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**MANGROVE PEAT ANALYSIS AND RECONSTRUCTION OF VEGETATION
HISTORY AT THE PELICAN CAYS, BELIZE**

BY

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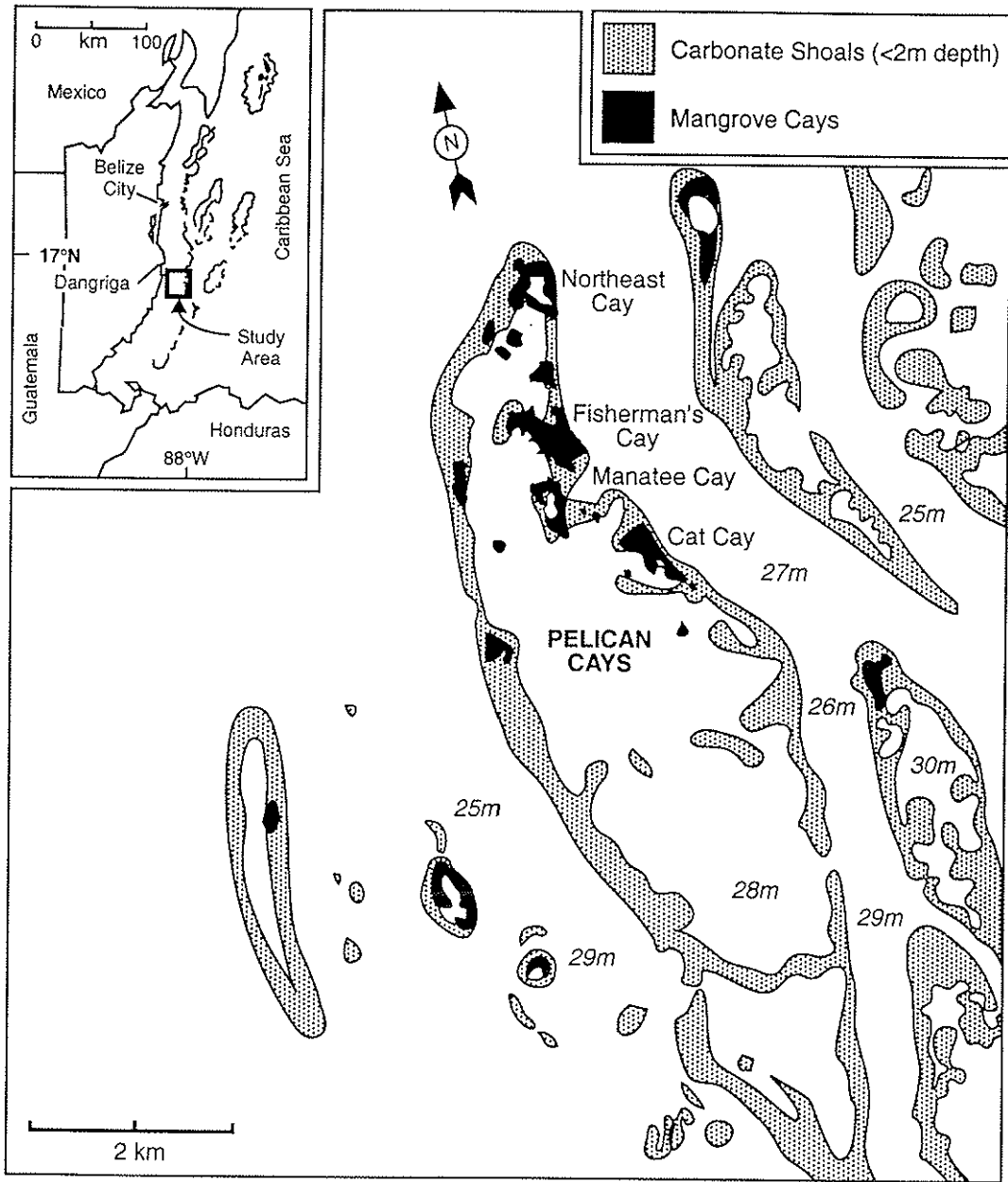


Figure 1. Index map showing the location of the Pelican Cays in the Belizean Barrier Reef Complex. Modified from a Landsat TM image acquired 18 September 1987.

MANGROVE PEAT ANALYSIS AND RECONSTRUCTION OF VEGETATION HISTORY AT THE PELICAN CAYS, BELIZE

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KAREN L. McKEE¹ and PATRICIA L. FAULKNER²

ABSTRACT

The substrate beneath mangrove forests in the Pelican Cays complex is predominately peat composed mainly of mangrove roots. Leaves and wood account for less than 20% of the peat mass. At Cat Cay, the depth of the peat ranges from 0.2 m along the shoreline to 1.65 m in the island center, indicating that the island has expanded horizontally as well as vertically through below-ground, biogenic processes. Mangrove roots thus play a critical role in the soil formation, vertical accretion, and stability of these mangrove cays. The species composition of fossil roots changes markedly with depth: *Rhizophora mangle* (red mangrove) was the initial colonizer on a coral base, followed by *Avicennia germinans* (black mangrove), which increased in abundance and expanded radially from the center of the island. The center of the *Avicennia* stand ultimately died, leaving an unvegetated, shallow pond. The peat thus retains a record of mangrove development, succession, and deterioration in response to sea-level change and concomitant hydroedaphic conditions controlling dispersal, establishment, growth, and mortality of mangroves on oceanic islands in Belize.

INTRODUCTION

Because the mangrove-dominated islands in the Pelican Cays group (Fig. 1) occur many kilometers from the Belizean mainland and from sources of terrigenous sediments, vertical accretion has occurred primarily through autochthonous processes. Mangrove-dominated areas at the Pelican Cays and elsewhere in the Belize Barrier Reef system are underlain by deposits of peat, in some cases several meters in depth (Cameron and Palmer, 1995; Macintyre et al., 1995; Macintyre et al., this volume). These conditions suggest that a major process contributing to vertical accretion has been organic matter deposition, as reported for Grand Cayman (Woodroffe, 1981), Bermuda (Ellison, 1993), and other mangrove forests located within carbonate settings (Parkinson et al., 1994). Therefore, one objective of this study was to investigate the composition of peat deposits in the Pelican Cays complex and to quantify the relative contribution of mangrove organic matter to the vertical growth of these islands. A second objective was to identify fossil plant fragments in mangrove peat and then reconstruct the vegetation history at the Pelican Cays. Current vegetation patterns and physico-chemical conditions were also examined

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to support interpretation of vegetation change in these island forests.

METHODS

This study was conducted at Cat Cay, in the Pelican Cays group (Fig. 1). This island currently has a well-developed mangrove community comprised of three species: *Rhizophora mangle* (red mangrove), *Avicennia germinans* (L.) Stearn (black mangrove), and *Laguncularia racemosa* (L.) Gaertn. f. (white mangrove).

A 270-m transect was established across Cat Cay (Fig. 2), in an east-west orientation, and forest composition and soil characteristics were measured at 10-m intervals. At each sampling station, maximum heights of the mangrove species present in the canopy were measured with an extendible rod, and their relative abundance was estimated visually. Soil variables (redox potential [Eh] at 1- and 15-cm depths, porewater sulfide, salinity, pH, and concentrations of $\text{NH}_4\text{-N}$ and $\text{PO}_4\text{-P}$) were determined as described previously (McKee et al., 1988; McKee, 1995). Soil cores (50 cm^3) were also collected for the determination of bulk density, percent ash, and percent organic matter.

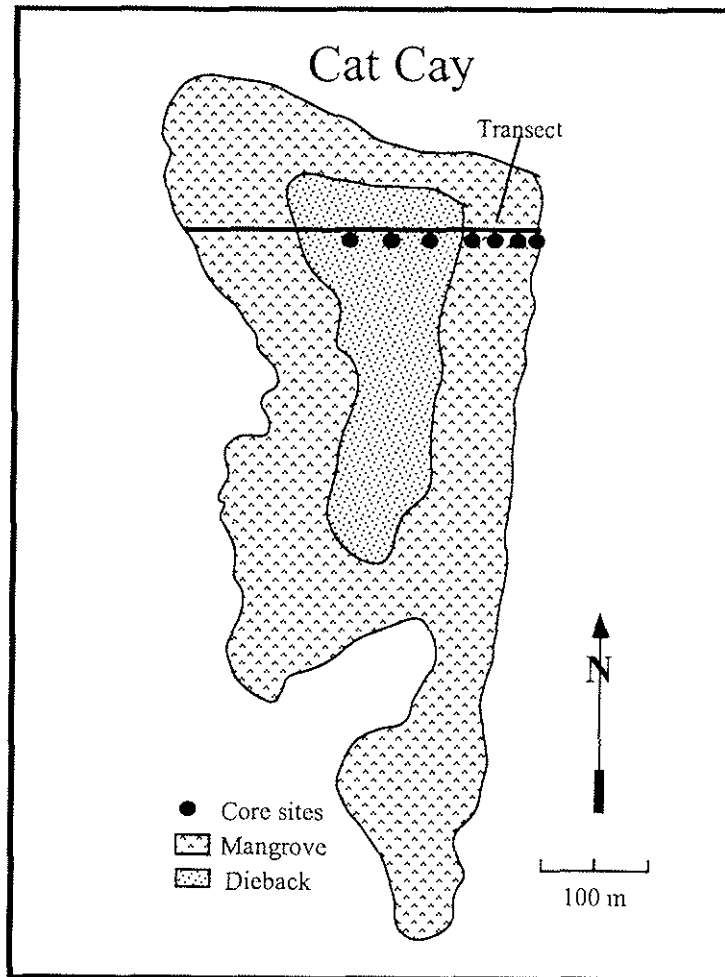


Figure 2. Map showing transect and core locations across Cat Cay.

To assess past vegetation composition in relation to current zonation patterns, deeper peat cores were collected along a portion of the transect, traversing vegetation zones (Fig. 2). Cores were taken with a Russian peat sampler, which caused no vertical compaction, to a maximum depth of 2 m and were divided into 10-cm sections (Fig. 3). Each peat section was initially examined for degree of decomposability (von Post Pressing technique; Parent and Caron, 1993), color, structure (e.g., crumbly, fibrous, etc.), and presence of live roots. A subsample (ca 1 g fr wt) was removed from each peat section and gently washed with seawater through a 2.0-mm and a 0.1-mm mesh sieve. All fragments retained on the 2.0-mm mesh sieve were examined under magnification and separated by type (root, leaf, wood, or other origin). Root fragments were identified to species using a key based on root microscopic and macroscopic features (McKee, unpublished data). The identified components were dried at 65°C and weighed. Fragments retained on the 0.1-mm mesh sieve were also quantified and examined for composition. Unsieved subsamples were analyzed for percent ash and organic matter using the loss-on-ignition method.



Figure 3. A 0.5 m section of a mangrove peat core and the Russian peat sampler.

RESULTS

The mangrove vegetation at Cat Cay was characterized by spatial zonation patterns

generated by variation in relative abundance of the two dominant species. The island periphery was dominated by a narrow fringe of *R. mangle*, followed by a landward zone of *A. germinans* (mixed or monospecific) and an interior pond devoid of emergent vegetation (Fig. 4). The pond was shallow (< 0.3 m) and contained remnant stumps and roots of *A. germinans* (Fig. 5). *Laguncularia racemosa* (up to 15 m high) occurred as scattered individuals about 20 m from the shoreline.

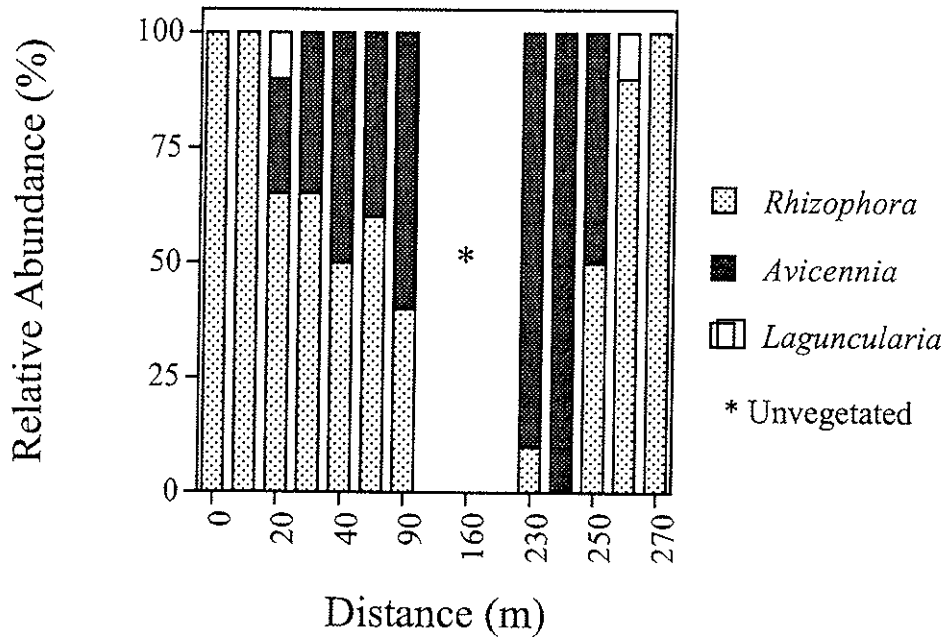


Figure 4. Relative abundance of mangrove species in the forest canopy across Cat Cay.

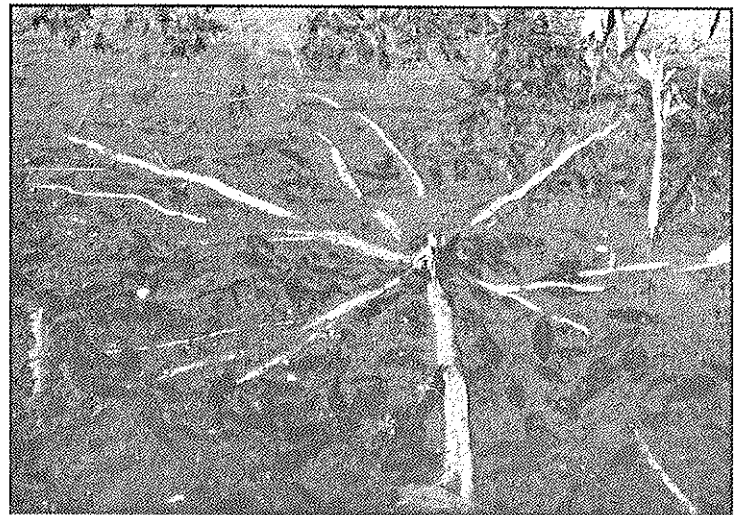
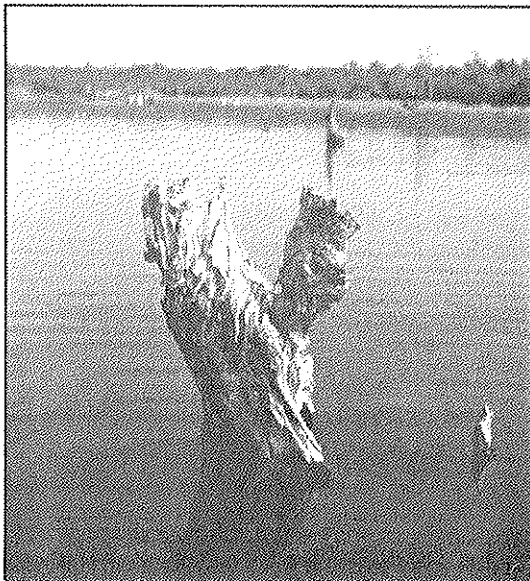


Figure 5. Remnant stump (left) and cable roots (above) of *Avicennia* trees in a dieback area.

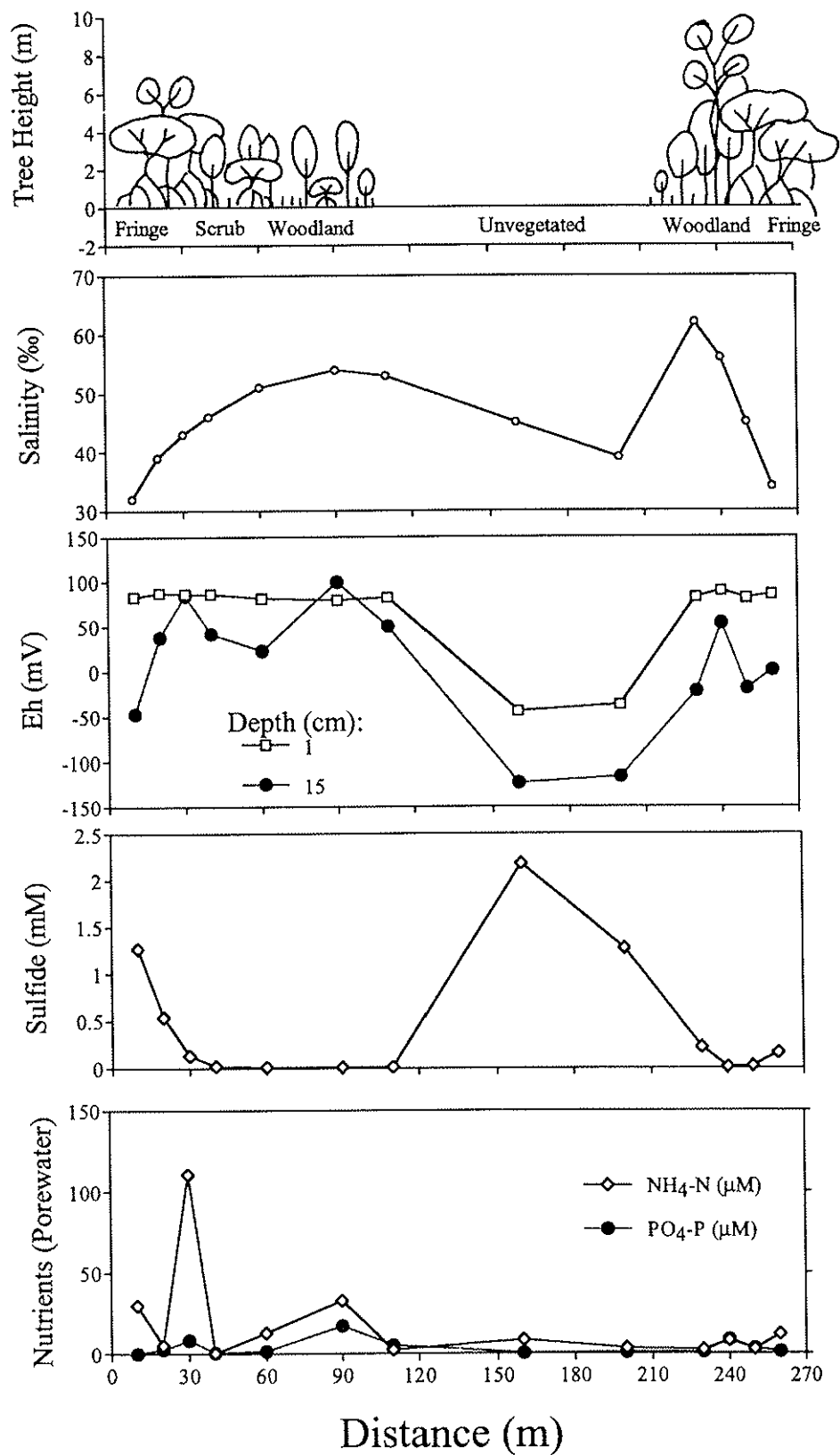


Figure 6. Variation in mangrove tree height and soil physico-chemical factors across Cat Cay.

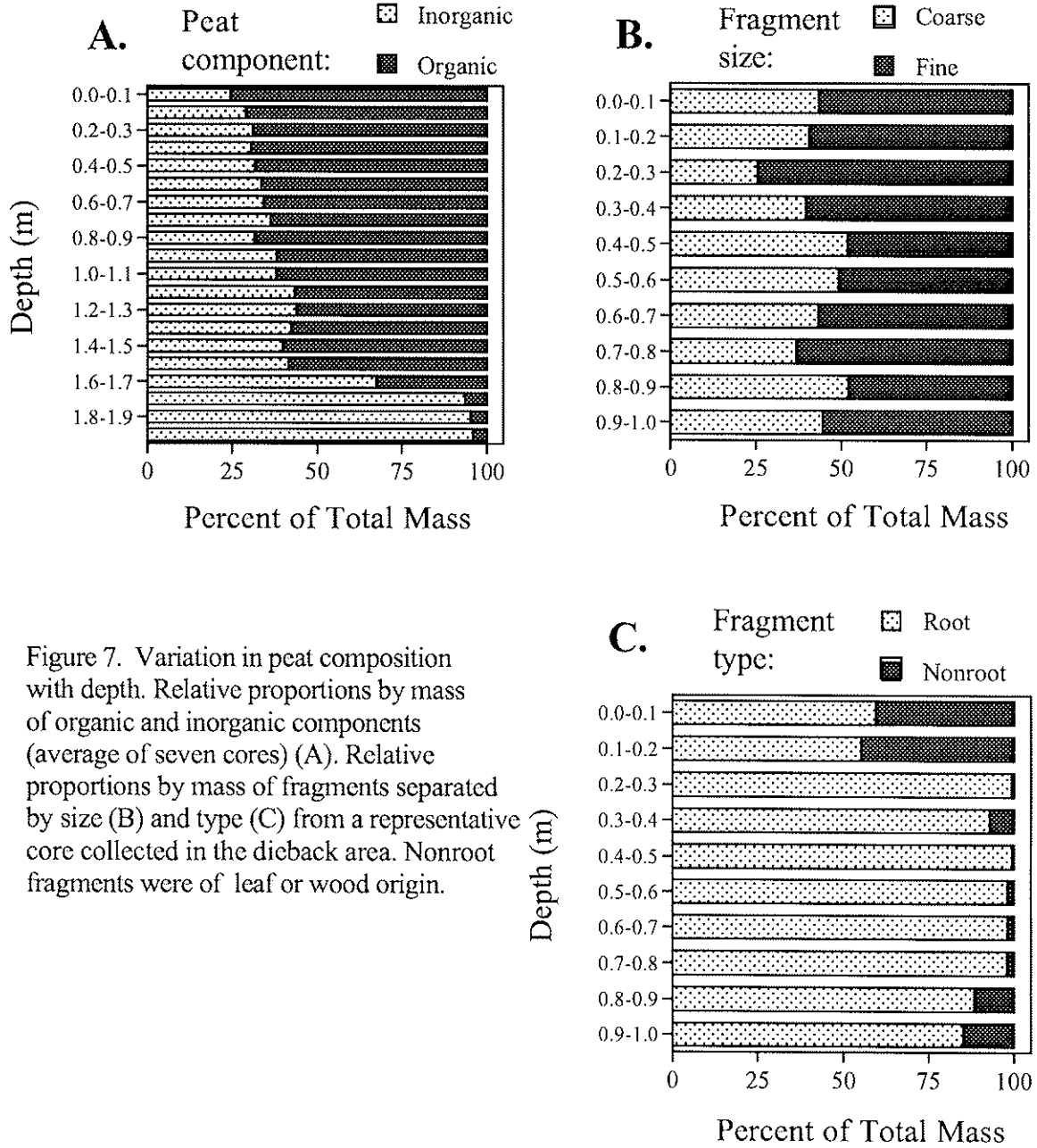


Figure 7. Variation in peat composition with depth. Relative proportions by mass of organic and inorganic components (average of seven cores) (A). Relative proportions by mass of fragments separated by size (B) and type (C) from a representative core collected in the dicback area. Nonroot fragments were of leaf or wood origin.

Cat Cay

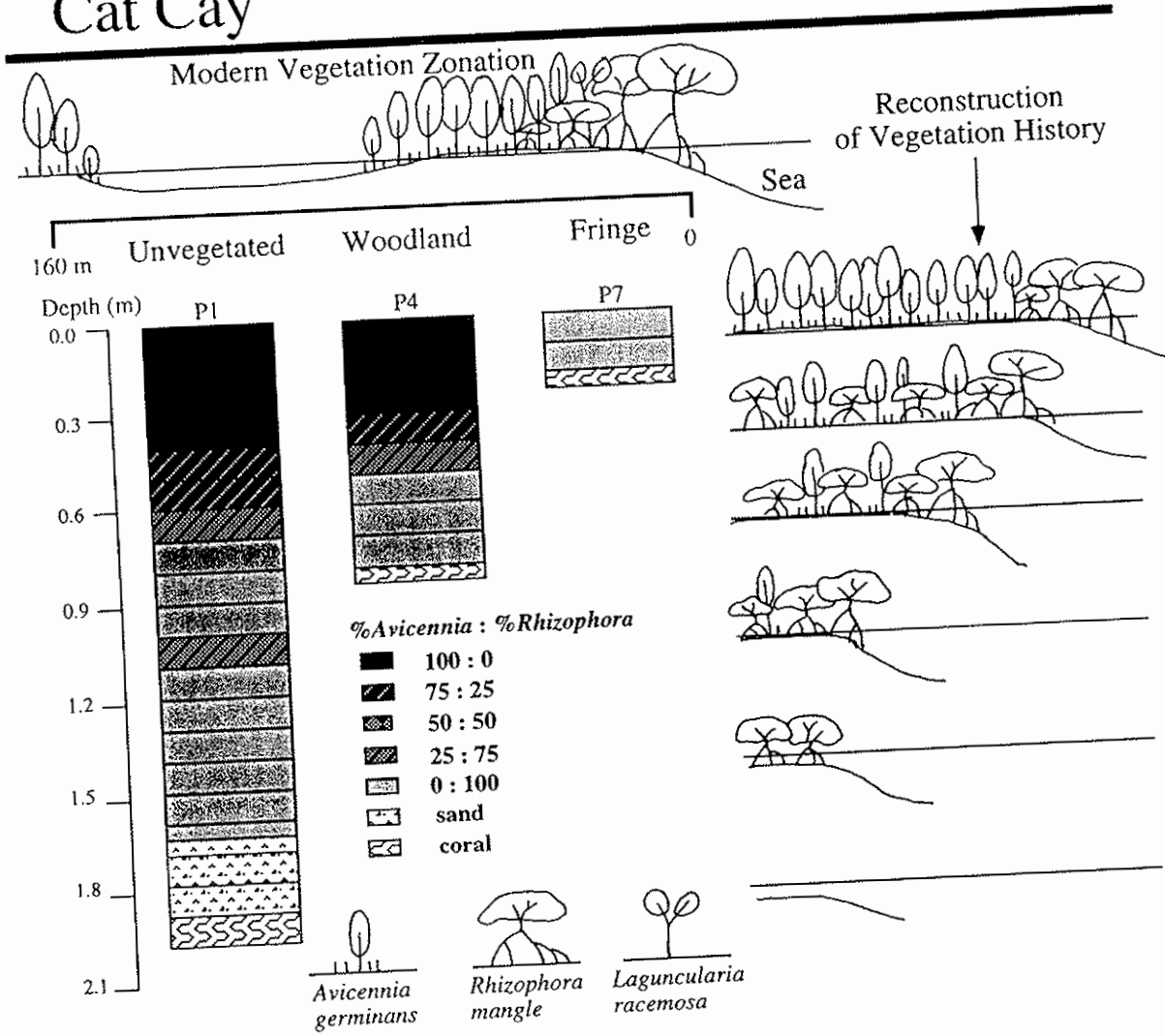


Figure 8. Reconstruction of vegetation history at Cat Cay based on peat analysis.

Soil physico-chemical conditions varied along the transect and in conjunction with changes in vegetative cover (Fig. 6). The soil (0- to 15-cm depth) at all sampling stations was peat (organic matter content 50–60% by mass). Algal-bacterial mats formed 0.25-m plates on the soil surface of the pond. Salinity varied from 32‰ at the shoreline to 62‰ at the east side of the pond. *Rhizophora*-dominated zones were generally characterized by lower salinity, whereas *Avicennia*-dominated zones and the unvegetated area were hypersaline. The vegetated soils were generally more oxidized with low sulfide, compared to the unvegetated pond where sulfide concentrations reached 2 mM (Fig. 6). Concentrations of readily available nutrients also varied across the transect, but did not differ between vegetated and unvegetated areas (Fig. 6).

The peat cores collected with the Russian peat sampler were predominately organic, except the basal sections where deposits of calcareous sand and coral were encountered (Fig. 7). On a mass basis, organic matter accounted for 50 to 60% of the cores, indicating a peat-based soil throughout. Except for the surface 30 cm where the majority of live roots occurred, the peat was moderately decomposed (#5 on the Von Post scale), somewhat pasty, and with distinct plant residues. Color ranged from reddish-brown to grayish-brown with blackened particles, and texture varied from fibrous to crumbly. Coarse fragments (> 2 mm) accounted for 25 to 50% of the peat cores (Fig. 7). Most (50 to 95%) of this coarse fraction consisted of mangrove root epidermis or small root sections (Fig. 7), whereas the fine fraction was mostly fine roots (0.1 to 0.2 mm in diameter) and fragments of spongy cortex from larger roots. The surface 20 cm of dieback cores contained more leaf and wood fragments than did deeper layers (Fig. 7). However, leaf and wood fragments decreased in abundance with depth and were minor components in peat overall (Fig. 7).

The root fragments were readily identified to species with the key and revealed that the bulk of the peat was composed of *Rhizophora* and *Avicennia* roots. Stratigraphy of cores collected in the dieback area at Cat Cay revealed a distinct change in dominant vegetation over time (Fig. 8). Basal sections of peat consisted solely of *Rhizophora* root fragments and fine roots and occasional leaf fragments. At a 1-m depth, *Avicennia* root fragments were encountered, and these increased in abundance to the surface layers, which were dominated by this species.

DISCUSSION

The vegetation and soil conditions currently found on Cat Cay are similar to those of other mangrove islands in the Belize Barrier Reef complex (McKee, 1995; Woodroffe, 1995). Variation in species composition and occurrence of dieback areas in association with changes in hydroedaphic conditions suggest that the zonation of these forests is strongly tied to processes controlling surface elevations in relation to mean sea level (MSL). Extensive unvegetated flats at Tobacco Range, Twin Cays, and Blue Ground Range have been attributed to catastrophic damage by hurricanes (Woodroffe, 1995). However, the location of these dieback areas primarily in the interior of the islands is inconsistent with this hypothesis.

An alternative explanation is that soil conditions affecting the growth of mangroves varies with distance from the shoreline and that infrequent flushing of the island interior by tides limits soil aeration and allows toxins to build up (Fig. 6). Variation in topographic relief, reflecting underlying coral ridges and depressions (Macintyre et al., this volume), may interact

with hydrology to generate these spatial differences in hydroedaphic conditions that ultimately influence mangrove establishment, growth, and survival (McKee, 1995).

A major question not yet resolved concerns the relative importance of biogenic versus geomorphologic processes in mangrove development. Early ecologists introduced the idea of mangroves as "land builders" or "walking trees" (Davis, 1940) because they could extend seaward by the accumulation of sediment around the aerial root system, which would elevate the soil surface and in turn allow seaward colonization. Geomorphologists later argued that mangroves were just passive players in shoreline changes, simply responding to the physical processes of sedimentation, erosion, and changing sea level (Egler, 1952; Spackman et al., 1966; Thom, 1967; Wanless, 1974).

Woodroffe (1983), however, pointed out the differences between geomorphologically active areas such as deltas and estuaries with large allochthonous inputs of sediment and carbonate settings in which peat deposition is the major sedimentary process. Woodroffe (1981) and Ellison (1993) have shown that mangroves in carbonate settings keep pace with rising sea level primarily through the deposition of peat. A similar conclusion may be made for the Pelican Cays in the Belize Barrier Reef complex. Cores obtained from the Tobacco Range Islands (Cameron and Palmer, 1995; Macintyre et al., 1995), Twin Cays, and Turneffe Atoll (McKee, unpublished data) show that other mangrove islands in Belize are similarly underlain by peat, which in some cases is up to 10 m in depth. Although deposits of sand or coral may be found at the base and as thin lenses within the peat core profiles (Cameron and Palmer, 1995; Macintyre et al., 1995; Fig. 8, this study; McKee, unpublished data), the bulk of the substrate underlying these islands is of mangrove origin. Surface trapping of calcareous sand by mangrove aerial roots occurs but is limited to island fringes and tidal creeks. This surface trapping may facilitate the seaward expansion of mangroves, but the development of an extensive below-ground root system is necessary to bind and consolidate the sand deposited along mangrove margins. Also, it is apparent from the Cat Cay cores that once mangroves establish, the main process maintaining surface elevations is peat formation. The high organic matter content of these cores provides further evidence that these systems are being maintained primarily by the deposition of organic matter.

Emphasis on geologic rather than biogenic processes may create an erroneous impression of what controls the development and maintenance of healthy mangrove ecosystems in sediment-poor environments (Woodroffe, 1983). In particular, few appreciate the integral role that mangrove vegetation plays in the growth of islands in the Belize Barrier Reef complex (McField et al., 1996). The preliminary findings reported here illustrate the direct contribution of mangrove organic matter, particularly roots, to vertical accretion at Cat Cay. The increase in wood and leaf fragments in the upper 20 cm of peat cores from the dieback zone is consistent with observations of large quantities of standing and fallen leaf and wood litter at recent dieback sites elsewhere (McKee, personal observation). However, surface litter accounts for a relatively small proportion of mangrove peat overall. Unlike aerial litter, mangrove roots generally remain where they are produced and decompose extremely slowly owing to the anaerobic conditions in the sediment (McKee et al., 1988; McKee, 1995; Fig. 6, this study). Surface litter is also subject to tidal export as well as to consumption by animals such as crabs and snails (Robertson, 1991). Our findings thus indicate that root production and decomposition are two important processes controlling peat formation and hence vertical accretion and the ability of these islands to keep pace with rising sea level.

The origin of current vegetation patterns cannot be understood without some knowledge of past vegetation patterns and the manner in which mangroves have established and developed on these islands. Like Davis (1940), we found *Rhizophora*-derived peat beneath peat produced by *Avicennia*. Davis's interpretations, which were based primarily on macroscopic peat characteristics, were criticized by Cohen and Spackman (1977). Unlike Davis, however, we identified the peat from Cat Cay cores down to species level with the aid of both macroscopic and microscopic features. The success of this technique depends on careful and extensive examination of living and fossil plant material from different environments (Cohen and Spackman, 1977; McKee, unpublished data).

Quantification of identified root fragments revealed that relative abundance of mangrove species varies over depth in the peat cores. In what is now a dieback area, red mangroves initially established upon a coral base and gradually built peat vertically. This colonization process can be observed occurring on shallow submerged reef ridges around Cat Cay and nearby islands, as noted by others (Macintyre et al., this volume). *Avicennia* appeared later, increasing in abundance and expanding outward from the island's center. At some point in the recent past, the center of the *Avicennia* stand began to deteriorate, creating a central dieback area devoid of emergent vegetation. Similar peat patterns of initial colonization by *Rhizophora*, followed by invasion, expansion, and dieback of *Avicennia* can be found at Twin Cays and Turneffe Atoll in the central and northern parts, respectively, of the Belize Barrier Reef system (McKee, unpublished data). Dieback areas on some of these islands are ultimately recolonized by *Rhizophora* (Woodroffe, 1995; McKee, personal observation), suggesting that dieback is part of a natural cycle of development and deterioration in response to changes in hydroedaphic conditions controlling dispersal, establishment, growth, and mortality of mangroves. Although the ultimate control over mangrove development and succession at Cat Cay is sea-level change, this external physical force affects in situ production and decomposition of mangrove organic matter, which in turn determine surface elevations relative to sea level.

CONCLUSIONS

In contrast to forests receiving large quantities of terrigenous or marine sediment (Woodroffe, 1983), the future existence of the Pelican Cays and other mangrove islands in the Belize Barrier Reef complex depends on the continued presence of mangroves and their contribution to peat formation. A lack of understanding and insufficient documentation of the direct contribution by mangroves to soil formation has many serious consequences, including policies allowing the trimming and clear-cutting of mangrove forests for urban expansion, tourist resorts, and shrimp ponds, to name a few activities occurring in the coastal zone of Belize (MacField et al., 1996). Because mangroves make a major contribution to soil formation, their removal eliminates a major source of material that maintains surface elevations in Belize's coastal zone. Since eustatic sea level rise is predicted to accelerate in the next century (Wigley and Raper, 1993), protection of mangroves will be essential to prevent submergence of these oceanic islands. The demise of these island forests would not only represent a significant land loss, but organisms unique to this habitat, particularly those solely dependent on mangroves for substrate, nursery, refuge, and food (Rützler and Feller, 1996), would also disappear. Thus, although mangrove systems throughout Belize will be affected by rising sea level and other global changes, oceanic island forests such as the Pelican Cays will be the most vulnerable and

will require management plans based on a clear understanding of the role mangroves play in counterbalancing sea-level rise.

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