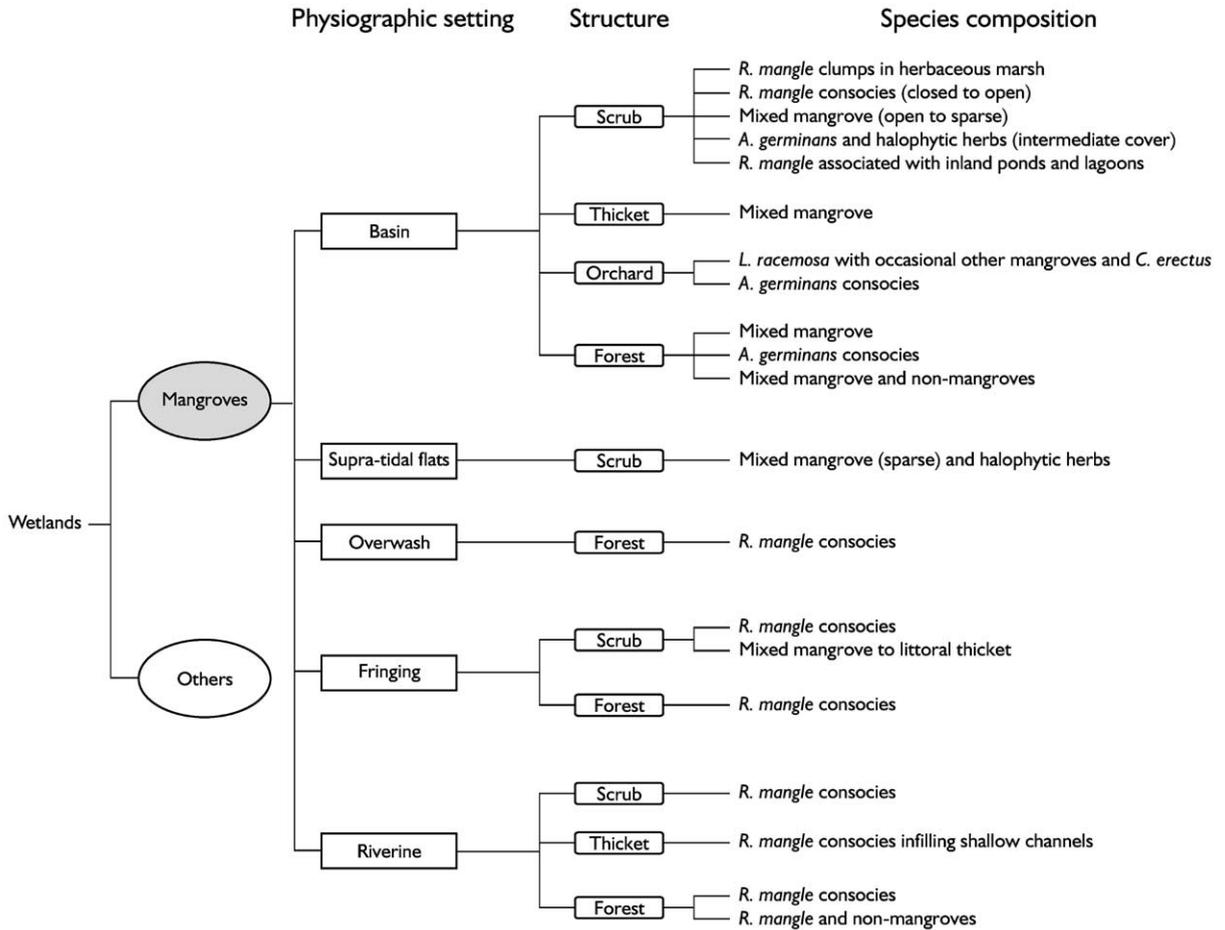


Fig. 5. Hierarchical classification of mangrove sub-communities in Belize.

Laguncularia and one *Pellicerra* (Lacerda et al., 1993; Duke, 1992).

The mangrove associate *Conocarpus erectus* is widespread in Belize. It is present in two forms, one smooth-leaved and one showing signs of pubescence. This pubescence has been the cause of some debate (see Schoener, 1987, 1988; Tomlinson, 1986; Semple, 1970), variously considered a xeromorphic adaptation or protection against herbivory. Its distribution in Belize implies that the first factor is responsible, because it is only present in the drier part of the country, north of Crooked Tree (mean annual rainfall 1750–2000 mm). Without further research, however, this relationship is not conclusive, and other factors may be involved.

4.2. Mangrove extent and distribution

Mangroves can be found in almost a continuous belt along the coast of Belize. There are two local absences, which comprise <10% of the coastline: in the north east near Consejo, and at Punta Negro and parts of Punta Gorda in the south. The country retains large areas of mangroves (unlike many of its neighbours), a situation which can be attributed to two factors—low historical development pressure (stemming from the small population) and the concentration of its population in one centre—Belize City.

This should not be taken as reason for complacency. The examination of early aerial photos, historical

records and ground conditions in this work, suggests that about 98% of Belize's original mangrove cover (80,016 ha) remained in 1990. More recent mapping for the Belize City area, using 1992 aerial photos, however, reveals that a further 519 ha has been cleared, a 0.7% reduction in the national total in just 2 years. Given the need for urban expansion and the growth of tourism, it is anticipated that development pressures will increase in the near future.

The large proportion of Belize's mangroves found on the cays is in itself significant from a management viewpoint. These islands are relatively isolated, tend to show the lowest species diversity and because they sit on or in front of the barrier reef, are extremely vulnerable to the destructive effects of hurricanes. Many of the outer cays such as the Dog Flea group on Turneffe Atoll are repeatedly scoured of all vegetation and reshaped by hurricanes. Offshore sites also face strong pressure from developers (for example the recent conversion of Cay Chapel to a golf course). For isolated cays, the natural re-establishment of mangrove cover may be much slower than on the mainland.

Areas of tall mangrove are restricted to inland locations and elevated parts of the largest cays. It is thought that it is only at these sites that there is the necessary combination of stable substrate, restricted salinity and sustained high levels of nutrients, to maintain stands of large trees. Thus, tall mangrove areas should be conservation priorities because of their limited extent.

Medium mangroves tend to thrive in inland locations. This class includes the large areas of dense fringing red mangrove growing at exposed sites such as on the cays and along the coast. Where medium and dwarf mangrove occur together, the gradation is usually diffuse making the boundary between the two difficult to define accurately from remote sensing.

Dwarf mangrove occur in areas where extreme environmental conditions (such as depressions in the middle of large cays or inland basins) restrict the vegetation to a scattered cover of short mangroves. These mangroves are the easiest to differentiate as they cover extensive areas of very homogeneous character. The main boundary definition problem here occurs when stands are open. Delimiting a boundary between dwarf mangrove and open water in these circumstances can be problematic.

4.3. *Community composition*

Literature on Caribbean mangroves uses inconsistent terminology to describe communities hindering regional comparisons, in many cases leading to a lack of clarity. Mangrove loss, for example, is frequently described as deforestation, when the vegetation lost is not forest, but scrub. Attention was therefore paid in this study to derive a classification that is logically constructed, appropriate to management requirements, and based on terms for which accepted definitions are available.

Like all breakdowns of this sort, gradations do exist between categories, but extensive fieldwork suggests the system devised covers all principal sub-communities encountered in a logical and systematic manner. It is hoped, therefore, that the resulting classification can be adopted throughout the region where these assemblages occur.

The classification provides a comprehensive framework to analyse the functional value of mangrove communities in Belize, and possibly the wider Caribbean. Its use as a basis for mapping depends on the availability of the required high resolution imagery and the field data to locate boundaries between fringing, riverine and basin mangroves. The first national scale mapping reported here uses only four classes (plus "altered/degraded mangrove"). This reflects the balance between the desire to produce a map for the whole of Belize (mainland plus cays) and the availability of suitable imagery and ground survey data. Although it was not possible to adopt the three tier classification in the national map, there is a strong correspondence between the classes used (tall, medium, dwarf and savanna) and the more detailed sub-community classification. The mangrove savanna class equates to the supra-tidal flats community; the dwarf mangrove contains all the scrub categories; the medium mangrove comprises thickets and orchard communities; the tall mangrove represents all the forest.

4.4. *Principal factors affecting mangrove distribution in Belize*

From the results of the fieldwork and mapping, three macro-scale geographical factors seem to be responsible for the distribution of mangroves in Belize. These are now examined in turn.

4.4.1. *The Belize barrier reef*

Belize has a near-continuous barrier reef running along almost the entire length of its coastline. Built on the crest of submarine fault-blocks, it is the longest reef in the Western Hemisphere and the fifth longest in the world. In relation to mangroves, its presence has two distinct impacts. Firstly, by absorbing the majority of in-coming wave energy, the reef shelters the shore and provides conditions amenable to mangrove seedling establishment. This function is most marked in the north, where the reef runs closest to the mainland, diminishing southwards. Secondly, the existence of the reef has enabled large numbers of cays to form. Those on the reef crest itself are highly exposed coral rubble islands which generally only support strandline vegetation, littoral thicket and/or coconut plantations (Fosberg et al., 1982). Here, mangroves, if present at all, are limited to small leeward patches. More significantly, however, are the islands of accumulated sand, mud or peat further towards the coast which form in more sheltered environments (Vermeer, 1959; Stoddart, 1962, 1963, 1969). These are generally larger and provide extensive environments suitable for mangrove colonisation (Zisman, 1992; Woodroffe, 1995).

In addition to the barrier reef itself, macro-geology and subsequent bio-accumulation (reef building and accumulation of mangrove peat) has created three atolls to the east (Stoddart, 1962). Turneffe Atoll in particular, has extensive mangroves, which occupy two thirds of the atoll's land area. By contrast, the remaining two atolls have fewer islands and cover a far smaller land area. The six cays of Lighthouse Reef and the seven of Glovers Reef atolls cover only 7.8 and 0.8 km², respectively (Stoddart, 1962). Being in more exposed positions and more distant from mainland seed pools, they do not support significant mangrove habitats.

4.4.2. *The coastal plain*

The configuration and shallow gradient of the coastal plain is the second major factor effecting mangrove extent. Almost all of Belize's coast is low lying, providing gently sloping inter-tidal areas suitable for mangrove colonisation. Only along two stretches does higher land abut the coast, with the resulting absence of mangrove. These are between Consejo and Sarteneja, and from Cattle Landing to

Orange Point. Broadleaf (non-mangrove) forest was the original vegetation, but in both cases it has been partly replaced by farmland or settlements.

The gradient of the coastal plain is shallowest in the north and this allows the ingress of saline influences for significant distances inland. On-shore southerly or south-easterly winds compound this by driving seawater into Chetumal Bay behind the Ambergris Cay peninsular, locally raising sea levels, increasing saline inundation and broadening the mangrove colonisation zone. Several large lagoons have also been formed by this process, forming a series of inter-linked wetlands between Sarteneja and Midwinters Lagoon (Wantland and Pusey, 1975). In combination, these characteristics have enabled mangroves to colonise a broader zone here than anywhere else in the country.

Further to the south, the coastal plain's influence on mangrove distribution becomes more limited. The plain is narrower and in central Belize is constrained by the arrangement of narrow storm and fossil beach ridges. Beyond this, the coastal plain of southern Belize is of intermediate width but its hinterland rises more steeply, restricting saline influences (King et al., 1993).

4.4.3. *Tidal range*

Finally, the third major influence on mangrove distribution in Belize is the Caribbean's small tidal range. Despite the shallow gradient of the coast, the small tidal range limits the width of the intertidal zone. With the exceptions already described, mangrove development is, therefore, generally restricted to a relatively narrow coastal fringe and the lower reaches of rivers.

4.5. *Localised physical influences on mangrove distribution in Belize*

Macro-scale influences alone are not sufficient to explain the distribution of mangroves in Belize. There are several additional local factors at play, these are discussed in this section.

4.5.1. *Tectonic subsidence*

Subsidence has evidently been a dominant factor in mangrove development in southern Belize. The first area affected lies around the mid-reaches of the Temash and Sarstoon Rivers, in a region with abundant and

complex faulting (Dixon, 1956). Movement has back-tilted drainage here, creating lagoons which have been colonised by mangroves (King et al., 1986). The second area affected by subsidence is Port Honduras, where transgression has resulted from a gentle tilt of the area towards the north-east (King et al., 1986). Along the rivers feeding into the bay (e.g. Deep River), the result is sinuous riverine mangroves fronting extensive backwater swamps (a pattern observed elsewhere, e.g. Woodroffe, 1988). Around Port Honduras itself, broad bands of fringing mangroves have resulted.

4.5.2. *Geomorphology*

Also related to recent geological change is the occurrence of mangroves along the limestone escarpments of the Rio Bravo area. These mangroves, the furthest inland of any in Belize are approximately 55 km from the sea. The presence of mangroves so far inland has been interpreted by some authors as evidence that these escarpments might be old shorelines from periods of higher sea level (e.g. Wright et al., 1959; King et al., 1993; Brokaw and Mallory, 1993). As yet no satisfactory mechanism has been proposed for their continued exploitation of this niche in the face of competition from terrestrial plants. The authors plan to explore alternative explanations in a future research project.

The next feature with a distinct local impact on mangrove distribution is the shallow valley system that runs north-east of Bomba. Entirely colonised by mangroves, this forms an extensive pan-shaped area of inland wetland known as Cobweb Swamp. Also in this north-east region, large numbers of sink holes in the underlying limestone supports widespread isolated pockets of fringing mangroves.

Further to the south, Placencia peninsula, the 21 km long sand spit running south from Riversdale, also has a significant effect. It gives extra shelter to a long section of coast, leading to greater mangrove development along the enclosed mainland. It also supports a broad band of fringing mangrove on the leeward side of the peninsula itself.

4.5.3. *Drainage network*

In addition to these physical features, the location of major rivers is an important further influence on mangrove distribution. Rainfall in Belize exhibits a strong gradient, from the lowest levels in the extreme

north (<1500 mm per annum) to >4500 mm in the south (Walker, 1973). In combination with geology (notably the large areas underlain by limestone) and the presence of the Maya Mountains, the only significant area of high relief (see Fig. 1) there is a marked concentration of rivers in the southern half of the country. Only two major channels drain the north. This basic pattern has significantly affected mangrove distribution, five of the seven rivers with large stretches of riverine mangrove lie in central or southern Belize. At the finest scale, an individual river's suitability for mangrove colonisation is further affected by its local topography, bathymetry, near-shore coastal dynamics and sediment load.

4.5.4. *Soil characteristics*

The character of coastal soils is noteworthy, given the increasing development of aquaculture in the coastal zone. Strictly speaking, the majority of material underlying mangroves are unconsolidated sediments rather than soils, since they are too young to have undergone any significant pedogenic processes. In addition, mangroves at certain locations grow directly on rock, typically platforms of limestone. However, for the sake of brevity, materials on which mangroves grow are referred to as soils in this paper.

Coastal soils in Belize have been examined from both national and mangrove-specific soil surveys. From the national soil survey, five of the nine main soil types identified by Baillie et al. (1993) occur to varying degrees in the coastal zone. The Ycacos sub-suite of the Tintal Suite is the most widespread one supporting mangroves. The Shipstern sub-suite of the Turneffe Suite also underlies significant mangrove areas, and the Ambergris and Hopkins sub-suites are also relatively common. The Consejo and Buttonwood sub-suites of the Bahia and Puletan Suites, respectively, underlie minor areas. In mangrove-specific work, chemical and physical soil analysis has been undertaken by Furley and Ratter (1992), McKee (1993), Murray (1995), and Murray et al. (1999). Findings generally confirm the patterns identified by Baillie et al. (1993).

Where mangrove soils are disturbed, acidification is minimised because of the availability of buffering carbonate in the near shore environment and the lack of sulphide minerals such as jarosite in Belizean watersheds (King et al., 1992). This avoids the acidification

problems arising from the disturbance of acid sulphate soils reported elsewhere (e.g. Simpson et al., 1983; Dost and van Breeman, 1982; Poernomo and Singh, 1982). The unconsolidated nature of the peat underlying most mangroves does, however, render them highly vulnerable to erosion if the overlying vegetation is removed.

The presence of clay-rich soils along the coastal plain behind the mangroves is also significant. They are easier to work and have the added advantage of reduced saline influence. Aquaculture developments have taken place on areas of savannas inland of the mangrove, because of their less demanding management requirements and cheaper construction costs. This has so far meant that aquacultural impacts on Belize's mangroves have been extremely modest in comparison to other countries in the region.

4.5.5. Breaks in the reef

Mangrove distribution is also influenced at a local level by the variable degree to which the barrier reef and cays protect the coast. Notably, between Monkey River and Punta Negra, breaks in the reef and the uneven distribution of cays allow through waves of greater fetch. As a result, wave energy is sufficiently high to inhibit the colonisation of mangroves and they are absent along this stretch. Combined with the gaps caused by the coastal plain's elevation, this means that Belize's mainland coast is devoid of mangroves for about 10% of its length.

4.5.6. Hurricanes

Belize's position in the tropical storm belt means swathes of mangroves are regularly damaged by high winds and flooding from hurricanes. Records compiled by Friesner (1993) reveal the path and frequency of these storms. Major hurricanes have a recurrence interval of approximately 30 years. Hurricane Hattie, which struck the central portion of Belize in 1961, is the most recent major hurricane to significantly impact on Belize. It is the only one whose impacts have been studied in detail through the work of Vermeer (1963) and Stoddart (1963, 1965, 1969). This illustrated the considerable role hurricanes can have in shaping the cays and retarding the structural development of mangrove vegetation. Eye-witness reports also add evidence of localised changes to topography from the reworking and deposition of sediment by flood waters.

Raised above the height of saline influence, one former mangrove area has been re-colonised by pine forest.

Hurricanes have also had significant indirect effects, repeatedly retarding economic development along the coast. Of the four main hurricanes of recent decades, the 1931 (un-named) hurricane virtually destroyed Belize City and took an estimated 1000 lives, 2% of the country's total population at the time (Hartshorn, 1984). It also devastated coconut and banana plantations, ending export agriculture for some 20 years. Hurricane Hattie affected less farmland, but encouraged a wave of emigration to the USA. It also caused the relocation of the capital city from the mangrove delta to an upland site 90 km inland. Hurricane Mitch (1999) had very little impact, due to a last minute change in track. Initial analysis of the consequences of Hurricane Keith (2000), caused significant damage to the vegetation of the cays and secondary effects on the Mainland due to extensive flooding (Frutos, 2000). It has also set back real estate speculation in areas such as Ambergris Cay. From such physical and socio-economic influences, hurricanes have, therefore, also had a considerable, albeit episodic influence on mangrove extent.

5. Conclusion

Belize, is a small country with a similar physical and ecological character to other parts of Central America and the Caribbean. It is unusual in the region, however, because the majority of its coastline retains a cover of mangrove. At the start of this study (the early 1990s) approximately 98% of its "pristine" cover remained.

In common with other parts of Central America, Belizean mangroves are relatively species-poor, with *Rhizophora mangle* being the most abundant. The physiographic classification developed in this paper, however, shows that mangrove species are able to exploit a wide range of ecological niches.

The present distribution of mangroves is largely controlled by three factors: the barrier reef, the shallow gradient of the Belizean coastline and the narrow tidal range. It is further modified on a smaller scale by local subsidence, limestone geomorphology, the drainage network, hinterland soils and past hurricane tracks.

The last decade has seen an acceleration of mangrove clearance, concentrated around existing settlements. With the possible exception of a major hurricane, human influences are the most significant factor in determining the future extent of mangrove cover in Belize.

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