Sedimentation and Nutrient Accumulation in Mangrove Ecosystems of the Gulf of Mexico

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SEDIMENTATION AND NUTRIENT ACCUMULATION IN MANGROVE ECOSYSTEMS OF THE GULF OF MEXICO

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SEDIMENTATION AND NUTRIENT ACCUMULATION

IN MANGROVE ECOSYSTEMS OF THE

GULF OF MEXICO

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INTRODUCTION

Mangroves are forested wetlands which dominate much of the intertidal coastline within the tropics and subtropics of the world. They are considered for the most part, "open" wetlands that exchange nutrients, organic matter, and sediment across their boundaries (Lugo and Snedaker 1974). The open nature of these wetlands creates a two-way flux of materials which links mangrove ecosystems to coastal waters. This exchange of materials has led to much speculation on the mechanisms associated with the structure and function of these ecosystems (Gosselink and Turner 1978, Lugo and Snedaker 1974, Twilley et al. 1986, Twilley 1988).

Mangroves ecosystems are located adjacent to aquatic ecosystems and have been indicated as providing nutrients important to the productivity of these waters (Odum 1971, 1974, Heald 1969, Odum and Heald 1972, Day et al. 1982, Rodelli et al. 1984, Twilley 1985, Twilley et al. 1986). The movement of nutrients to and from mangroves is determined by the balance of productivity, respiration and storage within mangrove forests. Many processes within mangrove forests are greatly affected by differences in environmental settings or forcing functions and hydrologic energy (defined as the input of from tides, rainfall and runoff relative to losses from evapotranspiration) is one of the most important forcing functions in wetland ecosystems (Twilley 1988).

Variations in hydrologic energy determine the nature and magnitude of processes in mangrove ecosystems and can affect the interaction between mangroves and aquatic systems. Apparent changes in water level (due to subsidence and/or sea level rise) and freshwater input interact to affect the conditions mangroves require for continued existence. It is generally accepted that the most productive mangrove forests are those in conjunction with hydrologically active areas (riverine or tidal activity). Decreases in hydrologic energy from fringe to more inland areas can affect most processes within a given mangrove forest. Productivity, decomposition, respiration, and the movement of materials into and out of the forest are closely linked to these local hydrologic conditions (Gosselink and Turner 1978, Brown and Lugo 1982, Twilley 1985, Twilley et al. 1986). This linkage between local hydrologic conditions and the structure of mangrove forests ultimately determines the magnitude and nature of the import and export of materials. This in turn determines the magnitude of vertical accretion (sedimentation) and burial (accumulation) that occurs within a given forest.

This paper examines the storage of nutrients in mangrove forests in Rookery Bay, Florida and Terminos Lagoon, Mexico. Sites at both locations have considerably different environmental settings. Storage in these mangrove forests is hypothesized to reflect the differences that hydrologic energy has on the processes within each forest. Vertical accretion (sedimentation) and accumulation (burial) are parameters which help to quantify the storage of nutrients in mangrove forests. Understanding the nature of storage in mangrove wetlands should help to better characterize the relationship between mangroves and adjacent waters.

CHAPTER 1

RECENT SEDIMENTATION IN MANGROVE ECOSYSTEMS BASED ON ^{137}Cs AND ^{210}Pb

INTRODUCTION

Mangrove wetlands need to maintain their intertidal nature for continued existence. Sea level rise, subsidence of the land, and/or freshwater runoff, are important factors which can change sedimentation patterns in these wetlands by influencing deposition and export of materials. The change in elevation of the forest floor, defined as accretion, is affected by these changing hydrologic and geomorphic conditions that result in an apparent rise in sea level.

Since continued existence of mangrove wetlands depends on this ability to maintain a vertical accretion rate greater than or equal to the rise in sea level, many authors have used the existence of mangrove peat deposits to record the rise in sea level over time (Davis 1940, Scholl and Stuiver 1967, Scholl et al. 1969, Woodroffe 1981). These studies have provided long term measures of accretion and are indicative of the changes in sea level that have occurred over the last 6000 years. Aside from a few studies that have investigated the nature and mechanisms of deposition and erosion in mangroves (Spenceley 1977, 1982, Scoffin 1970), very little information exists on recent (within the past 100 years) rates of accretion in mangrove wetlands.

The measure of recent accretion rates in wetland soils has been accomplished by various methods including the use of natural and man-made radionuclides, such as ^{137}Cs and ^{210}Pb.

These radionuclides have been used in numerous studies throughout the United States (Armentano and Woodwell 1975, DeLaune et al. 1981, 1983, 1986, Hatton et al. 1983, Baumann et al. 1984, Sharma et al. 1987, Stevenson et al. 1985) and abroad (Oenema and DeLaune 1988). Cesium-137 is a radioactive nuclide first introduced to the atmosphere with the advent of above-ground nuclear testing conducted in the 1950's and early 1960's. It has proven a useful marker for determining accretion rates in many saltmarsh ecosystems (Delaune et al. 1983, Baumann et al. 1984, Hatton et al. 1983, Sharma et al. 1987, Nixon 1980). Accretion rates are normally calculated assuming the depth of greatest ^{137}Cs activity corresponds to the year 1963, the year of maximum cesium fallout.

Lead-210 is a decay product of ^{238}U, a radionuclide naturally found in the earth's crust and has proven useful in determining accretion rates over the past 100-150 years (Koide et. al. 1972, Armentano and Woodwell 1975, Stevenson et al. 1985, Nixon 1980, Oldfield and Appleby, 1984). To this "supported" ^{210}Pb activity already present in the sediment is added ^{210}Pb from the atmosphere. This "non-supported" or "excess" lead activity results when radon gas (^{222}Rn), the effective parent nuclide of ^{210}Pb, escapes from the earth's crust. Radon-222 has a short half-life (3.2 days) and once in the atmosphere it rapidly decays to ^{210}Pb and is eventually deposited by rainfall or other means back to the ground. The half-life of ^{210}Pb is 22.3 years and it is the decay of this "excess" ^{210}Pb which is used to determine accretion rates in the sediment. Current methodologies allow one to measure ^{210}Pb excess for about 5 half-lives or about processes occurring 110 years before present. Beyond this it is difficult to distinguish between ^{210}Pb supported and ^{210}Pb excess.

The use of ^{137}Cs and ^{210}Pb radiotracers are useful in that they provide two independent means of measuring the same burial processes occurring within a given sediment core. Cesium-137 is an impulse marker and the measure of accretion using this nuclide usually focuses on the depth of the peak of maximum activity. Mixing of the sediments by biotic or abiotic processes can severely alter the depth and resolution of this peak. Therefore, the usefulness of this nuclide is usually reserved for areas with high deposition rates where burial of this peak is rapid with less chance for disturbance (Nittrouer et al. 1984, DeLaune et al. 1981, 1983, 1986, Hatton et al.1983). Lead-210 differs from ^{137}Cs in that it is assumed that there is an ongoing constant flux of ^{210}Pb to the surface of a wetland, resulting in continuous burial of the nuclide. The decay of this nuclide once buried can be used as a measure of longer term accretion rates, and is more useful in showing surface mixing than cesium. The differences in accretion rates as measured by these two radionuclides can be used as an indication of the presence or absence of mixing within the sediment and can provide a useful means for viewing the continual burial process in wetland sediments.

This study describes the measurement of accretion rates in mangrove wetlands in the Gulf of Mexico utilizing ^{137}Cs and ^{210}Pb. Very little information regarding the recent (~100 years) measure of accretion in mangrove forests is known and we are aware of no studies which use the above-mentioned radiotracers. The objective of this study was to determine the utility of these radiotracers in the measurement of accretion in mangrove wetlands.

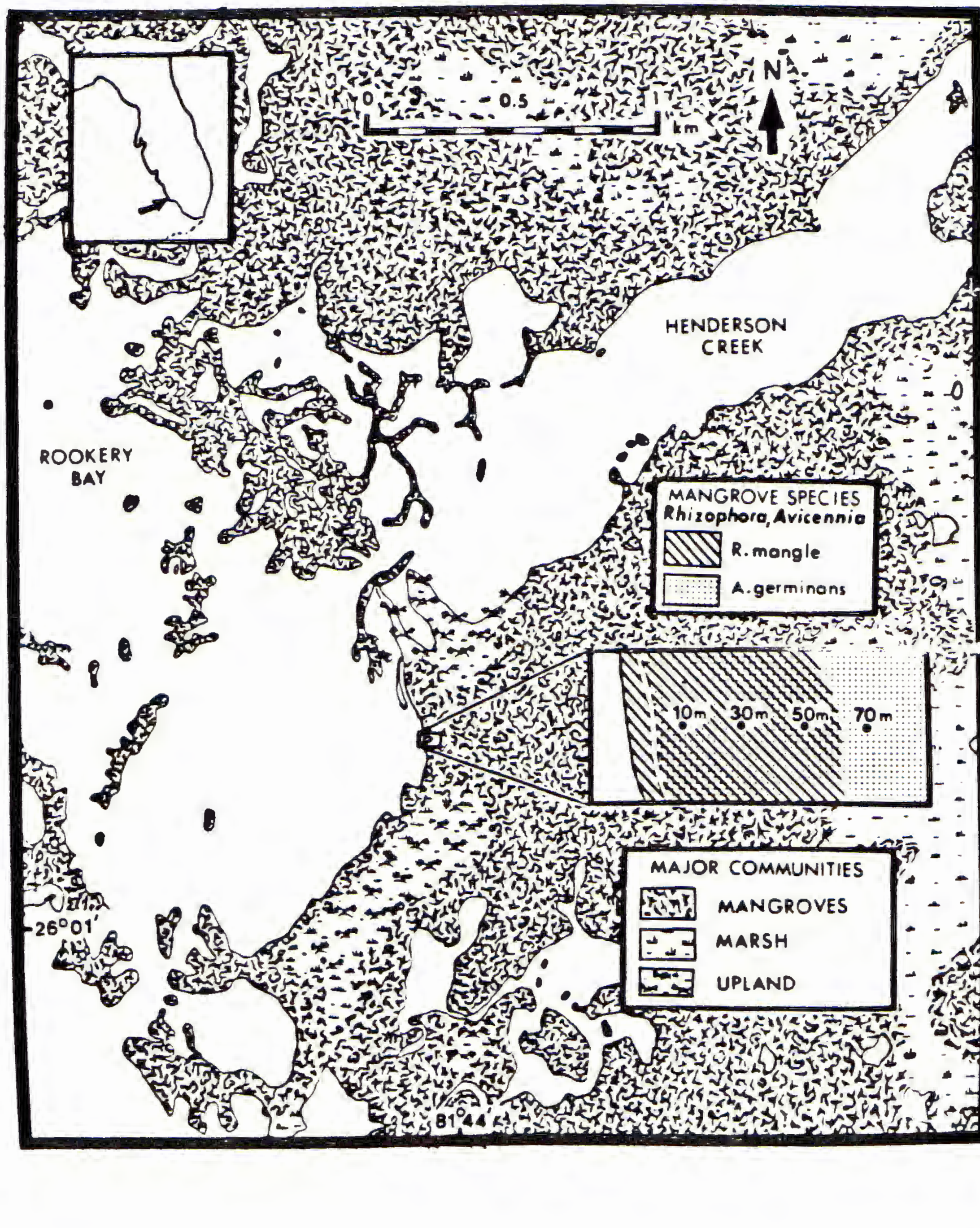
SITE DESCRIPTIONS

Rookery Bay

Rookery Bay National Estuarine Research Reserve (25°02'N and 81°34'W) is located in southwestern Florida, adjacent to the Everglades National Park and the Gulf of Mexico (Figure 1.1). The area has a warm temperate climate with an average temperature of 23.6 °C. Annual precipitation is 1346 mm, with most of the rainfall occurring from June to August. Rookery Bay is a shallow, non-stratified, mesohaline estuary with semidiurnal tides with an annual mean range of 0.55 m and an average depth of 2 m. The major source of freshwater input to the bay is from Henderson Creek with an average annual discharge rate of 0.68 m^3 s^{-1} (11 year average, USGS).

The mangrove site in Rookery Bay is located in a tidally influenced basin forest where there has been extensive mangrove research (Lugo and Snedaker 1975, Pool et al. 1975, Coultas 1978, Twilley 1982, 1985, 1988, Twilley et al. 1986). The forest is exposed to infrequent inundation occurring when

Figure 1.1 Map of Rookery Bay, Florida, USA.



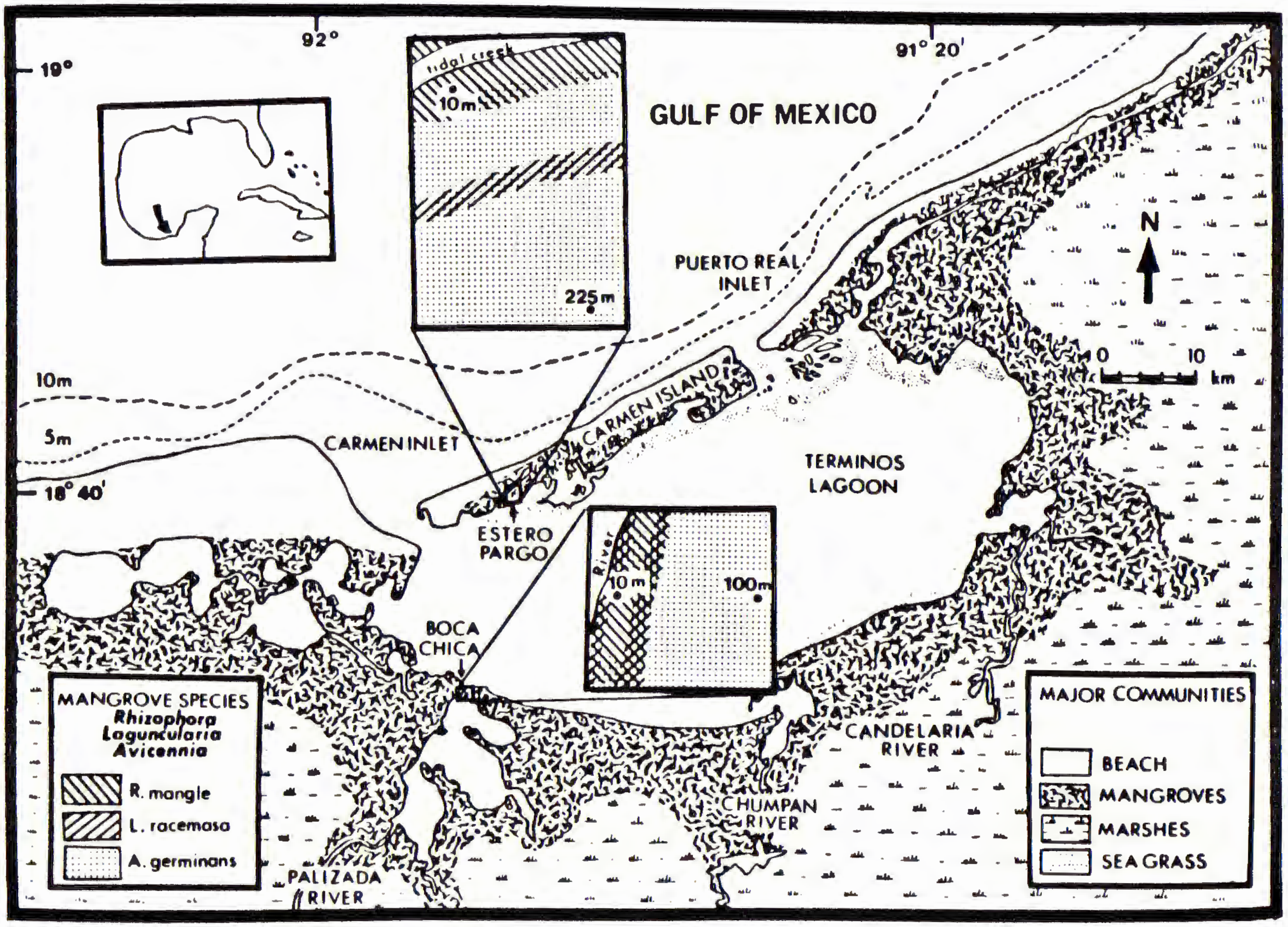
0
0.5
km
N
HENDERSON
CREEK
ROOKERY
BAY
MANGROVE SPECIES
Rhizophora, Avicennia
R. mangle
A. germinans
10m
30m
50m
70m
MAJOR COMMUNITIES
MANGROVES
MARSH
UPLAND
26°01'
81°44'

tidal amplitude reaches 0.61 m above mean sea level (msl), a height corresponding to the elevation of a berm which separates the fringe and basin mangroves (Twilley 1982). The monthly frequency of flooding in the basin site ranges from a low of 3 per month in February to a high of 32 in September (Twilley 1985). The annual average frequency of tides is 150 per year based on seven years of tidal records (Twilley 1985). Surface water salinities are stable at about 30 $^{o}/_{oo}$, whereas, soil salinities range from about 35 $^{o}/_{oo}$ to 50 $^{o}/_{oo}$ (Twilley et al. 1986).

Terminos Lagoon

Terminos Lagoon is located in southeastern Mexico (18°40'N and 91°30'W), adjacent to the western boundary of the Gulf of Mexico (Figure 2). The lagoon has an area of approximately 2500 km^2 with a mean depth of 3.5 m. The climate of the area is tropical with annual average temperatures ranging from a low of 18°C to a high of 36°C. The lagoon is subject to a rainy season lasting from June to January and a dry season from February to May with an average annual rainfall of 1680 mm. The Lagoon connects with the Gulf of Mexico at two locations and prevailing westerly winds create a distinct circulation of coastal waters in the lagoon from east to west. Tides in the lagoon are mixed diurnal with a mean tidal range of about 0.5 m. The Candelaria, Chumpan and Palizada rivers are major sources of freshwater discharge into the lagoon at

Figure 1.2 Map of Terminos Lagoon, Mexico.


92°
91° 20'
19°
18° 40'
GULF OF MEXICO
tidal creek
10m
225m
PUERTO REAL INLET
N
0 10 km
10m
5m
CARMEN INLET
CARMEN ISLAND
TERMINOS LAGOON
ESTERO PARGO
River
10 m
100m
BOCA CHICA
MANGROVE SPECIES
Rhizophora
Laguncularia
Avicennia
R. mangle
L. racemosa
A. germinans
PALIZADA RIVER
CHUMPAN RIVER
CANDELARIA RIVER
MAJOR COMMUNITIES
BEACH
MANGROVES
MARSHES
SEA GRASS

190 m^3 s^{-1} ($6x10^9$ m^3 yr^{-1}) (Phleger and Ayala-Castañares 1971) with maximum discharge from September to November. Details of the physical and biological processes in Terminos Lagoon are included in summaries by Phleger and Ayala-Castañares (1971), Yåñez-Arancibia and Day (1982), and Day et al. (1987).

Two mangrove sites were chosen representing the marine and freshwater influence in Terminos Lagoon based on previous studies by Yåñez-Arancibia and Day (1982) and Day et al. (1987). Site one was located at Boca Chica near the mouth of the Palizada river, a tributary of the Usumacinta river (Fig 1.2). The mangroves at Boca Chica are completely inundated with freshwater from September to November and nearly free of water during the dry months of April and May. Surface water salinities are low ranging from 0 to 5 $^{o}/_{oo}$. Soil water salinities range from about 20 to 50 $^{o}/_{oo}$ (Day et al 1987). This site is characteristic of a riverine mangrove forest as classified by Lugo and Snedaker (1974, see Day et al. 1987). The second site was Estero Pargo located along a 5.3 km tidal creek on the lagoon side of the barrier island, Isla del Carmen. This site is exposed to daily tidal activity and regular inundation. Estero Pargo is influenced by the flow of coastal waters from the Puerto Real inlet which results in surface water salinities ranging from 20 to 40 $^{o}/_{oo}$. Soil water salinities ranged from about 5 to 45 $^{o}/_{oo}$. The mangroves adjacent to the tidal creek are characteristic of a fringe forest and the inland mangroves are characteristic of a basin forest (Lugo and Snedaker 1974).

Sites in both Rookery Bay and Terminos Lagoon were composed mainly of three species of mangrove, Rhizophora mangle L. (red mangrove), Avicennia germinans (L.) L. (black mangrove), and Laguncularia racemosa (L.) Gaertn.f. (white mangrove). In Rookery Bay, the basin forest exhibited two zones of vegetation. Close to the berm was a mixed zone of A. germinans (importance value of 55.8) and R. mangle (54.2). Inland of this area was a monospecific zone composed of A. germinans (importance value of 88.0). L. racemosa was sparsely found in both areas of the basin forest. Canopy height in both the mixed and monospecific zones ranged from 8 to 11 m. Tree density did not differ between zones (3033-5327 trees/ha) though the mixed zone had a greater average basal area

illey 1982, 1985, Twilley et al. 1986).

In Terminos Lagoon, the Boca Chica site was dominated primarily by A. germinans (importance value of 54.8, Day et al. 1987) followed by L. racemosa (32.6) and R. mangle (12.6). Fringe zones were composed of a mix of all three species with the inland basin forest composed of all A. germinans. The tidal site, Estero Pargo, was dominated by R. mangle along the fringe and A. germinans in the basin forest (Will Conner, Personal Communication, Fig. 1.2). The riverine forest has greater basal area, diameter and average canopy height when compared to the tidal site. The tidal site had greater tree density than the riverine site (Day et al. 1987).

METHODS

Sampling

Cores were collected in Terminos Lagoon on 26-27 January 1987 and in Rookery Bay on 16-17 May 1987. Coring consisted of driving 15 or 20 cm diameter, thin-walled, aluminum tubing into the sediment approximately 0.5 m deep. Four cores were collected in Rookery Bay in the basin forest along a transect perpendicular to the shoreline. The first three cores were taken 10, 30 and 50 m inland from the berm in a mixed stand of *A. germinans* and *R. mangle*. The last core was taken 70 m inland from the berm in a stand composed of *A. germinans* (Fig. 1.1).

Two cores were collected in Terminos Lagoon at each site. At Boca Chica, one core was taken 15 m from the shore of the Palizada River in a fringe stand composed of *R. mangle*, *L. racemosa* and *A. germinans*. The second core was taken 100 m inland from the Palizada River in a basin stand composed of *A. germinans*. At Estero Pargo, one core was taken 10 m inland from the tidal channel in a fringe stand of *R. mangle* and the second core was taken approximately 225 m inland in a basin stand of *A. germinans* (Fig. 1.2).

Each core was sectioned at 2 cm intervals, dried at 55°C to constant weight, and weighed for dry bulk density. Each section was ground in a grinding mill (Straub Model 4E) and sieved through a 20 mesh screen to achieve a uniform particle size. Due to variations in bulk density with depth, sediment consolidation corrections were utilized in analyzing the cesium and lead profiles. Each section of core was normalized to the average bulk density of the bottom 5 sections using the following equation :

$$CI_x = (BD_x / BD_5) \times I ; \qquad (1)$$

where, CI_x is the compacted interval length (cm) of section x, BD_x is the bulk density of section x (g cm^{-3}), BD_5 is the average bulk density of the bottom five sections of core (g cm^{-3}), and I is the original section interval (2cm). The corrected interval values are stacked upon each other, and the new sample positions within the core were determined.

Radionuclides

Cesium-137 activity was determined on dried and ground samples from each section of core using standard gamma radiation techniques on a Canberra model 750 gamma detector (Meriwether et al. 1988). Accretion rates (S, mm yr^{-1}) were based on the depth of the section of core with greatest activity. The midpoint of this depth interval corresponding with the peak was divided by the years elapsed since deposition to obtain the accretion rate as follows :

$$S = Z / t ; \qquad (2)$$

where Z is the depth of 1963 peak (mm), and t equals 24 years (1987 - 1963). An assumption of this methodology is that the depth of ^{137}Cs particles contributing to the 1963 peak are solely due to accretion and not other processes.

Lead-210 activity was measured using methods similar to those described by Flynn (1968) and Nittrouer et al. (1979) which measure the daughter nuclide of ^{210}Pb, ^{210}Po. Polonium-210 is assumed to be in equilibrium with ^{210}Pb. Each section of core was counted in Canberra silicon barrier detectors to determine total ^{210}Pb activity. Supported ^{210}Pb was determined by the visual inspection of constant ^{210}Pb activity in the deeper sections of the core and this was subtracted from total ^{210}Pb activity to obtain excess ^{210}Pb activity (Oldfield and Appleby 1984, Nittrouer et al. 1984).

Calculation of accretion rates at time t after deposition are based on exponential decay of the excess ^{210}Pb in the upper sections of core :

$$AE = AT - AS \quad ; \qquad (3)$$

where, AE is excess ^{210}Pb activity, AT is total ^{210}Pb activity and AS is supported ^{210}Pb activity. The excess ^{210}Pb activity can be determined at any time based on the following:

$$AE_t = AE_0 e^{-kt} \quad ; \qquad (4)$$

where, AE_t is excess ^{210}Pb activity at time t, AE_0 is excess ^{210}Pb activity at time zero, k is the decay constant of ^{210}Pb (0.0311 yr^{-1}).

Accretion rates calculated from excess ^{210}Pb data assume that there is negligible migration of all pertinent radionuclides in sediments and that the initial ^{210}Pb excess activity at the marsh surface is constant through time.

Assuming that accretion rates are constant :

$$t = z/S \quad ; \qquad (5)$$

where z = depth in the profile and S = Accretion rate.

Substituting in equation (4) yields :

$$AE_t = (AE_0)e^{-kz/S} \quad ; \qquad (6)$$

$$\ln[AE_t/AE_0] = -kz/S \quad ; \qquad (7)$$

$$\ln[AE_t/AE_0]/z = -k/S. \quad ; \qquad (8)$$

A profile of ln[AE] versus depth (z) should yield a straight line of slope -(k)/S where,

$$\ln[AE_t/AE_0]/z = m \quad ; \text{ (slope of line)} \qquad (9)$$

$$m = -(k)/S \quad ; \qquad (10)$$

$$S = -(k)/m \quad ; \qquad (11)$$

which allows for the calculation of accretion rates (Guinasso and Schink 1975).

The use of advection-diffusion models for ^{210}Pb and ^{137}Cs (Guinasso and Schink 1975, Nittrouer et al. 1984) is an empirical way of modeling the distribution of ^{210}Pb and ^{137}Cs particles in a core and can provide additional information regarding the burial processes occurring. Both equations can account for mixing (D) within the core. For ^{137}Cs, equation (2) can be modified to account for a surface mixing zone which increases the depth of penetration of the 1963 peak (Guinasso and Schink 1975, Nittrouer et al. 1984):

$$z' = 2Dt + St \quad ; \qquad (12)$$

where z' = apparent depth of penetration of the peak, and D = mixing coefficient ($cm^2\ yr^{-1}$). For ^{210}Pb, equation (8) can be modified with the addition of a mixing coefficient (Guinasso and Schink 1975, Nittrouer et al. 1984):

$$S = kz/\ln[AE_0/AE_t] - (D/z)(\ln[AE_0/AE_t]) \; ; \qquad (13)$$

which can be simplified to:

$$S = (k)/m - Dm \; ; \qquad (14)$$

Knowing the value of z' and m, Equations (13) and (14) can be solved simultaneously to derive the values of D and S for both equations. This can be compared to actual values of S and is a useful tool to compare the measure of accretion with ^{210}Pb and ^{137}Cs and whether mixing has an affect on the profiles.

RESULTS AND DISCUSSION

The use of ^{210}Pb and ^{137}Cs radionuclides in the measure of accretion rates is highly dependent on the a mptions and models used to interpret the data. The accuracy of rates depends on the ability to correct for and/or minimize the potential errors encountered in the process of collecting and analyzing these cores. The following factors need to be considered :

1) Errors in the collection of the core such as disturbance of the natural distribution of the sediments.
2) Errors associated with biotic and/or abiotic disturbance of the radionuclide profiles in the core prior to removal for analysis, such as

compaction, migration, mixing and/or bioturbation of the radionuclides in the sediment.

3) Errors encountered following the removal of the core, such as sectioning, accuracy of the instrumentation, and validity of underlying assumptions (Nixon 1980, Oldfield and Appleby 1984, Davis et al. 1984, Casey et al. 1986 Sharma et al. 1987).

All of these points need to be addressed to resolve whether these techniques are an accurate representation of accretion in mangrove forests.

Compaction

In all eight cores taken in Rookery Bay and Terminos Lagoon, handling errors were assumed to be minimal. Compaction during extraction of the core was minimized by using wide diameter (15 or 20 cm), thin walled aluminum tubes and care was taken in sectioning each core. Instrument counting errors for ^{137}Cs were rather large at Rookery Bay, ranging from about 50-80% of the measured value. Much of this error can be attributed to smaller sample sizes, resulting from low bulk density, and decreased counting time relative to the Terminos Lagoon cores (Table 1.1, 1.2). Cesium-137 counting errors in Terminos Lagoon were smaller ranging from about 10-25% of the measured value (Table 1.1, 1.2). Counting errors for ^{210}Pb were small owing to the use of a high efficiency detector. Errors at

Table 1.1 ^{210}Pb and ^{137}Cs counting data for cores from Rookery Bay, Florida (dpm g^{-1} ± counting error). Depths are not corrected for sediment consolidation.

	10 m		30 m		50 m		70 m	
Depth	$^{210}Pb_{tot}$	^{137}Cs	$^{210}Pb_{tot}$	^{137}Cs	$^{210}Pb_{tot}$	^{137}Cs	$^{210}Pb_{tot}$	^{137}Cs
0-2 cm	10.62±0.23	0.45±0.31	12.30±0.39	0.18±0.12	8.89±0.18	0.35±0.28	7.44±0.32	0.34±0.22
2-4	7.26±0.34	1.37±0.84	10.46±0.30	0.36±0.22	10.99±0.27	0.96±0.77	6.67±0.16	0.90±0.45
4-6	6.89±0.26	1.20±0.71	9.60±0.26	1.04±0.56	7.87±0.11	0.95±0.73	5.99±0.18	1.09±0.53
6-8	6.38±0.30	1.92±1.14	6.25±0.08	1.23±0.64	7.80±0.15	1.59±1.21	4.24±0.07	1.57±0.73
8-10	4.98±0.14	0.79±0.48	5.05±0.11	0.79±0.43	4.91±0.08	1.16±0.89	3.44±0.03	0.64±0.31
10-12	4.63±0.07	0.55±0.34	3.98±0.09	0.41±0.24	4.48±0.08	0.45±0.36	3.75±0.06	0.18±0.09
12-14	3.38±0.05	0.08±0.05	4.36±0.08	0.30±0.18	5.33±0.04	0.14±0.12	3.86±0.07	
14-16	2.69±0.04		3.78±0.07		3.92±0.04		3.60±0.06	
16-18	3.35±0.06		3.19±0.05		2.96±0.03		2.29±0.10	
18-20	2.37±0.08		2.77±0.05		1.84±0.05		1.78±0.03	
20-22	2.17±0.05		2.20±0.04		2.52±0.04		2.50±0.03	
22-24	2.14±0.04		1.78±0.02		2.78±0.06		3.24±0.05	
24-26	1.58±0.04		3.05±0.04		2.55±0.05		2.77±0.04	
26-28	2.87±0.04		1.22±0.04		2.71±0.03		3.04±0.03	
28-30	1.72±0.02				2.82±0.03		2.95±0.04	
30-32	1.88±0.04				2.90±0.03		3.62±0.05	
32-34	1.29±0.02				2.40±0.05		3.16±0.04	
34-36	1.51±0.04				2.07±0.05		3.13±0.04	
36-38	1.36±0.02				3.00±0.07			
38-40	1.52±0.02				1.69±0.03		1.80±0.03	
$^{210}Pb_{sup}$	1.72±0.03		2.06±0.03		2.48±0.04		2.75±0.04	

Table 1.2 ^{210}Pb and ^{137}Cs counting data for cores from Terminos Lagoon, Mexico (dpm g^{-1} ± counting error). Depth are not corrected for sediment consolidation.

	Boca Chica				Estero Pargo			
	15m		100m		10m		225m	
Depth	$^{210}Pb_{tot}$	^{137}Cs	$^{210}Pb_{tot}$	^{137}Cs	$^{210}Pb_{tot}$	^{137}Cs	$^{210}Pb_{tot}$	^{137}Cs
0-2 cm	5.23±0.09	0.00±0.00	5.09±0.17	0.68±0.27	6.35±0.18	0.21±0.05	9.12±0.19	0.16±0.08
2-4	5.03±0.09	0.03±0.01	2.51±0.12	0.94±0.37	5.95±0.29	0.33±0.07	5.80±0.18	0.74±0.21
4-6	6.32±0.15	0.22±0.04	2.10±0.09	0.65±0.26	5.31±0.21	0.77±0.16	5.99±0.20	2.39±0.58
6-8	7.60±0.08	0.17±0.04	2.08±0.05	0.36±0.15	5.36±0.23	0.70±0.13	6.41±0.21	1.68±0.41
8-10	4.70±0.16	0.34±0.05	1.50±0.06	0.26±0.11	3.92±0.17	1.03±0.19	3.25±0.10	0.22±0.07
10-12	5.34±0.16	0.28±0.04	1.55±0.05	0.28±0.12	4.08±0.17	1.04±0.20	3.21±0.15	0.23±0.08
12-14	5.74±0.24	0.63±0.10	1.68±0.08	0.24±0.10	2.91±0.11	0.54±0.11	3.18±0.17	0.52±0.16
14-16	4.80±0.17	0.35±0.05	1.48±0.05		2.78±0.11	0.67±0.13	2.04±0.07	
16-18	4.08±0.13	1.08±0.14	1.19±0.04		2.95±0.06	0.28±0.07	1.67±0.07	
18-20	4.02±0.13	0.59±0.08	1.24±0.03		2.70±0.08	0.39±0.08	1.12±0.06	
20-22	4.04±0.16	0.68±0.10	1.29±0.03		2.16±0.07	0.24±0.05	1.46±0.07	
22-24	2.99±0.09	0.35±0.05	1.50±0.04		1.97±0.07		1.05±0.05	
24-26	2.62±0.05	0.21±0.04	1.32±0.02		1.87±0.05		0.89±0.03	
26-28	2.22±0.05	0.13±0.02	1.33±0.02		1.78±0.06		0.84±0.03	
28-30	2.68±0.07		1.21±0.03		1.48±0.04		0.63±0.02	
30-32	2.54±0.06		1.34±0.03		1.50±0.04		0.65±0.02	
32-34	2.41±0.04		1.36±0.03		1.17±0.03		0.64±0.02	
34-36	2.61±0.04		1.65±0.03		0.99±0.03		0.73±0.02	
36-38	2.18±0.03		1.39±0.02		1.00±0.03		0.91±0.02	
38-40	2.14±0.03		1.49±0.02		1.15±0.03		0.69±0.01	
40-42	1.71±0.02		1.44±0.02		0.94±0.02			
42-44					0.91±0.03			
44-46					0.82±0.02			
$210Pb_{sup}$	1.71±0.02		1.36±0.03		1.00±0.03		0.71±0.03	

Rookery Bay and Terminos Lagoon averaged around 2-4% of the measured value (Table 1.1, 1.2).

The natural processes occurring within each core, such as compaction and mixing of the sediments was of most concern in interpreting radionuclide data. Failure to account for compaction and mixing of sediments can overestimate the accretion rate (Nixon 1980, Nittrouer et al. 1984). Foremost of these was the interpretation and/or correction of each core for consolidation of the sediments with depth. A generally accepted rule is that compaction is more prevalent in sediments with higher organic content (Busch and Keller, 1982). All four of the Rookery Bay cores and one of the Estero Pargo cores (225 m) have very high organic matter content in the surface sections as reflected by the very low bulk density values. These values increase considerably with depth . Consolidation corrections which account for these differences, considerably changed radionuclide depth profiles for all cores from Rookery Bay and the basin core from Estero Pargo (Table 1.3, 1.4).

Compaction corrections have the greatest impact in the porous surface regions (high organic content, higher water content, low bulk density) of the core by normalizing core section widths to that of the deeper regions (lower organic content, lower water content, higher bulk density). This decreases each section width of the upper core and can decrease the apparent penetration of both cesium and lead

Table 1.3 Bulk density data (g cm^{-3}) for cores from Rookery Bay, Florida, showing consolidation corrected depth values normalized to the average bulk density of the deepest five sections per core. Depths shown are the midpoint (cm) for each section.

	Bulk Density				Corrected Depth			
	Distance behind berm				Distance behind berm			
Depth	10m	30m	50m	70m	10m	30m	50m	70m
0-2cm	0.160	0.156	0.157	0.143	0.57	0.56	0.65	0.49
2-4	0.159	0.155	0.156	0.183	1.70	1.69	1.94	1.61
4-6	0.227	0.197	0.183	0.179	3.07	2.97	3.34	2.84
6-8	0.155	0.196	0.192	0.274	4.43	4.39	4.88	4.39
8-10	0.162	0.175	0.159	0.198	5.56	5.73	6.33	6.01
10-12	0.227	0.153	0.198	0.199	6.94	6.92	7.81	7.37
12-14	0.224	0.186	0.153	0.263	8.54	8.15	9.25	8.95
14-16	0.242	0.167	0.258	0.184	10.20	9.42	10.95	10.48
16-18	0.208	0.200	0.231	0.228	11.80	10.75	12.97	11.89
18-20	0.290	0.229	0.188	0.188	13.57	12.31	14.69	13.31
20-22	0.267	0.268	0.199	0.180	15.55	14.11	16.29	14.57
22-24	0.330	0.322	0.250	0.227	17.67	16.24	18.14	15.97
24-26	0.335	0.238	0.217	0.184	20.03	18.27	20.07	17.37
26-28	0.294	0.324	0.252	0.200	22.27	20.30	22.00	18.69
28-30	0.300		0.226	0.218	24.38		23.98	20.12
30-32	0.228		0.251	0.240	26.25		25.94	21.68
32-34	0.257		0.266	0.244	27.98		28.08	23.34
34-36	0.292		0.195	0.324	29.93		29.98	25.28
36-38	0.314		0.236	0.326	32.08		31.76	27.51
38-40	0.316		0.264	0.327	34.32		33.82	29.74
Avg:	0.250	0.212	0.212	0.225				
S.E.:	0.013	0.016	0.009	0.012				

Table 1.4 Bulk density data (g cm^{-3}) for cores from Terminos Lagoon, Mexico, showing consolidation corrected depth values normalized to the average bulk density of the deepest five sections per core. Depths shown are the midpoint (cm) for each section.

	Bulk Density				Corrected Depth			
	Boca Chica		Estero Pargo		Boca Chica		Estero Pargo	
Depth	15m	100m	10m	225m	15m	100m	10m	225m
0-2	---	0.826	0.323	0.174	0.50	0.82	0.91	0.29
2-4	0.267	0.796	0.238	0.229	1.60	2.42	2.32	0.84
4-6	0.296	0.924	0.222	0.297	2.86	4.11	3.62	1.72
6-8	0.258	1.136	0.270	0.239	4.10	6.15	5.01	2.62
8-10	0.385	0.962	0.268	0.250	5.55	8.22	6.53	3.43
10-12	0.414	0.865	0.212	0.196	7.34	10.02	7.89	4.18
12-14	0.381	0.831	0.325	0.188	9.12	11.69	9.41	4.82
14-16	0.450	0.986	0.267	0.264	10.99	13.49	11.08	5.58
16-18	0.399	0.807	0.209	0.346	12.89	15.25	12.43	6.60
18-20	0.348	0.932	0.252	0.414	14.57	16.97	13.73	7.87
20-22	0.419	0.894	0.313	0.376	16.29	18.77	15.33	9.19
22-24	0.458	0.910	0.298	0.471	18.25	20.55	17.06	10.61
24-26	0.467	1.125	0.329	0.419	20.33	22.56	18.83	12.10
26-28	0.527	0.896	0.350	0.466	22.56	24.55	20.75	13.58
28-30	0.492	0.998	0.346	0.677	24.84	26.42	22.72	15.49
30-32	0.489	0.863	0.324	0.529	27.05	28.26	24.61	17.51
32-34	0.383	1.163	0.347	0.548	29.00	30.26	26.51	19.31
34-36	0.540	0.941	0.393	0.762	31.07	32.34	28.60	21.50
36-38	0.428	1.072	0.377	0.626	33.24	34.32	30.78	23.82
38-40	0.436	0.910	0.350	0.524	35.18	36.28	32.84	25.75
40-42	0.442	0.981	0.360		37.15	38.14	34.85	
42-44			0.358				36.88	
44-46			0.323				38.80	
Avg :	0.413	0.944	0.307	0.400				
S.E.:	0.017	0.023	0.011	0.039				

radionuclides. Consolidation corrections were assumed to account for compaction of sediments in the upper regions of a core as they are buried and unless otherwise noted, all references to profile depth are corrected for sediment consolidation (Table 1.3, 1.4).

Depth profiles in the Rookery Bay and Terminos Lagoon cores corrected for compaction considerably altered accretion rates in some cases (Table 1.5). Cesium-137 activity in the four Florida cores was mainly confined to the top 10 cm with maximum decay, corresponding to 1963, occurring around 4-5 cm in each core (Fig. 1.3). Deepest penetration of the nuclide occurred in the cores closest to the fringe (Table 1.3). Accretion rates for all four cores were very similar in value at around 1.8 mm yr^{-1} (Table 1.5). This is a decrease of 38% from the original accretion rates of 2.9 mm yr^{-1}.

The penetration of ^{137}Cs activity in the Terminos Lagoon cores varied in depth ranging from about 5 cm of activity at the Estero Pargo basin site to about 25 cm at the Boca Chica fringe site (Fig. 1.4). Like Rookery Bay, deepest penetration of nuclides occurred at the fringe cores. Accretion rates varied considerably among cores. Those from the fringe sites had accretion rates of 5.4 mm yr^{-1} and 3.3 mm yr^{-1} in the Boca Chica and Estero Pargo sites, respectively. Accretion rates in the two basin sites were lower at 1.0 mm yr^{-1} and 0.7 mm yr^{-1}, respectively. The Boca Chica cores had an average accretion rate of 3.2 mm yr^{-1} and the Estero Pargo cores had an

Table 1.5 Original and consolidation corrected accretion rates ($mm\ yr^{-1}$) in Rookery Bay, Florida and Terminos Lagoon, Mexico.

	^{210}Pb		^{137}Cs	
	Original	Corrected	Original	Corrected
		Florida		
Basin cores				
10 m	2.2	1.7	2.9	1.8
30 m	2.2	1.4	2.9	1.8
50 m	2.5	1.6	2.9	2.0
70 m	2.2	1.7	2.9	1.8
Average	2.3	1.6	2.9	1.8
		Mexico		
Boca Chica				
Fringe	4.7	4.4	7.1	5.4
Basin	1.4	1.3	1.2	1.0
Estero rgo				
Fringe	3.8	2.9	4.6	3.3
Basin	2.0	1.0	2.1	0.7
Average	3.0	2.4	3.8	2.6

Figure 1.3 ^{137}Cs activity for the Rookery Bay, Florida cores showing original (○) and consolidation corrected (■) profiles. A) 10 m inland, B) 30 m inland, C) 50 m inland, and D) 70 m inland.

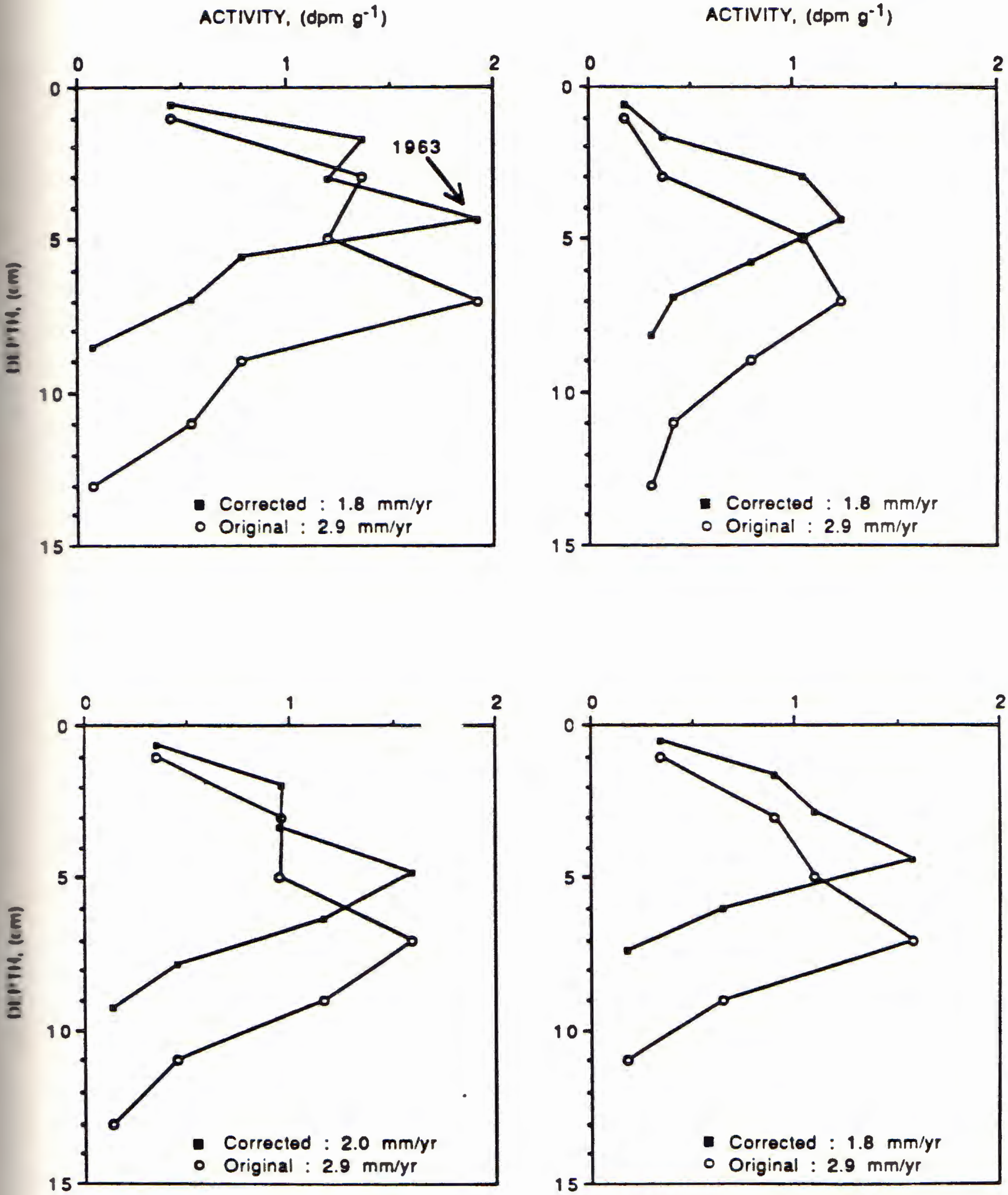
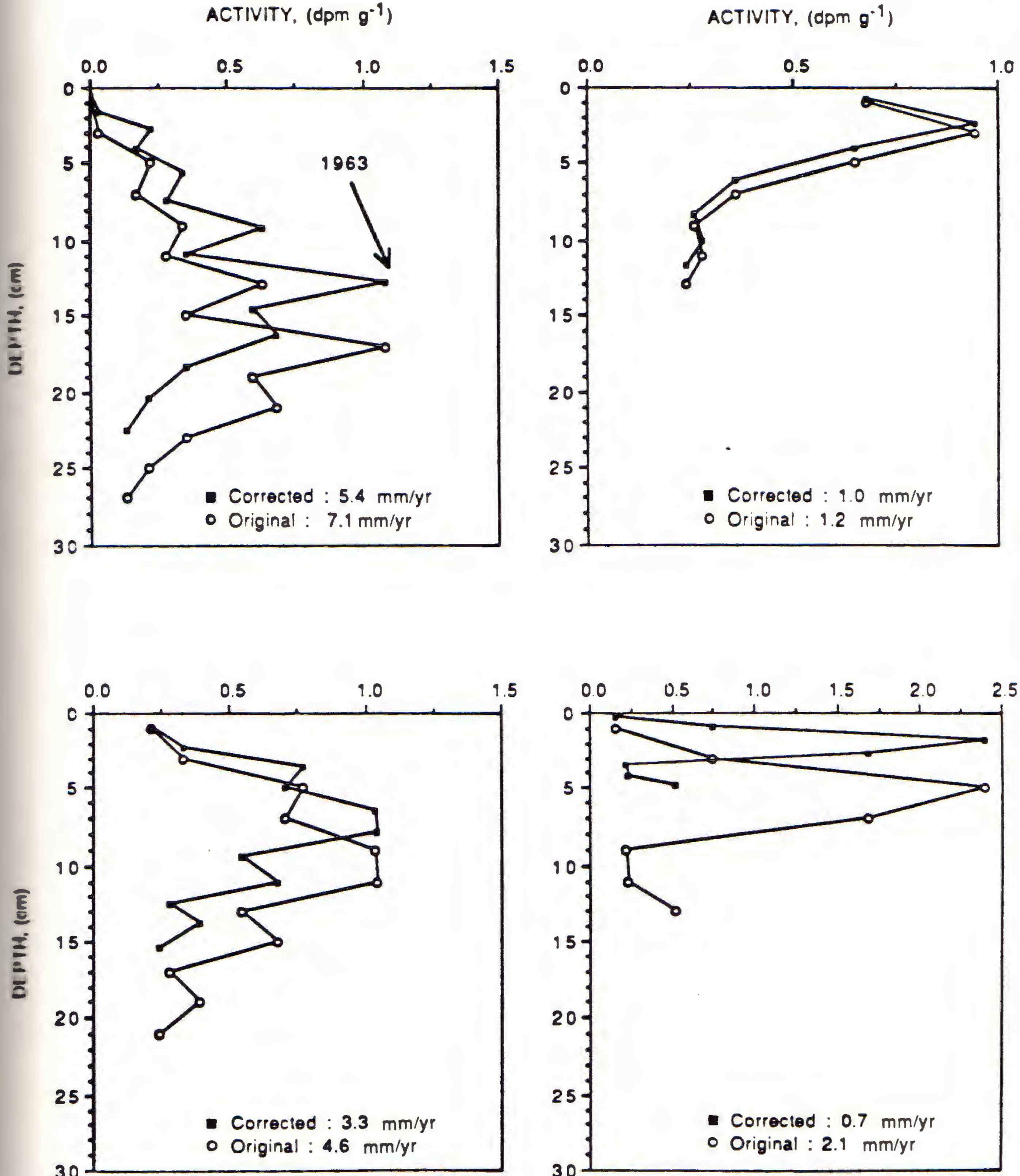

ACTIVITY, (dpm g-1)
ACTIVITY, (dpm g-1)
0
1
2
0
5
10
15
1963
Corrected : 1.8 mm/yr
Original : 2.9 mm/yr
Corrected : 1.8 mm/yr
Original : 2.9 mm/yr
Corrected : 2.0 mm/yr
Original : 2.9 mm/yr
Corrected : 1.8 mm/yr
Original : 2.9 mm/yr

Figure 1.4 ^{137}Cs activity for the Terminos Lagoon, Mexico cores showing original (○) and consolidation corrected (■) profiles. A) Boca Chica fringe, B) Boca Chica basin, C) Estero Pargo fringe, and D) Estero Pargo basin.


ACTIVITY, (dpm g-1)
ACTIVITY, (dpm g-1)
DEPTH, (cm)
DEPTH, (cm)
1963
Corrected : 5.4 mm/yr
Original : 7.1 mm/yr
Corrected : 1.0 mm/yr
Original : 1.2 mm/yr
Corrected : 3.3 mm/yr
Original : 4.6 mm/yr
Corrected : 0.7 mm/yr
Original : 2.1 mm/yr

average accretion rate of 2.0 mm yr^{-1}. The average accretion rate for all four cores was 2.6 mm yr^{-1} (Table 1.5).

Accretion rates (based on ^{137}Cs) in the cores from Boca Chica were not as affected by consolidation corrections as were the Rookery Bay cores. The accretion rates decreased 24% from 7.1 mm yr^{-1} to 5.4 mm yr^{-1} at the fringe site and decreased 17% from 1.2 mm yr^{-1} to 1.0 mm yr^{-1} at the basin site. At Estero Pargo, accretion rates decreased 28% from 4.6 mm yr^{-1} to 3.3 mm yr^{-1} at the fringe site and decreased 77% from 2.1 mm yr^{-1} to 0.7 mm yr^{-1} at the basin site (Table 1.5).

Excess ^{210}Pb activity in the Rookery Bay cores was predominantly found in the top 15 cm of core (Fig. 1.5). Each core was similar in profile with little or no indication of an intensely mixed surface zone. Accordingly, accretion rates were similar in value ranging from a low of 1.4 mm yr^{-1} at the 30 m site to a high of 1.7 mm yr^{-1} at the 10 and 70 m site. Average accretion rate in the four cores was 1.6 mm yr^{-1} (Table 1.5). Accretion rates were not as drastically changed as with ^{137}Cs profiles in Rookery Bay but corrected rates decreased 23 to 36% from original accretion rates.

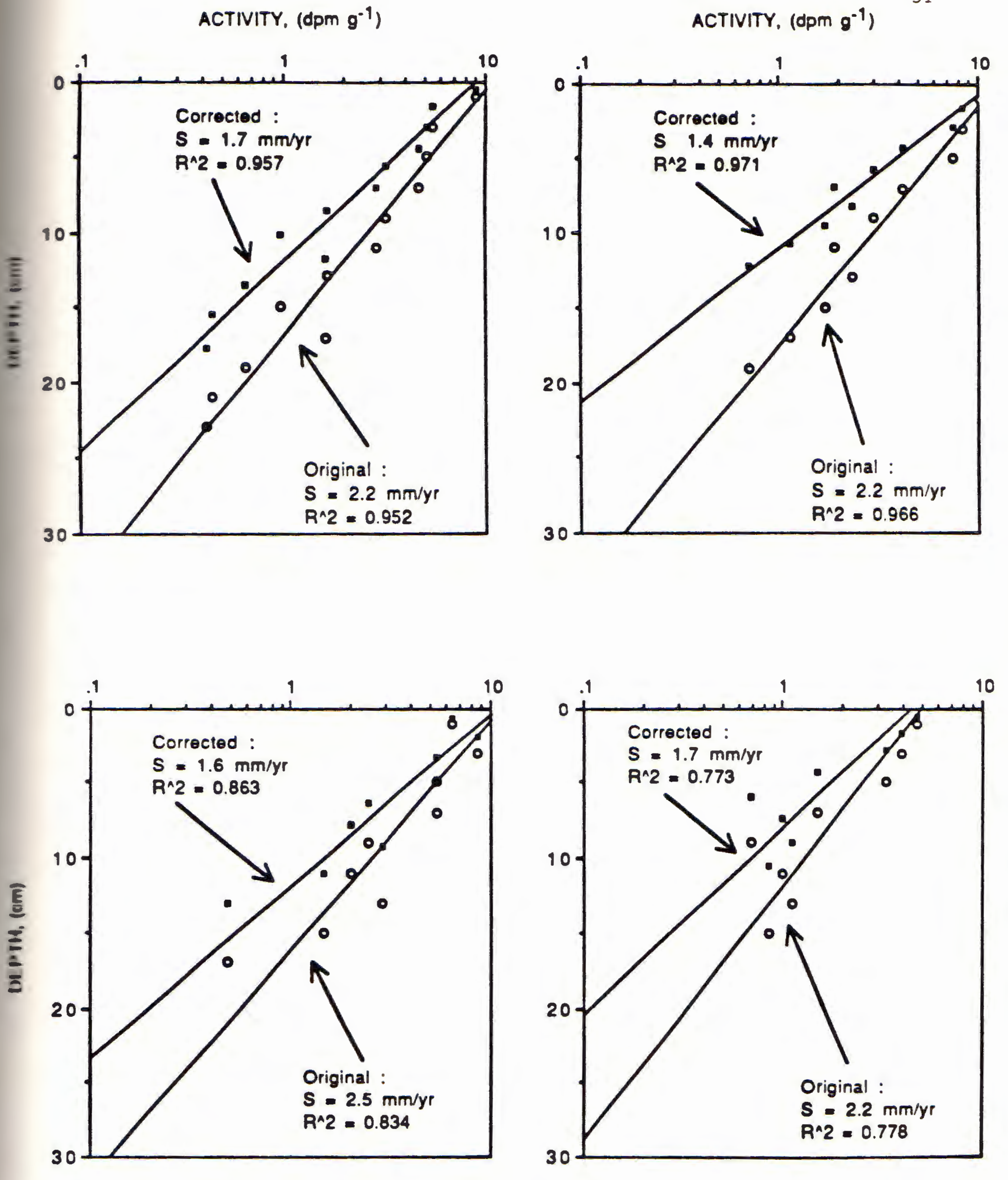
Depth profiles of excess ^{210}Pb activity in the Terminos Lagoon cores were more variable than in the Rookery Bay cores and accretion rates ranged from a low of 1.0 mm yr^{-1} at the Estero Pargo basin site to 4.4 mm yr^{-1} at the Boca Chica fringe site (Fig. 1.6). The fringe cores had accretion rates of 4.4 mm yr^{-1} and 2.9 mm yr^{-1} in the Boca Chica and Estero Pargo cores, respectively. Like ^{137}Cs accretion rates, the basin cores were lower with rates of 1.3 mm yr^{-1} and 1.0 mm yr^{-1}, respectively. Consolidation corrected accretion rates at Boca Chica did not change very much from the original values. The fringe and basin accretion rates decreased only 6 to 7% from original rates. At Estero Pargo however, rates decreased 24 and 50% at the fringe and basin cores, respectively.

The use of consolidation corrections appears to be a very important consideration in the interpretation of accretion rates in highly organic mangrove soils such as the basin sites at Estero Pargo and Rookery Bay. Accretion rates at these locations were much more affected by the consolidation corrections than cores taken from Boca Chica and the fringe at Estero Pargo. Consolidation corrections are commonly considered in analysis of marine, lake and estuarine sediment cores (Nittrouer et al. 1984, Brush et al. 1982, Busch and Keller 1982). Compaction is also a common phenomenon found in wetland sediments (Nixon 1980, Woodroffe 1981, Stevenson et al. 1983), but has not appeared to be an important consideration in the determination of accretion in many wetland systems. The highly organic nature of many wetland soils warrants consideration of these corrections. Failure to account for the affects of compaction could lead to accretion rates which overestimate actual values.

Mixing

An intensely mixed surface layer is another important

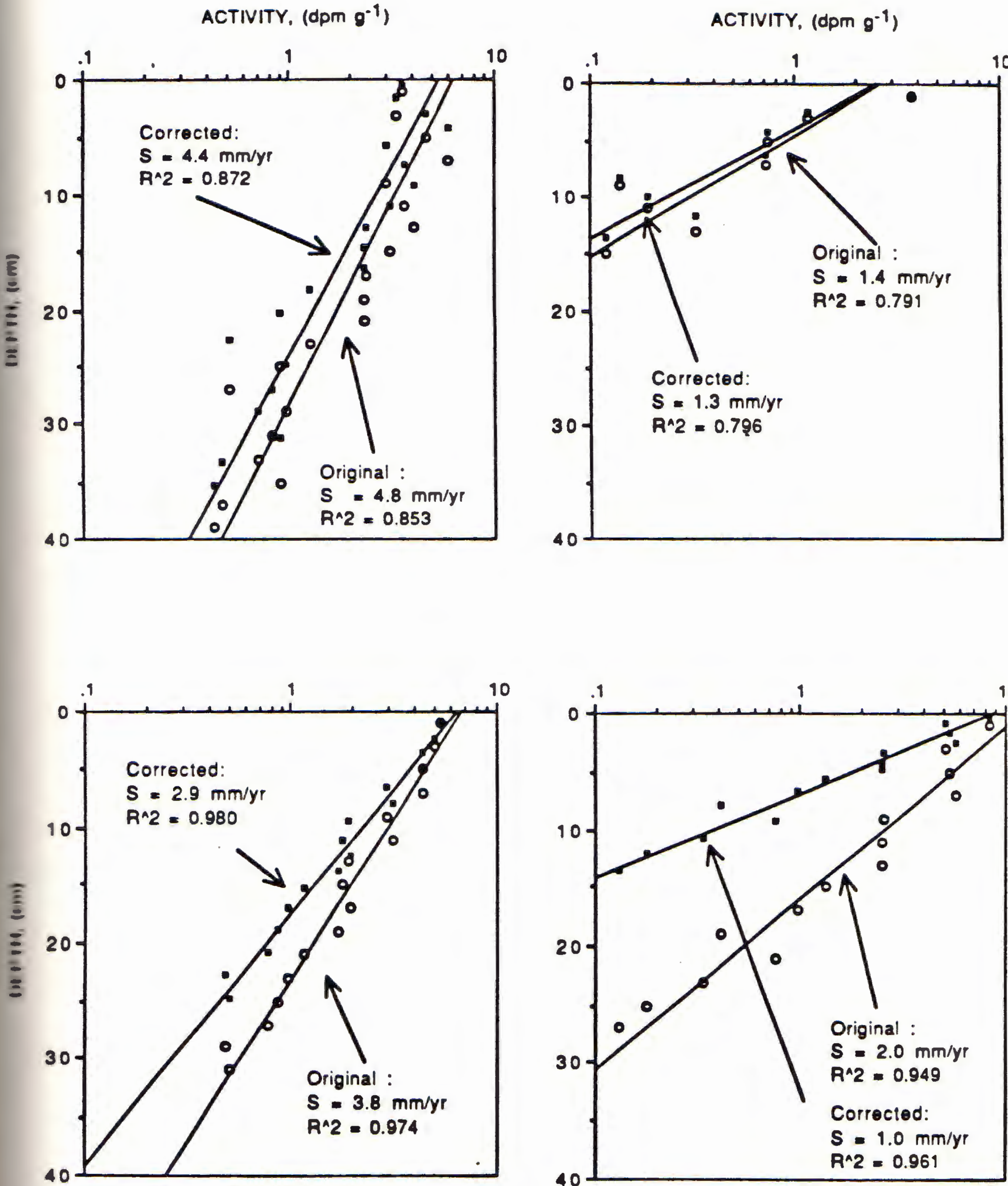
Figure 1.5 ^{210}Pb activity for the Rookery Bay, Florida cores showing original (○) and consolidation corrected (■) profiles. A) 10 m inland, B) 30 m inland, C) 50 m inland, and D) 70 m inland.


ACTIVITY, (dpm g-1)
ACTIVITY, (dpm g-1)
.1
1
10
0
10
20
30
Corrected :
S = 1.7 mm/yr
R^2 = 0.957
Original :
S = 2.2 mm/yr
R^2 = 0.952
Corrected :
S 1.4 mm/yr
R^2 = 0.971
Original :
S = 2.2 mm/yr
R^2 = 0.966
DEPTH, (cm)
Corrected :
S = 1.6 mm/yr
R^2 = 0.863
Original :
S = 2.5 mm/yr
R^2 = 0.834
Corrected :
S = 1.7 mm/yr
R^2 = 0.773
Original :
S = 2.2 mm/yr
R^2 = 0.778

factor to consider when comparing accretion rates obtained by ^{137}Cs and ^{210}Pb. Under these conditions a particle deposited to the wetland surface is quickly mixed to the base of this surface layer, where the actual burial process begins. Lead-210 can be useful in observing this phenomenon due to the continual input of the radionuclide to the marsh surface. Indication of a mixing zone is usually revealed by a homogeneous layer of activity at the surface (Guinasso and Schink 1975, Nittrouer et al. 1979). The use of ^{137}Cs however, is not as useful in determining the presence or absence of a mixed layer because one is essentially looking for the occurrence of 1 single event which occurred about 24 years in the past (the 1963 peak). However, these two nuclides together can provide information regarding the mixing throughout the core.

Initial observations reveal relatively close agreement in accretion rates using these two radiotracers for the Rookery Bay and Terminos Lagoon cores (Table 1.5) supporting the initial assumption of no mixing. The Rookery Bay, Estero Pargo and Boca Chica basin cores show no indication of a mixed surface zone. However, the Boca Chica fringe core could be interpreted as having a mixed zone as indicated by the excess ^{210}Pb profile (Fig. 1.4). The ^{137}Cs accretion rate (5.4 mm yr^{-1}) differs from that of the ^{210}Pb rate (4.4 mm yr^{-1}). Consideration of a consolidation corrected 2.9 cm (corresponding to the 3 surface sections of the core which are

Figure 1.6 ^{210}Pb activity for the Terminos Lagoon, Mexico cores showing original (○) and consolidation corrected (■) profiles. A) Boca Chica fringe, B) Boca Chica basin, C) Estero Pargo fringe, and D) Estero Pargo basin.


ACTIVITY, (dpm g-1)
ACTIVITY, (dpm g-1)
.1
1
10
0
10
20
30
40
Corrected:
S = 4.4 mm/yr
R^2 = 0.872
Original :
S = 4.8 mm/yr
R^2 = 0.853
Original :
S = 1.4 mm/yr
R^2 = 0.791
Corrected:
S = 1.3 mm/yr
R^2 = 0.796
Corrected:
S = 2.9 mm/yr
R^2 = 0.980
Original :
S = 3.8 mm/yr
R^2 = 0.974
Original :
S = 2.0 mm/yr
R^2 = 0.949
Corrected:
S = 1.0 mm/yr
R^2 = 0.961

irregular in activity) mixed layer at this site does little to change the ^{210}Pb accretion rate (4.2 mm yr^{-1}) but proves useful in the interpretation of the ^{137}Cs accretion rates (Table 1.2). A 2.9 cm mixed surface layer (subtracted from the apparent depth, z', of the 1963 peak, Table 1.2) changes the ^{137}Cs rate from 5.4 mm yr^{-1} to 4.2 mm yr^{-1}, equaling the corrected accretion rate determined by ^{210}Pb.

Accretion rates using both radionuclides were used to compare mixing coefficients as calculated from equations 12 and 14. By manipulating these equations, one can compare the presence or absence of mixing in each core based on differences in accretion from using the two radionuclides. Calculation of these values yielded very low mixing coefficients (<<1.0) indicating little or no mixing in all the cores. However, the Boca Chica fringe core did have the highest mixing coefficient indicating that this is the most likely core in which mixing occurs. The lack of a larger mixing coefficient is not unusual as both ^{137}Cs and ^{210}Pb accretion rates are similar in value for most of the cores at all locations. This indicates that accretion rates as measured by these two nuclides, are apparently free from appreciable sediment mixing.

Assuming no mixing in all eight cores, the average accretion rate for the Rookery Bay was 1.6 mm yr^{-1}. Estero Pargo had an average rate of 2.0 mm yr^{-1} and the Boca Chica site was 2.8 mm yr^{-1}. The average accretion rate for all four Terminos Lagoon cores was 2.4 mm yr^{-1}.

Fringe versus Inland Accretion

Many authors studying accretion in salt marsh ecosystems have documented the variation between streamside and backmarsh accretion rates (Hatton et al. 1983, DeLaune et al. 1983, Feijtel et al. 1985, Stevenson et al. 1985). This is apparently the case in the Terminos Lagoon cores as well. Accretion rates in the fringe cores of Terminos Lagoon are much greater in value than that of basin cores regardless of whether the rate was calculated from ^{137}Cs or ^{210}Pb data. This relationship is also true of the depth of penetration of nuclides in the cores. In most of the cores taken, penetration of ^{210}Pb and ^{137}Cs nuclides is greater at the fringe sites than at the more inland basin sites (Table 1.1 and 1.2).

Using ^{137}Cs, fringe accretion rates at Boca Chica and Estero Pargo are about 5 times greater than basin rates. Using ^{210}Pb data, fringe rates are about 3 times greater than basin rates at both sites (Table 1.5). Differences between these two radiotracers indicate that there may be surface mixing in the fringe cores which leads to higher apparent accretion rates.

Subsidence and Sea Level Rise

Vertical accretion rates are the result of subsidence of the land and/or rise of sea level. Topography at both sites in Terminos Lagoon reveals very little difference in elevation between fringe and inland sites. Differences in accretion between fringe and basin mangroves can most likely be attributed to the increased subsidence at the fringe sites compared to the basin sites. Inundation is associated with the transport and deposition of water born inorganic sediments and fringe cores are subject to greater loading from these waters. Values of sea level rise are generally estimated to be about 1.4 - 1.6 mm yr^{-1} (Gornitz et al. 1982, DeLaune et al. 1983), which compares favorably with accretion rates in most basin cores (Table 1.5). Accretion rates in excess of this sea level rise can be assumed to be due to subsidence at that location. In general, the accretion rates as measured by these two methods appear to agree in value. The Rookery Bay basin forest has an accretion rate that ranges from about 1.6 to 1.8 mm yr^{-1} whereas, e Terminos Lagoon cores have accretion rates that range from about 1 to 5 mm yr^{-1} with an average of about 2.4 mm yr^{-1}. Accretion rates in the basin forests at Rookery Bay and Terminos Lagoon are similar to the reported rise in sea level of 1.4 - 1.6 mm yr^{-1} for the Gulf of Mexico (Gornitz et al. 1982, DeLaune et al. 1983) indicating that subsidence is not an important factor in determining accretion rates at these locations. Fringe sites at Terminos Lagoon have higher accretion rates than reported sea level rise and subsequently higher rates of subsidence.

These values do not agree with stratigraphic studies (Scholl et al. 1969, Woodroffe 1981) which estimated long term accretion rates of about 0.3 mm yr^{-1} for this region. However, very little information exists on the recent measure of accretion and/or apparent sea level rise in mangrove ecosystems. Lack of other supporting data (such as long term tide gauge records, pollen dates, etc.) regarding recent values for accretion, subsidence and/or sea level rise indicate that further analysis is needed before these rates can be accepted as representative for these locations.

The use of ^{137}Cs and ^{210}Pb radionuclides manifests the advantage of using more than one method to determine accretion. Differences in the accretion rates as measured with these radionuclides indicate that further investigation is needed to determine whether surface mixing is occurring in the fringe cores. It is apparent from this study that multiple independent measurements are needed to accurately characterize the magnitude of physical processes in mangroves.

CHAPTER 2

SEDIMENT AND NUTRIENT ACCUMULATION IN MANGROVE ECOSYSTEMS OF THE GULF OF MEXICO

INTRODUCTION

Wetland ecosystems are uniquely positioned at transitions from upland terrestrial ecosystems to permanently flooded, aquatic ecosystems. Most wetlands are considered open systems with exchange of materials across their boundaries. Wetlands receive organic and inorganic matter from upland terrestrial environments by way of riverine flow and runoff, and are coupled with aquatic ecosystems by tidal and/or riverine activity. Intertidal wetlands are representative of ecosystems that have significant linkages to coastal environments.

Much research has focused on the coupling among aquatic ecosystems and saltmarsh wetlands. Many investigators have attempted to determine whether saltmarshes are "autotrophic" and subsidize adjacent regions with nutrients, or "heterotrophic" and dependent on nutrient inputs from adjacent regions (Hopkinson 1988, Odum 1980). Such studies have often characterized a system as either "sinks" or "sources" of nutrients to the adjacent water column depending on the net flux of materials across the saltmarsh boundary (Nixon 1980, Odum 1980). High fisheries productivity in many waters has been linked to the contribution of materials such as detritus from these wetland communities (Nixon 1980). Thus, the determination of wetlands as nutrient source or sink describes the function of these ecosystems in this transition zone between terrestrial and aquatic environments.

The exchange of materials among mangrove wetlands and adjacent aquatic ecosystems also includes the flow of nutrients, yet much less research has been accomplished. Mangroves have been shown to supply detritus to adjacent waters in the form of litter from the forest and appear to play an important part in the productivity of the aquatic community (Odum 1971, 1974, Heald 1969, Odum and Heald 1972, Day et al. 1982, Rodelli et al. 1984, Twilley 1985, Twilley et al. 1986). Though mangroves have been shown to contribute materials and affect productivity in local waters, they also remove nutrients and materials due to burial in the soil compartment. The magnitude of fluxes between mangroves and aquatic ecosystems is dependent on processes within the mangrove ecosystem. Studies of processes within an ecosystem are important in understanding wetlands as either sources or sinks for nutrients in the coastal zone.

A mass balance approach can be used to evaluate many of the flows between and within a mangrove forest and adjacent aquatic communities (Twilley 1988, Hopkinson 1988). The net exchange that can occur within a mangrove forest can be written as a production equation,

$$N_{ex} = GPP - R_a - R_h - NEP$$
$$NPP = GPP - R_a$$
$$N_{ex} = NPP - R_h - NEP$$

where, N_{ex} = net exchange to or from the forest, GPP = gross primary production, R_a = respiration of autotrophs, R_h = respiration of heterotrophs, NEP = net ecosystem production, and NPP = net primary productivity (Hopkinson 1988). NEP in mangrove ecosystems has two components, net burial of materials in mangrove soils and storage in plant biomass (tree growth). Direct determination of some of these values is not easily accomplished and subject to indirect calculation. However, this methodology provides a useful framework in which conceptualize flows within mangroves and can provide information regarding the autotrophic or heterotrophic nature of a mangrove forest (Hopkinson 1988).

Environmental settings vary considerably among mangrove ecosystems. Geomorphologists have suggested that these local environmental settings, or forcing functions may determine the structure and function of mangrove ecosystems (Thom 1968, 1982). Temperature, tidal frequency, rainfall, sunlight, and presence of hurricanes are a few of the forcing functions that can vary considerably among mangrove forests. Forcing functions may also vary within a given mangrove forest. Tidal activity and/or riverine inundation decrease from fringe mangroves, adjacent to the shoreline, to inland basin mangroves. This continuum in inundation frequency affects many of the processes within wetlands such as productivity, decomposition, respiration, export and import of materials (Gosselink and Turner 1978, Brown and Lugo 1982, Twilley 1985, 1988, Twilley et al. 1986, Mitsch and Gosselink 1986). For example, fringe mangrove communities, generally exposed to frequent tidal inundation, are characterized by high net productivity, low in situ decomposition and respiration, high export of litterfall, and high deposition of allochthonous materials. Inland basin mangroves, with less frequent tidal activity or inundation, have lower net productivity, higher in situ decomposition and respiration, lower export of litterfall, and high deposition of autochthonous materials (Lugo and Snedaker 1974, Twilley 1985, Twilley et al. 1986, Boto and Bunt 1981, Heald 1969).

The balance of these processes influences the relative magnitude of GPP, R and NEP that ultimately determines the nature and magnitude of exchange with adjacent waters. These processes also influence the amount of NEP that is buried or accumulated within a mangrove forest. The varying nature of the environmental processes related to specific forcing functions are hypothesized to lead to differences in the mechanisms controlling accumulation.

This study describes the accumulation rates of organic matter, nitrogen and phosphorus for mangrove forests in different environmental settings. Sites located in Rookery Bay, Florida and Terminos Lagoon, Mexico are representative of different tidal and/or riverine conditions. Very little is known about the NEP in mangroves. The objective of this study was to learn more about the factors which control burial in mangrove forests and to provide estimates of the mass balance of these ecosystems.

METHODS

Sampling

Cores were collected in Terminos Lagoon on 26-27 January 1987 and in Rookery Bay on 16-17 May 1987. Coring consisted of driving 15 or 20 cm diameter, thin-walled, aluminum core tubes into the sediment approximately 0.5 m deep. Four cores were collected in Rookery Bay in a basin mangrove forest along a transect perpendicular to the shoreline. Cores were taken 10, 30, 50, and 70 m inland from a berm which separates the fringe and basin mangroves (Fig. 1.1, see Chapter 1).

Four cores were collected in Terminos Lagoon at two sites. At Boca Chica, a site influenced by the Palizada River, two cores were taken 15 and 100 m inland from the river's edge. At Estero Pargo, a site influenced by tidal activity, two cores were taken 10 and 225 m inland from a tidal creek (Fig. 1.2, see Chapter 1).

Chemical Analyses

Bulk density, organic content, inorganic content, total carbon, total nitrogen, and total phosphorus concentrations were determined on each dried and ground section of core from both the Rookery Bay and Terminos Lagoon sites. Bulk density values were determined based on the dry weight of a known volume of soil for each section of core. Organic content (% ash free dry mass) and inorganic content (% ash dry mass) were determined by combusting each sample at 480°C for at least 4 hours. Total carbon and nitrogen for the Florida cores were determined on a Perkin-Elmer Model 240, C-H-N elemental analyzer. Total phosphorus concentrations for the Florida cores were determined by hydrochloric and nitric acid digestions on ashed samples followed by colorimetric analysis. Total carbon for the Mexico cores was indirectly determined by assuming that 45% of the organic content is carbon (Nixon 1980). Total nitrogen and phosphorus for the Mexico cores were determined using a Kjeldahl digestion with a mixture of sulfuric acid, hydrogen peroxide and cupric sulfate followed by colorimetric analysis (Isaac and Johnson 1976, Schumann et al. 1973). Conversion of Kjeldahl nitrogen to total nitrogen was made by the addition of DeVardo's reagent to the digestate. Ammonium concentrations were determined using an Orion ammonia gas sensing electrode (Model 95.12) with an Orion Model 407A ionanalyzer (Powers 1981). Phosphate concentrations were determined by colorimetric analyses using the molybdate test (U.S. Environmental Protection Agency 1982).

Accumulation rates

The equation of Hatton et al. (1983) was used to determine the rate of accumulation (A) of materials in mangrove sediments based on dry mass concentrations of materials (C_d, g gdw^{-1}), bulk density (D, gdw cm^{-3}) and the vertical accretion rate (R, cm yr^{-1}):

$$A = C_d \times R \times D \times 10^4 \ (g\ m^{-2}\ yr^{-1}).$$

Average nutrient concentrations, bulk density and accretion rates are based on the maximum depth of penetration of ^{210}Pb activity (see Chapter 1). Accumulation rates for each core describe recent events (last 100 years) and therefore the mean concentration of materials within the depth of excess ^{210}Pb reflect this time interval.

RESULTS

Bulk Density

Bulk density values for all four core in Rookery Bay generally increased with depth ranging in density from about 0.150 g cm^{-3} in the surface regions to about 0.300 g cm^{-3} in the deepest sections (Table 2.1). The average bulk density for Rookery Bay is 0.200 g cm^{-3} (Table 2.1). Bulk density in cores in Terminos Lagoon were much more variable among sites and with depth than in Rookery Bay (Table 2.2). Values at Boca Chica were much higher than Estero Pargo with average bulk densities of 0.764 g cm^{-3} and 0.298 g cm^{-3}, respectively. This is mainly due to the very high bulk density at Boca Chica in the basin core which had an average of 0.916 g cm^{-3}. This is more than twice the value of 0.412 g cm^{-3} for the fringe core at Boca Chica. Bulk density in the cores at The Estero Pargo were lower than Boca Chica, but were higher than Rookery Bay with an average of 0.298 g cm^{-3}. The fringe and basin cores at this site were similar with bulk densities of 0.288 g cm^{-3} and

Table 2.1 Bulk density (g cm^{-3}), organic matter, and inorganic matter concentrations (mg gdw^{-1}) with depth for cores from Rookery Bay, Florida. Values shown correspond to the extent of penetration of excess ^{210}Pb in the core.

	Bulk Density				Organic Matter				Inorganic matter			
Depth	10 m	30 m	50 m	70 m	10 m	30 m	50 m	70 m	10 m	30m	50 m	70 m
0-2	0.160	0.156	0.157	0.143	646.3	713.1	724.6	720.5	353.7	286.9	275.4	279.5
2-4	0.159	0.155	0.156	0.183	640.7	702.8	713.1	661.4	359.3	297.2	286.9	338.6
4-6	0.227	0.197	0.183	0.179	611.1	671.9	704.9	618.6	388.9	328.1	295.1	381.4
6-8	0.155	0.196	0.192	0.274	550.4	608.0	635.2	605.4	449.6	392.0	364.8	394.6
8-10	0.162	0.175	0.159	0.198	545.5	555.2	649.9	619.8	454.5	444.8	350.1	380.2
10-12	0.227	0.153	0.198	0.199	523.7	548.7	639.0	589.9	476.3	451.3	361.0	410.1
12-14	0.224	0.186	0.153	0.263	481.6	514.5	621.0	567.9	518.4	485.5	379.0	432.1
14-16	0.242	0.167	0.258	0.184	499.0	515.8	563.8	578.6	501.0	484.2	436.2	421.4
16-18	0.208	0.200	0.231		492.6	492.6	532.7		507.4	507.4	467.3	
18-20	0.290	0.229			462.4	448.6			537.6	551.4		
20-22	0.267	0.268			419.5	429.9			580.5	570.1		
22-24	0.330				401.7				598.3			
Average	0.221	0.189	0.188	0.203	522.9	563.7	642.7	620.3	477.1	436.3	357.3	379.7
Std err	0.016	0.011	0.012	0.016	23.1	29.6	21.9	17.6	23.1	29.6	21.9	17.6

Table 2.2 Bulk density (g cm^{-3}), organic matter, and inorganic matter concentrations (mg gdw^{-1}) with depth for cores in Terminos Lagoon, Mexico. Values shown correspond to the extent of penetration of excess ^{210}Pb in the core.

	Bulk Density (g cm^{-3})				Organic Matter (mg gdw^{-1})				Inorganic Matter (mg gdw^{-1})			
	Boca Chica		Estero Pargo		Boca Chica		Estero Pargo		Boca Chica		Estero Pargo	
	15 m	100 m	10 m	225 m	15 m	100 m	10 m	225 m	15 m	100 m	10 m	225 m
0-2 cm	----	0.826	0.323	0.174	----	179.4	394.4	724.8	----	820.6	605.6	275.2
2-4	0.267	0.796	0.238	0.229	298.6	118.1	382.6	666.3	701.4	881.9	617.4	333.7
4-6	0.296	0.924	0.222	0.297	353.1	102.3	373.1	577.6	646.9	897.7	626.9	422.4
6-8	0.258	1.136	0.270	0.239	334.0	97.0	350.4	587.7	666.0	903.0	649.6	412.3
8-10	0.385	0.962	0.268	0.250	284.0	112.2	340.9	535.4	716.0	887.8	659.1	464.6
10-12	0.414	0.865	0.212	0.196	240.7	106.4	348.7	429.4	759.3	893.6	651.3	570.6
12-14	0.381	0.831	0.325	0.188	264.2	109.1	336.5	481.1	735.8	890.9	663.5	518.9
14-16	0.450	0.986	0.267	0.264	232.7	95.3	330.7	404.9	767.3	904.7	669.3	595.1
16-18	0.399		0.209	0.346	214.2		355.4	326.4	785.8		644.6	673.6
18-20	0.348		0.252	0.414	207.3		344.4	272.8	792.7		655.6	727.2
20-22	0.419		0.313	0.376	203.8		319.5	241.1	796.2		680.5	758.9
22-24	0.458		0.298	0.471	191.4		295.5	240.8	808.6		704.5	759.2
24-26	0.467		0.329	0.419	168.2		282.1	230.0	831.8		717.9	770.0
26-28	0.527		0.350	0.466	170.3		276.7	191.5	829.7		723.3	808.5
28-30	0.492		0.346		181.3		269.7		818.7		730.3	
30-32	0.489		0.324		176.1		257.7		823.9		742.3	
32-34	0.383		0.347		180.8		249.5		819.2		750.5	
34-36	0.540				199.4				800.6			
36-38	0.428				201.1				798.9			
38-40	0.436				191.1				808.9			
Average	0.412	0.916	0.288	0.309	225.9	114.5	324.0	422.1	774.1	885.5	676.0	577.9
S.E.	0.018	0.040	0.012	0.028	12.8	9.6	10.8	47.3	12.8	9.6	10.8	47.3

0.309 g cm^{-3}, respectively.

Nutrient Concentration

Organic and inorganic material concentrations represent 100% of the sediment composition in a given section of core. Therefore, low organic composition implies high inorganic composition and vise versa. Organic content in all cores was highest in the surface sections and decreased with depth. Organic composition varied considerably among the two locations and the cores at Rookery Bay averaged 587.4 mg gdw^{-1} of organic matter. At Terminos Lagoon, cores from Estero Pargo averaged 373.0 mg gdw^{-1} organic matter, while sediments at Boca Chica averaged 170.2 mg gdw^{-1}. Conversely, the Boca Chica cores had the highest inorganic content and the Rookery Bay cores the lowest.

Profiles of carbon are similar to that of the organic matter concentrations and average carbon concentrations were highest at Rookery Bay and lowest at Boca Chica. At Rookery Bay, carbon concentrations ranged from a low of about 240 mg gdw^{-1} at 10 meters inland to a high of about 287 mg gdw^{-1} at the 50 and 70 m cores. At Estero Pargo, the same relationship was exhibited with values ranging from 145 mg gdw^{-1} to 190 mg gdw^{-1} at the fringe and basin cores, respectively. Boca Chica cores were much lower in carbon that at the other sites. Carbon concentrations were highest at the fringe site and lowest at the basin site with concentrations of 102 mg gdw^{-1} and 52 mg

Table 2.3 Total carbon, total nitrogen and total phosphorus concentrations (mg gdw^{-1}) for cores from Rookery Bay, Florida. Values shown correspond to the extent of penetration of excess ^{210}Pb in the core.

	Total Carbon				Total Nitrogen				Total Phosphorus			
Depth	10 m	30 m	50 m	70 m	10 m	30 m	50 m	70 m	10 m	30 m	50 m	70 m
0-2cm	282.1	343.6	322.5	346.8	16.5	19.5	17.2	22.6	0.67	0.67	0.67	0.75
2-4	288.8	318.1	335.6	318.5	17.7	18.6	19.2	19.6	0.63	0.71	0.60	0.64
4-6	288.1	288.8	312.6	279.8	16.3	18.7	17.9	18.3	0.55	0.68	0.55	0.55
6-8	254.3	271.3	273.1	278.4	[illegible]	17.3	14.2	16.3	0.51	0.65	0.49	0.48
8-10	235.2	247.0	299.5	272.1	[illegible]	16.1	15.7	16.3	0.59	0.63	0.48	0.41
10-12	227.0	266.0	287.3	262.9	[illegible]	17.3	16.0	14.2	0.58	0.63	0.45	0.39
12-14	240.8	229.7	259.8	268.8	13.6	14.9	14.4	16.2	0.47	0.60	0.49	0.37
14-16	235.7	234.3	261.2	258.6	14.0	12.8	13.7	15.1	0.42	0.61	0.46	0.38
16-18	220.0	244.4	235.9		12.4	13.2	12.5		0.47	0.26	0.37	
18-20	204.9	203.3			11.5	12.4			0.45	0.51		
20-22	211.1	217.6			11.4	12.7			0.44	0.44		
22-24	201.5				11.1				0.43			
Average	240.8	260.4	287.5	285.7	14.0	15.8	15.6	17.3	0.52	0.58	0.51	0.50
S.E.	9.0	12.9	11.0	10.9	0.6	0.8	0.7	1.0	0.02	0.04	0.03	0.05

Table 2.4 Total carbon, total nitrogen and total phosphorus concentrations (mg gdw^{-1}) for cores from Terminos Lagoon, Mexico. Values shown correspond to the extent of penetration of excess ^{210}Pb in the core.

	Total Carbon (mg gdw^{-1})				Total Nitrogen (mg gdw^{-1})				Total Phosphorus (mg gdw^{-1})			
	Boca Chica		Estero Pargo		Boca Chica		Estero Pargo		Boca Chica		Estero Pargo	
Depth	15 m	100 m	10 m	225 m	15 m	100 m	10 m	225 m	15 m	100 m	10 m	225 m
0-2cm	---	80.7	177.5	326.2	3.9	3.1	6.8	18.1	0.47	0.58	0.60	0.62
2-4	134.4	53.1	172.2	299.8	4.1	1.6	6.6	16.7	0.50	0.59	0.64	0.56
4-6	158.9	46.0	167.9	259.9	4.5	1.1	6.6	13.7	0.37	0.56	0.64	0.52
6-8	150.3	43.6	157.7	264.5	4.6	0.9	6.9	13.8	0.40	0.53	0.60	0.35
8-10	127.8	50.5	153.4	240.9	4.1	0.9	6.6	10.2	0.46	0.59	0.60	0.40
10-12	108.3	47.9	156.9	193.2	3.6	0.9	6.1	7.8	0.43	0.59	0.59	0.36
12-14	118.9	49.1	151.4	216.5	4.0	0.8	6.8	9.2	0.45	0.55	0.59	0.43
14-16	104.7	42.9	148.8	182.2	3.5	0.8	6.3	7.8	0.47	0.55	0.59	0.40
16-18	96.4		159.9	146.9	3.0		6.4	6.3	0.43		0.55	0.30
18-20	93.3		155.0	122.8	3.1		5.9	4.8	0.43		0.57	0.29
20-22	91.7		143.8	108.5	3.0		5.9	3.4	0.41		0.56	0.18
22-24	86.1		133.0	108.4	3.1		4.2	2.9	0.52		0.54	0.24
24-26	75.7		127.0	103.5	2.[illegible]		4.5	3.0	0.41		0.57	0.28
26-28	76.6		124.5	86.2	[illegible]		4.7	2.4	0.41		0.55	0.20
28-30	81.6		121.4		[illegible]		4.4		0.39		0.53	
30-32	79.2		116.0		2.4		3.9		0.38		0.54	
32-34	81.4		112.3		2.3		3.6		0.35		0.54	
34-36	89.7				2.6				0.38			
36-38	90.5				2.7				0.51			
38-40	86.0				2.6				0.37			
Average	101.7	51.7	145.8	190.0	3.2	1.3	5.7	8.6	0.43	0.57	0.58	0.37
S.E.	5.8	4.3	4.9	21.3	0.2	0.3	0.3	1.4	0.01	0.01	0.01	0.04

* - Carbon concentrations based on 45% of organic matter content.

gdw^{-1}, respectively.

Total nitrogen concentrations were also highest in Rookery Bay and lowest in Boca Chica. Rookery Bay cores averaged 15.7 mg gdw^{-1} with highest values in the more inland cores. Estero Pargo cores averaged 7.2 mg gdw^{-1} and highest values were also in the basin cores. Sediments at Boca Chica averaged 2.2 mg gdw^{-1} with the fringe core having the highest concentration.

Total phosphorus concentrations were all similar among the sites. Rookery Bay cores had the highest phosphorus concentration with an average of 0.53 mg gdw^{-1}. Boca Chica and Estero Pargo had average concentrations of 0.50 mg gdw^{-1} and 0.48mg gdw^{-1}.

Accumulation Rates

Nutrient accumulation rates (Table 2.5) we computed for all cores based on average values of concentration, bulk density (Tables 2.1 - 2.4) and accretion rates (Chapter 1) based on excess ^{210}Pb activity profiles. Sediment accumulation rates varied considerably among the different sites. Boca Chica had the highest sediment accumulation rate of 1502 g m^{-2} yr^{-1} (Table 2.5, Fig. 2.1) and Rookery Bay the lowest with 322 g m^{-2} yr^{-1}. Estero Pargo had an average sediment accumulation rate of 572 g m^{-2} yr^{-1}. Inorganic and organic composition of sediment accumulation rates varied considerably among the sites, and those at Terminos Lagoon cores were composed mainly of inorganic material while sediments at Rookery Bay cores

Table 2.5 Accretion (mm yr^{-1}), bulk density (g cm^{-3}), and accumulation rates (g m^{-2} yr^{-1}) for cores from Rookery Bay, Florida, USA, and Terminos Lagoon, Mexico.

Rookery Bay, Florida	Distance behind berm (meters)				
	10	30	50	70	Avg
Accretion rates (mm yr^{-1})	1.7	1.4	1.6	1.7	1.6
Bulk Density (g cm^{-3})					
Sediments (all material)	0.221	0.189	0.188	0.203	0.200
Organic matter	0.116	0.107	0.121	0.126	0.117
Inorganic matter	0.105	0.082	0.067	0.077	0.083
Total carbon[1]	0.053	0.049	0.054	0.058	0.054
Total nitrogen*	3.094	2.986	2.933	3.516	3.132
Total phosphorus*	0.115	0.110	0.109	0.104	0.110
Accumulation rates (g m^{-2} yr^{-1})					
Sediments	376	265	301	345	322
Organic matter	197	150	194	214	189
Inorganic matter	179	115	107	131	133
Total carbon	90	69	86	99	86
Total nitrogen	5.26	4.18	4.69	5.98	5.03
Total phosphorus	0.20	0.15	0.17	0.18	0.18

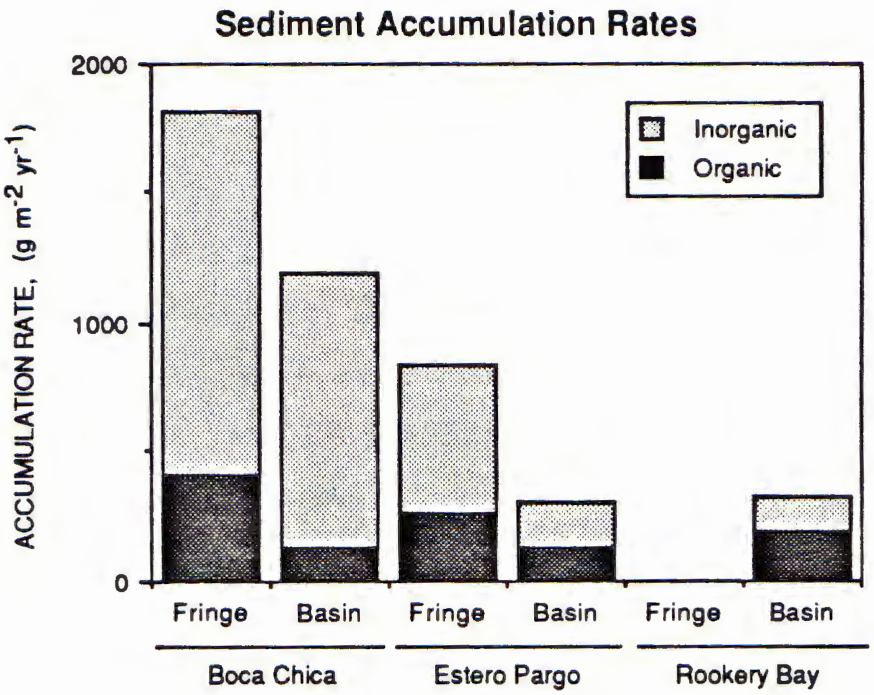
Terminos Lagoon, Mexico	Boca Chica			Estero Pargo		
	15m	100m	Avg	10m	225m	Avg
Accretion rates (mm yr^{-1})	4.4	1.3	2.8	2.9	1.0	2.0
Bulk Density (g cm^{-3})						
Sediments	0.412	0.916	0.664	0.288	0.309	0.298
Organic matter	0.093	0.105	0.099	0.093	0.130	0.112
Inorganic matter	0.319	0.811	0.565	0.195	0.179	0.187
Total Carbon[2]	0.042	0.047	0.044	0.042	0.059	0.050
Total Nitrogen*	1.318	1.191	1.254	1.642	2.657	2.150
Total Phosphorus*	0.177	0.522	0.350	0.167	0.114	0.140
Accumulation rates (g m^{-2} yr^{-1})						
Sediments	1813	1191	1502	835	309	572
Organic matter	409	136	272	270	130	200
Inorganic matter	1404	1054	1229	566	179	372
Total carbon	185	61	123	122	59	90
Total nitrogen	5.80	1.55	3.68	4.76	2.66	3.71
Total phosphorus	0.78	0.68	0.73	0.48	0.11	0.30

* - values in mg cm^{-3}

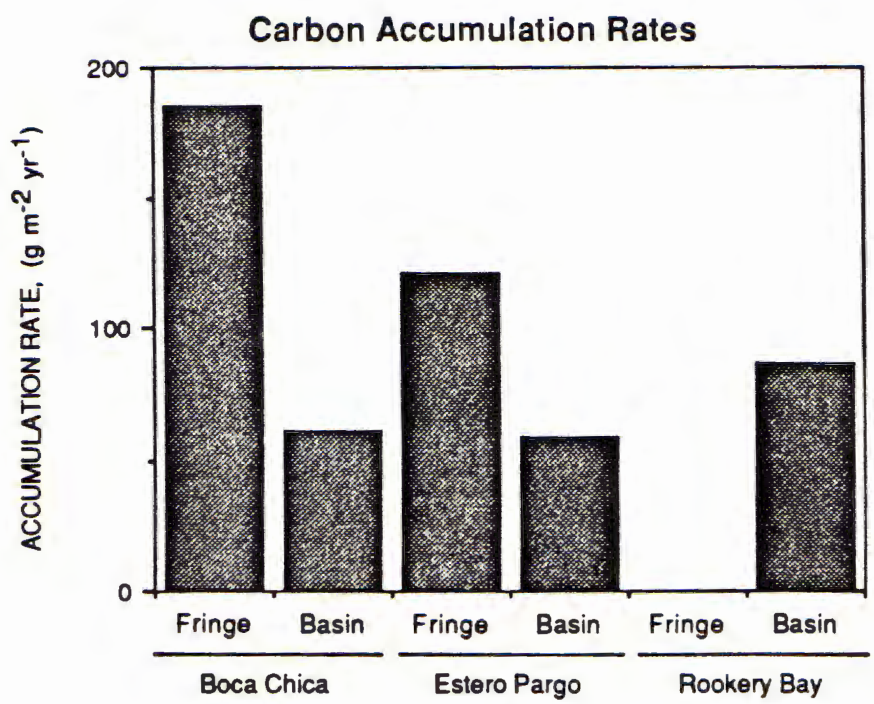
1 - carbon values determined directly by combustion

2 - carbon values determined indirectly by assuming 45% of Ash-free dry mass is carbon.

Figure 2.1 Sediment and carbon accumulation rates ($g\ m^{-2}\ yr^{-1}$) for the Terminos Lagoon, Mexico and Rookery Bay, Florida cores.



Sediment Accumulation Rates
ACCUMULATION RATE, (g m-2 yr-1)
2000
1000
0
Inorganic
Organic
Fringe
Basin
Fringe
Basin
Fringe
Basin
Boca Chica
Estero Pargo
Rookery Bay



Carbon Accumulation Rates
ACCUMULATION RATE, (g m-2 yr-1)
200
100
0
Fringe
Basin
Fringe
Basin
Fringe
Basin
Boca Chica
Estero Pargo
Rookery Bay

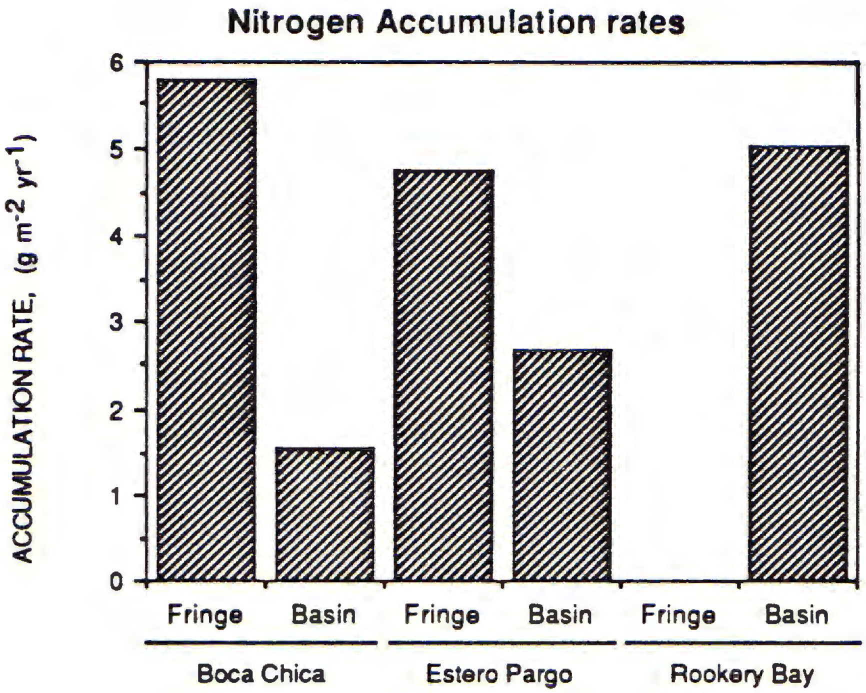
composed mainly of organic material. At both sites in Terminos Lagoon, fringe cores had greater sedimentation rates than inland cores (Fig 2.1).

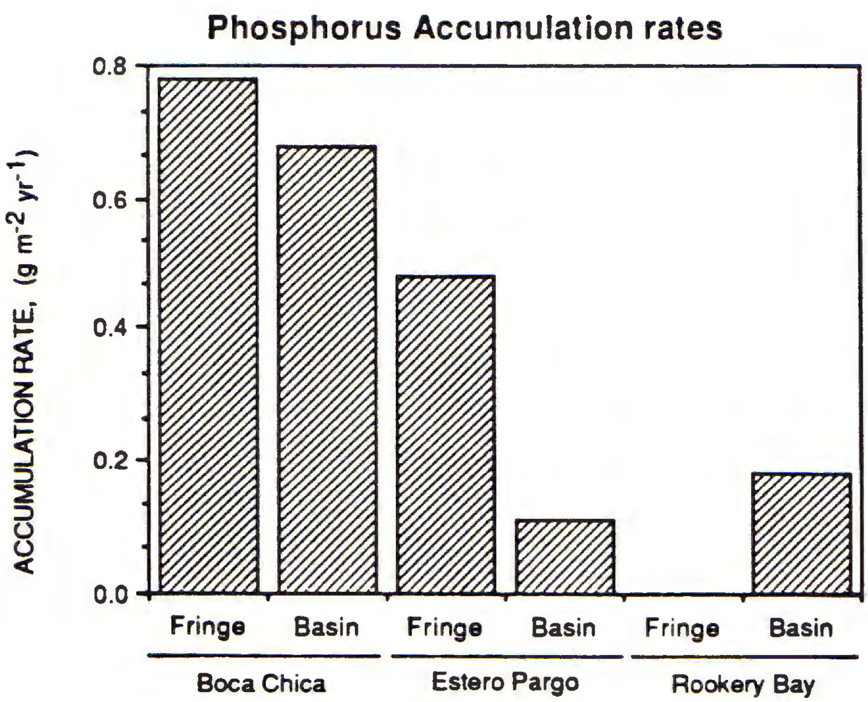
Carbon accumulation rates were similar to sediment accumulation rates with Boca Chica having the highest and Rookery Bay the lowest carbon accumulation. Accumulation rates of carbon at Boca Chica averaged 123 g m^{-2} yr^{-1} and ranged from 185 to 61 g m^{-2} yr^{-1} at the fringe and basin cores, respectively. At Estero Pargo carbon accumulation averaged 90 g m^{-2} yr^{-1} and ranged from 122 to 59 g m^{-2} yr^{-1} at the fringe and basin cores, respectively. Carbon accumulation at Rookery Bay was lowest (Table 2.5) with an average of 86 g m^{-2} yr^{-1} ranging from 69 to 99 g m^{-2} yr^{-1}.

Nitrogen accumulation was highest in Rookery Bay and about equal in Boca Chica and Estero Pargo. Accumulation rates of nitrogen at Rookery Bay averaged 5.03 g m^{-2} yr^{-1} and ranged from 4.18 to 5.98 g m^{-2} yr^{-1}. At Boca Chica, the fringe had a very high rate of 5.80 g m^{-2} yr^{-1}, while inland the accumulation was only 1.55 g m^{-2} yr^{-1}, with an average of 3.68 g m^{-2} yr^{-1}. Accumulation at Estero Pargo averaged 3.71 g m^{-2} yr^{-1} and ranged from 4.76 to 2.66 g m^{-2} yr^{-1} at the fringe and basin cores, respectively.

The pattern for phosphorus accumulation was similar to sediment accumulation with the highest rates at Boca Chica and lowest at Rookery Bay (Fig 2.2). Boca Chica had an average accumulation rate of 0.73 g m^{-2} yr^{-1} ranging from 0.78 to 0.68 g

Figure 2.2 Nitrogen and phosphorus accumulation rates ($g\ m^{-2}\ yr^{-1}$) for the Terminos Lagoon, Mexico and Rookery Bay, Florida cores.


Nitrogen Accumulation rates
ACCUMULATION RATE, (g m-2 yr-1)
6
5
4
3
2
1
0
Fringe
Basin
Fringe
Basin
Fringe
Basin
Boca Chica
Estero Pargo
Rookery Bay


Phosphorus Accumulation rates
ACCUMULATION RATE, (g m-2 yr-1)
0.8
0.6
0.4
0.2
0.0
Fringe
Basin
Fringe
Basin
Fringe
Basin
Boca Chica
Estero Pargo
Rookery Bay

m^{-2} yr^{-1} in the fringe and basin cores respectively. Estero Pargo had much more variable accumulation rates which ranged from 0.48 g m^{-2} yr^{-1} in the fringe to 0.11 g m^{-2} yr^{-1} in the basin, with an average accumulation rate of 0.30 g m^{-2} yr^{-1}. Accumulation rates at Rookery Bay were very similar among the cores with an average rate of 0.18 g m^{-2} yr^{-1}.

DISCUSSION

Net ecosystem production or accumulation in mangroves is dependent on the balance of export, production and respiration within a given forest location. Variations in nutrient concentrations and accumulation at Rookery Bay and Terminos Lagoon can generally be explained in the context of the differing environmental settings which in turn, determine export, production and respiration. Hydrologic energy decreases within any given mangrove forest as one travels inland (Twilley et al. 1986) and differences between fringe and inland accumulation rates are apparently related to this decrease in hydrologic energy. Most processes within and among mangroves, including accumulation, are hypothesized to follow a pattern which relates to the local hydrologic activity.

Nutrient Concentrations

Nutrient concentrations indicate that sediments in Boca Chica are influenced the most by inorganic materials, followed by Estero Pargo and Rookery Bay. Rookery Bay soils were very high in organic matter, carbon and especially nitrogen content. Compared with available published data, organic matter, carbon and nitrogen concentrations at Rookery Bay were generally 2-3 times higher than other reported values for mangrove sediments (Table 2.6). Phosphorus concentrations appear to be similar among most mangroves at about 0.5 mg

Table 2.6 Reported literature values of bulk density (BD, g cm^{-3}), organic matter (OM, mg/gdw) and carbon, nitrogen and phosphorus concentrations (mg gdw^{-1}) for mangrove sediments.

Location	Depth (cm)	BD	OM	C	N	P	Notes/Forest type	Source
Australia								
N. Queensland	0-5 & 95-100	0.47		102	2.4	0.36	average of 9 sites	Boto and Wellington
(1984)								
Sydney	surface		113					Clark and Hannon
(1967)								
	subsurface		52					
New Zealand								
Tuff Crater	surface		131	30	2.8	0.61	<u>Avicennia</u>	Woodroffe (1985)
Malaysia								
Rejang delta	?					0.29		Chai (1974)
Lawas reserve	?					0.17		
Matang	?			137	5.4			Putz and Chan (1986)
Japan								
Ishigaki Is.	0-50			127	4.9		<u>Rhizophora</u>	Higashi & Shinagawa
(1985)								
				176	10.0		Mixed forest	
				137	8.0		<u>Bruguiera</u>	
India								
	?			22	3.6		<u>Avicennia</u>	Navalkar &
Bharuchar(1949)								
Africa								
South Africa	0-40	0.88	50				<u>Rhizophora</u>	Naidoo (1980)
		0.95	42				<u>Bruguiera</u>	
Sierra Leone	?			46	3.5	0.75	Alluvium	Hesse (1961)
	?			119	4.4	1.51	<u>Rhizophora</u>	
	?			55	3.9	1.29	<u>Avicennia</u>	
Senegal	0-40	[illegible]		44	1.6		Casamance river	Marius (1981)
		1.00		18	0.8		Saloum river	
Gambia		0.57		43	1.7		Gambia river	
	0-52			66			<u>Rhizophora</u>	Giglioli &
Thornton(1965)								
	0-46			71			<u>Avicennia</u>	
North America								
United States								
Florida	0-48		495	262	12.2		Mixed forest	Coultas (1978)
	0-46		348	191	14.0		<u>Rhizophora</u>	
	0-49		154	72	2.4		<u>Avicennia</u>/<u>Laguncularia</u>	
	0-45		421	215	11.7	0.65	Mixed forest	Twilley (1982)
			414	191	12.8	0.53	<u>Avicennia</u>	
10,30,50m	0-40	0.22	504	234	12.9	0.49	Mixed forest	This study
70m		0.22	542	256	14.1	0.41	<u>Avicennia</u>	
Mexico								
Boca Chica								
Fringe	0-40	0.41	224	101	3.2	0.43	<u>Rhiz</u>/<u>Lagunc</u>/<u>Avicenn</u>	This study
Basin		0.94	98	44	1.0	0.53	<u>Avicennia</u>/<u>Laguncularia</u>	
Estero Pargo								
Fringe		0.31	300	135	5.3	0.57	<u>Rhizophora</u>	
Basin		0.40	338	152	6.5	0.33	<u>Avicennia</u>/<u>Laguncularia</u>	

gdw^{-1}. Sediments at Sierra Leone are the only exception with reported phosphorus concentrations of about 1.5 mg gdw^{-1} (Table 2.9). Though numbers for comparison are sometimes few, the differences in organic material concentrations may reflect the low flushing and export that occurs in these low energy mangrove forests. Hydrologic information on the other mangroves could help to explain the differences in sediment concentrations among different forests.

Concentrations of carbon and nitrogen at Rookery Bay are generally higher when compared to temperate saltmarshes whereas, concentrations in Terminos Lagoon are similar to temperate saltmarshes. Carbon concentrations averaged 268 and 122 mg gdw^{-1} at the Florida and Mexico sites, respectively. These values compare to carbon values ranging from about 16 to 240 mg gdw^{-1} in temperate saltmarshes (Nixon 1980, DeLaune et. al. 1981). Nitrogen concentrations averaged 15.7 and 4.7 mg gdw^{-1} at the Rookery Bay and Terminos Lagoon sites, respectively. Nitrogen concentration in saltmarsh sediments appear to be much lower than that of Rookery Bay sediments ranging from about 1.5 to 8.8 mg gdw^{-1} (Nixon 1980, DeLaune et al. 1981). Phosphorus concentrations at Rookery Bay and Terminos Lagoon are similar in value and slightly higher than many saltmarsh systems (Nixon 1980) though similar in value to a saltmarsh in Louisiana (DeLaune et al. 1981).

Nutrient Accumulation

Lack of sampling in the fringe zone at Rookery Bay makes comparisons between fringe and basin mangroves impossible. However, within the basin forest, a continuum can be observed with respect to these nutrients if one compares nutrient accumulation as a percentage of total sediment accumulation (Table 2.7). Sediments nearest to the fringe at Rookery Bay were higher in inorganic content than the sediments inland. Inland, basin cores had higher percentages of organic matter, carbon and nitrogen.

Estero Pargo was similar to Rookery Bay with higher percentages of inorganic material and phosphorus at the fringe and higher percentages of organic matter, carbon and nitrogen in the basin sediments. At Boca Chica, the fringe cores had higher percentages of organic matter, carbon and nitrogen than inland cores which had higher percentages of inorganic matter and phosphorus. The unique hydrology of this site may account for the highly inorganic nature of the basin forest. Boca Chica is rarely inundated by tidal activity and the hydrologic energy at this site revolves around the seasonal inundation of the entire forest floor during the rainy season. Peak litterfall in mangroves generally occurs during the rainy season (Day et al. 1987, Twilley 1985) and at Boca Chica, this usually occurs when the forest floor is completely covered with freshwater, thus any litterfall is carried out of the forest and very little organic matter accumulates in the basin

Table 2.7 Rookery Bay, Florida and Terminos Lagoon, Mexico contributions of organic matter, inorganic matter, carbon, nitrogen, and phosphorus expressed as a percentage of total sediment accumulation. Also, the percentage of net primary productivity and litterfall that is accumulated in sediments (based on carbon flux).

	% of total sediment accumulation					%NPP	%Litter
	Org	Inorg	C	N	P		
Boca Chica	18.1	81.8	8.2	0.24	0.049	11.9	23.4
Fringe	22.6	77.4	10.2	0.32	0.043		
Basin	11.4	88.5	5.1	0.13	0.057		
Estero Pargo	35.0	65.0	15.7	0.65	0.052	13.3	25.7
Fringe	32.3	67.8	14.6	0.57	0.057		
Basin	42.1	57.9	19.1	0.86	0.036		
Rookery Bay	58.7	41.3	26.7	1.56	0.056	17.1	27.3
10 m	52.4	47.6	23.9	1.40	0.053		
30 m	56.6	43.4	18.9	1.58	0.057		
50 m	64.4	35.5	28.6	1.56	0.056		
70 m	62.0	38.0	28.7	1.73	0.052		

($g\ C\ m^{-2}\ yr^{-1}$)	Boca Chica[1]	Estero Pargo[1]	Rookery Bay[2]
NPP	1032.2	674.5	504.0
Litterfall	525.8	350.3	318.0

1 - Day et al 1987 : assumes 42% of dry mass is carbon.
2 - Twilley 1988

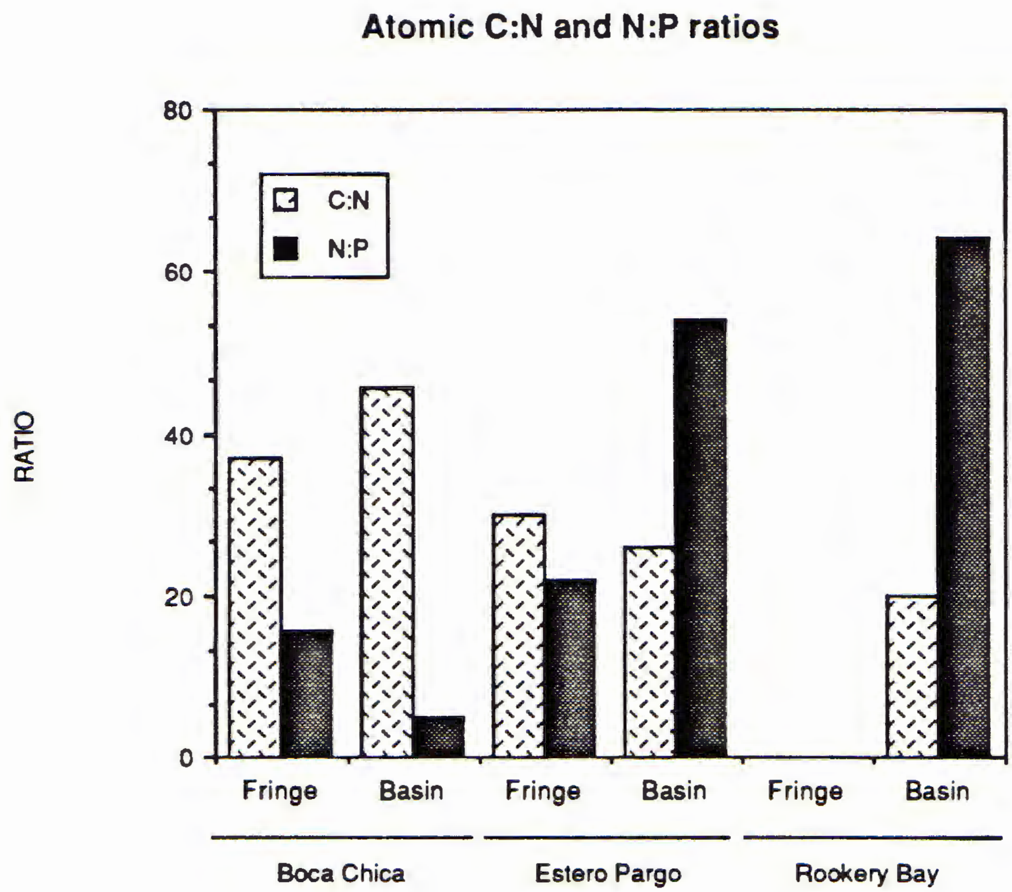
sediments. Species composition may also account for some differences as the basin site is composed of A. germinans and the fringe site, A. germinans, R. mangle and L. racemosa.

Average nutrient contributions relative to total sediment accumulation can be ranked among these three different mangrove forests in a manner similar to that used to describe the structure and productivity in mangrove forests (Lugo and Snedaker 1974, Pool et al. 1975, Twilley 1985, 1988) where riverine productivity> fringe productivity> basin productivity). In terms of sediment burial the riverine, Boca Chica forest clearly has the highest rates, followed by Estero Pargo and Rookery Bay (Fig. 2.1). Inorganic matter composed the greatest percentage of sediment accumulation at Boca Chica, accounting for over 80% of all materials buried. Rookery Bay had the lowest inorganic contribution of 41%. Organic contributions to sediment accumulation were highest at Rookery Bay, where almost 60% of the sediment accumulation is due to organic materials (Fig 2.1). Estero Pargo sediment accumulation was composed of 35% organic matter and Boca Chica was lowest with 18% organic composition (Table 2.7). Rookery Bay also had the highest percentages of carbon, nitrogen and phosphorus accumulation to sediment accumulation (Table 2.7).

Atomic C:N and N:P ratios provide information on the relative nutrient status of these three forests (Fig. 2.3). In general, the Boca Chica cores have higher C:N ratios due to low nitrogen accumulation in the sediments. This ratio drops in the Estero Pargo and is lowest in Rookery Bay where there is large accumulation of nitrogen. The opposite is true with respect to N:P ratios. The high loading of phosphorus associated with inorganic material at Boca Chica results in low N:P ratios. The basin cores at Estero Pargo and Rookery Bay have very high N:P ratios due to the lack of phosphorus accumulation. Differences in the relative burial of these nutrients may be useful in accounting for the differences in structure/productivity among mangrove forests.

One can better understand the importance of storage to mangrove processes by looking at the burial of carbon relative to net primary productivity (NPP) or litterfall (Table 2.8). Hopkinson (1988) looked at this parameter in examining the coupling of coastal saltmarshes and adjacent waters. The greater the storage of carbon in the sediments, the less available for export and or production. Storage of carbon relative to NPP was greatest at Rookery Bay (17%) and was least at Boca Chica (12%, Table 2.7). It has been suggested that mangrove forests with lower levels of hydrologic energy would have higher carbon storage in the sediments due to the lack of inundation (Heald 1969, Lugo and Snedaker 1974, Boto and Bunt 1981, Twilley 1985, Twilley et al. 1986). This is the first study to show that burial of organic matter is higher in mangroves exposed to low hydrologic energy. Comparison of carbon accumulation and litterfall, a component of NPP, also indicates that carbon storage is indeed, greater

Figure 2.3 Atomic C:N and N:P ratios for the Terminos Lagoon, Mexico and Rookery Bay, Florida cores.


Atomic C:N and N:P ratios
80
60
40
20
0
RATIO
C:N
N:P
Fringe
Basin
Fringe
Basin
Fringe
Basin
Boca Chica
Estero Pargo
Rookery Bay

in lower energy environments.

Burial of carbon relative to NPP in mangroves averages about 10-15% and is higher than many saltmarshes in the United States (Hopkinson 1988). Flax Pond in New York is the one marsh which had higher values of 19-37%. Values of organic carbon burial are also less than the high rates reported for coastal wetlands in Louisiana (Smith et al. 1983, DeLaune et al. 1981, Hatton et al. 1983) which represented 21 to 54% of the net production (Feijtel et al. 1985). Storage in mangrove forests is a combination of burial and biomass increases in the trees. Actual percentages of NPP that is buried in mangrove forests should be higher due to this storage of biomass within mangrove trees. This is not assumed to be the case with salt marsh vegetation where burial only reflects storage in the sediments (Hopkinson 1988).

One of the most important applications of accumulation rates in mangroves relates to nutrient budgets. Net ecosystem production (NEP) or burial is a component of the organic matter budget and can be used in a mass balance of fluxes within a mangrove forest. Determining whether or not a mangrove ecosystem is autotrophic or heterotrophic is dependent on knowing the storage within the forest.

Average carbon storage within the basin forest at Rookery Bay can be used with existing data to determine the carbon budget for this forest. Average carbon accumulation removes an average of 86 gC m^{-2} yr^{-1} which does not agree with NEP-growth values of 652 gC m^{-2} yr^{-1}. Accuracy of a nutrient budget are only as accurate as the measurements of each flow within the system. Determination of accumulation is only one flux in this system. Even though most flows are determined for this basin forest, further investigations are needed to correct for the apparent inaccurate carbon fluxes. Irregardless, the measure of nutrient burial in mangrove ecosystems is useful in that it provides a means to understand the structure and function of wetlands and how they interact with other ecosystems.

SUMMARY

Accretion rates

Both mangrove forests in Florida and Mexico appear to be maintaining their position relative to the apparent sea level rise in the Gulf of Mexico based upon their accretion rates. Though values for comparison are few, sea level rise values ranging from 1.4 - 1.6 mm yr^{-1} (Gornitz et al. 1982, DeLaune et al. 1983) compare favorably with the average rates of accretion at both the Rookery Bay and basin Terminos Lagoon sites. Values in excess of sea level rise at the fringe sites in Terminos Lagoon are assumed to be a result of subsidence.

Consolidation corrections are commonly considered in analysis of marine, lake and estuarine sediment cores (Nittrouer et al. 1984, Brush et al. 1982, Busch and Keller ..2). Compaction is also a common phenomenon found in wetland sediments (Harrison and Bloom 1977, Nixon 1980, Woodroffe 1981, Stevenson et al. 1983), but has not appeared to be an important consideration in the determination of accretion in many wetland systems. This phenomenon however, appears to be of great importance in the interpretation of many of the cores taken in Florida and Mexico. Cores with high organic content are greatly affected by these corrections as seen in the Estero Pargo and Rookery Bay cores. The calculation of these rates is dependent on many variables and is a highly subjective practice. One can only assume that these rates are representative values for the system as a whole. Further detailed analyses of consolidation are needed in correlation with other analysis to better understand the nature of accretion and the validity of these radionuclides in quantifying this process in mangrove wetlands.

Accumulation rates

Accumulation rates in mangrove wetlands are closely linked to local environmental settings and especially differences in hydrologic energy. Differences in hydrologic energy are quite evident in the Terminos Lagoon cores where the riverine influenced Boca Chica cores were very high in sediment accumulation of which a majority was due to inorganic materials. Phosphorus accumulation is apparently linked with these inorganic sediments as seen in the Boca Chica cores. Accumula n in the tidally influenced Estero Pargo and Rookery Bay is much more influenced by organic materials such as carbon and nitrogen. Atomic C:N and N:P ratios indicate that the riverine influenced Boca Chica cores are possibly limited relative to nitrogen and more tidally influenced, Estero Pargo and Rookery Bay cores by phosphorus. The high productivity of the Boca Chica site indicates that the high phosphorus loading and or freshwater input at this site may contribute to the increased productivity in these mangroves. The association of productive mangroves with these hydrologically active areas warrants further study.

The interaction between mangrove ecosystems and adjacent bodies of water is dependent of the balance of material flows within mangrove forests. An accurate characterization of the importance of mangrove ecosystems to these waters must involve the determination of these material fluxes.

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APPENDIX

Table A.1 Data for Rookery Bay, Florida, 10 meters inland from berm including consolidation corrected depth (cm), ^{210}Pb total, ^{210}Pb excess and ^{137}Cs activities (dpm g^{-1}).

Original Depth (cm)	Compaction Corrected Depth (cm)	^{210}Pb total (dpm g^{-1})	^{210}Pb excess (dpm g^{-1})	^{137}Cs (dpm g^{-1})
1±1	0.57±0.57	10.62±0.23	8.90±0.24	0.45±0.31
3±1	1.70±0.57	7.26±0.34	5.54±0.28	1.37±0.84
5±1	3.07±0.81	6.89±0.26	5.17±0.22	1.20±0.71
7±1	4.43±0.55	6.38±0.30	4.66±0.23	1.92±1.14
9±1	5.56±0.58	4.98±0.14	3.26±0.11	0.79±0.48
11±1	6.94±0.81	4.63±0.07	2.91±0.07	0.55±0.34
13±1	8.54±0.80	3.38±0.05	1.66±0.04	0.08±0.05
15±1	10.20±0.86	2.69±0.04	0.97±0.02	
17±1	11.80±0.74	3.35±0.06	1.64±0.04	
19±1	13.57±1.03	2.37±0.08	0.65±0.02	
21±1	15.55±0.95	2.17±0.05	0.45±0.01	
23±1	17.67±1.17	2.14±0.04	0.42±0.01	
25±1	20.03±1.19	1.58±0.04		
27±1	22.27±1.04	2.87±0.04		
29±1	24.38±1.07	1.72±0.02		
31±1	26.25±0.81	1.88±0.04		
33±1	27.98±0.91	1.29±0.02		
35±1	29.93±1.04	1.51±0.04		
37±1	32.08±1.12	1.36±0.02		
39±1	34.32±1.12	1.52±0.02		

^{210}Pb supported = 1.72±0.03

Accretion rate :
^{137}Cs no compaction = 2.9 mm yr^{-1}
^{137}Cs compaction = 1.8 mm yr^{-1}
^{210}Pb no compaction = 2.5 mm yr^{-1}
^{210}Pb compaction = 1.7 mm yr^{-1}

Table A.2 Data for Rookery Bay, Florida, 10 meters inland from berm including consolidation corrected depth (cm), bulk density (g cm^{-3}), water content (%), organic and inorganic matter (mg gdw^{-1}).

Original Depth (cm)	Compaction Corrected Depth (cm)	Bulk Density (g cm^{-3})	Water Content (%)	Organic Matter (mg gdw^{-1})	Inorganic Matter (mg gdw^{-1})
1±1	0.57±0.57	0.160	79.6	646.3	353.7
3±1	1.70±0.57	0.159	80.4	640.7	359.3
5±1	3.07±0.81	0.227	79.3	611.1	388.9
7±1	4.43±0.55	0.155	80.3	550.4	449.6
9±1	5.56±0.58	0.162	80.5	545.5	454.5
11±1	6.94±0.81	0.227	80.1	523.7	476.3
13±1	8.54±0.80	0.224	78.9	481.6	518.4
15±1	10.20±0.86	0.242	78.8	499.0	501.0
17±1	11.80±0.74	0.208	79.9	492.6	507.4
19±1	13.57±1.03	0.290	76.7	462.4	537.6
21±1	15.55±0.95	0.267	72.7	419.5	580.5
23±1	17.67±1.17	0.330	72.5	401.7	598.3
25±1	20.03±1.19	0.335	72.9	336.6	663.4
27±1	22.27±1.04	0.294	75.4	324.5	675.5
29±1	24.38±1.07	0.300	73.0	367.0	633.0
31±1	26.25±0.81	0.228	73.5	341.2	658.8
33±1	27.98±0.91	0.257	71.7	334.9	665.1
35±1	29.93±1.04	0.292	75.9	392.3	607.7
37±1	32.08±1.12	0.314	74.6	292.9	707.1
39±1	34.32±1.12	0.316	73.5	290.7	709.3
Average :		0.250	76.5	447.7	552.3
Std error:		0.013	0.7	25.5	25.5

Table A.3 Data for Rookery Bay, Florida, 10 meters inland from berm including consolidation corrected depth (cm), total carbon, nitrogen, and phosphorus (mg gdw^{-1}) and atomic carbon : nitrogen (C:N) and nitrogen : phosphorus ratios.

Original Depth (cm)	Compaction Corrected Depth (cm)	Carbon Content	Nitrogen Content (mg gdw^{-1})	Phosphorus Content	Atomic C:N Ratio	Atomic N:P Ratio
1±1	0.57±0.57	282.1	16.5	0.67	20	55
3±1	1.70±0.57	288.8	17.7	0.63	19	62
5±1	3.07±0.81	288.1	16.3	0.55	21	65
7±1	4.43±0.55	254.3	14.9	0.51	20	64
9±1	5.56±0.58	235.2	14.2	0.59	19	53
11±1	6.94±0.81	227.0	14.3	0.58	18	54
13±1	8.54±0.80	240.8	13.6	0.47	21	64
15±1	10.20±0.86	235.7	14.0	0.42	20	73
17±1	11.80±0.74	220.0	12.4	0.47	21	59
19±1	13.57±1.03	204.9	11.5	0.45	21	57
21±1	15.55±0.95	211.1	11.4	0.44	22	57
23±1	17.67±1.17	201.5	11.1	0.43	21	57
25±1	20.03±1.19	142.7	8.1	0.46	21	39
27±1	22.27±1.04	158.3	7.6	0.48	24	35
29±1	24.38±1.07	167.9	9.2	0.40	21	51
31±1	26.25±0.81	254.0	11.7	0.42	25	62
33±1	27.98±0.91	134.3	5.6	0.43	28	29
35±1	29.93±1.04	164.0	8.2	0.40	23	45
37±1	32.08±1.12	149.1	7.3	0.40	24	40
39±1	34.32±1.12	201.1	9.7	0.38	24	56
Average :		213.0	11.8	0.48	22	54
Std error :		10.8	0.8	0.02	1	2

Table A.4 Data for Rookery Bay, Florida, 30 meters inland from berm including consolidation corrected depth (cm), ^{210}Pb total, ^{210}Pb excess and ^{137}Cs activities (dpm g^{-1}).

Original Depth (cm)	Compaction Corrected Depth (cm)	^{210}Pb total (dpm g^{-1})	^{210}Pb excess (dpm g^{-1})	^{137}Cs (dpm g^{-1})
1±1	0.56±0.56	12.30±0.39	10.24±0.36	0.18±0.12
3±1	1.69±0.56	10.46±0.30	8.39±0.28	0.36±0.22
5±1	2.97±0.71	9.60±0.26	7.54±0.24	1.04±0.56
7±1	4.39±0.71	6.25±0.08	4.19±0.09	1.23±0.64
9±1	5.73±0.63	5.05±0.11	2.98±0.08	0.79±0.43
11±1	6.92±0.55	3.98±0.09	1.91±0.06	0.41±0.24
13±1	8.15±0.67	4.36±0.08	2.30±0.06	0.30±0.18
15±1	9.42±0.60	3.78±0.07	1.71±0.04	
17±1	10.75±0.72	3.19±0.05	1.13±0.03	
19±1	12.31±0.83	2.77±0.05	0.71±0.02	
21±1	14.11±0.97	2.20±0.04	0.13±0.00	
23±1	16.24±1.17	1.78±0.02		
25±1	18.27±0.86	3.05±0.04		
27±1	20.30±1.17	1.22±0.04		

^{210}Pb supported = 2.06±0.03

Accretion rate : ^{137}Cs no compaction = 2.9 mm yr^{-1}
^{137}Cs compaction = 1.8 mm yr^{-1}
^{210}Pb no compaction = 2.1 mm yr^{-1}
^{210}Pb compaction = 1.4 mm yr^{-1}

Table A.5 Data for Rookery Bay, Florida, 30 meters inland from berm including consolidation corrected depth (cm), bulk density (g cm^{-3}), water content (%), organic and inorganic matter (mg gdw^{-1}).

Original Depth (cm)	Compaction Corrected Depth (cm)	Bulk Density (g cm^{-3})	Water Content (%)	Organic Matter (mg gdw^{-1})	Inorganic Matter (mg gdw^{-1})
1±1	0.56±0.56	0.156	80.1	713.1	286.9
3±1	1.69±0.56	0.155	79.6	702.8	297.2
5±1	2.97±0.71	0.197	78.4	671.9	328.1
7±1	4.39±0.71	0.196	79.0	608.0	392.0
9±1	5.73±0.63	0.175	79.9	555.2	444.8
11±1	6.92±0.55	0.153	80.4	548.7	451.3
13±1	8.15±0.67	0.186	79.9	514.5	485.5
15±1	9.42±0.60	0.167	79.6	515.8	484.2
17±1	10.75±0.72	0.200	79.4	492.6	507.4
19±1	12.31±1.83	0.229	78.7	448.6	551.4
21±1	14.11±0.97	0.268	76.7	429.9	570.1
23±1	16.24±1.17	0.322	73.6	404.8	595.2
25±1	18.27±0.86	0.238	75.1	424.1	575.9
27±1	20.30±1.17	0.324	74.6	376.4	623.6
Average :		0.212	78.2	529.0	471.0
Std error :		0.016	0.6	29.6	29.6

Table A.6 Data for Rookery Bay, Florida, 30 meters inland from berm including consolidation corrected depth (cm), total carbon, nitrogen, and phosphorus (mg gdw^{-1}) and atomic carbon : nitrogen (C:N) and nitrogen : phosphorus (N:P) ratios.

Original Depth (cm)	Compaction Corrected Depth (cm)	Carbon Content (mg gdw^{-1})	Nitrogen Content (mg gdw^{-1})	Phosphorus Content (mg gdw^{-1})	Atomic C:N Ratio	Atomic N:P Ratio
1±1	0.56±0.56	343.6	19.5	0.67	21	64
3±1	1.69±0.56	318.1	18.6	0.71	20	58
5±1	2.97±0.71	288.8	18.7	0.68	18	61
7±1	4.39±0.71	271.3	17.3	0.65	18	59
9±1	5.73±0.63	247.0	16.1	0.63	18	56
11±1	6.92±0.55	266.0	17.3	0.63	18	60
13±1	8.15±0.67	229.7	14.9	0.60	18	55
15±1	9.42±0.60	234.3	12.8	0.61	21	46
17±1	10.75±0.72	244.4	13.2	0.26	22	111
19±1	12.31±0.83	203.3	12.4	0.51	19	53
21±1	14.11±0.97	217.6	12.7	0.44	20	63
23±1	16.24±1.17	186.8	9.1	0.40	24	50
25±1	18.27±0.86	206.1	10.9	0.38	22	64
27±1	20.30±1.17	201.6	9.8	0.36	24	62
Average :		247[illegible]	14.5	0.54	20	62
Std error :		12[illegible]	0.9	0.04	1	4

Table A.7 Data for Rookery Bay, Florida, 50 meters inland from berm including consolidation corrected depth (cm), ^{210}Pb total, ^{210}Pb excess and ^{137}Cs activities (dpm g^{-1}).

Original Depth (cm)	Compaction Corrected Depth (cm)	^{210}Pb total (dpm g^{-1})	^{210}Pb excess (dpm g^{-1})	^{137}Cs (dpm g^{-1})
1±1	0.65±0.65	8.89±0.18	6.41±0.17	0.35±0.28
3±1	1.94±0.64	10.99±0.27	8.51±0.26	0.96±0.77
5±1	3.34±0.75	7.87±0.11	5.39±0.12	0.95±0.73
7±1	4.88±0.79	7.80±0.15	5.32±0.14	1.59±1.21
9±1	6.33±0.66	4.91±0.08	2.43±0.06	1.16±0.89
11±1	7.81±0.82	4.48±0.08	2.00±0.05	0.45±0.36
13±1	9.25±0.63	5.33±0.04	2.85±0.06	0.14±0.12
15±1	10.95±1.06	3.92±0.04	1.44±0.03	
17±1	12.97±0.95	2.96±0.03	0.48±0.01	
19±1	14.69±0.78	1.84±0.05		
21±1	16.29±0.82	2.52±0.04		
23±1	18.14±1.03	2.78±0.06		
25±1	20.07±0.90	2.55±0.05		
27±1	22.00±1.04	2.71±0.03		
29±1	23.98±0.93	2.82±0.03		
31±1	25.94±1.04	2.90±0.03		
33±1	28.08±1.10	2.40±0.05		
35±1	29.98±0.80	2.07±0.05		
37±1	31.76±0.97	3.00±0.07		
39±1	33.82±1.09	1.69±0.03		

^{210}Pb supported = 2.48±0.04

Accretion rate :
^{137}Cs no compaction = 2.9 mm yr^{-1}
^{137}Cs compaction = 2.0 mm yr^{-1}
^{210}Pb no compaction = 2.5 mm yr^{-1}
^{210}Pb compaction = 1.6 mm yr^{-1}

Table A.8 Data for Rookery Bay, Florida, 50 meters inland from berm including consolidation corrected depth (cm), bulk density (g cm^{-3}), water content (%), organic and inorganic matter (mg gdw^{-1}).

Original Depth (cm)	Compaction Corrected Depth (cm)	Bulk Density (g cm^{-3})	Water Content (%)	Organic Matter (mg gdw^{-1})	Inorganic Matter (mg gdw^{-1})
1±1	0.65±0.65	0.157	80.9	724.6	275.4
3±1	1.94±0.64	0.156	79.8	713.1	286.9
5±1	3.34±0.75	0.183	80.2	704.9	295.1
7±1	4.88±0.79	0.192	79.4	635.2	364.8
9±1	6.33±0.66	0.159	81.8	649.9	350.1
11±1	7.81±0.82	0.198	82.4	639.0	361.0
13±1	9.25±0.63	0.153	80.9	621.0	379.0
15±1	10.95±1.06	0.258	78.8	563.8	436.2
17±1	12.97±0.95	0.231	78.9	532.7	467.3
19±1	14.69±0.78	0.188	80.1	506.7	493.3
21±1	16.29±0.82	0.199	79.5	482.0	518.0
23±1	18.14±1.03	0.250	78.5	477.8	522.2
25±1	20.07±0.90	0.217	78.4	455.6	544.4
27±1	22.00±1.04	0.252	77.1	448.6	551.4
29±1	23.98±0.93	0.226	77.7	451.7	548.3
31±1	25.94±1.04	0.251	77.1	460.7	539.3
33±1	28.08±1.10	0.266	78.1	409.1	590.9
35±1	29.98±0.80	0.195	79.3	431.2	568.8
37±1	31.76±0.97	0.236	74.7	432.6	567.4
39±1	33.82±1.09	0.264	74.4	408.2	591.8
Average :		0.212	78.9	537.4	462.6
Std error :		0.009	0.5	24.3	24.3

Table A.9 Data for Rookery Bay, Florida, 50 meters inland from berm including consolidation corrected depth (cm), total carbon, nitrogen, and phosphorus (mg gdw^{-1}) and atomic carbon : nitrogen (C:N) and nitrogen : phosphorus (N:P) ratios.

Original Depth (cm)	Compaction Corrected Depth (cm)	Carbon Content (mg gdw^{-1})	Nitrogen Content (mg gdw^{-1})	Phosphorus Content (mg gdw^{-1})	Atomic C:N Ratio	Atomic N:P Ratio
1±1	0.65±0.65	322.5	17.2	0.67	22	57
3±1	1.94±0.64	335.6	19.2	0.60	20	70
5±1	3.34±0.75	312.6	17.9	0.55	20	71
7±1	4.88±0.79	273.1	14.2	0.49	22	64
9±1	6.33±0.66	299.5	15.7	0.48	22	72
11±1	7.81±0.82	287.3	16.0	0.45	21	78
13±1	9.25±0.63	259.8	14.4	0.49	21	65
15±1	10.95±1.06	261.2	13.7	0.46	22	65
17±1	12.97±0.95	235.9	12.5	0.37	22	74
19±1	14.69±0.78	241.4	13.3	0.39	21	75
21±1	16.29±0.82	210.4	11.4	0.39	21	65
23±1	18.14±1.03	239.0	11.7	0.42	24	61
25±1	20.07±0.90	202.0	10.0	0.42	24	52
27±1	22.00±1.04	186.8	9.9	0.40	22	54
29±1	23.98±0.93	199.2	9.7	0.40	24	54
31±1	25.94±1.04	209.0	9.8	0.39	25	56
33±1	28.08±1.10	193.6	8.6	0.37	26	52
35±1	29.98±0.80	175.6	8.2	0.35	25	52
37±1	31.76±0.97	191.8	8.6	0.35	26	54
39±1	33.82±1.09	191.3	8.1	0.35	28	51
Average :		241.4	12.5	0.44	23	62
Std error :		11.2	0.8	0.02	0	2

Table A.10 Data for Rookery Bay, Florida, 70 meters inland from berm including consolidation corrected depth (cm), ^{210}Pb total, ^{210}Pb excess and ^{137}Cs activities (dpm g^{-1}).

Original Depth (cm)	Compaction Corrected Depth (cm)	^{210}Pb total (dpm g^{-1})	^{210}Pb excess (dpm g^{-1})	^{137}Cs (dpm g_{-1})
1±1	0.49±0.49	7.44±0.32	4.69±0.22	0.34±0.22
3±1	1.61±0.63	6.67±0.16	3.92±0.11	0.90±0.45
5±1	2.84±0.61	5.99±0.18	3.24±0.11	1.09±0.53
7±1	4.39±0.94	4.24±0.07	1.49±0.03	1.57±0.73
9±1	6.01±0.68	3.44±0.03	0.69±0.01	0.64±0.31
11±1	7.37±0.68	3.75±0.06	1.00±0.02	0.18±0.09
13±1	8.95±0.90	3.86±0.07	1.10±0.03	
15±1	10.48±0.63	3.60±0.06	0.84±0.02	
17±1	11.89±0.78	2.29±0.10		
19±1	13.31±0.64	1.78±0.03		
21±1	14.57±0.62	2.50±0.03		
23±1	15.97±0.78	3.24±0.05		
25±1	17.37±0.63	2.77±0.04		
27±1	18.69±0.68	3.04±0.03		
29±1	20.12±0.75	2.95±0.04		
31±1	21.68±0.82	3.62±0.05		
33±1	23.34±0.84	3.16±0.04		
35±1	25.28±1.11	3.13±0.04		
37±1	27.51±1.12			
39±1	29.74±1.12	1.80±0.03		

^{210}Pb supported = 2.75±0.04

Accretion rate : ^{137}Cs no compaction = 2.9 mm yr^{-1}
^{137}Cs compaction = 1.8 mm yr^{-1}
^{210}Pb no compaction = 2.3 mm yr^{-1}
^{210}Pb compaction = 1.6 mm yr^{-1}

Table A.11 Data for Rookery Bay, Florida, 70 meters inland from berm including consolidation corrected depth (cm), bulk density (g cm^{-3}), water content (%), organic and inorganic matter (mg gdw^{-1}).

Original Depth (cm)	Compaction Corrected Depth (cm)	Bulk Density (g cm^{-3})	Water Content (%)	Organic Matter (mg gdw^{-1})	Inorganic Matter (mg gdw^{-1})
1±1	0.49±0.49	0.143	82.8	720.5	279.5
3±1	1.61±0.63	0.183	80.6	661.4	338.6
5±1	2.84±0.61	0.179	79.8	618.6	381.4
7±1	4.39±0.94	0.274	76.4	605.4	394.6
9±1	6.01±0.68	0.198	79.0	619.8	380.2
11±1	7.37±0.68	0.199	79.4	589.9	410.1
13±1	8.95±0.90	0.263	78.6	567.9	432.1
15±1	10.48±0.63	0.184	79.9	578.6	421.4
17±1	11.89±0.78	0.228	78.3	549.0	451.0
19±1	13.31±0.64	0.188	80.4	576.7	423.3
21±1	14.57±0.62	0.180	81.1	546.4	453.6
23±1	15.97±0.78	0.227	78.1	497.2	502.8
25±1	17.37±0.63	0.184	80.3	488.8	511.2
27±1	18.69±0.68	0.200	80.8	513.2	486.8
29±1	20.12±0.75	0.218	78.4	474.3	525.7
31±1	21.68±0.82	0.240	77.2	469.2	530.8
33±1	23.34±0.84	0.244	74.3	463.1	536.9
35±1	25.28±1.11	0.324	74.2	462.8	537.2
37±1	27.51±1.12	0.326	70.8	426.0	574.0
39±1	29.74±1.12	0.327	70.3	415.1	584.9
Average :		0.225	78.0	542.2	457.8
Std error :		0.012	0.7	18.2	18.2

Table A.12 Data for Rookery Bay, Florida, 70 meters inland from berm including consolidation corrected depth (cm), total carbon, nitrogen, and phosphorus (mg gdw^{-1}) and atomic carbon : nitrogen (C:N) and nitrogen : phosphorus (N:P) ratios.

Original Depth (cm)	Compaction Corrected Depth (cm)	Carbon Content (mg gdw^{-1})	Nitrogen Content (mg gdw^{-1})	Phosphorus Content (mg gdw^{-1})	Atomic C:N Ratio	Atomic N:P Ratio
1±1	0.49±0.49	346.8	22.6	0.75	18	66
3±1	1.61±0.63	318.5	19.6	0.64	19	68
5±1	2.84±0.61	279.8	18.3	0.55	18	73
7±1	4.39±0.94	278.4	16.3	0.48	20	75
9±1	6.01±0.68	272.1	16.3	0.41	19	87
11±1	7.37±0.68	262.9	14.2	0.39	22	81
13±1	8.95±0.90	268.8	16.2	0.37	19	97
15±1	10.48±0.63	258.6	15.1	0.38	20	88
17±1	11.89±0.78	264.5	14.8	0.31	21	105
19±1	13.31±0.64	279.5	15.2	0.34	21	100
21±1	14.57±0.62	273.5	13.8	0.36	23	86
23±1	15.97±0.78	238.3	12.5	0.33	22	84
25±1	17.37±0.63	243.6	13.0	0.35	22	81
27±1	18.69±0.68	241.7	13.0	0.34	22	84
29±1	20.12±0.75	220.2	11.6	0.29	22	90
31±1	21.68±0.82	238.8	11.7	0.34	24	75
33±1	23.34±0.84	217.9	9.8	0.36	26	60
35±1	25.28±1.11	198.8	9.1	0.39	25	51
37±1	27.51±1.12	213.1	9.7	0.38	26	57
39±1	29.74±1.12	205.0	9.6	0.37	25	57
Average :		256.0	14.1	0.41	22	78
Std error :		8.3	0.8	0.02	1	3

Table A.13 Data for Boca Chica, Mexico, 15 meters inland from river including consolidation corrected depth (cm), ^{210}Pb total, ^{210}Pb excess and ^{137}Cs activities (dpm g^{-1}).

Original Depth (cm)	Compaction Corrected Depth (cm)	^{210}Pb total (dpm g^{-1})	^{210}Pb excess (dpm g^{-1})	^{137}Cs (dpm g^{-1})
1±1	0.50±0.50	5.23±0.09	3.52±0.08	0.00±0.00
3±1	1.60±0.60	5.03±0.09	3.32±0.07	0.03±0.01
5±1	2.86±0.66	6.32±0.15	4.61±0.12	0.22±0.04
7±1	4.10±0.58	7.60±0.08	5.90±0.10	0.17±0.04
9±1	5.55±0.86	4.70±0.16	2.99±0.11	0.34±0.05
11±1	7.34±0.93	5.34±0.16	3.64±0.12	0.28±0.04
13±1	9.12±0.85	5.74±0.24	4.04±0.18	0.63±0.10
15±1	10.99±1.01	4.80±0.17	3.09±0.12	0.35±0.05
17±1	12.89±0.90	4.08±0.13	2.37±0.08	1.08±0.14
19±1	14.57±0.78	4.02±0.13	2.31±0.08	0.59±0.08
21±1	16.29±0.94	4.04±0.16	2.33±0.10	0.68±0.10
23±1	18.25±1.03	2.99±0.09	1.28±0.04	0.35±0.05
25±1	20.33±1.05	2.62±0.05	0.91±0.02	0.21±0.04
27±1	22.56±1.18	2.22±0.05	0.51±0.01	0.13±0.02
29±1	24.84±1.10	2.68±0.07	0.97±0.03	
31±1	27.05±1.10	2.54±0.06	0.83±0.02	
33±1	29.00±0.86	2.41±0.04	0.70±0.01	
35±1	31.07±1.21	2.61±0.04	0.90±0.02	
37±1	33.24±1.96	2.18±0.03	0.47±0.01	
39±1	35.18±0.98	2.14±0.03	0.43±0.01	
41±1	37.15±0.99	1.71±0.02		

^{210}Pb supported = 1.71±0.02

Accretion rate : ^{137}Cs no compaction = 7.1 mm yr^{-1}
^{137}Cs compaction = 5.4 mm yr^{-1}
^{210}Pb no compaction = 4.7 mm yr^{-1}
^{210}Pb compaction = 4.4 mm yr^{-1}

Table A.14 Data for Boca Chica, Mexico, 15 meters inland from river including consolidation corrected depth (cm), bulk density (g cm^{-3}), organic and inorganic matter (mg gdw^{-1}).

Original Depth (cm)	Compaction Corrected Depth (cm)	Bulk Density (g cm^{-3})	Organic Matter (mg gdw^{-1})	Inorganic Matter (mg gdw^{-1})
1±1	0.50±0.50	---	---	---
3±1	1.60±0.60	0.267	298.6	701.4
5±1	2.86±0.66	0.296	353.1	646.9
7±1	4.10±0.58	0.258	334.0	666.0
9±1	5.55±0.86	0.385	284.0	716.0
11±1	7.34±0.93	0.414	240.7	759.3
13±1	9.12±0.85	0.381	264.2	735.8
15±1	10.99±1.01	0.450	232.7	767.3
17±1	12.89±0.90	0.399	214.2	785.8
19±1	14.57±0.78	0.348	207.3	792.7
21±1	16.29±0.94	0.419	203.8	796.2
23±1	18.25±1.03	0.458	191.4	808.6
25±1	20.33±1.05	0.467	168.2	831.8
27±1	22.56±1.18	0.527	170.3	829.7
29±1	24.84±1.10	0.492	181.3	818.7
31±1	27.05±1.10	0.489	176.1	823.9
33±1	29.00±0.86	0.383	180.8	819.2
35±1	31.07±1.21	0.540	199.4	800.6
37±1	33.24±0.96	0.428	201.1	798.9
39±1	35.18±0.98	0.436	191.1	808.9
41±1	37.15±0.99	0.442	185.2	814.8
Average :		0.413	223.9	776.1
Std error :		0.018	12.6	12.6

Table A.15 Data for Boca Chica, Mexico, 15 meters inland from river including consolidation corrected depth (cm), total carbon, nitrogen, and phosphorus (mg gdw^{-1}) and atomic carbon : nitrogen (C:N) and nitrogen : phosphorus (N:P) ratios.

Original Depth (cm)	Compaction Corrected Depth (cm)	Carbon Content (mg gdw^{-1})	Nitrogen Content (mg gdw^{-1})	Phosphorus Content (mg gdw^{-1})	Atomic C:N Ratio	Atomic N:P Ratio
1±1	0.50±0.50	---	3.9	0.47	---	18
3±1	1.60±0.60	134.4	4.1	0.50	40	18
5±1	2.86±0.66	158.9	4.5	0.37	42	26
7±1	4.10±0.58	150.3	4.6	0.40	38	26
9±1	5.55±0.86	127.8	4.1	0.46	36	20
11±1	7.34±0.93	108.3	3.6	0.43	35	18
13±1	9.12±0.85	118.9	4.0	0.45	35	19
15±1	10.99±1.01	104.7	3.5	0.47	35	16
17±1	12.89±0.90	96.4	3.0	0.43	37	16
19±1	14.57±0.78	93.3	3.1	0.43	35	16
21±1	16.29±0.94	91.7	3.0	0.41	35	16
23±1	18.25±1.03	86.1	3.1	0.52	33	13
25±1	20.33±1.05	75.7	2.4	0.41	37	13
27±1	22.56±1.18	76.6	2.2	0.41	40	12
29±1	24.84±1.10	81.6	2.1	0.39	45	12
31±1	27.05±1.10	79.2	2.4	0.38	39	14
33±1	29.00±0.86	81.4	2.3	0.35	41	15
35±1	31.07±1.21	89.7	2.6	0.38	41	15
37±1	33.24±0.96	90.5	2.7	0.51	39	12
39±1	35.18±0.98	86.0	2.6	0.37	39	15
41±1	37.15±0.99	83.3				
Average :		100.7	3.2	0.43	38	16
Std error :		5.5	0.2	0.01	1	1

* - carbon values calculated indirectly by assuming 45% of organic matter is carbon.

Table A.16 Data for Boca Chica, Mexico, 100 meters inland from river including consolidation corrected depth (cm), ^{210}Pb total, ^{210}Pb excess and ^{137}Cs activities (dpm g^{-1}).

Original Depth (cm)	Compaction Corrected Depth (cm)	^{210}Pb total (dpm g^{-1})	^{210}Pb excess (dpm g^{-1})	^{137}Cs (dpm g^{-1})
1±1	0.82±0.82	5.09±0.17	3.73±0.14	0.68±0.27
3±1	2.42±0.79	2.51±0.12	1.15±0.06	0.94±0.37
5±1	4.11±0.91	2.10±0.09	0.74±0.03	0.65±0.26
7±1	6.15±1.12	2.08±0.05	0.72±0.02	0.36±0.15
9±1	8.22±0.95	1.50±0.06	0.14±0.01	0.26±0.11
11±1	10.02±0.85	1.55±0.05	0.19±0.01	0.28±0.12
13±1	11.69±0.82	1.68±0.08	0.33±0.02	0.24±0.10
15±1	13.49±0.97	1.48±0.05	0.12±0.00	
17±1	15.25±0.80	1.19±0.04		
19±1	16.97±0.92	1.24±0.03		
21±1	18.77±0.88	1.29±0.03		
23±1	20.55±0.90	1.50±0.04		
25±1	22.56±1.11	1.32±0.02		
27±1	24.55±0.88	1.33±0.02		
29±1	26.42±0.98	1.21±0.03		
31±1	28.26±0.85	1.34±0.03		
33±1	30.26±1.15	1.36±0.03		
35[illegible]	32.34±0.93	1.65±0.03		
37±1	34.32±1.06	1.39±0.02		
39±1	36.28±0.90	1.49±0.02		
41±1	38.14±0.97	1.44±0.02		

^{210}Pb supported = 1.36±0.03

Accretion rate : ^{137}Cs no compaction = 1.2 mm yr^{-1}
^{137}Cs compaction = 1.0 mm yr^{-1}
^{210}Pb no compaction = 1.4 mm yr^{-1}
^{210}Pb compaction = 1.3 mm yr^{-1}

Table A.17 Data for Boca Chica, Mexico, 100 meters inland from river including consolidation corrected depth (cm), bulk density (g cm^{-3}), organic and inorganic matter (mg gdw^{-1}).

Original Depth (cm)	Compaction Corrected Depth (cm)	Bulk Density (g cm^{-3})	Organic Matter (mg gdw^{-1})	Inorganic Matter (mg gdw^{-1})
1±1	0.82±0.82	0.826	179.4	820.6
3±1	2.42±0.79	0.796	118.1	881.9
5±1	4.11±0.91	0.924	102.3	897.7
7±1	6.15±1.12	1.136	97.0	903.0
9±1	8.22±0.95	0.962	112.2	887.8
11±1	10.02±0.85	0.865	106.4	893.6
13±1	11.69±0.82	0.831	109.1	890.9
15±1	13.49±0.97	0.986	95.3	904.7
17±1	15.25±0.80	0.807	113.2	886.8
19±1	16.97±0.92	0.932	107.2	892.8
21±1	18.77±0.88	0.894	107.9	892.1
23±1	20.55±0.90	0.910	107.9	892.1
25±1	22.56±1.11	1.125	107.7	892.3
27±1	24.55±0.88	0.896	81.3	918.7
29±1	26.42±0.98	0.998	83.3	916.7
31±1	28.26±0.85	0.863	75.6	924.4
33±1	30.26±1.15	1.163	77.2	922.8
35±1	32.[illegible]±0.93	0.941	81.9	918.1
37±1	34.32±1.06	1.072	72.1	927.9
39±1	36.28±0.90	0.910	77.5	922.5
41±1	38.14±0.97	0.981	74.1	925.9
43±1			80.4	919.6
Average :		0.944	98.5	901.5
Std error :		0.023	5.0	5.0

Table A.18 Data for Boca Chica, Mexico, 100 meters inland from river including consolidation corrected depth (cm), total carbon, nitrogen, and phosphorus (mg gdw^{-1}) and atomic carbon : nitrogen (C:N) and nitrogen : phosphorus (N:P) ratios.

Original Depth (cm)	Compaction Corrected Depth (cm)	Carbon Content	Nitrogen Content (mg gdw^{-1})	Phosphorus Content	Atomic C:N Ratio	Atomic N:P Ratio
1±1	0.82±0.82	80.7	3.1	0.58	30	12
3±1	2.42±0.79	53.1	1.6	0.59	38	6
5±1	4.11±0.91	46.0	1.1	0.56	48	4
7±1	6.15±1.12	43.6	0.9	0.53	57	4
9±1	8.22±0.95	50.5	0.9	0.59	63	4
11±1	10.02±0.85	47.9	0.9	0.59	61	4
13±1	11.69±0.82	49.1	0.8	0.55	70	3
15±1	13.49±1.97	42.9	0.8	0.55	60	3
17±1	15.25±0.80	50.9	0.8	0.56	74	3
19±1	16.97±0.92	48.2	0.7	0.54	82	3
21±1	18.77±0.88	48.6	1.0	0.50	56	4
23±1	20.55±0.90	48.6	1.0	0.50	58	4
25±1	22.56±1.11	48.5	0.9	0.53	60	4
27±1	24.55±0.88	36.6	1.0	0.51	41	4
29±1	26.42±0.98	37.5	0.8	0.51	52	4
31±1	28.26±0.85	34.0	0.8	0.52	48	4
33±1	30.26±1.15	3[illegible].7	0.8	0.50	52	4
35±1	32.34±0.93	36.9	0.8	0.46	55	4
37±1	34.32±1.06	32.4	0.8	0.50	47	4
39±1	36.28±0.90	34.9	0.6	0.49	65	3
41±1	38.14±0.97	33.3				
Average :		44.3	1.0	0.53	56	4
Std error :		2.3	0.1	0.01	3	0

* - carbon values calculated indirectly by assuming 45% of organic matter is carbon.

Table A.19 Data for Estero Pargo, Mexico, 10 meters inland from tidal creek including consolidation corrected depth (cm), ^{210}Pb total, ^{210}Pb excess and ^{137}Cs activities (dpm g^{-1}).

Original Depth (cm)	Compaction Corrected Depth (cm)	^{210}Pb total (dpm g^{-1})	^{210}Pb excess (dpm g^{-1})	^{137}Cs (dpm g^{-1})
1±1	0.91±0.91	6.35±0.18	5.36±0.22	0.21±0.05
3±1	2.32±0.67	5.95±0.29	4.95±0.28	0.33±0.07
5±1	3.62±0.63	5.31±0.21	4.32±0.21	0.77±0.16
7±1	5.01±1.76	5.36±0.23	4.36±0.23	0.70±0.13
9±1	6.53±0.76	3.92±0.17	2.92±0.15	1.03±0.19
11±1	7.89±0.60	4.08±0.17	3.08±0.16	1.04±0.20
13±1	9.41±0.92	2.91±0.11	1.91±0.09	0.54±0.11
15±1	11.08±0.76	2.78±0.11	1.78±0.09	0.67±0.13
17±1	12.43±0.59	2.95±0.06	1.96±0.07	0.28±0.07
19±1	13.73±0.71	2.70±0.08	1.70±0.07	0.39±0.08
21±1	15.33±0.89	2.16±0.07	1.17±0.05	0.24±0.05
23±1	17.06±0.84	1.97±0.07	0.97±0.04	
25±1	18.83±0.93	1.87±0.05	0.87±0.03	
27±1	20.75±0.99	1.78±0.06	0.78±0.03	
29±1	22.72±0.98	1.48±0.04	0.48±0.02	
31±1	24.61±0.92	1.50±0.04	0.50±0.02	
33±1	26.51±0.98	1.17±0.03	0.17±0.01	
35±1	28.60±1.11	0.99±0[illegible]		
37±1	30.78±1.07	1.00±[illegible]3		
39±1	32.84±0.99	1.15±0.03		
41±1	34.85±1.02	0.94±0.02		
43±1	36.88±1.01	0.91±0.03		
45±1	38.80±0.91	0.82±0.02		

^{210}Pb supported = 1.00±0.03

Accretion rate :
^{137}Cs no compaction = 4.6 mm yr^{-1}
^{137}Cs compaction = 3.3 mm yr^{-1}
^{210}Pb no compaction = 3.8 mm yr^{-1}
^{210}Pb compaction = 2.9 mm yr^{-1}

Table A.20 Data for Estero Pargo, Mexico, 10 meters inland from tidal creek including consolidation corrected depth (cm), bulk density (g cm^{-3}), organic and inorganic matter (mg gdw^{-1}).

Original Depth (cm)	Compaction Corrected Depth (cm)	Bulk Density (g cm^{-3})	Organic Matter (mg gdw^{-1})	Inorganic Matter (mg gdw^{-1})
1±1	0.91±0.91	0.323	394.4	605.6
3±1	2.32±0.67	0.238	382.6	617.4
5±1	3.62±0.63	0.222	373.1	626.9
7±1	5.01±1.76	1.270	350.4	649.6
9±1	6.53±0.76	0.268	340.9	659.1
11±1	7.89±0.60	0.212	348.7	651.3
13±1	9.41±0.92	0.325	336.5	663.5
15±1	11.08±0.76	0.267	330.7	669.3
17±1	12.43±0.59	0.209	355.4	644.6
19±1	13.73±0.71	0.252	344.4	655.6
21±1	15.33±0.89	0.313	319.5	680.5
23±1	17.06±0.84	0.298	295.5	704.5
25±1	18.83±0.93	0.329	282.1	717.9
27±1	20.75±0.99	0.350	276.7	723.3
29±1	22.72±0.98	0.346	269.7	730.3
31±1	24.61±0.92	0.324	257.7	742.3
33±1	26.51±0.98	0.347	249.5	750.5
35±1	28.60±1.11	0.393	24[illegible]	755.7
37±1	30.78±1.07	0.377	242.3	757.7
39±1	32.84±0.99	0.350	230.2	769.8
41±1	34.85±1.02	0.360	230.3	769.7
43±1	36.88±1.01	0.358	226.8	773.2
45±1	38.80±0.91	0.323	226.5	773.5
Average :		0.307	300.3	699.7
Std error :		0.011	11.6	11.6

Table A.21 Data for Estero Pargo, Mexico, 10 meters inland from tidal creek including consolidation corrected depth (cm), total carbon, nitrogen, and phosphorus (mg gdw^{-1}) and atomic carbon : nitrogen (C:N) and nitrogen : phosphorus (N:P) ratios.

Original Depth (cm)	Compaction Corrected Depth (cm)	Carbon Content (mg gdw^{-1})	Nitrogen Content (mg gdw^{-1})	Phosphorus Content (mg gdw^{-1})	Atomic C:N Ratio	Atomic N:P Ratio
1±1	0.91±0.91	177.5	6.8	0.60	30	25
3±1	2.32±0.67	172.2	6.6	0.64	30	23
5±1	3.62±0.63	167.9	6.6	0.64	30	23
7±1	5.01±1.76	157.7	6.9	0.60	27	25
9±1	6.53±0.76	153.4	6.6	0.60	27	24
11±1	7.89±0.60	156.9	6.1	0.59	30	23
13±1	9.41±0.92	151.4	6.8	0.59	36	25
15±1	11.08±0.76	148.8	6.3	0.59	28	24
17±1	12.43±0.59	159.9	6.4	0.55	29	26
19±1	13.73±0.71	155.0	5.9	0.57	30	23
21±1	15.33±0.89	143.8	5.9	0.56	28	23
23±1	17.06±0.84	133.0	4.2	0.54	36	17
25±1	18.83±0.93	127.0	4.5	0.57	33	18
27±1	20.75±0.99	124.5	4.7	0.55	31	19
29±1	22.72±0.98	121.4	4.4	0.53	32	18
31±1	24.61±0.92	116.0	3.9	0.54	35	16
33±1	26.51±0.98	112.3	3.6	0.54	36	15
35±1	28.60±1.11	109.9	3.5	0.50	36	16
37±1	30.78±1.07	109.0	3.4	0.50	37	15
39±1	32.84±0.99	103.6	3.2	0.51	37	14
41±1	34.85±1.02	103.6				
43±1	36.88±1.01	102.1				
45±1	38.80±0.91	101.9				
Average :		135.2	5.3	0.57	32	21
Std error :		5.2	0.3	0.01	1	1

* - carbon values calculated indirectly be assuming 45% of organic matter is carbon.

Table A.22 Data for Estero Pargo, Mexico, 225 meters inland from tidal creek including consolidation corrected depth (cm), ^{210}Pb total, ^{210}Pb excess and ^{137}Cs activities (dpm g^{-1}).

Original Depth (cm)	Compaction Corrected Depth (cm)	^{210}Pb total (dpm g^{-1})	^{210}Pb excess (dpm g^{-1})	^{137}Cs (dpm g^{-1})
1±1	0.29±0.29	9.12±0.19	8.41±0.29	0.16±0.08
3±1	0.84±0.38	5.80±0.18	5.09±0.21	0.74±0.21
5±1	1.72±0.50	5.99±0.20	5.28±0.23	2.39±0.58
7±1	2.62±0.40	6.41±0.21	5.70±0.24	1.68±0.41
9±1	3.43±0.42	3.25±0.10	2.54±0.10	0.22±0.07
11±1	4.18±0.33	3.21±0.15	2.50±0.14	0.23±0.08
13±1	4.82±0.31	3.18±0.17	2.48±0.15	0.52±0.16
15±1	5.58±0.44	2.04±0.07	1.33±0.06	
17±1	6.60±0.58	1.67±0.07	0.96±0.05	
19±1	7.87±0.69	1.12±0.06	0.41±0.02	
21±1	9.19±0.63	1.46±0.07	0.75±0.04	
23±1	10.61±0.79	1.05±0.05	0.34±0.02	
25±1	12.10±0.70	0.89±0.03	0.18±0.01	
27±1	13.58±0.78	0.84±0.03	0.13±0.01	
29±1	15.49±1.13	0.63±0.02		
31±1	17.51±0.88	0.65±0.02		
33±1	19.31±0.92	0.64±0.02		
35±1	21.50±1.27	0.73±0.02		
37±1	23.82±1.05	0.91±0.02		
39±1	25.75±0.88	0.69±0.01		

^{210}Pb supported = 0.71±0.02

Accretion rate : ^{137}Cs no compaction = 4.0 mm yr^{-1}
^{137}Cs compaction = 2.8 mm yr^{-1}
^{210}Pb no compaction = 2.0 mm yr^{-1}
^{210}Pb compaction = 1.0 mm yr^{-1}

Table A.23 Data for Estero Pargo, Mexico, 225 meters inland from tidal creek including consolidation corrected depth (cm), bulk density (g cm^{-3}), organic and inorganic matter (mg gdw^{-1}).

Original Depth (cm)	Compaction Corrected Depth (cm)	Bulk Density (g cm^{-3})	Organic Matter (mg gdw^{-1})	Inorganic Matter (mg gdw^{-1})
1±1	0.29±0.29	0.174	724.8	275.2
3±1	0.84±0.38	0.229	666.3	333.7
5±1	1.72±0.50	0.297	577.6	422.4
7±1	2.62±0.40	1.239	587.7	412.3
9±1	3.43±0.42	0.250	535.4	464.4
11±1	4.18±0.33	0.196	429.4	570.6
13±1	4.82±0.31	0.188	481.1	518.9
15±1	5.58±0.44	0.264	404.9	595.1
17±1	6.60±0.58	0.346	326.4	673.6
19±1	7.87±0.69	0.414	272.8	727.2
21±1	9.19±0.63	0.376	241.1	758.9
23±1	10.61±0.79	0.471	240.8	759.2
25±1	12.10±0.70	0.419	230.0	770.0
27±1	13.58±0.78	0.466	191.5	808.5
29±1	15.49±1.13	0.677	141.6	858.4
31±1	17.51±0.88	0.529	159.8	840.2
33±1	19.31±0.82	0.548	133.2	866.8
35±1	21.50±1.27	0.762	134.1	865.9
37±1	23.82±1.05	0.626	143.1	856.9
39±1	25.75±0.88	0.524	132.4	867.6
Average :		0.400	337.7	662.3
Std error :		0.039	44.1	44.1

Table A.21 Data for Estero Pargo, Mexico, 225 meters inland from tidal creek including consolidation corrected depth (cm), total carbon, nitrogen, and phosphorus (mg gdw^{-1}) and atomic carbon : nitrogen (C:N) and nitrogen : phosphorus (N:P) ratios.

Original Depth (cm)	Compaction Corrected Depth (cm)	Carbon Content (mg gdw^{-1})	Nitrogen Content (mg gdw^{-1})	Phosphorus Content (mg gdw^{-1})	Atomic C:N Ratio	Atomic N:P Ratio
1±1	0.29±0.29	326.2	18.1	0.62	21	65
3±1	0.84±0.38	299.8	16.7	0.56	20	66
5±1	1.72±0.50	259.9	13.7	0.52	22	59
7±1	2.62±0.40	264.5	13.8	0.35	22	86
9±1	3.43±0.42	240.9	10.2	0.40	28	56
11±1	4.18±0.33	193.2	7.8	0.36	29	48
13±1	4.82±0.31	216.5	9.2	0.43	28	47
15±1	5.58±0.44	182.2	7.8	0.40	27	43
17±1	6.60±0.58	146.9	6.3	0.30	27	46
19±1	7.87±0.69	122.8	4.8	0.29	30	38
21±1	9.19±0.63	108.5	3.4	0.18	37	42
23±1	10.61±0.79	108.4	2.9	0.24	43	26
25±1	12.10±0.70	103.5	3.0	0.28	40	24
27±1	13.58±0.78	86.2	2.4	0.20	41	27
29±1	15.49±1.13	63.7	1.8	0.27	41	15
31±1	17.51±0.88	71.9	1.8	0.21	47	19
33±1	19.31±0.92	59.9	1.5	0.30	48	11
35±1	21.50±1.27	60.3	1.5	0.22	48	15
37±1	23.82±1.05	64.4	1.6	0.22	48	16
39±1	25.75±0.88	59.6	1.4	0.27	50	12
Average	:	152.0	6.5	0.3	35	38
Std error	:	19.8	1.2	0.03	2	5

* - carbon values calculated indirectly by assuming 45% of organic matter is carbon.

ABSTRACT

ABSTRACT: Accretion and accumulation rates were measured in fringe and basin mangrove forests each in river and tidally dominated sites in Terminos Lagoon, Mexico, and a basin mangrove forest in Rookery Bay, Florida, USA. Accretion rates were determined using the radionuclides ^{210}Pb and ^{137}Cs. Consolidation corrected accretion rates for the Rookery Bay cores ranged from 1.4 to 1.7 mm yr^{-1} with an average rate of 1.6 mm yr^{-1}. Rates at the Mexico sites ranged from 1.0 to 4.4 mm yr^{-1} with an average of 2.4 mm yr^{-1}. Determination of rates in these mangrove forests was greatly affected by the consolidation corrections which decreased the apparent accretion rate by over 50% in one case. Accretion rates at basin sites compare favorably with a reported 1.4-1.6 mm yr^{-1} rates of sea level rise indicating little or no subsidence at inland locations. Accretion rates in fringe sites are generally greater in value than basin sites indicating greater subsidence rates in these sediments.

Sediment and nutrient accumulation rates were determined at each site. The rank in sediment accumulation was riverine fringe > riverine basin > tidal fringe $\geq$ tidal basin with rates ranging from 1813 to 309 g m^{-2} yr^{-1}. Sedimentation rates in the riverine forests were dominated by inorganic composition, while sedimentation in the tidal forests was mainly organic matter. High phosphorus accumulation was associated with inorganic sediment loading, while carbon and nitrogen accumulation rates were highest in the fringe and basin forest of tidally dominated sites. The location of more productive mangrove forests along riverine environments may be related to the high loading of phosphorus associated with inorganic material flooding these wetlands.

BIOGRAPHICAL SKETCH

James Christian Lynch was born in Wilmington, Delaware on April 17, 1963. He graduated from Concord High School, Wilmington, Delaware in May, 1981. Following high school, he attended the United States Coast Guard Academy in New London, Connecticut. He transferred to the University of Delaware in September, 1982 and received a Bachelor of Arts degree in Biology and Chemistry in May 1986. Jim enrolled at the University of Southwestern Louisiana in August 1986 and is pursuing his interests as a candidate for a Master of Science degree in Biology.