PN-ABD-203 1

THE IMPORTANCE OF MANGROVES IN SUSTAINING FISHERIES AND CONTROLLING WATER QUALITY IN COASTAL ECOSYSTEMS

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Progress Report
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I. Project Overview and Objectives:

Mangroves are forested wetlands that inhabit the intertidal zone of tropical and subtropical estuaries. It has been suggested that these wetlands provide both food and habitat for a diverse fishery, and that the yields of some commercially important species are dependent on the area of this vegetation along the coastline. These forests may also serve as either a nutrient source or sink, and influence the fate of sediments in estuarine ecosystems. Because of the possible importance of mangroves to the coastal zone, human activities such as forestry, aquaculture, agriculture and residential development that impact this natural resource are of concern to coastal zone managers. Mangroves have received considerable botanical investigation, yet little is known concerning the ecology of these ecosystems. A better understanding of the function of mangroves relative to their contribution to the organic matter and nutrient budgets of estuaries is needed for development of best management plans for the coastal zone. This mangrove research project in Ecuador and Mexico is part of a continuing effort to understand the ecology of mangrove ecosystems.

The goal of this research program is to investigate specific mangrove properties under different types of geomorphology. Predictions of ecosystem function based on models of mangrove processes are presently restricted to specific environmental settings. Thus the application of mangrove management practices from one part of the tropics to another is limited by a general understanding of mangrove ecology. Thom (1982) introduced the idea of specific geomorphic and ecologic responses of the coastal zone to degrees of environmental processes such as magnitude of rainfall, river discharge, tidal amplitude, turbidity and wave power. For example, the Guayas River estuary is an area with high tidal amplitude, medium rainfall and high river discharge and would be a number I setting, whereas Terminos Lagoon in Mexico has low tides, medium rainfall and river discharge and would be a number IV setting. The geomorphic and ecologic responses are different for each coastline due to these differences in environmental processes. The hypothesis of this proposed study is that mangrove properties such as litter productivity, sedimentation, detritus export, and nutrient cycling are controlled by the magnitude of hydrologic energy. By using mangrove sites representing various environmental settings as sites for comparative studies of ecosystem structure and function, we can test whether differences in ecological processes can be explained by differences in these coastal processes.

The following are the proposed objectives and tasks of this project based on the hypotheses stated above:

1. To measure organic matter production and transport in different types of mangrove forests under various tidal and fertile conditions to better define the function of these

wetlands in tropical estuarine ecosystems;

2. Determine the importance of nutrient accumulation (burial) and denitrification in mangroves to losses of nutrients from estuarine ecosystems;
3. Determine if mangroves are a net source or sink of nutrients in estuarine ecosystems;
5. Determine the utilization of mangroves for habitat and food by economically important fisheries.

II. Project Accomplishments to Date:

1. Program organization and personnel

The following personnel have been supported at the University of Southwestern Louisiana partly from the funds of this project:

Robert Twilley - Principal investigator in charge of the project. Support includes summer salary.

James Lynch - Graduate research assistant responsible for the determination of sedimentation rates in mangroves. Support includes 10% of full time salary.

Wai Choong - Senior at USL with a degree in Business Administration responsible for office management, data processing and library research. Wai has also been involved with processing of litter samples from Mexico.

The following personnel are participating on the mangrove project in Ecuador:

Mireya Pozo - Leader of the student group and responsible for litter collections. Mireya is a recent graduate who is now working full time on the mangrove project.

Victor Garcia - Student responsible for the hydrology measurements in the mangrove forest including salinity and water quality sampling. Supported by this mangrove project.

Nikita Gaibor - Student responsible for the collection of litter and the utilization of litter by crustaceans and fish within the mangrove forests. Also participates on the estuary cruises sampling for shrimp and fish populations in the Guayas River estuary. Supported by this mangrove project.

Washington Cardenas - Student responsible for the sampling and chemical analysis of water during the cruises in the Guayas River estuary. Works at the National Institute of Fisheries. Supported by this mangrove project.

Jorge Espinoza - Student aiding Washington Cardenas with the collection and analyses of water samples from the Guayas River estuary. Supported by this mangrove project.

Kruger Loor - Student responsible for the phenology studies of mangrove. Supported by the Department of Forestry in Guayaquil.

Enrique Castella - Student helping with the litter collections and processing. Supported by the Department of Forestry in Guayaquil.

Rosa Garcia - Full time employee at the National Fisheries Institute who has overall responsibility of the estuary cruises each month. Supported by the National Fisheries Institute.

Rocio Sueseum - Full time employee at the National Fisheries Institute who is directing the chemical assay of water samples collected from estuary cruises. Supported by the National Fisheries Institute.

2. Site Selection and Logistics

a. Mangrove sites:

Ecuador - The mangrove forests at Churute Mangrove Preserve have been classified by tree heights into three categories: M1 - trees > 15 m; M2 - trees 7 to 15 m; M3 - trees < 7 m. This classification system was developed by CLIRSEN and the preserve has been mapped and areas of forest within each classification determined. The project plans to establish studies of litter production in each of the three types of forests. In February 1989, a site was established in an M3 type of forest near the future site of a field station by the Department of Forestry (Figure 1). This site offers excellent logistics and served as a training site for future studies of M1 and M2 types of forests which are more isolated. All three types of mangrove forests in the Churute Preserve are dominated by <u>Rhizophora</u> <u>harrisonii</u> and <u>R</u>. <u>mangle</u>.

Mexico - Sites in Terminos Lagoon were described in the proposal and include a fringe and basin mangrove forest in Estero Pargo, and a riverine site in Boca Chica. Other sites may be considered for expansion of present studies in Terminos Lagoon.

b. Estuary sites: Monthly surveys of selected chemical, physical and biological characteristics of the Guayas River estuary will be conducted at 21 stations aboard the RV Proteo (Figure 2). Chemical and physical measurements will be taken at all 21 stations while fish and shrimp populations will be sampled only at 9 stations. The research vessel is operated by the National Fisheries Institute and each cruise requires about 3 days.

3. Tasks and Objectives

a. Mangrove Productivity:

Ecuador - Ten litter baskets (0.25 m^2) were randomly placed in a M3 mangrove forest in the Churute Mangrove Preserve in February 1989. Collections have been made biweekly and results are given in Figures 3 and 4. Beginning in May, the litter productivity study was expanded to M1 and M2 sites in the preserve with 10 baskets at each site. In addition, measurements have started on the accumulation of litter on the forest floor. Other measurements in each forest are water depth, salinity of surface and pore waters, and precipitation. Monthly measurements of important climatological information such as wind speed, solar radiation, humidity, precipitation and evaporation potential are collected by a military installation adjacent to the preserve and copied monthly by one of the students.

Mexico - Litter collections are part of a continuing program in Terminos Lagoon in Estero Pargo. Collections have been made biweekly for the last 12 months in a fringe and basin mangrove forest, and prepared for nutrient analyses in Dr. Twilley's laboratory at USL.

b. Estuarine Nutrient Cycling:

Ecuador - Monthly cruises on selected chemical, physical and biological characteristics of the Guayas River estuary will be performed at the 21 stations described above. In May 1989, an abbreviated cruise was performed at seven stations in the Churute Preserve. Measurements of chemical, physical and biological parameters at each station are listed in Table 1 and results for some of the chemical parameters are given in Table 2. The full cruise schedule is anticipated to begin in August 1089 and monthly cruises will be performed for approximately one year.

c. Sedimentation:

Ecuador - Two cores to a depth of 0.75 m were collected in the M3 mangrove site in May 1989 and sliced at 2-cm sections for the determination of sedimentation using Pb-210 and Cs-137 techniques. Total carbon, nitrogen, and phosphorus concentrations will be determined on each section, along with bulk density (Table 3), to determine the burial rate of these primary nutrients in this site.

Mexico - Cores from Estero Pargo and Boca Chica were collected in 1987 and funding from the present mangrove project allowed for the additional assay of sedimentation using Pb-210 along with previously determined Cs-137 analyses. This work has been presented in a thesis by Mr. James Lynch and will be published in part in Estuaries. A copy of this manuscript is attached as part of this report. A second manuscript is in preparation for submission to Limnology and Oceanography on the burial of carbon, nitrogen and phosphorus in the sediments of two mangrove ecosystems (Rookery Bay, Florida, and Terminos Lagoon, Mexico).

d. Denitrification and Nitrogen Fixation: No work has been accomplished towards this task.

e. Detritus Utilization:

Ecuador - A preliminary survey of the natural isotope composition of a variety of samples from the mangrove and estuary systems of the Churute Mangrove Preserve was made in May 1989. Samples included in this survey are listed in Table 4.

These samples have been dried and are being prepared for assay at the natural isotope laboratory at Woods Hole Oceanographic Institute under the direction and consultation of Dr. Brian Fry.

III. Project Problems:

One of the problems in the project has been with the participation of co-principal investigators in Ecuador. Dr. Roberto Jimenez has left the National Fisheries Institute and is presently affiliated with a consulting firm in Guayaquil. He has agreed to give some assistance in the identification of phytoplankton populations in the estuary surveys, but has given notice that his participation will be much less than originally planned. Also, Dr. Lucia Solorzano is presently on an indefinite leave of absence from the National Fisheries Institute, however her technicians are carrying on the chemical analyses as previously planned, and INP has continued their commitment to laboratory space for the project. In Mexico, the mangrove project will benefit from the strong collaboration of Dr. Alejandro Yanez-Arancibia, professor of fish ecology at UNAM, who has an active research program on the utilization of mangrove habitats by fish in Terminos Lagoon.

The initiation of program is taken longer than anticipated; for instance in Ecuador this mangrove project has been in coordination with other AID programs in Ecuador investigating biomass and silviculture of mangroves. There will certainly be time overruns that will require no-cost extension to complete one year sampling routines for some programs, and time for reporting results and preparation of manuscripts.

IV. Tasks for Next Reporting Period:

1. Litter Productivity:

Ecuador - Continue collections in M3 site and begin collections in M2 and M1 sites; prepare collections for nutrient assay.

Mexico - Continue collections in Estero Pargo; begin nutrient assay of some collected samples.

2. Estuarine Nutrient Cycling (Ecuador): The 21 station surveys of the Guayas River estuary should begin by August 1989 and run monthly thereafter for one year.

3. Denitrification and Nitrogen Fixation (Mexico): Mr. Victor Rivera-Monroy will do studies of denitrification and nitrogen fixation in mangroves at Terminos Lagoon as part of his dissertation program. Victor will complete his thesis proposal by November 1989 and then move to the marine laboratory in Carmen, Mexico, site of Terminos Lagoon. His research and thesis will be supported by this mangrove project.

4. Sedimentation (Ecuador): During the next six months work will continue on the assay of Cs-137 and Pb-210 on the sediment cores collect in M3 mangrove site in Churute Mangrove Preserve in May 1989. Additional analyses on these core sections will include total carbon, nitrogen and phosphorus.

5. Detritus Utilization (Ecuador): Samples from the initial survey of various trophic compartments of the Guayas River estuary will be prepared for assay of natural isotopes of carbon, nitrogen and sulfur at WHOI isotope laboratory by Dr. Brian Fry.

V. Publications and Presentations:

1) Lynch, J.C., J.R. Meriwether, B.A. McKee, F. Vera-Herrera, and R.R. Twilley. 1989. Recent accretion in mangrove ecosystems based on 137Cs and 210Pb. Estuaries 12:(in press). (Copy is attached).

2) Smithsonian Institution, Mangrove Symposium, "Factors controlling the productivity of mangroves: the influence of nutrients", November 1988.

3) International Wetlands Meeting, Rennes, France. "The properties of mangrove ecosystems relevant to sustaining shrimp mariculture in Ecuador", October 1988.

4) Seminars on the Ecology of Mangroves have been made in Ecuador to the following institutions: Mangrove Working Group, University of Guayaquil, and ESPOL

Table 1. Analyses included in the sampling program of the Guayas River estuary.

Physical Parameters
- Salinity
- Temperature
- Secchi Depth
- Depth
- Current direction

Chemical Parameters
- pH
- Dissolved Oxygen
- Inorganic Nutrients
  - Phosphate
  - Nitrate
  - Nitrite
  - Ammonium
  - Silicate
- Total Nitrogen
- Total Phosphorus
- Dissolved Organic Nitrogen
- Dissolved Organic Phosphorus
- Total Suspended Materials

Biological Parameters
- Phytoplankton community identification
- Chlorophyll a
- Phaeopigments
- Shrimp
- Fish

Table 2. Concentrations of selected nutrients at the sampling stations in the Churute Mangrove Preserve on 1 June 1989.

Station	Inorganic Nutrients NO_2	 NO_3	 PO_4	 SIO_4	DOP*
1	0.44	1.48	3.03	368.19	0.59
3	0.52	4.01	3.21	405.68	0.40
5	0.55	8.74	2.98	340.18	0.20
7	0.38	15.51	2.56	283.63	0.15
9	0.43	16.75	2.49	254.59	0.12
11	0.20	9.73	1.53	138.52	0.27
13	0.69	7.66	2.91	271.89	0.49

* Dissolved Organic Phosphorus

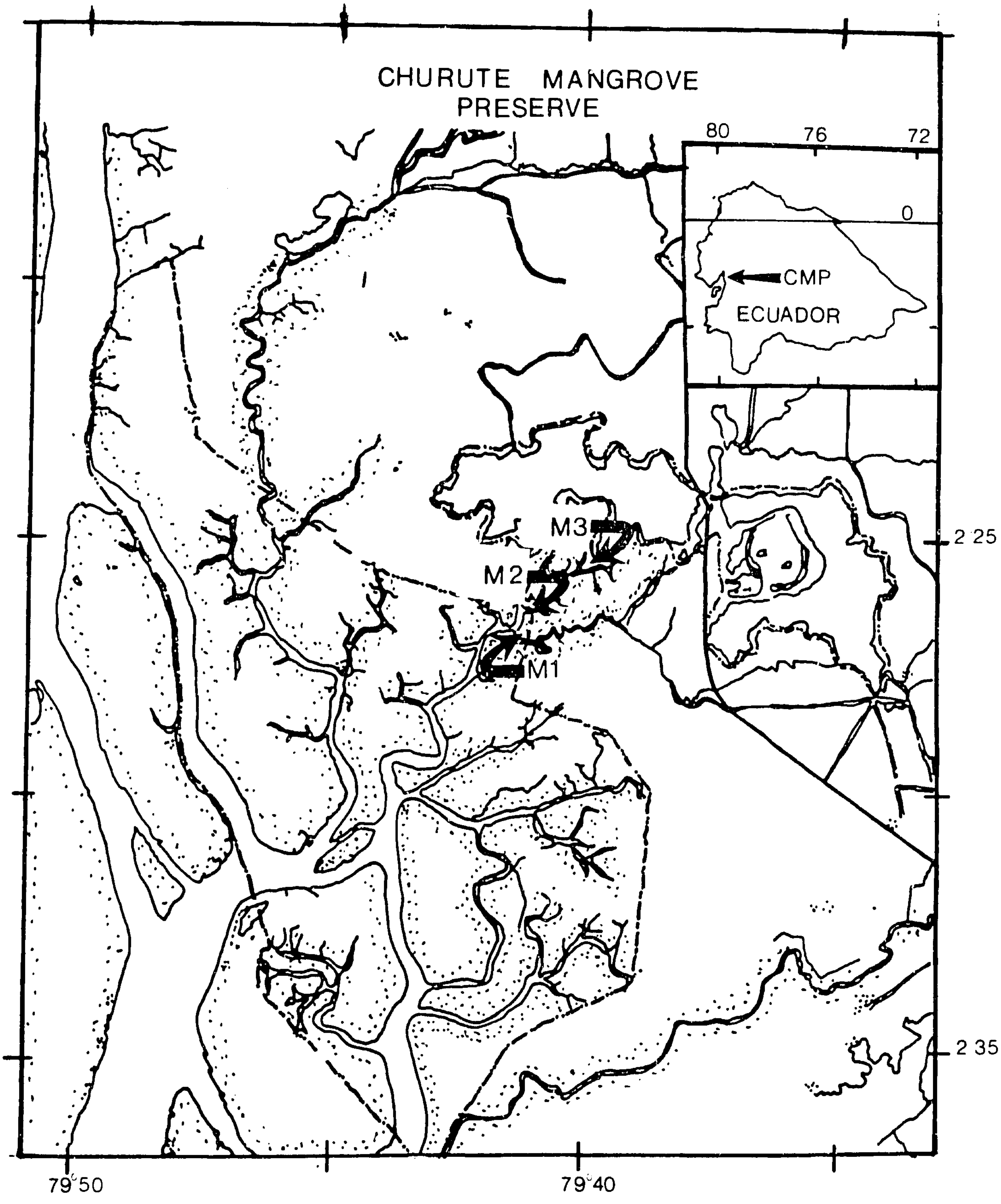
Table 3. Bulk density (g/cm^3) in the sediment cores from M3 mangrove site in Churute Mangrove Preserve.

Depth (cm)	Bulk Density Core 1	Bulk Density Core 2
0-2	0.35	0.30
2-4	0.29	0.32
4-6	0.37	0.44
6-8	0.48	0.34
8-10	0.54	0.35
10-12	0.32	0.32
12-14	0.34	0.33
14-16	0.33	0.44
16-18	0.40	0.47
18-20	0.29	0.46
20-22	0.42	0.37
22-24	0.40	0.56
24-26	0.39	0.42
26-28	0.38	0.49
28-30	0.42	0.45
30-32	0.32	0.52
32-34	0.37	0.57
34-36	0.37	0.66
36-38	0.43	0.50
38-40	0.30	0.49
40-42	0.45	0.55
42-44	0.40	0.52
44-46	0.51	0.57
46-48	0.45	0.57
48-50	0.00	0.58
52-54	0.00	0.56
60-62	0.00	0.44

Table 4. Samples collected for natural abundance of isotopes of carbon, nitrogen, and sulfur from the Churute Mangrove Preserve in May 1989.

Sample Identification
Mangrove Material (*Rhizophora harrisonii*)
Green leaves
Senescent leaves
Decaying leaves
Bark
Roots
Orchids in mangrove canopy
Termites on *R. harrosonii*
Caterpillars feeding on mangrove leaves
Mangrove sediment
Mangrove crabs (*Uca* sp.)
Mangrove crabs (*Ucides occidentalis*)
Chitin
Egg sac
Mangrove leaves in estuary
Water hyacinth in estuary (*Eichhornia crassipes*)
Adult shrimp (*Penaeus vannamei*)
Larvae shrimp (*Penaeus californiensis*)

LIST OF FIGURES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76
72
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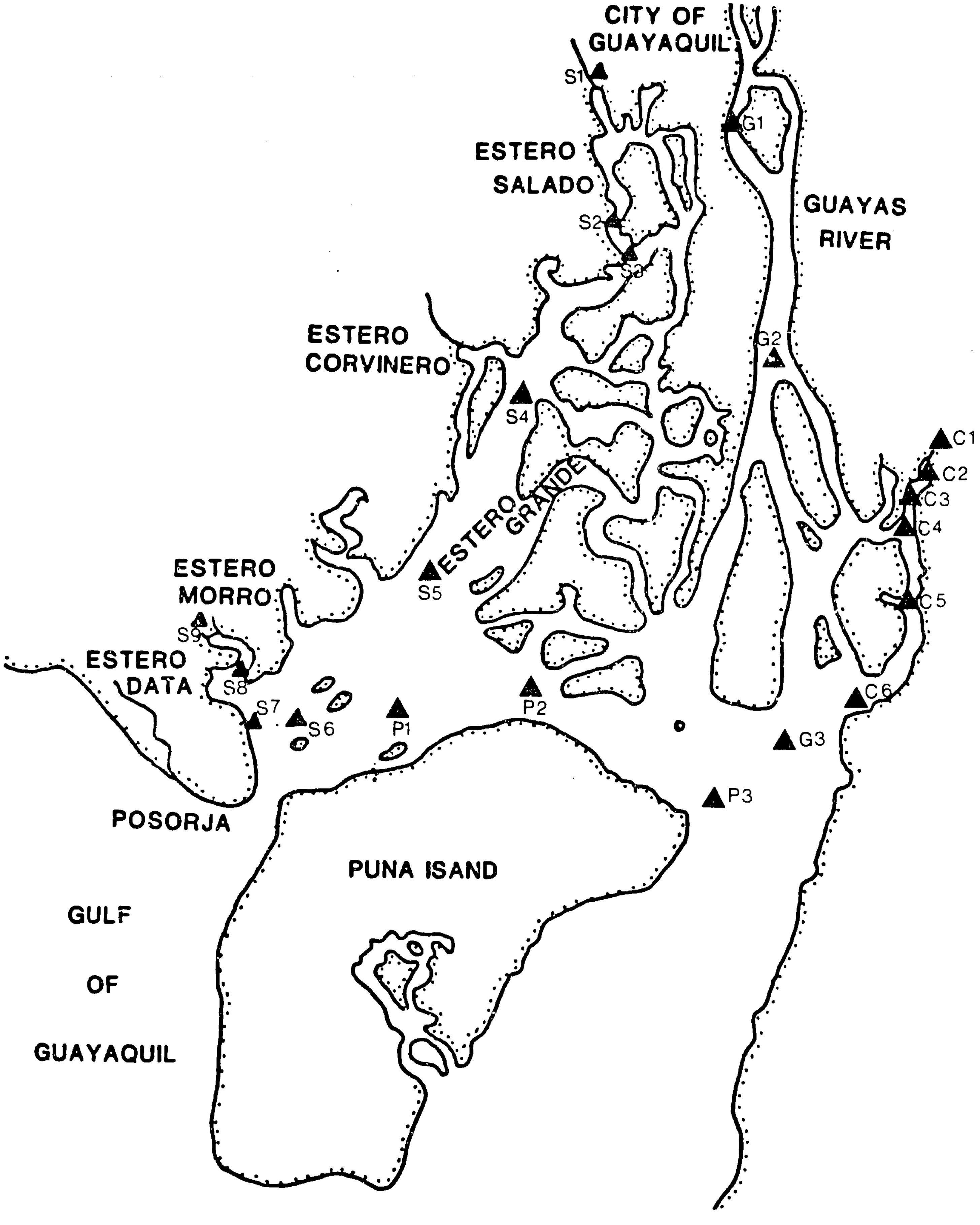
CMP
ECUADOR
M3
M2
M1
2°25
2°35
79°50
79°40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ESTERO GRANDE
S5
C5
ESTERO MORRO
S9
ESTERO DATA
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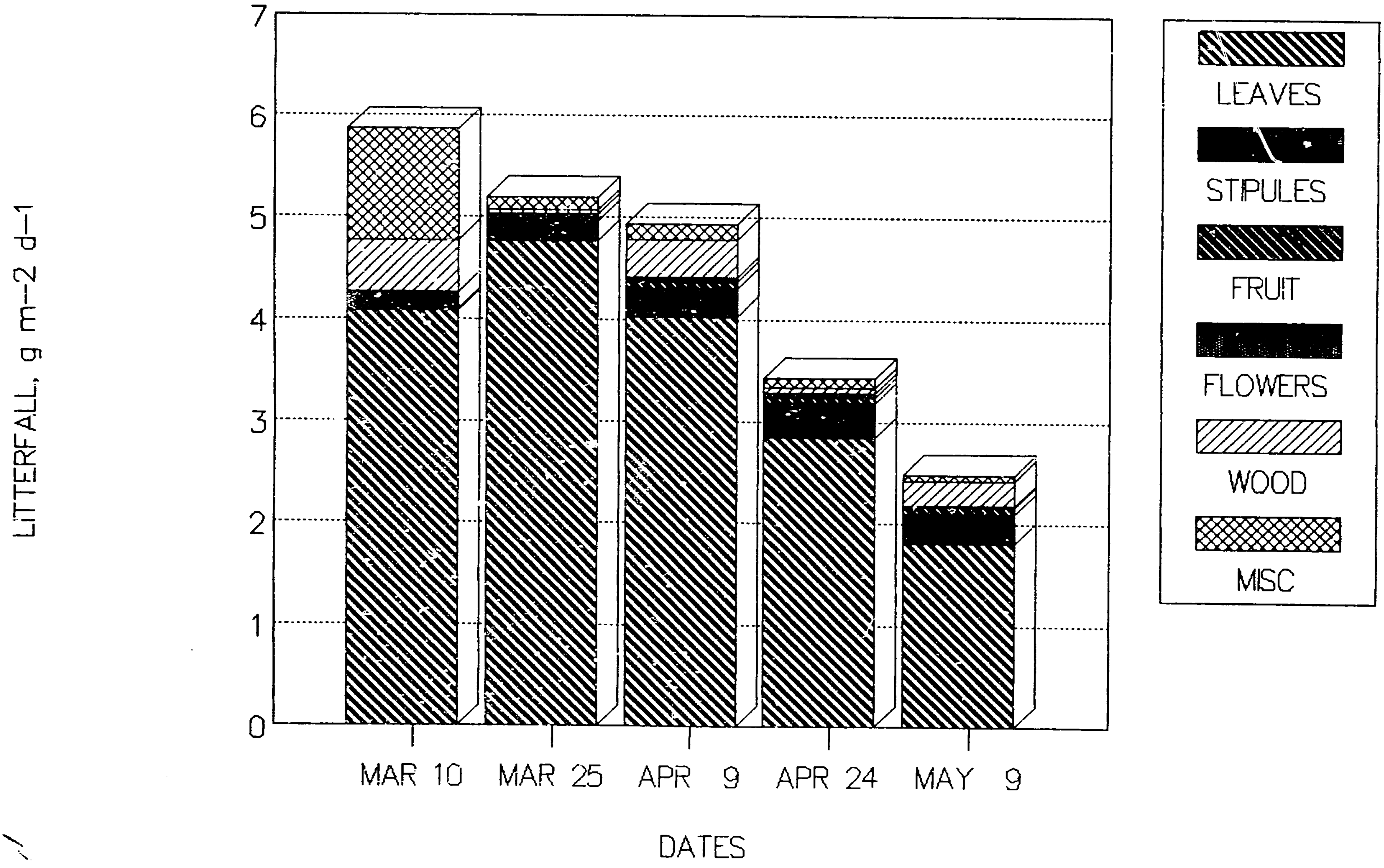
LITTERFALL, g m−2 d−1
0
1
2
3
4
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6
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MAR 10
MAR 25
APR 9
APR 24
MAY 9
DATES
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STIPULES
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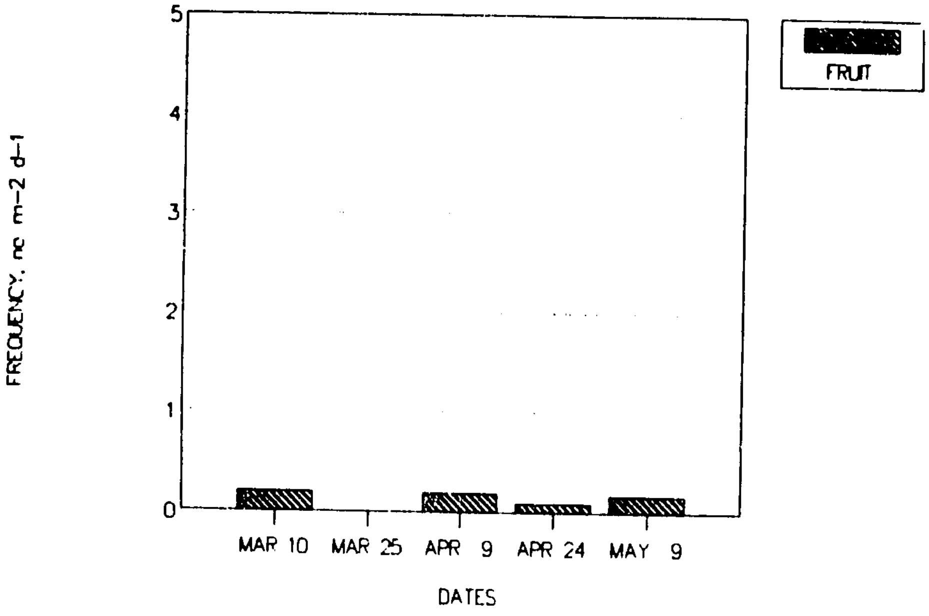
FLOWERS
WOOD
MISC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MAY 9
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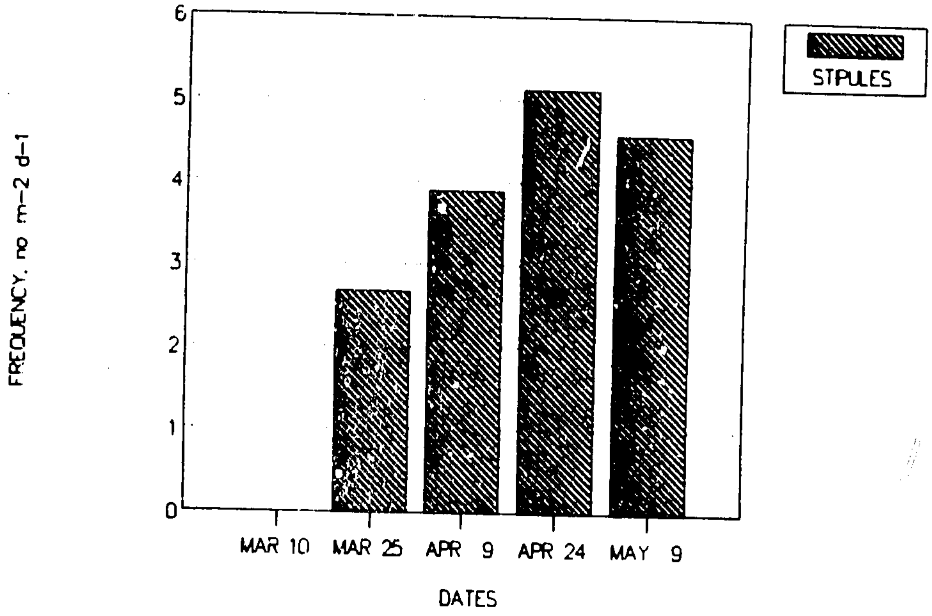
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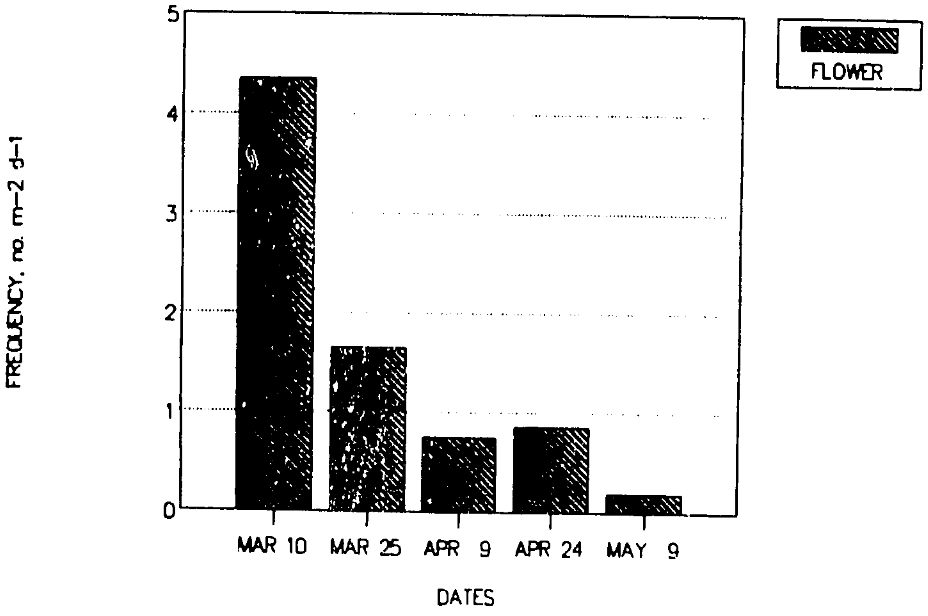
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MAR 10
MAR 25
APR 9
APR 24
MAY 9
DATES

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

Mangrove accretion rates

B'

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ABSTRACT

Accretion 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 over longer time intervals.

INTRODUCTION

The structure and distribution of mangrove wetlands is linked to the intertidal nature of coastal environments. Tides, rainfall, and/or river flow contribute to patterns of sedimentation in mangroves by influencing deposition and export of materials. The change in elevation of the forest floor, defined as accretion, is influenced by these hydrologic energies relative to regional geomorphology (Thom 1982). Relative changes in hydrology and accretion result in an apparent rise in sea level, that determine the nature of intertidal environments.

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 (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 Oenema and DeLaune 1988). Cesium-137 is a radionuclide 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 naturally occurring radionuclide in the ^{238}U decay series 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). Lead-210 activity in natural sediments is supported by the decay of its effective parent ^{226}Ra. To this "supported" ^{210}Pb activity already present in sediment is added ^{210}Pb from the atmosphere. This "non-supported" or "excess" lead activity is introdued into the atmosphere when radon gas (^{222}Rn) 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 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 sediment.

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). Unlike ^{137}Cs supply, it is assumed that a constant flux of ^{210}Pb reaches the wetland surface 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. 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 soils.

The objective of this study was to determine recent 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 location of mangrove sites chosen also offers an opportunity to test the these procedures under different hydrologic regimes.

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). The area has a warm temperate climate with an average temperature of 23.6 °C and annual precipitation of 1346 mm. 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 (Lugo and Snedaker 1975, Twilley 1985, Twilley et al. 1986). The forest is exposed to infrequent inundation occurring when 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 °/oo, whereas, soil porewater salinities range from about 35 °/oo to 50 °/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 1). 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 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 190 $\text{m}^3\ \text{s}^{-1}$ (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), Yáñez-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 Yáñez-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). 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 ‰ while soil porewater salinities are higher ranging from about 20 to 50 °/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 °/oo. Soil water salinities ranged from about 5 to 45 °/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).

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 *Avicennia germinans* (L.) L. (importance value of 55.8) and *Rhizophora mangle* L. (importance value of 54.2). The last core was taken 70 m inland from the berm in a monospecific stand of *A. germinans* (importance value of 88.0) (Fig. 1). *Laguncularia racemosa* (L.) Gaertn. f. was sparsely found in both areas of the basin forest.

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).

Each core was sectioned at 2 cm intervals, dried at 55°C to constant weight, and weighed for 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 peak activity 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. 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 ^{210}Po, the daughter nuclide of ^{210}Pb. 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).

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 soil surface is constant through time. The excess ^{210}Pb activity can be modeled based on the following:

$$E_t = E_0 e^{-kt} \quad ; \qquad (3)$$

where, E_t is excess ^{210}Pb activity at time t, E_0 is excess ^{210}Pb activity at time zero, k is the decay constant of ^{210}Pb (0.0311 yr^{-1}). Assuming that accretion rates are constant :

$$t = z/S \quad ; \qquad (4)$$

where z = depth in the profile and S = accretion rate. Substituting in equation (4) yields :

$$E_t = (E_0)e^{-kz/S} \quad ; \qquad (5)$$

$$\ln[E_t/E_0] = -kz/S \quad ; \qquad (6)$$

$$\ln[E_t/E_0]/z = -k/S. \quad ; \qquad (7)$$

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

$$\ln[E_t/E_0]/z = m \quad ; \text{(slope of line)} \qquad (8)$$

$$m = -(k)/S \quad ; \qquad (9)$$

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

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 associated with 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 deep mixing which increases the depth of penetration of the 1963 peak (Guinasso and Schink 1975, Nittrouer et al. 1984):

$$z' = (2Dt)^{1/2} + St \ ; \qquad (11)$$

where z' = apparent depth of penetration of the peak, and D = mixing coefficient ($cm^2\ yr^{-1}$). For ^{210}Pb, equation (7) can be modified with the addition of a mixing coefficient (Guinasso and Schink 1975, Nittrouer et al. 1984):

$$S = kz/\ln[E_0/E_t] - (D/z)(\ln[E_0/E_t]) \ ; \qquad (12)$$

which can be simplified to:

$$S = (k)/m - Dm \ ; \qquad (13)$$

Knowing the value of z' and m, Equations (11) and (13) 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 to determine whether mixing has an affect on the profiles of radionuclides.

RESULTS AND DISCUSSION

The use of ^{210}Pb and ^{137}Cs radionuclides in the measure of accretion rates is highly dependent on the assumptions 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. Compression 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 (Table 1). Cesium-137 counting errors in Terminos Lagoon were smaller ranging from about 10-25% of the measured value (Table 1). Much of this difference in error can be attributed to smaller sample sizes in sections from Rookery Bay due to low bulk density (Tables 3 and 4) and decreased counting time in Rookery Bay cores relative to the Terminos Lagoon cores. Counting errors for ^{210}Pb averaged 2-4% of the measured value and were small compared to ^{137}Cs owing to the use of a high efficiency detector (Tables 1 and 2).

The natural processes occurring within each core, such as compaction and sediment mixing complicate radionuclide data interpretations. Failure to account for compaction and sediment mixing can result in overestimating the accretion rate (Nixon 1980, Nittrouer et al. 1984). The correction of each radionuclide profile for consolidation of the sediments with depth is important. A generally accepted rule is that compaction is more prevalent in sediments with lower bulk density due to higher organic content (Busch and Keller, 1982). All four of the Rookery Bay cores and one of the Estero Pargo cores (225 m) have low bulk density values in the surface sections and increase with depth . Consolidation corrections which account for these differences, changed radionuclide depth profiles for all cores from Rookery Bay and the basin core from Estero Pargo (Tables 3 and 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 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 (Tables 3 and 4).

Depth profiles in the Rookery Bay and Terminos Lagoon cores corrected for compaction altered accretion rates in some cases

(Table 5). Cesium-137 activity in the four Florida cores was mainly confined to the top 10 cm with peak activity occurring around 4-5 cm in each core (Fig. 2). Deepest penetration of the nuclide occurred in the cores closest to the fringe. Accretion rates for all four cores were very similar in value at around 1.8 mm yr^{-1} (Table 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. 3). Like Rookery Bay, deepest penetration of nuclides occurred at the fringe cores. Accretion rates varied among fringe sites Boca Chica and Estero Pargo at 5.4 mm yr^{-1} and 3.3 mm yr^{-1}, respectively (Table 5). 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 average accretion rate of 2.0 mm yr^{-1}. The average accretion rate for all four cores was 2.6 mm yr^{-1} (Table 5).

Consolidation corrections resulted in a decrease in accretion rates (based on ^{137}Cs) which varied from 17 to 77% (Table 5). Corrections for accretion rates at the two fringe sites at Boca Chica and Estero Pargo were similar at 24 and 28%, respectively. The lowest correction was for the basin site at Boca Chica at 17% compared to a decrease of 77% at the basin site at Estero Pargo. Corrected accretion rates for the basin site at Rookery Bay decreased by 38% from the uncorrected rates.

Excess ^{210}Pb activity in the Rookery Bay cores was predominantly found in the top 15 cm of core (Fig. 4). Each core was similar in profile with little or no indication of a 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 (Table 5). Average accretion rate in the four cores was 1.6 mm yr^{-1} (Table 5). Corrected accretion rates decreased 23 to 36% from original rates exhibiting less change than observed for ^{137}Cs profiles in Rookery Bay.

Depth profiles of excess ^{210}Pb activity in the Terminos Lagoon cores were more variable than in the Rookery Bay cores (Table 5) 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 (Table 5). Accretion rates in the basin site based on ^{210}Pb were lower than the fringe; similar to results based on ^{137}Cs. Corrected accretion rates at Boca Chica change little in the fringe and basin sites by only 6 to 7% lower than 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 the interpreting 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). While compaction is common in wetland soils (Nixon 1980, Woodroffe 1981, Stevenson et al. 1983), corrections such as those described in this study have not appeared to be an important consideration in the determination of accretion in many wetland systems. The highly organic nature of wetland soils warrants consideration of these corrections. Failure to account for the affects of compaction could overestimate actual accretion rates.

Mixing

An intensely mixed surface layer is another important factor to consider when comparing accretion rates obtained by ^{137}Cs and ^{210}Pb. Under these conditions a particle deposited to the soil surface is quickly mixed to the base of the 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 soil surface. Indication of a surface mixing zone is usually revealed by a homogeneous layer of activity (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 a single event which occurred in 1963. 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 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. 3). The ^{137}Cs accretion rate (5.4 mm yr^{-1}) is greater than that of the ^{210}Pb rate (4.4 mm yr^{-1}). A mixed layer of 2.9 cm corresponds to the 3 surface sections of the core which are irregular in ^{210}Pb activity and the corrections based on this depth 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. A 2.9 cm mixed surface layer (subtracted from the apparent depth, z', of the 1963 peak, Table 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 11 and 13. By manipulating these equations, one can compare the presence or absence of deep mixing in each core based on differences in accretion from using the two radionuclides. Calculation of these values yielded very low mixing coefficients ($D<<1.0$ cm^2/yr) indicating little or no deep mixing in all the cores. However, the Boca Chica fringe core did have the highest mixing coefficient. The lack of a larger mixing coefficient is not unexpected since both ^{137}Cs and ^{210}Pb accretion rates are similar 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 the eight ^{210}Pb cores, the average accretion rate for 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}.

Spatial Variation in Accretion

Many authors studying accretion in salt marsh ecosystems have documented the variation among 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 higher in value than that of basin cores regardless of whether the rate was calculated using ^{137}Cs or ^{210}Pb data. This relationship is also indicated by the deeper penetration of ^{137}Cs nuclides at the fringe sites than at the more inland basin sites (Table 2). Accretion rates between fringe and more inland sites may differ due to different processes occurring at each location. Relative elevation among these sites is small suggesting that either subsidence, redistribution or some other process occurring in the fringe zones accounts for the observed differences in accretion.

Subsidence and Sea Level Rise

Vertical accretion rates are influenced by subsidence of the land and/or rise in sea level. 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 the basin sites that ranged from 1.0 to 1.6 mm yr^{-1} (^{210}Pb, Table 5). Accretion rates in excess of this sea level rise can be assumed to be due to accumulation of more recent sediments that will subside over longer time periods (This assumes that erosion is constant for both areas). Fringe sites at Terminos Lagoon have higher accretion rates than reported sea level rise and will subsequently have higher rates of subsidence in the future. Thus recent accretion rates in basin sites may be more representative of longer terms rates in mangrove ecosystems.

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, 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 and pollen dating, indicate that further analysis is needed before these rates can be accepted as representative for these locations. However, the accretion rates determined in this study do indicate that mangrove wetlands are in equilibrium with apparent sea level rise.

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.

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REFERENCES

Armentano, T.V. and G.M. Woodwell. 1975. Sedimentation rates in a Long Island marsh by ^{210}Pb dating. Limnol. Oceanogr. 20: 452-456.

Baumann, R.H., J.W. Day, Jr., and C.A. Miller. 1984. Mississippi deltaic wetland survival: sedimentation versus coastal submergence. Science 224:1093-1094.

Brush, G., K.E.A. Martin, R.S. DeFries, and C.A. Rice. 1982. Comparisons of 210-Pb and pollen methods for determining rates of estuarine sediment accumulation. Quaternary Research 18:196-217.

Busch, W.H. and G.H. Keller. 1982. Consolidation characteristics of the sediments from the Peru-Chile continental margin and implications for past sediment instability. Marine Geology 45:17-39.

Casey, W.H., A. Guber, C. Bursey and C.R. Olsen. 1986. Chemical controls on ecology in a coastal wetland. Eos. November 11. pp. 1305-1311.

Davis, R.B., C.T. Hess, S.A. Norton, D.W. Hanson, K.D. Hoagland and D.S. Anderson. 1984. Cesium-137 and Lead-210 dating of sediments from soft-water lakes in New England (U.S.A.) and Scandinavia, a failure of Cesium-137 dating. Chem. Geol. 44: 151-185.

Day, J.W., W.H. Conner, F. Ley-lou, R.H. Day, and A.M. Navarro. 1987. The productivity and composition of mangrove forests, Laguna de Terminos, Mexico. Aquatic Botany 27:267-284.

Davis J.H., Jr. 1940. The ecology and geologic role of mangroves in Florida. Pages 303-412. In Carnegie Institute Washington Pub. No. 517. Papers from the Tortugas Lab, Volume 32.

DeLaune, R.D., C.N. Reddy and W.H. Patrick Jr. 1981. Accumulation of plant nutrients and heavy metals through sedimentation processes and accretion in a Louisiana salt marsh. Estuaries 4(4):328-334.

DeLaune, R.D., R.H Baumann and J.G.Gosselink. 1983. Relationships among vertical accretion, coastal submergence, and erosion in a Louisiana gulf coast marsh. J. Sed. Petr. 53: 147-157.

DeLaune, R.D., C.J. Smith, and W.H. Patrick Jr. 1986.Sedimentation patterns in Gulf coast backbarrier marsh: response to increasing submergence. Earth Surface Processes and Landforms 11:485-490.

Feijtel, T.C., R.D. DeLaune, and W.H. Patrick, Jr. 1985. Carbon flow in coastal Louisiana. Mar. Ecol. Pro. Ser. 24: 255-260.

Flynn, R.W. 1968. The determination of low levels of polonium-210 in environmental materials. Anal. Chim. Acta 43:221-227.

Gornitz, V., S. Lebedeff, and J. Hansen. 1982. Global sea level trend in the past century. Science. 215:1611-1614.

Guinasso, N.L. Jr., and D.R. Schink. 1975. Quantitative estimates of biological mixing rates in abyssal sediments. J. Geophys. Res. 80(21):3032-3043.

Hatton, R.S., DeLaune, R.D. and W.H. Patrick, Jr. 1983. Sedimentation, accretion and subsidence in marshes of Barataria Basin, Louisiana. Limnol. Oceanogr. 28: 494-502.

Koide, M., A. Soutar, and E.D. Goldberg. 1972. Marine geochronology with Lead-210. Earth and Planet. Sci. Lett. 14:442-446.

Lugo, A.E., and S.C. Snedaker. 1974. The ecology of mangroves. Ann. Rev. Ecol. and Syst., 5:39-64.

Lugo, A.E. and S.C. Snedaker. 1975. Properties of a mangrove forest in southern Florida. In: G.E. Walsh, S.C. Snedaker, and H.J. Teas, (eds.), Proceeding of the International Symposium on Biology and Management of Mangroves. pp. 170-212. Institute of Food and Agricultural Sciences, University of Florida, Gainesville, Florida, USA.

Meriwether, J.R., J.N. Beck, D.F. Keeley, M.P. Langley, R.H. Thompson, and J.C. Young. 1988. Radionuclides in Louisiana soils. J. Env. Quality 17:562-568.

Nittrouer, C.A., D.J. DeMaster, B.A. Mckee, N.H. Cutshall and I.L. Larson. 1984. The effect of sediment mixing on Pb-210 accumulation rates for the Washington continental shelf. Marine Geology 54:201-221.

Nittrouer, C.A., R.W Sternberg, R.Carpenter, and J.T. Bennett. 1979. The use of Pb-210 geochronology as a sedimentological tool: application to the Washington continental shelf. Marine Geology 31:297-316.

Nixon, S.W. 1980. Between coastal marshes and coastal waters -- a review of twenty years of speculation and research on the role of salt marshes in estuarine productivity and water chemistry. In: P. Hamilton and K.B. MacDonald (eds.), Estuarine and Wetland Processes. pp. 437-525. Plenum, New York, New York.

Oldfield F., and P.G. Appleby. 1984. Empirical testing of Lead-210 dating models for lake sediments. In: E.Y. Haworth and J.W.G. Lund (eds.), Lake Sediments and Environmental History. pp. 93-124. University of Minnesota Press, Minneapolis, Minnesota.

Oenema, O. and R.D. DeLaune. 1988. Accretion rates in salt marshes in the eastern Scheldt, south-west Netherlands. Estuarine, coastal and shelf science 26:379-394.

Phleger, F.B. and Ayala-Castañares, A. 1971. Processes and History of Terminos Lagoon, Mexico. Amer. Assoc. Pet. Geol. Bull. 55(12):2130-2140.

Scholl, D.W. and M. Stuiver. 1967. Recent submergence of southern Florida: A comparison with adjacent coasts and other eustatic data. Ecological Soc. Am. Bull. 78: 437-454.

Scholl, D.W., F.C. Craighead, and M. Stuiver. 1969. Florida submergence curve revised: Its relation to coastal sedimentation rates. Science 163:562-564.

Scoffin, T.P. 1970. The trapping and binding of subtidal carbonate sediments by marine vegetation in Bimini Lagoon, Bahamas. J Sed. Petrol. 40(1):249-273.

Sharma, P., L.R. Gardner, W.S. Moore, and M.S. Bollinger. 1987. Sedimentation and bioturbation in a salt marsh as revealed by Lead-210, Cesium-137, and Beryllium-7 studies. Limnol. Oceanogr. 32(2):313-326.

Spenceley, A.P. 1977. The role of pneumatophores in sedimentary processes. Mar. Geol. 24:M31-M37.

Spenceley, A.P. 1982. Sedimentation patterns in mangal on

Magnetic island near Townsville, North Queensland, Australia. Singapore J of Trop Geog. pp. 100-107.

Stevenson, J.C., M.S. Kearney, and E.C. Pendleton. 1985. Sedimentation and erosion in a Chesapeake Bay brackish marsh system. Mar. Geol. 67:213-235.

Thom, B.G., 1982. Mangrove ecology - a geomorphological perspective. In B.F. Clough (ed.): Mangrove ecosystems in Australia, pp. 3-17. Austr. Nat. Univ. Press, Canberra.

Twilley, R.R. 1982. Litter dynamics and organic carbon exchange in black mangrove (Avicennia germinans) basin forests in a southwest Florida estuary. Dissertation. University of Florida, Gainesville, Florida, USA.

Twilley, R.R. 1985. The exchange of organic carbon in basin mangrove forests in a southwest Florida estuary. Estuarine, Coastal and Shelf Sci. 20:543-557.

Twilley, R.R., A.E. Lugo, and C. Patterson-Zucca. 1986. Litter production and turnover in basin mangrove forests in Southwest, Florida. Ecology 67:670-683.

Woodroffe, C.D. 1981. Mangrove swamp stratigraphy and holocene, transgression, Grand Cayman Island, West Indies. Mar. Geol. 41:271-294.

Yáñez-Arancibia, A. and J.W. Day. 1982. Ecological characterization of Terminos Lagoon, a tropical lagoon-estuarine system in the southern Gulf of Mexico. Oceanologica Acta SP:431-440.

Table 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. Missing values for ^{137}Cs in deeper sections were undetectable above background activity. Missing values for ^{210}Pb indicate the section was not sampled.

	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 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. Missing values for ^{137}Cs in deeper sections were undetectable above background activity. Missing values for ^{210}Pb indicate the section was not sampled..

	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	

Table 3 Bulk density (g cm^{-3}) for cores from Rookery Bay, Florida, showing consolidation corrected depth values normalized to the average (Avg) bulk density of the deepest five sections per core. Corrected depths shown are the midpoint (cm) for each section. S.E. = standard error.

	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 4 Bulk density (g cm^{-3}) for cores from Terminos Lagoon, Mexico, showing consolidation corrected depth values normalized to the average (Avg) bulk density of the deepest five sections per core. Corrected depths shown are the midpoint (cm) for each section. S.E. = standard error.

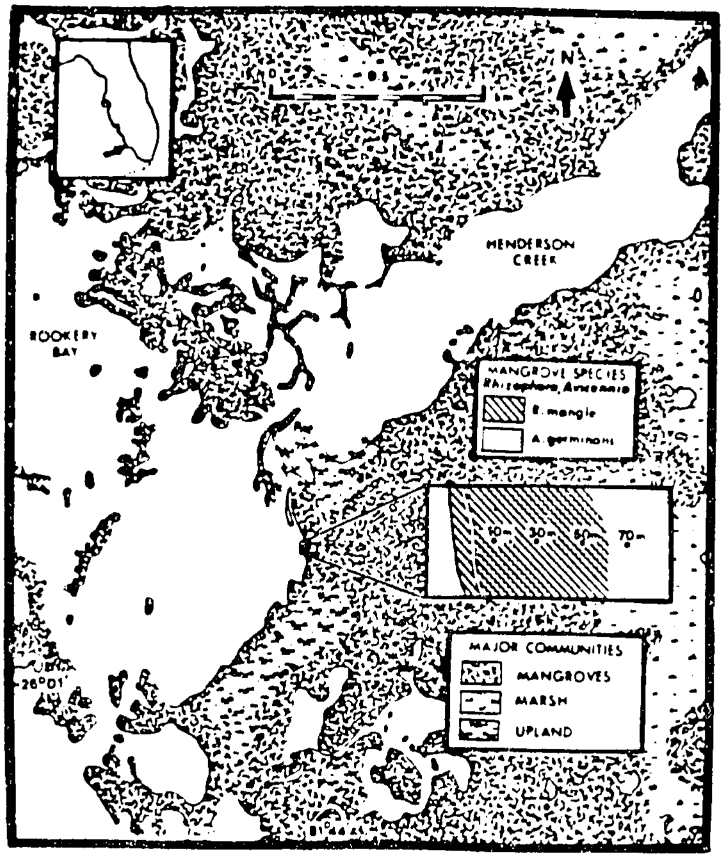
	Bulk Density				Corrected Depth			
	Boca Chica		Estero Pargo		Boca Chica		Estero Pargo	
Depth	15m	100m	10m	225m	15m	100m	10m	225m
0-2	---	0.826	0.323	0.174	0.50	0.82	0.91	0.29
2-4	0.267	0.796	0.238	0.229	1.60	2.42	2.32	0.84
4-6	0.296	0.924	0.222	0.297	2.86	4.11	3.62	1.72
6-8	0.258	1.136	0.270	0.239	4.10	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				

Table 5 Original and consolidation corrected accretion rates ($\mathrm{mm\ yr^{-1}}$) 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 Pargo				
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

50

List of Figures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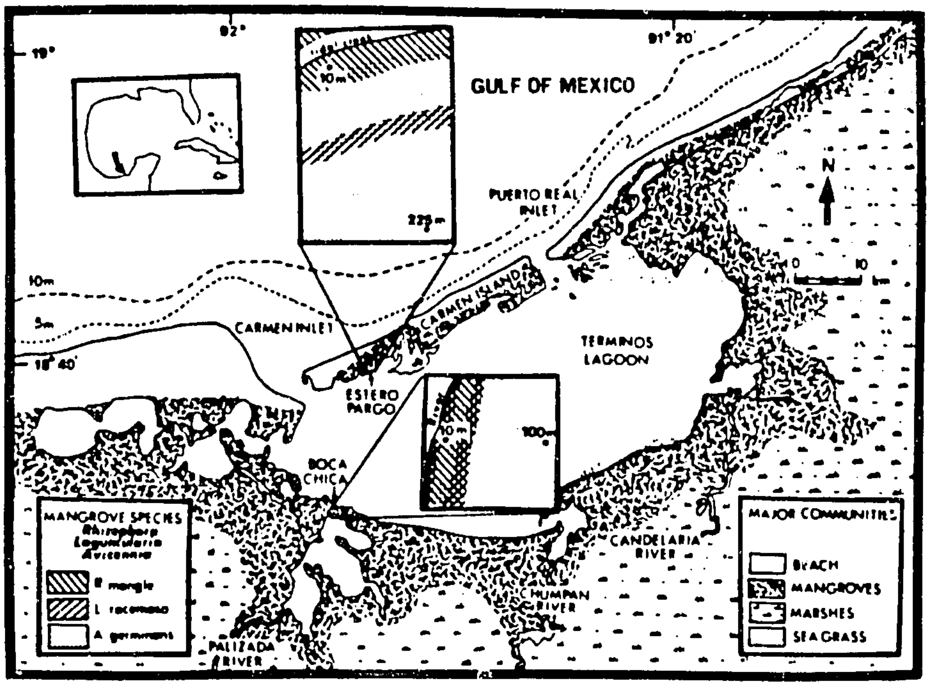
ROOKERY BAY
26°01'
MANGROVE SPECIES
Rhizophora, Avicennia
▨ R. mangle
☐ A. germinans
10m
30m
50m
70m
MAJOR COMMUNITIES
MANGROVES
MARSH
UPLAND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92°
91° 20'
GULF OF MEXICO
10m
225m
N
PUERTO REAL INLET
0
10
km
10m
5m
CARMEN INLET
CARMEN ISLAND
18° 40'
TERMINOS LAGOON
ESTERO PARGO
10m
100m
BOCA CHICA
MANGROVE SPECIES
Rhizophora
Laguncularia
Avicennia
▨ R. mangle
▨ L. racemosa
☐ A. germinans
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CHUMPAN RIVER
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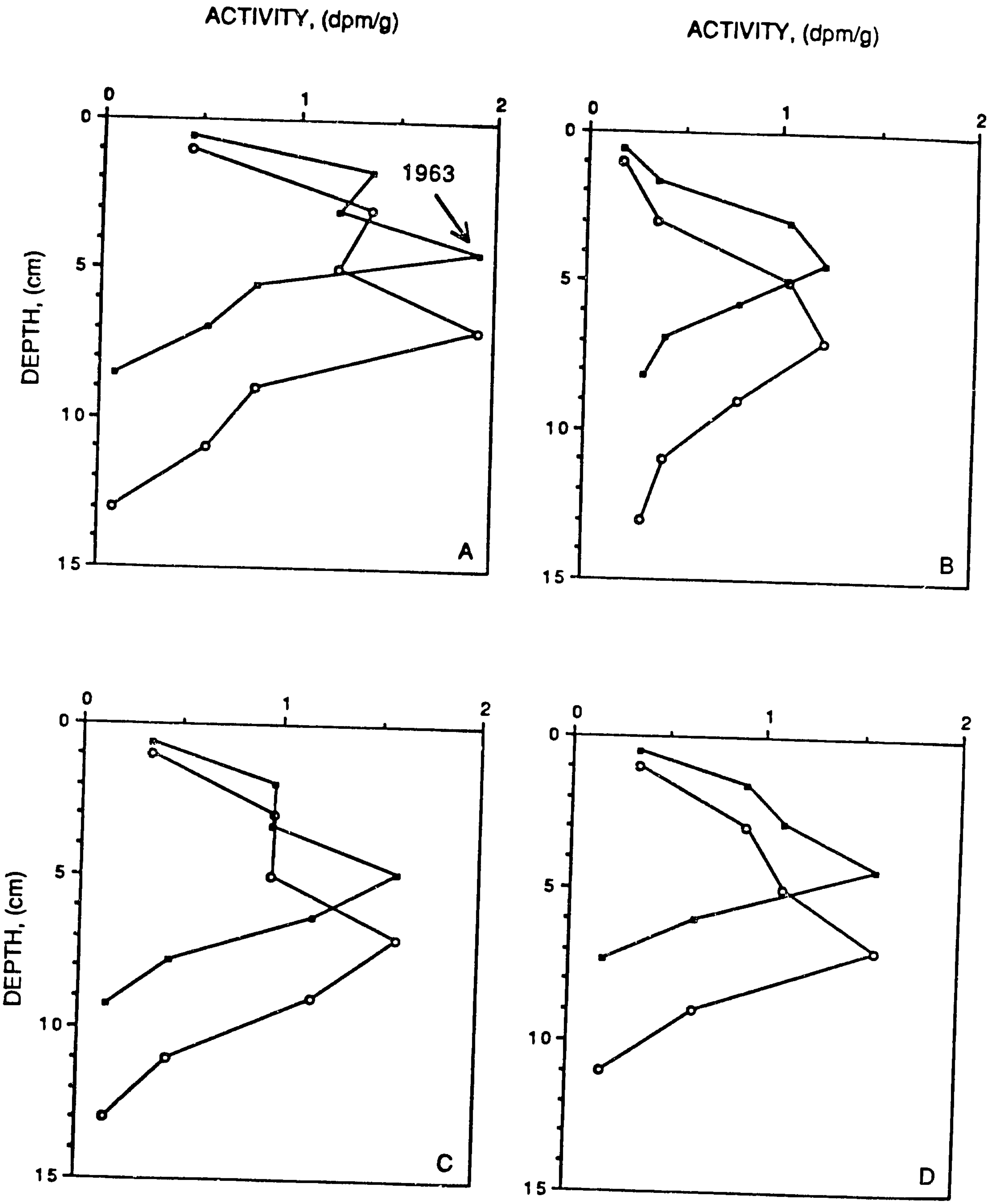
MANGROVES
MARSHES
☐ SEAGRASS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ACTIVITY, (dpm/g)
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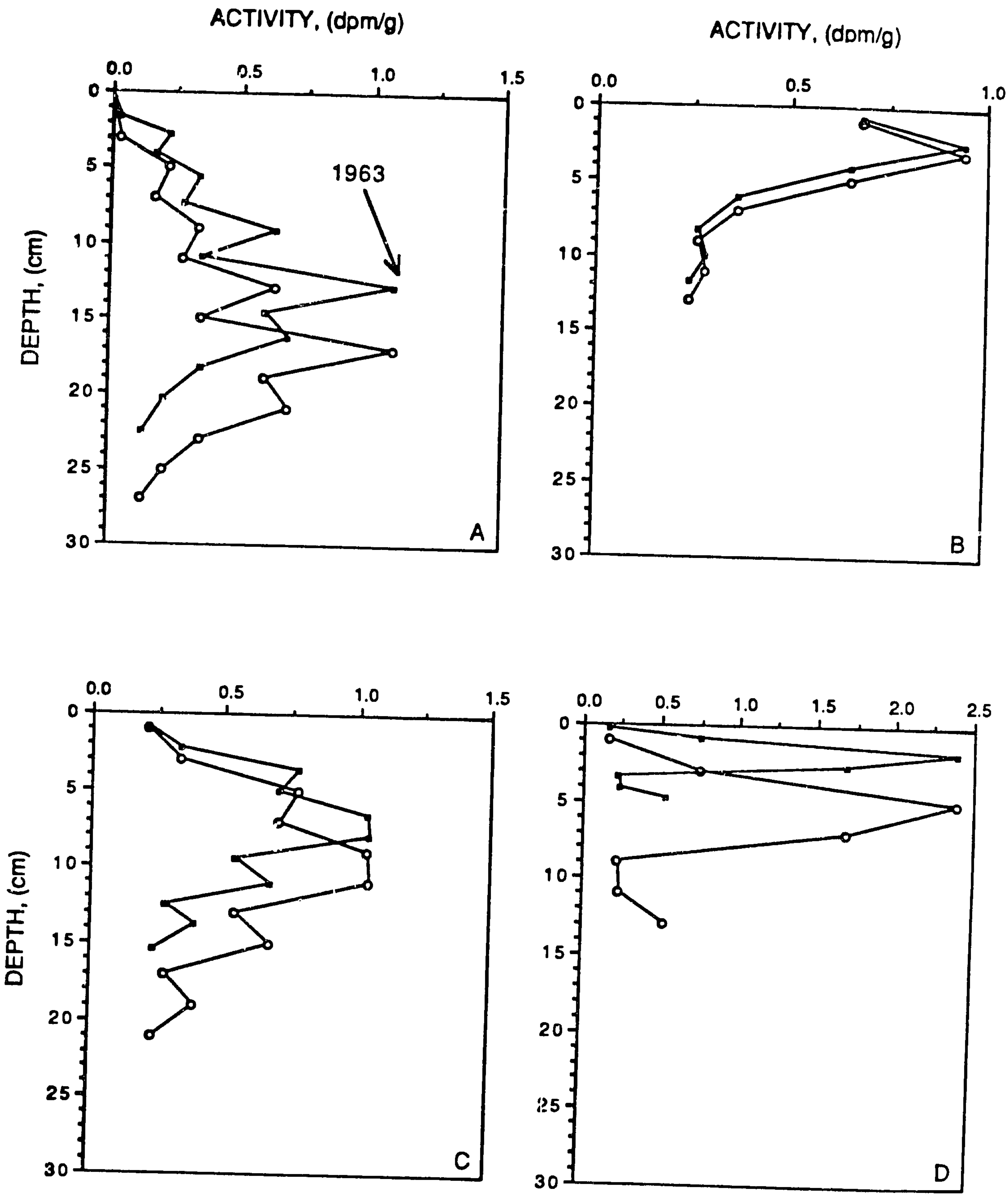
2
0
5
10
15
DEPTH, (cm)
1963
A
B
C
D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DEPTH, (cm)
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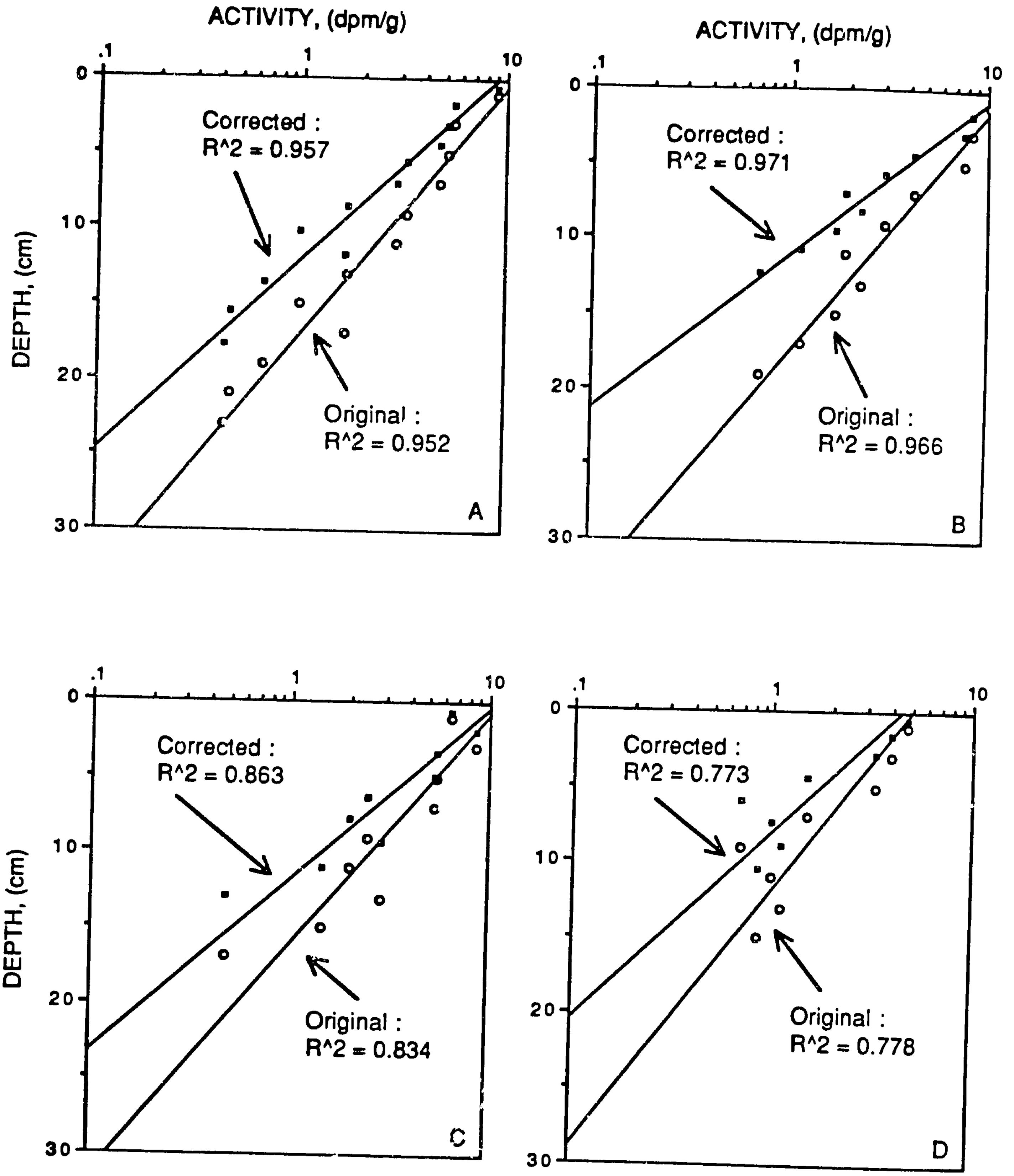
5
10
15
20
25
30
1963
A
ACTIVITY, (dpm/g)
0.0
0.5
1.0
B
0.0
0.5
1.0
1.5
C
0.0
0.5
1.0
1.5
2.0
2.5
D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1
10
DEPTH, (cm)
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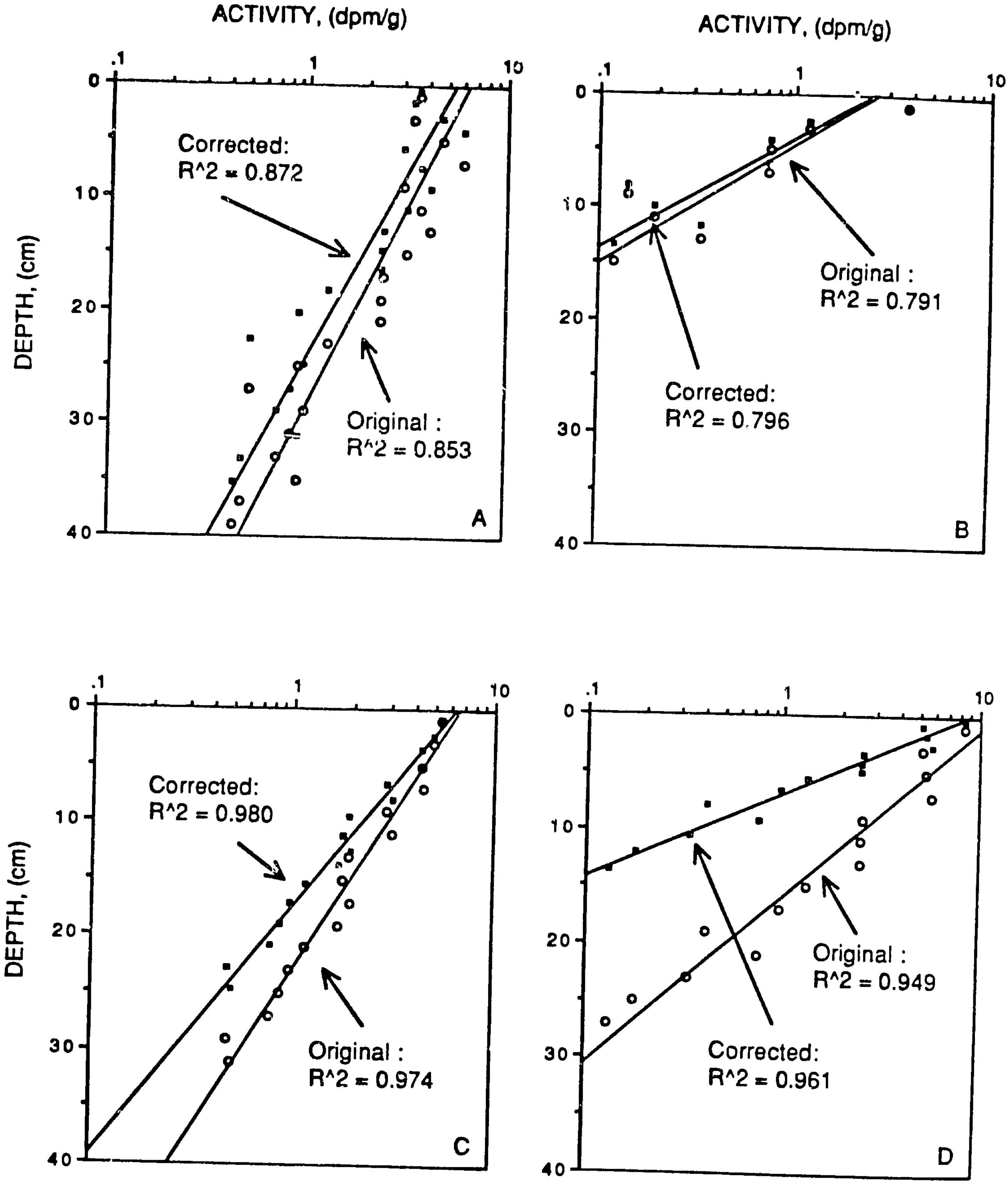
10
20
30
Corrected :
R^2 = 0.957
Original :
R^2 = 0.952
A
ACTIVITY, (dpm/g)
Corrected :
R^2 = 0.971
Original :
R^2 = 0.966
B
Corrected :
R^2 = 0.863
Original :
R^2 = 0.834
C
Corrected :
R^2 = 0.773
Original :
R^2 = 0.778
D


ACTIVITY, (dpm/g)
ACTIVITY, (dpm/g)
DEPTH, (cm)
DEPTH, (cm)
.1
1
10
0
10
20
30
40
Corrected:
R^2 = 0.872
Original :
R^2 = 0.853
A
Original :
R^2 = 0.791
Corrected:
R^2 = 0.796
B
Corrected:
R^2 = 0.980
Original :
R^2 = 0.974
C
Original :
R^2 = 0.949
Corrected:
R^2 = 0.961
D