8.333
PN-ABN-067
ISN 80528

TITLE PAGE

FINAL REPORT

June 1988 to May 1991

Submitted to the Office of the Science Advisor
U.S. Agency for International Development

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

Robert R. Twilley, Ph.D.
University of Southwestern Louisiana

Dr. Lucía Solórzano
Instituto Nacional de Pesca

Dr. Roger Zimmerman
National Marine Fisheries Service

Project 8.333
Grant No. DPE-5542-G-SS-8011-00

cc: CDIE [illegible] June 1988 to May 1991

PROJECT COORDINATION and ACKNOWLEDGMENTS

The following persons provided technical and administrative assistance to this project and special thanks to their commitment to excellence in ecological research of mangrove ecosystems.

Alejandro Bodero
Coastal Resource Management Project, Guayaquil, Ecuador

Victor Rivera-Monroy
Louisiana State University, Baton Rouge, LA

Mireya Pozo
University of Guayaquil, Guayaquil, Ecuador

Ramón Zambrano
Guayas Forestry District Office, Guayaquil, Ecuador

Victor Garcia
University of Guayaquil, Guayaquil, Ecuador

Krugel Loor
University of Guayaquil, Guayaquil, Ecuador

Rosa Garcia
National Fisheries Institute, Guayaquil, Ecuador

Washington Cardenas
National Fisheries Institute, Guayaquil, Ecuador

Nikita Gaibor
National Fisheries Institute, Guayaquil, Ecuador

Jorge Espinoza
National Fisheries Institute, Guayaquil, Ecuador

Ing. Leno Delgado, Chief
Guayas Forestry District Office, Guayaquil, Ecuador

Dr. Gladys Tazán, Professor
University of Guayaquil, Guayaquil, Ecuador

Mariano Montano Arijmos, Professor
Escuela Superior Politecnica del Littoral, Guayaquil, Ecuador

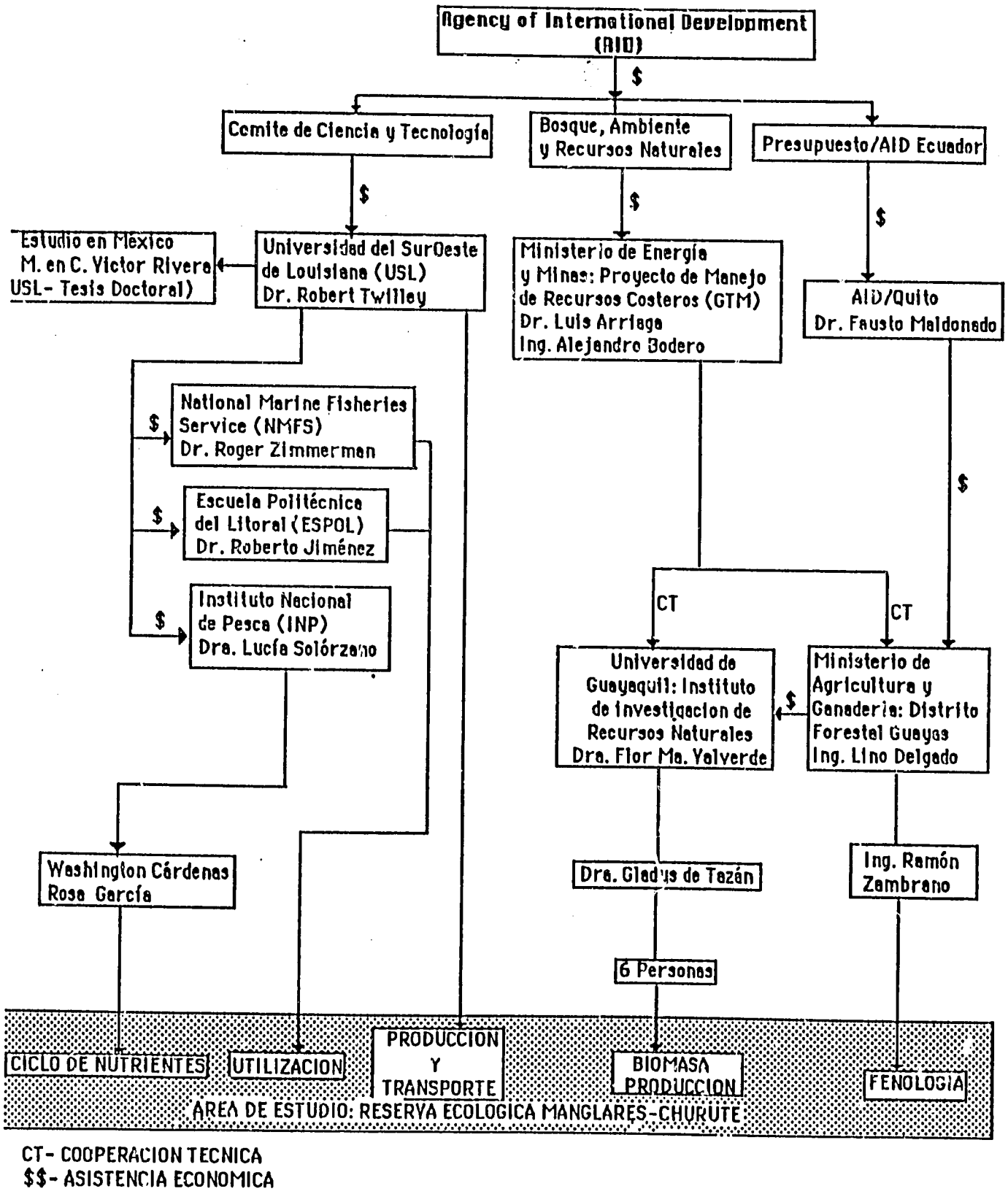
Jose Manuel Valdivieso, Director
Centro de Levantamientos Integrados de Recursos Naturales por Sensores Remotos (CLIRSEN), Guayaquil, Ecuador

James C. Lynch
University of Southwestern Louisiana

The success of this project is due largely to the newly formed coordinated efforts of several institutions in the United States and Ecuador as indicated in Fig. 1. The University of Rhode Island Coastal Resource Center, directed by Steve Olsen, provided the mandate for this mangrove ecology project. Others in the URI CRC program that provided assistance include Donald Robadue, director of the Ecuador project, Lynne Hale, Brian Crawford, Gordon Foer, and Bruce Eppler. The URI/CRC Ecuador project, funded by USAID, established an office in Guayaquil for the Proyecto de Manejo de Recursos Costeros (PMRC), directed by Dr. Luis Arriaga M. This office was instrumental in the coordination of the mangrove study and provided logistical, administrative, and clerical assistance. Special thanks to Alejandro Bodero and Elizabeth de Silva for their efforts in keeping this project on schedule. This project also received strong consideration as part of the AID/Quito mission by the efforts of Dr. Fausto Maldonado and Dr. Fernando Ortis Crespo. Local support was also provided by Guayas Forestry District Office (DINAF), Guayaquil, directed by Ing. Leno Delgado. This office was responsible for the inclusion of the Churute Ecological Preserve as a focus of the mangrove study, and provided much of the logistical support for the mangrove component of this project. The mangrove field study was also supported by the School of Natural Sciences, University of Guayaquil. Special thanks to Dr. Flora Valverde, dean of the School of Natural Science for use of laboratory facilities at the University. The estuarine program was assisted by the Instituto Nacional de Pesca, in Guayaquil, which is under the supervision of the Director General of Fisheries, Dr. Jaime Roldós. The Directors of INP during this mangrove project provided ship support for the estuarine program, and special thanks to Dr. Roberto Jiménez, Emilio Cucalón, and M.Sc. Luis Arriaga O. Access to shrimp farms and tours for visiting scientists was essential to the training sessions during this project and thanks to President of Shrimp Producers Association, Ing. Luis Arcentales, for supporting our efforts.

In Mexico, the mangrove studies were performed at the Universidad Autonoma de Mexico, Estacion de Carmen, directed by M. en C. Francisco Vera-Herrera. The Instituto de Ciencias del Mar y Limnologia at UNAM allowed access to laboratory space and provided boat support for the project. Our research efforts at Terminos Lagoon were also supported by the assistance of Dr. Alex Yáñez Arancibia, director of EPOMEX, in Campeche, Mexico.

There were several persons at the University of Southwestern Louisiana that assisted on this project and provided valuable support to the program. Dr. Brent McKee at LUMCON Marine Center provided laboratory support for the lead-210 analyses and Dr. John Meriwether supported some initial counts of cesium-137 on soil cores from Ecuador. Technical assistance on the project was provided by Jim Lynch, Karen Tyschen, Monica Solar, and Anand Singh. Matching funds from the Department of Biology and USL also contributed to this research program.



CT- COOPERACION TECNICA
$$- ASISTENCIA ECONOMICA

Figure 1. Organizational chart of the mangrove project funded by PSTC of AID and the other related mangrove and coastal management projects in Ecuador.

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EXECUTIVE SUMMARY

In August 1986, a workshop was organized in Guayaquil to evaluate the shrimp farming industry in Ecuador, which had recently suffered loss of production due to the lack of available post larvae for ponds. Total production and export of shrimp was down in 1984 and during 1985, only half of the 75,000 ha of shrimp ponds constructed in the coastal provinces were in operation. Several factors had been associated with the decline in post larvae in the estuaries along the coast of Ecuador including lower water temperatures (back to normal temperatures following an El Niño event), loss of mangrove habitat, decline in water quality (increased occurrence of red tide, pesticides, and heavy metals), and to indiscriminate overfishing of available wild stocks. From 1980 to 1987 nearly 15,000 ha of ponds were authorized for construction annually increasing the total to 150,000 ha by 1991; and most of these ponds had been constructed in the intertidal zone. There was immediate concern that the unregulated growth of this industry had destroyed the ecological processes of coastal ecosystems, which threatened the sustainability of shrimp farming in Ecuador. Most of the concern was centered around the loss of ecological functions of mangroves, which is attributed to maintaining habitat and water quality of coastal ecosystems. The lack of recruitment and survival of wild post larvae demonstrated the susceptibility of this industry to the environmental quality of the coastal zone of Ecuador.

This final report describes an ecosystem analysis of the Guayas River estuary , Ecuador, along with ecological studies in Terminos Lagoon, Mexico, to quantify the function of mangroves in different environmental settings. Mangroves may provide food and habitat to a variety of trophic levels, as well as influence nutrient and sediment concentrations in estuarine waters. Based on 1991 aerial surveys of the coast, there has been a loss of about 14% of the mangrove resources in Ecuador, but in some watersheds the loss of mangroves is greater than 90%. The environmental settings of mangroves in the four coastal provinces of Ecuador vary from high tidal amplitude and river discharge (Esmeraldas and Guayas provinces) to arid environments with minor tides and little freshwater input (Manabi province). This study describes the unique features of mangrove ecosystems in the Guayas River estuary, Ecuador. There are few studies of mangrove ecology in the New World that have been conducted in environmental settings with the high geophysical energies of the Guayas River estuary. This comparison will help us develop conceptual models of the ecosystem properties of mangroves in Ecuador, as well as worldwide, to provide information needed for the development of coastal zone management.

There were five objectives in this study to describe the ecological functions of mangroves in Ecuador and Mexico. *Objective One*: Litter produced in the canopy of mangrove forests represents a major source of organic matter and nutrients for outwelling to adjacent coastal waters. Thus the dynamics of mangrove litter including productivity, decomposition, and export influence the coupling of mangroves to coastal ecosystems. Mangroves in Churute Ecological Preserve (CEP) produce about 10 Mg ha^{-1} yr^{-1} of detritus. Very little of this litter accumulates on the forest floor except for the months of September and October, resulting in some of the highest litter turnover rates for mangroves in the world (>10 yr^{-1}). Given rates of leaf decomposition in the three mangrove sites, most of the loss of litter is via tidal export. However, leaf litter was harvested by the mangrove crab, *Ucides occidentalis*, and burrowed within the forest. Thus the level of detritus export depends on tidal and crab activity. It is estimated that detritus export from mangroves in CEP is average at about 200 gC m-2 yr^{-1}, although high litter productivity and large tidal range would suggest more contribution of organic matter to the estuary. Detritus export to estuarine food webs is limited due to the activity of the mangrove crab, which results in more direct utilization of organic matter within the mangrove.

Objective Two: There is evidence that sedimentation and nutrient accumulation along with denitrification are important sinks of sediments and nutrients in estuaries. The relative influence of these ecological processes on the fate of sediments and nutrients depends on the geomorphological characteristics of the coastal zone. The Churute Ecological Preserve represented an opportunity to compare these processes in riverine mangroves with much greater river discharge and tidal

amplitude than in other mangrove studies. Sedimentation rates of 2200 g m-2 yr-1 for mangroves in CEP are higher than for mangroves other riverine mangroves, and much higher than basin mangroves in lagoons. Denitrification studies are incomplete, but indicate that together with sedimentation, these systems are an important nutrient sink in coastal margin ecosystems.

Objective Three: The fact that mangroves provide a source of organic detritus to coastal waters contradicts the idea that they also serve as a nutrient sink. The key to understanding the function of mangroves in food webs and nutrient cycles of coastal waters is to compare the different form of nutrients in estuarine waters that are exchanged with mangroves. A fringe mangrove in Estero Pargo, Mexico, demonstrates the effect of mangroves on removing inorganic nutrients transported during flood tide, to organic detritus on the ebb tide. The net flux of inorganic nutrients into mangroves may be associated with sedimentation and/or denitrification, and these fluxes are higher than net release of organic nutrients from the forests. The net flux of total nutrients is into mangroves supporting their function as a nutrient sink The net export of organic nutrients are associated with the function of mangroves in providing detritus to coastal food webs.

Objective Four: There are very few studies on the ecology of tropical estuaries, and most of our understanding comes from comparisons with much different temperate systems. Seasonality in the tropics is controlled in many cases by the presence and absence of precipitation, and in the Guayas River estuary there were also strong seasonal patterns of salinity associated with seasonal river discharge. Other physical, chemical and biological characteristics of this natural estuary were linked to seasonal patterns in river flow such as turbidity, total suspended sediments, nutrients (particularly silicate) and phytoplankton. Differences between natural (Churute) and altered (Salado) systems were salinity, light, and silicate concentrations, and the utilization of mangrove habitat by estuarine fauna.

Objective Five: The habitat quality of mangroves are a function of both the detritus that support the mixed tropic food webs of estuaries, and refugia that provide nekton protection from predators. Recruits of three species of *Penaeus*, *P. californiensis*, *P. vannamei*, and *P. stylirostris*, were abundant and shown to use nursery habitats associated with mangroves. Juveniles of the other two species, *P. occidentalis* and *P. brevirostris*, occurred infrequently and their nursery habitats were not found in the estuary. Juveniles of the abundant species were each more numerous during wet than dry seasons, but the effect of rainfall varied significantly among species. The white shrimp, *P. vannamei,* was highly affected by greater rainfall and was most abundant during the El Niño year of 1987. The use of natural isotope abundance to discern the utilization of mangrove detritus in estuarine food webs is masked by the complex flow of energy in tropical estuaries. Bacteria may be mobilizing nitrogen onto organic detritus changing the nature of nitrogen poor detritus from mangroves, suggesting that care must be taken when interpreting natural isotope abundance samples for food-web studies in these types of systems.

There are six key ecological functions of mangroves that maintain the habitat and water quality of coastal ecosystems. Mangroves are important in sustaining the shrimp farm industry by providing wild stock of postlarvae, a productive pond environment, and minimum water quality problems. Negative feedbacks of the shrimp industry are associated with the loss of mangroves, and the associated free services they provide to sustaining farm production. In addition, negative feedback results from the replacement of these natural intertidal systems with those that are nutrient sources and provide no refugia for estuarine fauna. Integrated shrimp pond management is recommended that utilizes the habitat quality and nutrient sinks of mangroves. Systems should be design that use mangroves to improve the quality of water that is exported from shrimp ponds. The habitat quality of ponds could be utilized by returning a portion (10%) of the shrimp stock to the estuary to sustain the PL supply. In addition, estuarine food webs of mangroves in Ecuador include the mangrove crab, *Ucides occidentalis*, which is harvested for 10 months and is sold locally. There are no reports of the value of this fishery to the local economy, but it is listed as an important management issue in the Esmeraldas, Manabi, and Guayas provinces.

RESEARCH OBJECTIVES

Mangroves are one of the dominant features of coastal ecosystems of the tropics. While ecologically they have been considered an important component of coastal watersheds, they are continually exploited for aquaculture, agriculture, charcoal, urban development and other economic activities. Attention has been focused on the utilization of mangrove habitat for the expansion of shrimp ponds, particularly in Ecuador, where in some watersheds such as Rio Chone over 80% of the mangroves have been reclaimed for mariculture. The success of this economic activity in Ecuador is quickly spreading to other developing countries in Central and South America where there is concern for sustaining the value of ecological and social systems. Management of these problems is limited because the various ecological functions of natural resources such as mangroves are poorly understood. In addition, there is not a methodology to determine the economic value of ecosystem function. In addition, some of the less understood functions of mangroves, such as their importance to water quality, has not been adequately studied. This report will describe an ecosystem study of mangroves to provide information for the development of integrated management of shrimp farming in Ecuador.

The first commercial shrimp operations in Ecuador began in 1969 (Siddall et al. 1985), nearly 400 years following the Incas practice of closing off lagoons which were temporarily flooded with seawater and penaeid shrimp larvae Ecuadorean farmed shrimp production rose dramatically from 1979 to 1984 and by 1989, shrimp ponds produced over 50,000 metric tons while production from the trawl industry remained at 7,500 metric tons (Fig. 2A). The value of production from shrimp ponds increased from $56.9 to $287.9 million US dollars from 1980 to 1986 (Fig. 2A). The export value of the 1991 crop increased to $482 million US dollars, ranked second only to petroleum as an export commodity for Ecuador (Olsen and Arriaga 1989, Aiken 1990). The cash generated by this mariculture activity is more important to the economy of Ecuador than bananas and cacao combined, and twice as important as coffee (Aiken 1990). The tremendous growth of this industry has made Ecuador the second leading farm shrimp producer in the world providing nearly 16% of the world market (McPadden 1985). Nearly all of this market is consumed in the United States.

The construction of shrimp ponds averaged nearly 14,000 ha annually from 1980 to 1991 resulting in a total area of over 150,000 ha by 1991 (Fig. 2B). Nearly all of these ponds were constructed in the intertidal zone, with most of the initial sites located in the upper zone or salinas. As these zones disappeared, more of the construction was located in the forested intertidal vegetation, or mangroves. Although there has been a steady increase in the construction of shrimp ponds, not all of these ponds have been in operation (Fig. 2C). In the initial stages of the development of this industry, nearly all the ponds constructed were in operation up to 1983. From 1983 to 1985, the area of ponds increased from about 60,000 ha to 100,000 ha, but the area of ponds in operation actually decreased to about 50,000 ha. The abundant supply of post larvae during the El Niño event of 1983 created an excessive demand for construction of shrimp ponds from 1985 to 1987. However, the natural supply of post larvae during the more normal years of recruitment could not stock the existing ponds, resulting in decline in pond operation. The fluctuation in the available PL during other El Niño events suggest that the optimum carrying capacity of the natural system is about 60,000 ha of shrimp ponds (Fig. 2C). The difference between ponds constructed and those in operation has placed a major emphasis to produce addition post larvae with hatcheries, and acclimate these shrimp to growout ponds.

The expansion of the farmed shrimp industry has been largely confined to the two southern coastal provinces of Guayas and El Oro. This coastal region handles 95% of the country's imports and 50% of its exports, and its coastline includes the most populated city in Ecuador, Guayaquil (Engineering Journal 1972). The population in Guayaquil has doubled to 2.5 million inhabitants in the last 10 years, and nearly 82% of the city discharges its waste directly into coastal waters (Twilley 1989). In addition, over 50% of the agriculture activity in the four coastal provinces of Ecuador occurs in the Guayas River basin. The Daule-Peripa dam was recently constructed to provide water for expansion of agriculture, particularly rice, by 17,000 ha during

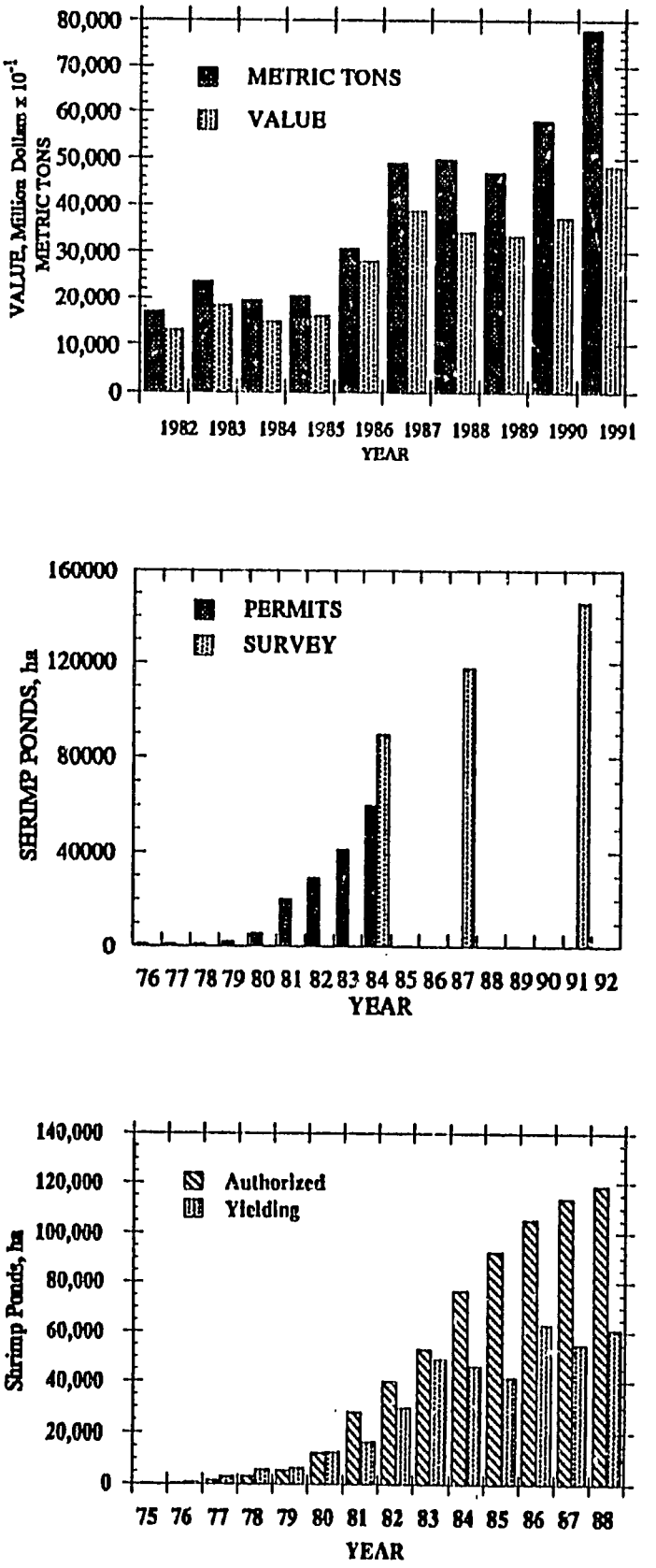


Figure 2. A) Productivity of the shrimp pond industry from 1982 to 1991 based on United States dollars and mass of shrimp sold per year. B) Index of the rate of shrimp pond construction in Ecuador based on permits issued by the Ministry of Agriculture, compared with direct delineation of shrimp pond area using remote sensing (1983, 1987, and 1991). C) Areas of shrimp ponds authorized for operation and estimates of the actual areas of shrimp ponds in production from 1975 to 1988 according to Espinoza (1989).

the initial phases of the project. This dam will also limit the discharge of freshwater into the Guayas River estuary. This coastal zone region also maintains an extensive area of intertidal communities including nearly 83% of all mangroves in Ecuador. It is the exploitation of mangrove resources, together with the diverse nature of these economic and ecological resources of this region, that result in complex issues of coastal resource management.

The multi-use nature of mangrove ecosystems are attributed to the diverse ecological processes that they provide including primary productivity, detritus export, refugia, sedimentation, and nutrient cycling (Fig. 3). These ecological processes support the functions of mangroves in providing habitat and water quality, and shoreline stabilization. The uses and values of mangroves in any coastal region depend on the nature of these functions, together with the cultural and economic conditions of the area. These uses can have a feedback effect on the ecological processes of the ecosystem, and thus influence the capacity of natural systems to provide these functions. In Ecuador, the production of shrimp depends on the function of mangroves, while the construction and present management of ponds represent negative feedback to the ecological processes of mangroves. The controversy in coastal resource management centers around the relative impacts of these connections and feedbacks. Are they significant enough to threaten the sustainability of shrimp farming in Ecuador? And how do we establish systems that can interface both the natural and social functions and values of the coastal zone? The success of developing management plans for the coastal zone depends on the ability to integrate the ecological function of mangroves with the properties of coastal ecosystems and the management of shrimp ponds (Fig. 3). The function of mangroves in water and habitat quality are key to understanding the ecological significance of their loss in Ecuador. This research project was designed to test these hypotheses.

The many complex interactions of human and natural resources in the coastal zone of Ecuador underscore the problems with interfacing the shrimp farm industry with coastal ecosystems (Fig. 4). The estuarine resources of Ecuador are strongly influenced by inland watersheds that control riverine inputs, and offshore water temperatures that trigger the recruitment of shrimp. The coupling of the estuary with the intertidal zone is enhanced by 3-5 m tides that links the exchange of sediments, nutrients, detritus and organisms with mangroves (Fig. 4). The replacement of mangroves with shrimp ponds in the intertidal zone changes the relative flow of energy and money in the coastal zone. For example, the exchange of materials between the intertidal zone and estuarine waters normally controlled by tides are replaced with fossil fuel that operate pumps that couple ponds with the estuary. Changes in the exchange of nutrients and habitat utilization of the estuary with the development of shrimp pond has to be analyzed in perspective to the function of natural resources in the coastal zone (Fig. 4).

This final report describes an ecosystem analysis of the Guayas River estuary , Ecuador, along with ecological studies in Terminos Lagoon, Mexico, to quantify the function of mangroves in different environmental settings. The specific ecological function of mangrove ecosystems may be related to environmental settings or forcing functions of the coastal zone, including river discharge, tidal amplitude, wave power, and precipitation. The environmental settings of mangroves in the four coastal provinces of Ecuador vary from high tidal amplitude and river discharge (Esmeraldas and Guayas province) to arid environments with minor tides and little freshwater input (Manabi province). Based on the assumptions described above, the function of mangroves in water and habitat quality may also vary among each watershed. This study will describe the unique features of mangrove ecosystems in the Guayas River estuary, Ecuador. There are few studies of mangroves in the New World that have been conducted in environmental settings with the high geophysical energies of the Guayas River estuary. This comparison will help us develop conceptual models of the ecosystem properties of mangroves in Ecuador, as well as worldwide, to provide information needed to develop best management plans for the coastal zone. The following are the proposed objectives and tasks of this project:

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;

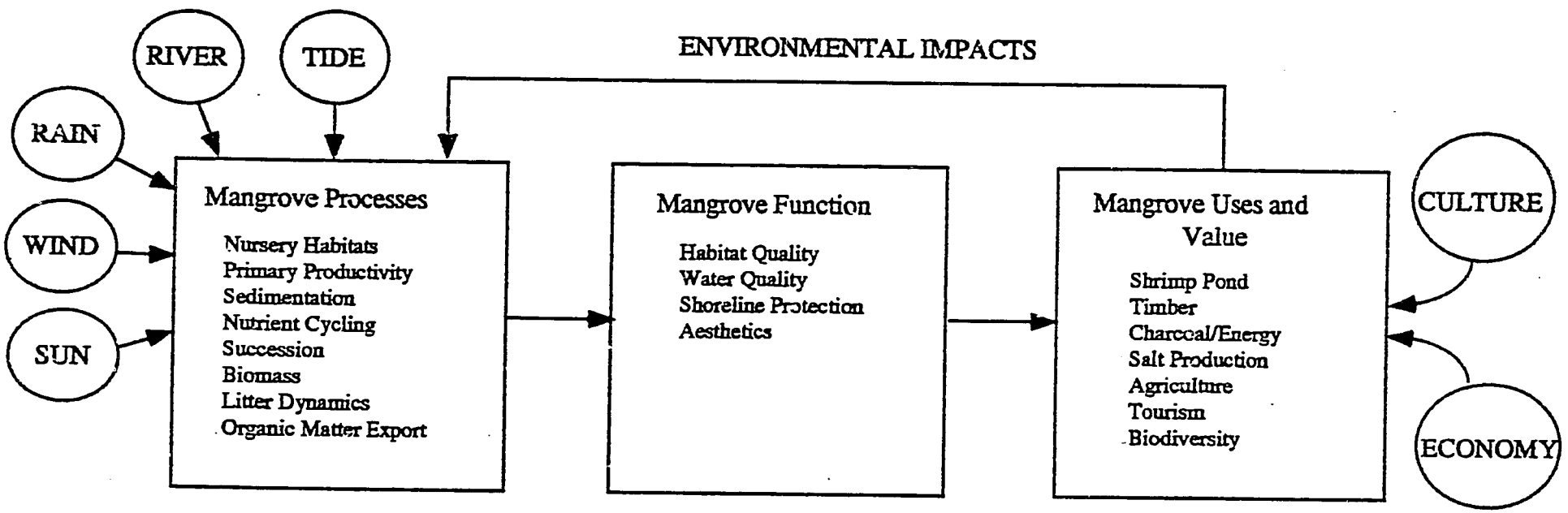


Figure 3. Diagram of the linkages among the environmental setting, ecological processes, functions, and uses of mangrove ecosystems.

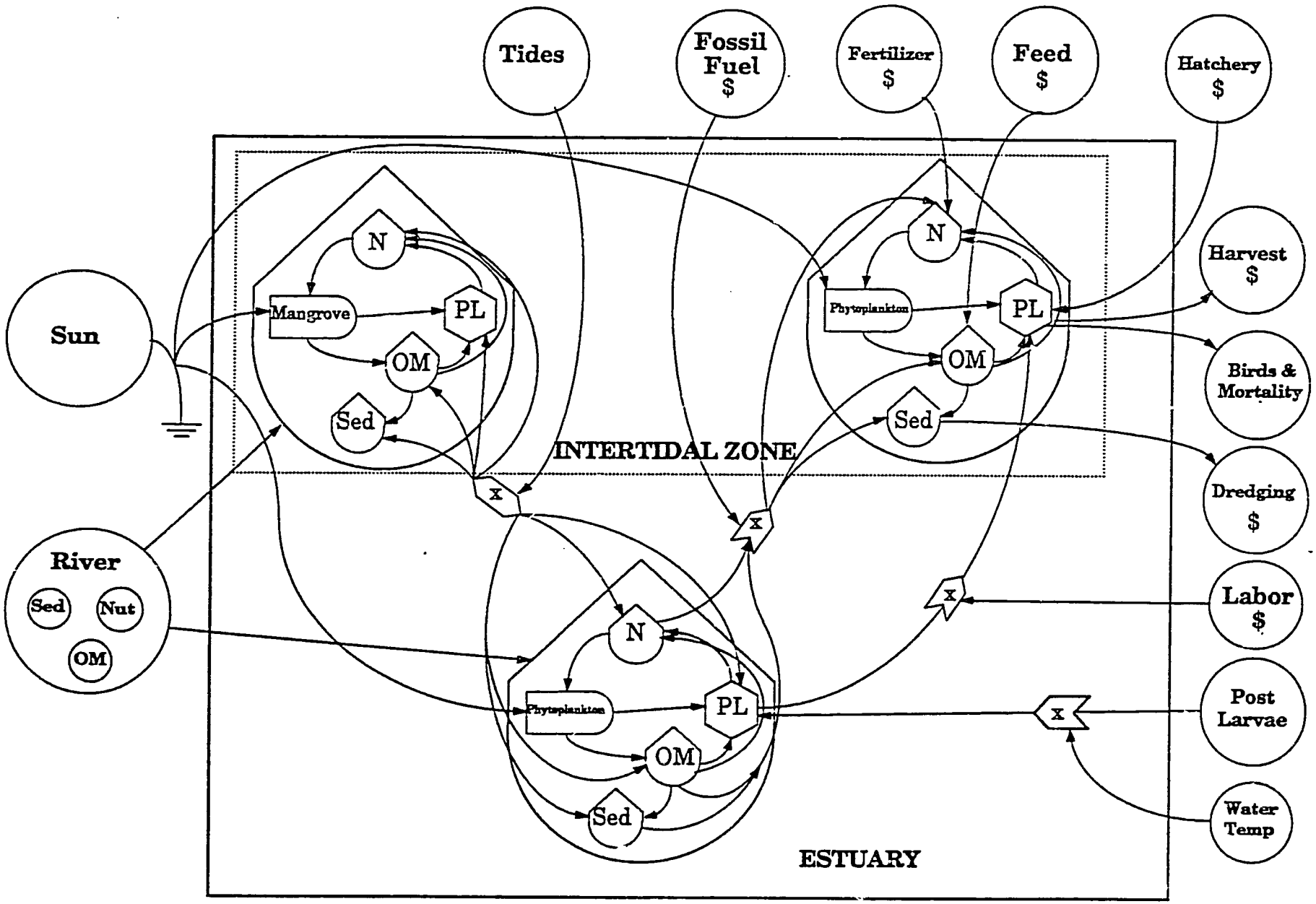


Figure 4. Ecological relationships of the coastal zone of Ecuador including the exchange of materials between estuary and mangroves, and the interface of shrimp farming with these ecological processes.

3. Determine if mangroves are a net source or sink of nutrients in estuarine ecosystems;
4. Provide basic understanding of the seasonal patterns of water quality parameters in a tropical estuary;
5. Determine the utilization of mangroves for habitat and food by economically important fisheries.

METHODS AND RESULTS

Study Site

The AID Mangrove Project was performed at two sites to allow for comparison of ecosystem processes related to different types of coastal systems. Studies in Ecuador were the focus of the study on litter production and utilization, along with surveys of nutrient parameters of Guayas River estuary. In Mexico, there are several previous studies of mangroves and properties of Terminos Lagoon (Yáñez-Arancibia and Day 1982, 1988). The focus of our study in Mexico was the exchange of nutrients between mangroves and coastal waters, and the role of denitrification in the flux of nitrogen at this boundary.

Ecuador

The coastal zone of Ecuador (1°N to 3°S 20'S) consists of four coastal provinces (Esmeraldas, Manabi, Guayas, and El Oro) situated in 284,000 km^2 of lowlands between the Pacific Ocean and the Andean highlands (Fig. 5). There are three climatic zones along the coast: a moderately wet climate in the south with abundant fresh water from runoff around Guayaquil; an arid central province with very sparse vegetation; and in the north near Esmeraldas, a more humid, tropical zone with abundant rainfall and runoff. More than 95 percent of the annual precipitation falls during the wet season from January to May (Stevenson 1981), and varies from less than 500 mm in the central provinces and the coast of the southern provinces, to over 3000 mm at Santo Domingo de las Colarados in the north (Engineering Journal 1972, Schaeffer-Novelli 1983). Annual mean temperatures (from 24.2 to 27 °C) vary little along the coast, thus potential evapotranspiration is about 1300 mm/yr.

The two major river and estuarine ecosystems of the coast are Esmeraldas River estuary in the north and Guayas River estuary which flows into the Gulf of Guayaquil in the south (Fig. 6). The Gulf of Guayaquil receives runoff from some 20 rivers with a watershed of 51,230 km^2 and is the largest estuarine ecosystem on the western Pacific coast of South America (Cucalon 1984). The major source of freshwater is the Guayas River, which forms 60 km upstream at the confluence of Rio Daule and Rio Babahoyo. The mean discharge of 1143.7 m^3/s for the Guayas River is the highest among the 30 rivers in the coastal zone of Ecuador representing 39% of the total discharge from this lowland region. Discharge is strongly seasonal ranging from 200 m^3/s during the dry season to 1600 m^3/s in the wet season with an average amount of precipitation (Fig. 7). Mean precipitation in the Guayas River drainage system north of Guayaquil is 885 mm/yr, which may range from less than 400 to more than 1800 mm during any one year. The huge variation in precipitation and discharge indicates that normal conditions are very arbitrarily defined, and masks the importance of freshwater to coastal processes, such as life cycle of estuarine organisms (Fig. 7).

The intensity of shrimp farming relies on oceanographic processes near Ecuador because of the strong influence that currents have on the availability of post larvae. Coastal Ecuador is a transition zone, or equatorial front, between southerly flowing tropical water from the Panama Bight and northerly flowing Humboldt Current from Peru. The mixing of these two water masses occurs between Manta and Punta Santo Elena along the coast of Ecuador and gradually moves southwards into the Gulf of Guayaquil. The dominance of the Panamanian Current occurs during the summer causing an increase in sea water temperature and initiates the onset of the rainy season (Cucalon 1984). Years of abnormally warm water temperatures and high rainfall are

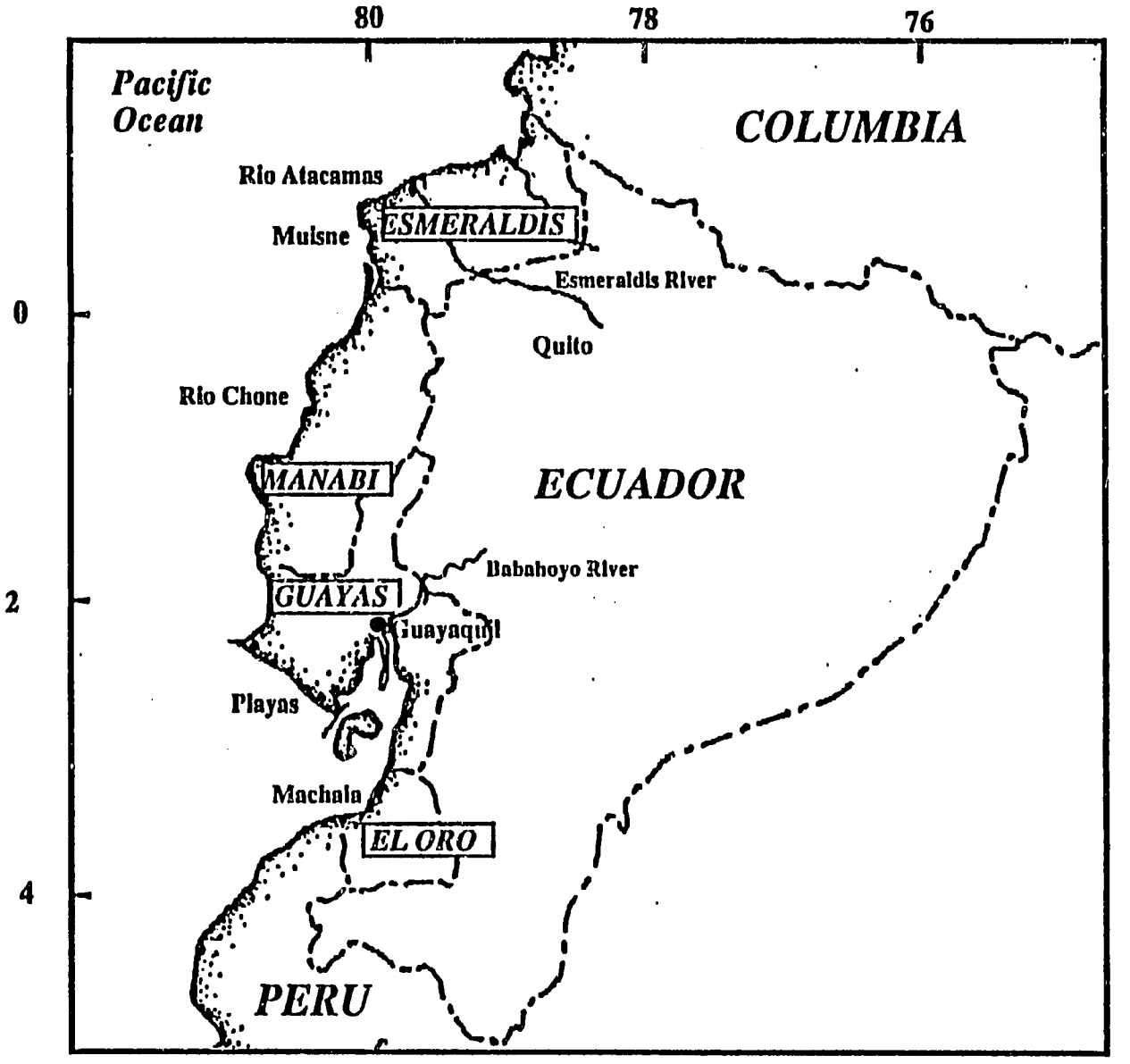


Figure 5. Map of Ecuador showing the four coastal provinces of Esmeraldas, Manabi, Guayas, and El Oro, and the five special management zones (ZEMs).

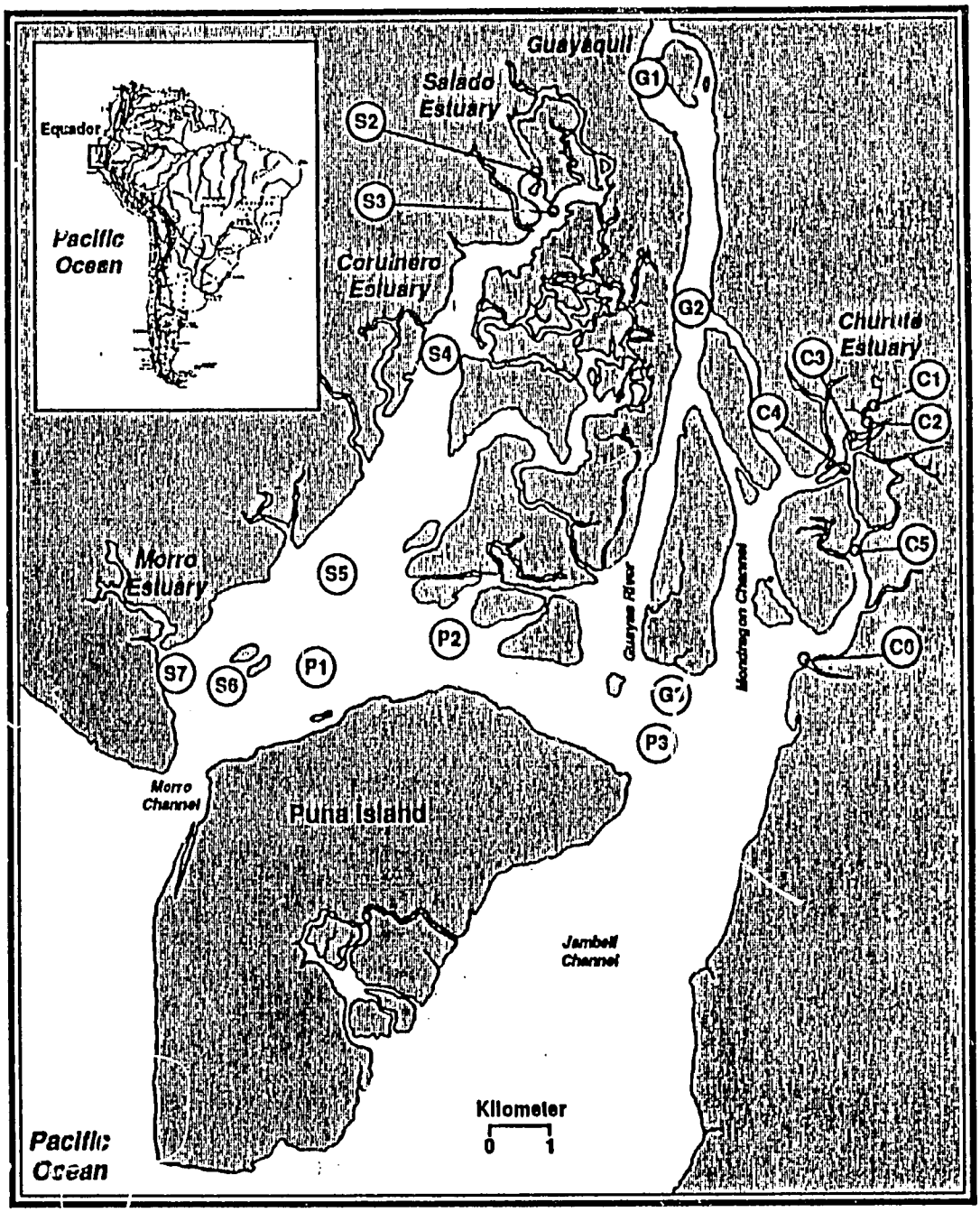
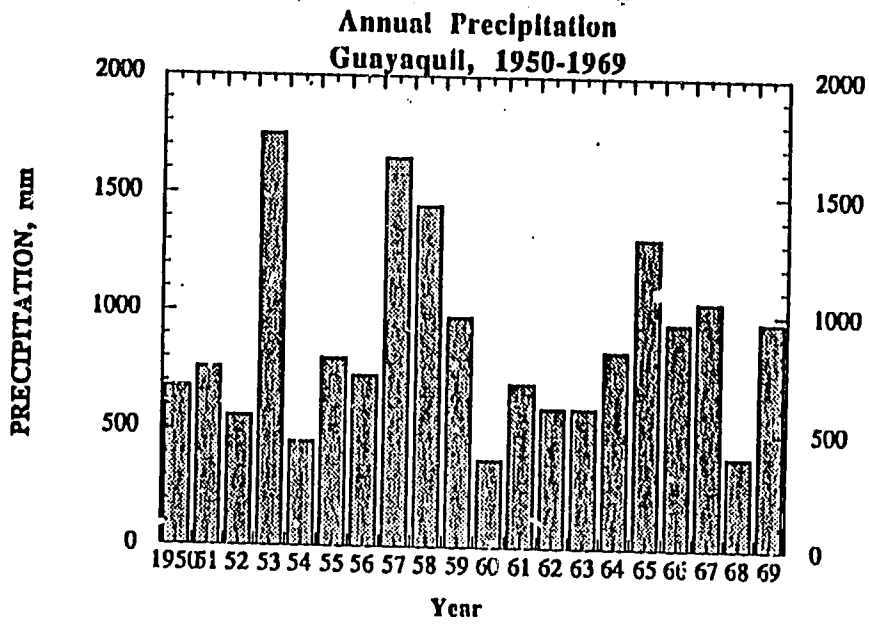


Figure 6. Map of the Guayas River estuary including the Guayas river, Churute estuary, and Estero Salado, and the sampling stations in the estuary sampling program of this study.



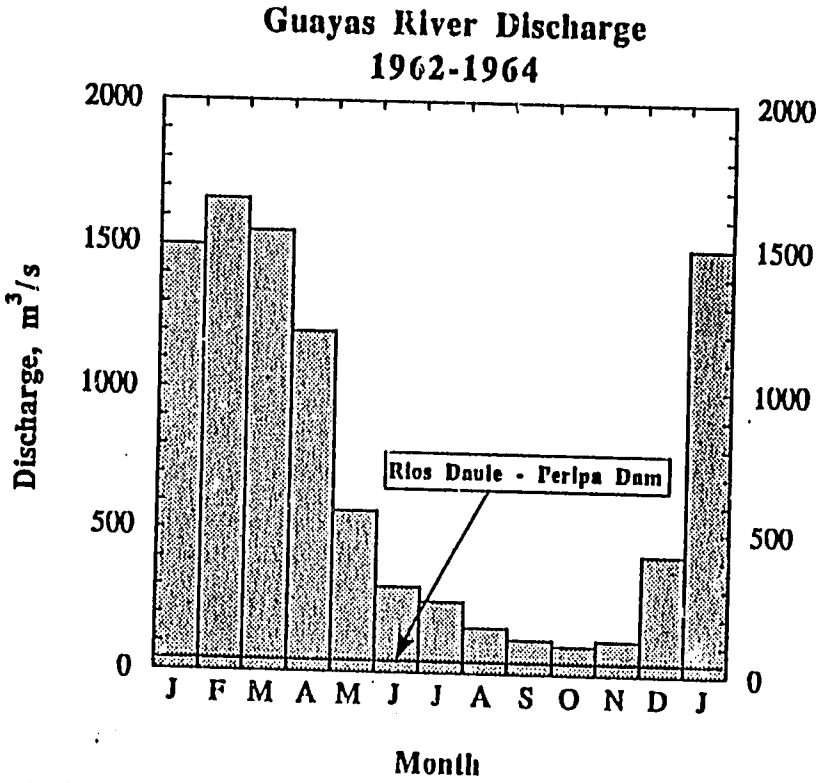


Figure 7. The interannual variation of precipitation in the Guayas River estuary watershed (Guayaquil) from 1950 to 1969; and the seasonal natuer of discharge of the Guayas River based on average monthly flow from 1962 to 1964 (Stevenson 1981).

associated with El Niño climate patterns due to the influx of unusually warm surface water in southeast Pacific Ocean. The warmer offshore waters have resulted in the explosive populations of white shrimp off the coast of Ecuador from enhanced spawning, maturation, and recruitment. In the last century, major El Niño events were recorded in 1925, 1929, 1939, 1941, 1953, 1957-58, 1965, 1972-73, 1976, and 1982-83 (Cucalon 1986). The high availability of post larvae that supported the expansion of the shrimp industry in 1983 and 1984 has been associated with the latter El Niño event. The unpredictable nature of oceanographic events and their influence on the ecological processes of upland and coastal watersheds contributes to the complex nature of coastal resource management in Ecuador.

Estuary Sites

The Guayas River estuary is composed of three different sub-estuaries: the Guayas River channel, Churute River tributary, and Estero Salado (Fig. 6). Monthly surveys of selected chemical, physical and biological characteristics of the Guayas River estuary have been conducted at 21 stations aboard the RV Proteo (Fig. 6). Chemical and physical measurements were taken at all 21 stations while fish and shrimp populations were sampled at 9 stations.

There is a strong seasonal pattern of salinity in the Churute and Guayas estuaries associated with the wet season from February to May (Fig. 8). Estero Salado is connected to the Guayas River by a shipping channel that restricts the flow of freshwater in this system. Thus there is less of a seasonal change in salinity in Estero Salado and the residence time of water is much greater (Fig. 8). The salinity differences in these three subestuaries of the Gulf of Guayaquil are important to the biological resources of this region. The lack of seasonal pulse of salinity Estero Salado is an interesting comparison to the more naturally pulsed systems of the Guayas River and Churute River estuaries. These comparisons will be made in the respective sections on nutrient cycling and habitat utilization.

Mangrove sites:

The Churute Ecological Preserve along the Guayas River estuary was established in 1989 by the Direccion Nacional Forestal (DINAFOR) as part of the 14 forestry reserve areas in the country. The preserve includes 30,000 ha of coastal and freshwater wetlands serving as important feeding and habitat for fish, waterfowl, and other wildlife. Three mangrove study sites were established in the Churute Ecological Preserve in a M1 (trees > 15 m), M2 (trees 7 to 15 m), and M3 (trees < 7 m) type of forest (Fig. 9). This classification system was developed by CLIRSEN and the ecological preserve along with the entire coast of Ecuador has been mapped and areas of forest within each classification determined. All three types of mangrove forests in the Churute Preserve are dominated by *Rhizophora harrisonii* and *R. mangle*. The seasonal nature of the influence of the Guayas River to the Churute estuary is demonstrated by the change in salinity of surface waters in mangroves (Fig. 10). Salinities vary from less than 5 ‰ during June and July to nearly 30 ‰ in January and February. Soil salinity within mangroves exhibits much less variation and average about 20 ‰, indicative of riverine mangrove forests (Fig. 10). Field observations and tidal recordings within the forest confirm that tides are more frequent in the M1 and M2 sites compared to the M3 site.

Mexico

Terminos Lagoon is located in southeastern Mexico (18°40'N and 91°30'W), adjacent to the western boundary of the Gulf of Mexico (Fig. 11). The lagoon has an area of approximately 2500 km^2 with a mean depth of 3.5 m. The lagoon is subject to a rain season from June to January 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 $m^3 s^{-1}$ (Phleger and Ayala-Castanares 1971) with maximum discharge from September to November. Mangrove sites in Terminos Lagoon included

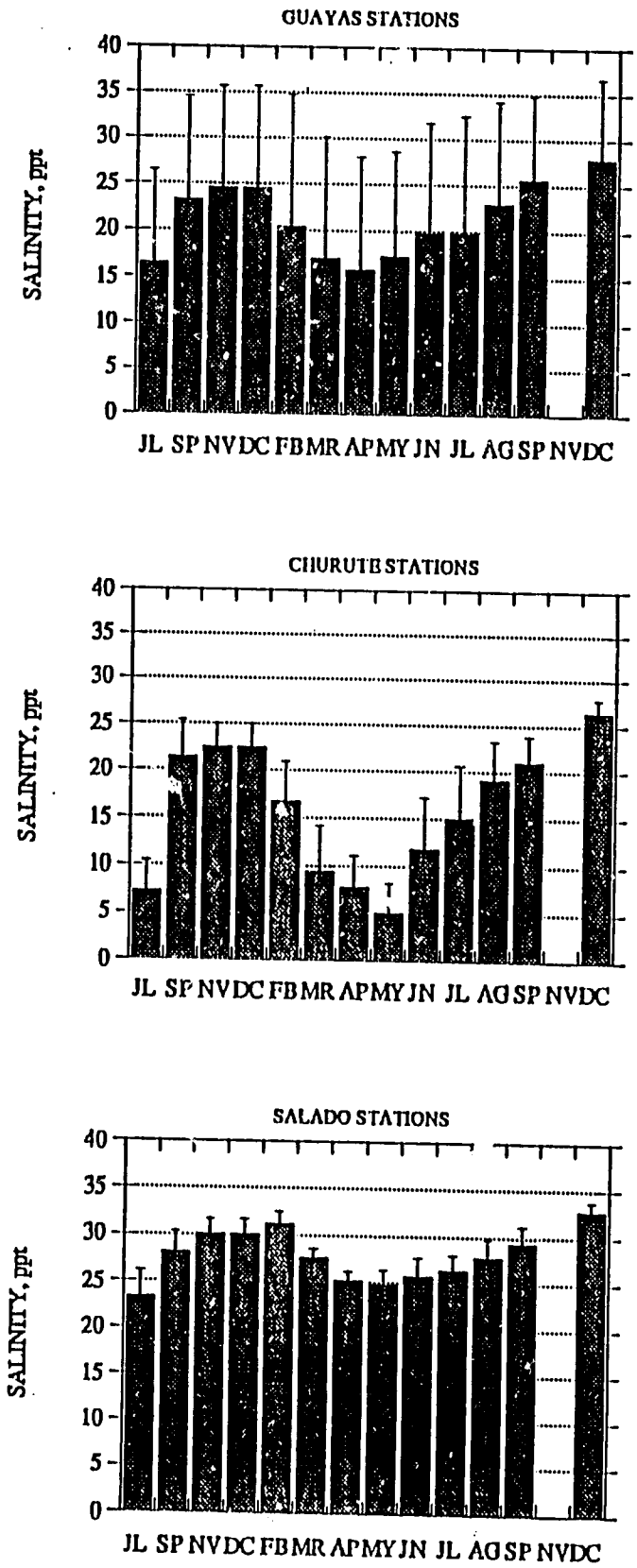


Figure 8. Seasonal patterns of salinity in the three subestuaries of the Guayas River estuary from July (JL) 1989 to December (DC) 1990. Means and standard error are for all stations in each subestuary for one sampling per month based on 0.5 m depth.

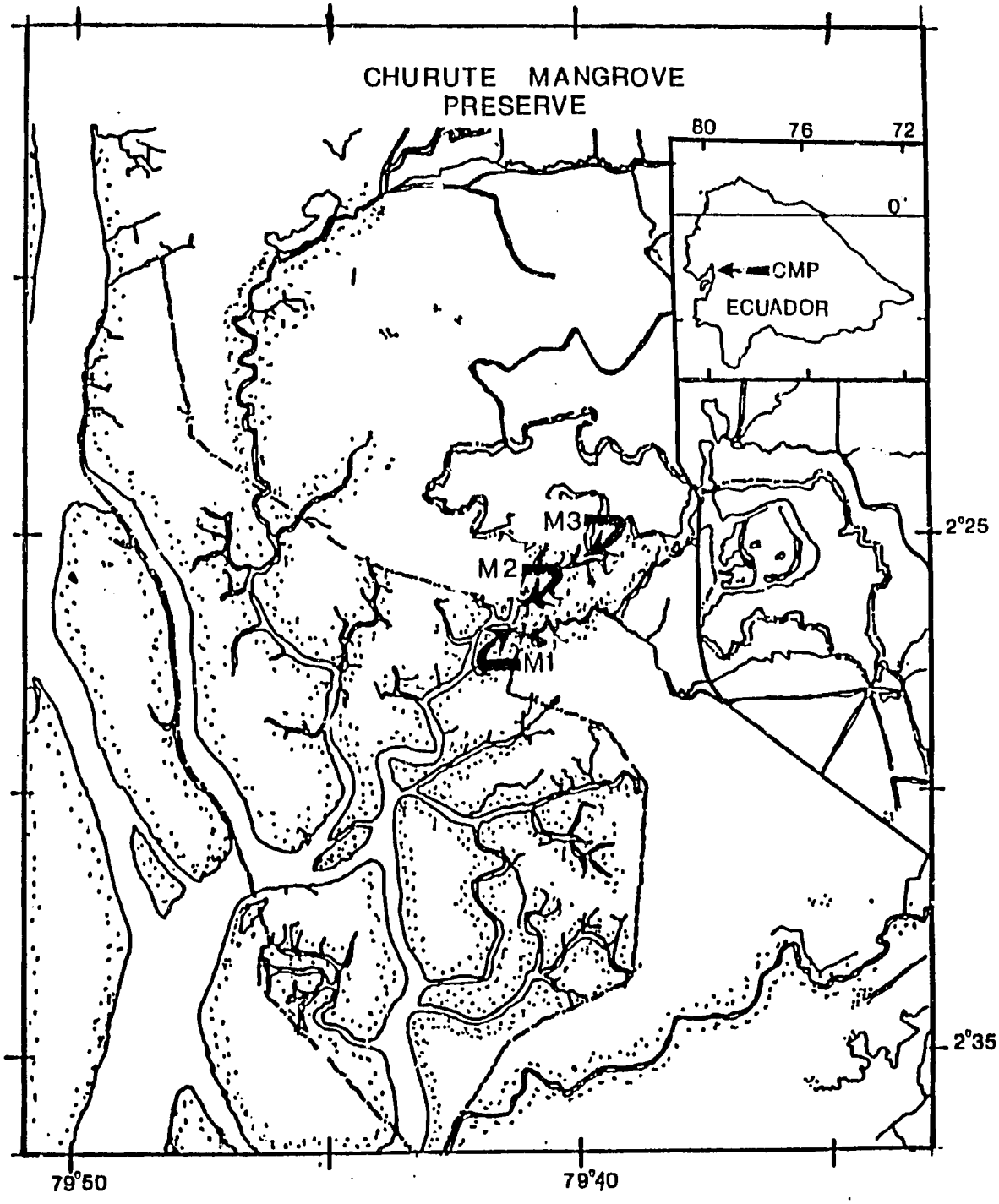


Figure 9. Map of the Churute Ecological Preserve in the Churute estuary including the three research sites in the mangrove program of this study.

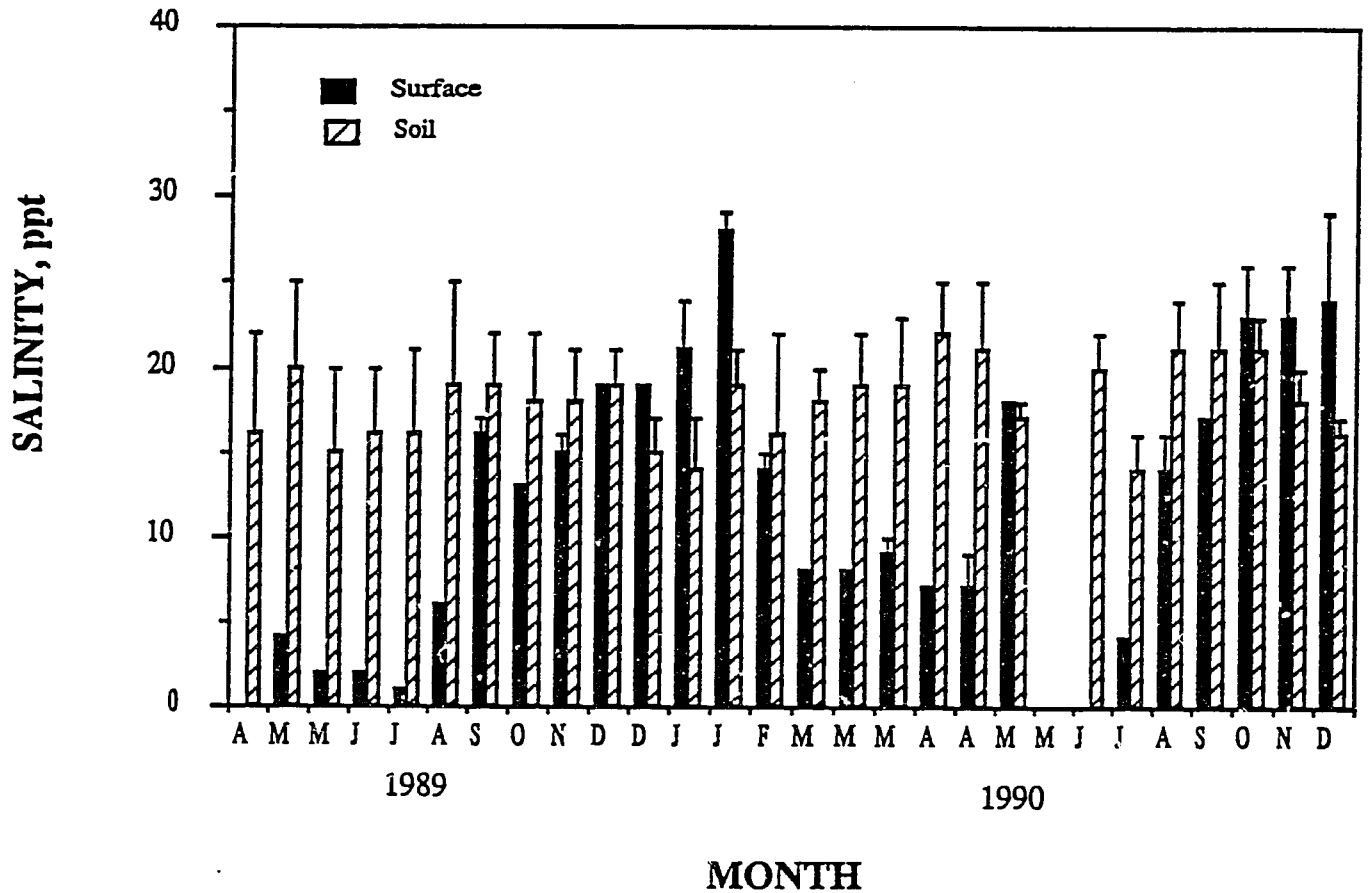


Figure 10. Seasonal patterns of salinity in the M3 mangrove site in Churute estuary based on monthly sampling of surface and soil (0.5 m depth) from April 1989 to December 1990.

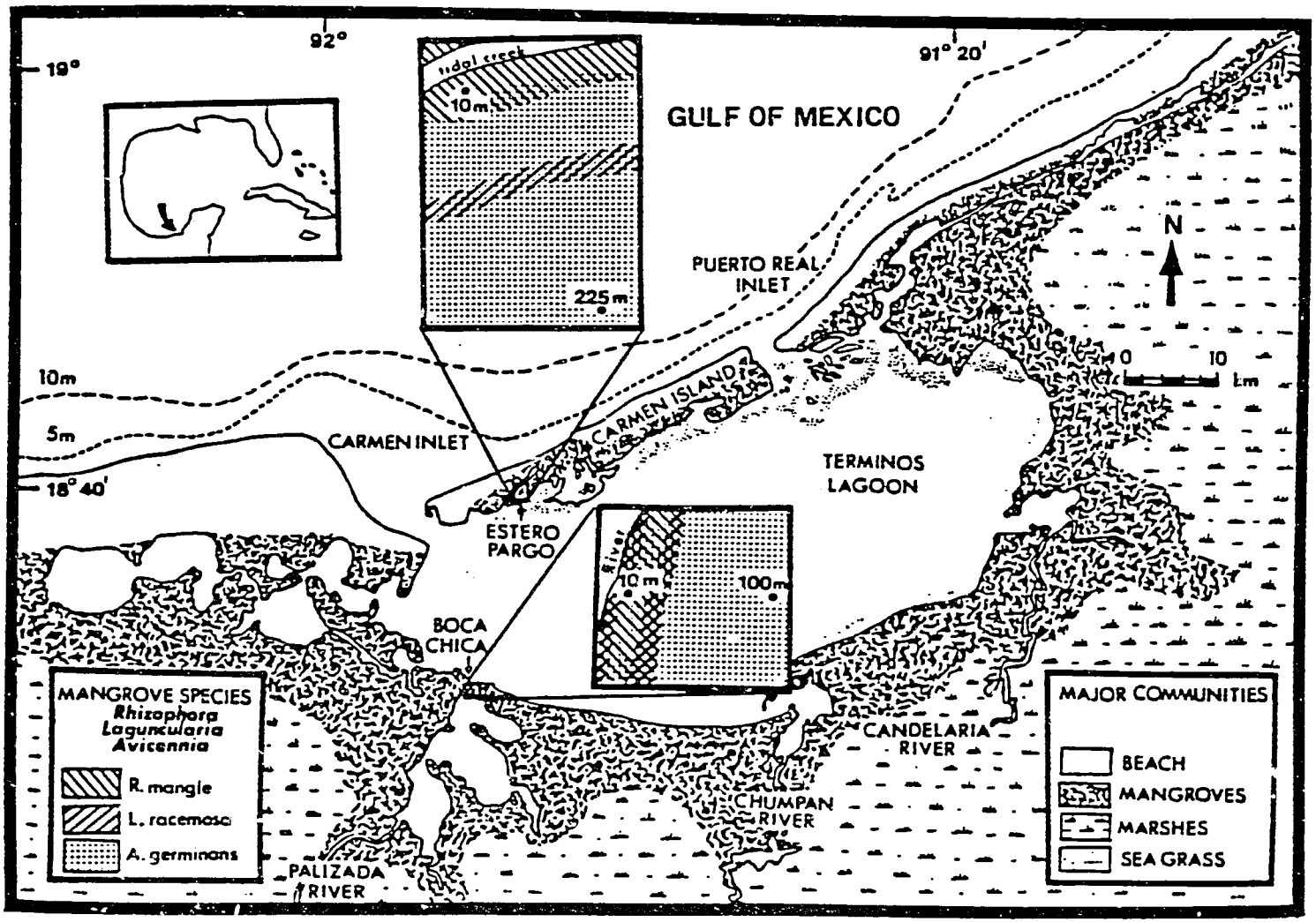


Figure 11. Map of Terminos Lagoon, Mexico, showing the area of ecological mangrove studies at Estero Pargo.

a fringe and basin mangrove forest in Estero Pargo, and a riverine site in Boca Chica. The hydrology of the riverine mangrove site in this study is seasonally dominated by river inundation resulting in surface water salinities from 0 to 25 ‰. 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 ‰ (Day et al. 1987).

Mangrove Exploitation in Ecuador

Eight species of mangroves are distributed along a relatively narrow band of the intertidal zone of Ecuador with a nonvegetated area called salinas in more inland intertidal areas. Narrow zones of mangroves are due to high rates of evapotranspiration relative to precipitation that occur in the southern regions of Ecuador, therefore the existence of 121,464 ha of mangrove in the Guayas province has been attributed to extensive river flow from the Guayas river basin (Schaeffer-Novelli 1983). High tidal frequency and river discharge create conditions suitable for mangrove forest structure in the northern provinces with a tree density of 185/ha and a basal area of 62.4 m^2/ha. This forest structure is greater than for mangroves in Venezuela, Columbia, Malaysia and Puerto Rico (Cintrón 1981).

The most observable exploitation of mangroves along the coastal zone of Ecuador is the construction of shrimp ponds, particularly in the southern provinces of El Oro and Guayas. A survey from CLIRSEN (1984, 1991) cites that these two southern provinces have 79,396 ha or 88.8% of the total area of shrimp ponds which are constructed in the intertidal zone. The close proximity of ponds to the shore lowers costs associated with supplying water and larvae to the ponds. Initially shrimp ponds were constructed in more inland intertidal areas called salinas that are basically void of any vegetation. As the more inland areas became scarce, more of the ponds were constructed in mangrove habitats resulting in the increased loss of this natural resource from the coastal zone. The loss of mangroves by 1984 was estimated at 10.6% (21,587 ha) of the 1969 estimate of 203,695 ha of total mangrove area in Ecuador (Fig. 12). Urban expansion contributed to a loss of 1,200 ha, and the remaining loss was associated with construction of shrimp ponds. By 1984 there were 89,367 ha of ponds, suggesting that 23 % of shrimp ponds had reclaimed mangrove areas. Recent surveys of mangrove areas by CLIRSEN (1991) estimate that 14.4 % of the national mangrove resources has been lost from coastal zone of Ecuador from 1967 to 1989. Based on a total area of 114,000 shrimp ponds, only 26% of the ponds have been constructed in mangrove habitat, the remaining apparently have utilized more upland areas of the intertidal zone. Surveys of land use in the coastal zone in 1991 estimate that pond construction increased to 150,000 ha, responding to the available post larvae during the 1988 El Niño. The loss of mangroves continues to increase, demonstrating the susceptibility of this natural resource to the availability of post larvae along the coast.

The average annual loss of mangroves between 1969-1984 was 1,434 ha/yr, compared to 2,618 ha/yr from 1984-1987 (Fig. 12) (CLIRSEN 1984). While the national average of mangrove loss is about 14%, the range for the four coastal provinces was from 8.4 % for the Guayas province to 30.5 % for Manabi. In Manabi, the loss of mangroves was nearly 6 % per year from 1984 to 1987. By late 1988 the destruction of mangrove habitat in some estuaries was virtually complete, such as in Rio Chone estuary, a large estuary in the province of Manabi. From 1974 to 1988 mangrove area along this estuary declined from 3,973 to 600 ha, and nearly all of the mangrove loss was associated with construction of shrimp ponds. In Rio Atacames, there are only 50 ha of mangroves remaining of the 578 reported in 1970s, representing a loss of 90.1 % of the mangrove resources. In the southern province of El Oro, the Machala-Puerto Bolivar area lost over 50 % of a very productive mangrove system. Thus, the perspective of mangrove loss in Ecuador is both national and regional, and the significance of mangrove loss is site specific. Historical documentation of mangrove loss along the coastal zone of Ecuador remains one of the key issues associated with resource management.

In the northern coastal province of Esmeraldas, mangrove timber is used for the production of charcoal in the local region. Mangrove wood produces 4,500 kcal per kg of wood, and is considered an economical supply of energy in the rural coastal areas of Ecuador. This is the only location in Ecuador that extensively uses mangrove wood for charcoal, although much of the

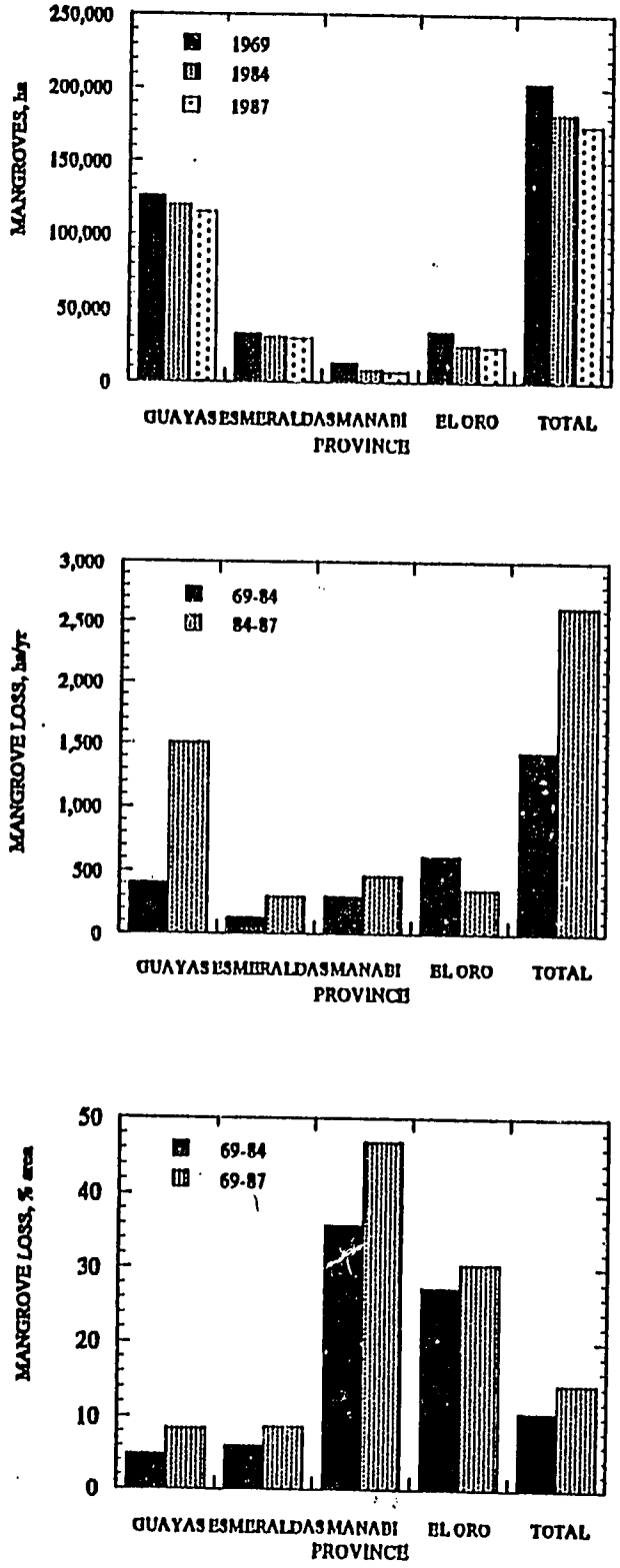


Figure 12. Loss of mangroves in Ecuador from each of the four coastal provinces and the analysis based on the following indeces: A) area of mangroves, B) change per year, and C) percentage of the total mangrove area in each province (from CLIRSEN).

woody debris from clear cutting mangrove forests for shrimp pond construction in the southern provinces was also converted to charcoal. Much of the cheap mangrove timber that supplied the charcoal industry in the northern provinces was from clearing the woody debris from initial stages of pond construction. Once pond construction declined, particularly following El Niño periods when post larvae were scarce, wood from pond construction was limited and the charcoal industry lost a cheap and adequate supply of mangrove timber. Now there is a strong demand for mangrove timber to supply an industry that expanded along with the shrimp pond industry. In Esmeraldas, it is estimated that 2,000 m^3/yr of mangrove wood is needed to supply the current demand, which would require 20 ha of mangrove forests per yr. However, mangrove silviculture is not commonly practiced as a form of mangrove management and even the minimum rotation of 20 ha of timber per yr to supply the charcoal industry is a problem.

There is also a natural loss of mangroves that has been observed in the southern coastal province of Guayas associated with excessive leaf herbivory. A massive defoliation of mangroves has been documented in the Churute Ecological Preserve, in the Guayas province, caused by the bagworm, *Oiketicus kirbyi* Guilling (Sarango 1990). Initial observations of the impact of the insect larvae were made in February, 1989, and it was estimated that nearly 1,000 ha of mangroves had been defoliated. Leaf defoliation of complete tree canopies was most extensive in the fringe zone, dominated by *Rhizophora mangle*, where nearly 75% of the trees in infected areas were damaged by the bagworm. However, the insect larvae also defoliated about 10% of three other mangrove species, *Avicennia germinans*, *Conocarpus erectus*, and *Laguncularia racemosa*. Most of the damage was located in the vicinity of Isla Churitillo, but by 1990 the insect damage had spread into the less saline regions of the Guayas River estuary. This area of the Guayas River estuary is the most extensive area of mangrove defoliation caused by insect herbivory observed along the coast of Ecuador. It is postulated that the change in production of secondary compounds such as tannins in response to stress causes mangroves to be more susceptible to herbivory. Another factor that may influence the outbreak of these larvae is the loss of natural predators, such as parasites and birds.

Litter Production and Dynamics:

Litter produced in the canopy of mangrove forests represents a major source of organic matter and nutrients for outwelling to adjacent coastal waters (Odum and Heald 1972). Thus the dynamics of mangrove litter including productivity, decomposition, and export influence the coupling of mangroves to coastal ecosystems (Twilley 1988). There are now ten estimates of carbon export from mangrove ecosystems that range form 1.86 to 401 gC m-2 yr-1 (Twilley et al. 1992). The average rate of carbon export from mangroves is about 210 gC m^{-2} yr^{-1}. This is nearly double the rate suggested by Nixon (1980) for carbon export from salt marshes (100 gC m-^{2} yr^{-1}). Greater carbon export from mangroves may be associated with the more buoyant mangrove leaf litter, higher precipitation in tropical wetlands, and greater tidal amplitude in mangrove systems studied (Twilley 1988).

Methods

Ecuador - Ten litter baskets (0.25 m^2) were randomly placed in the M1, M2 and M3 mangrove forests in the Churute Ecological Preserve. Collections from each basket were made biweekly and brought back to the University of Guayaquil for analyses. Samples were dried for three days at 60 C and sorted into leaves, reproductive structures, flowers, wood and miscellaneous. The number of leaves, propagules and stipules were also recorded. Measurements were also made on the accumulation of litter on the forest floor in each of the three sites by sampling the surface litter in 0.1 m^2 quadrats at each of the litter baskets. Studies were also performed on the rate of leaf decomposition (*Rhizophora* sp.) in each site using nylon mesh bags. Approximately 10 g air dry mass of leaves was placed in each bag and a transect of bags was placed in each of the mangrove sites. Three bags were randomly collected from the transect for each of the three sites. Studies during the wet season were initiated in February 1991, and dry

season rates were initiated in August 1991. Samples from litterfall, litter standing crop, and decomposition were ground in a wiley mill for latter assay of nutrient content.

Mexico - Litter collections are part of a continuing program in Terminos Lagoon in Estero Pargo. Collections were made biweekly in a fringe and basin mangrove forest, and prepared for nutrient analyses in Dr. Twilley's laboratory at USL. Mr. Victor Rivera is presently doing statistical analyses on the seasonal and annual rates of litterfall in the different sites in Terminos Lagoon.

Results

The litter productivity of the three mangrove sites was similar at about 10 Mg ha-1 yr-1 (Fig. 13). Rates were somewhat seasonal with bimodal peaks from March to April and another peak in litterfall from September to October. Although litterfall was continuos throughout the year at all three sites, litter on the forest floor was only observed for three to four months at all three sites (Fig. 14). Peak leaf litter standing crop was observed from August to September, and amounts during this period varied with the highest litter in M3 and lowest amount in M1 (Fig. 14). Decomposition studies demonstrate that there is more seasonal effects than site effects on loss of leaf litter on the forest floor (Fig. 15). During the wet season, 50% loss occurred by approximately 50 days, whereas during the dry season 50% loss did not occur during the 120 day experiment. There were significant effects of site on decomposition rates during the dry season, with higher rates occurring in site M2 (Fig. 15).

The production of litter from the canopy and subsequent storage on the forest floor describes the dynamics of litter in different types of mangrove ecosystems (Fig. 16). Turnover rates of the litter compartment can be evaluated using the model $K = L/Xss$, where L is litterfall, Xss is the steady state value of litter on the forest floor and K is the litter turnover rate (Nye 1961). This assumes that the litter compartment is in steady state, with litter production equal to litter losses. Litter turnover rates in temperate forest are less than 1 yr^{-1} compared to between 1 and 2 yr^{-1} for tropical forests (Olson 1963). Differences are associated with the influence of temperature and soil moisture on the decomposition and consumption of litter on the forest floor. In mangroves, an additional fate of litter is transport by tides to adjacent coastal waters. Litter turnover rates for mangroves are generally higher than 2 yr^{-1} with some rates at 10 yr^{-1} indicating the potential significance of export on litter dynamics (Fig. 16). The range in litter production in fringe, overwash, and basin forests is less than three-fold (Lugo and Snedaker 1974, Pool et al. 1975, Twilley et al. 1986), however the range of leaf litter turnover on the forest floor is almost twelve-fold. This suggests that processes on the forest floor such as decomposition and export are important factors regulating litter turnover in mangroves.

Trends for litter productivity and export suggest that as geophysical energy increase, the exchange of organic matter between mangroves and adjacent estuarine waters also increase. Frequently flooded mangrove forests such as riverine and fringe forests can be characterized as having elevated rates of litter turnover, generally greater than 5 yr^{-1}. Litter productivity in a riverine forest in Ecuador is similar to a riverine forest in south Florida at about 10 Mg ha^{-1} yr^{-1} (Fig. 16). However, the riverine forest in Ecuador has a 3 m tidal amplitude, while the tides in the riverine forests in south Florida are 0.5 m. Leaf litter on the forest floor in Ecuador is absent except for three months of the year (Fig. 14). This may be expected to be associated with greater export owing to the effect of tides on the transport of leaf litter from the forest. Yet observations in the mangroves in Ecuador suggest that most of the leaf litter on the forest floor is harvested by the mangrove crab, *Ucides occidentalis*, and transported to sediment burrows. Field experiments were performed where 10 leaves were placed in 4 m2 area and crab predation was observed from the canopy of the forest. During each observation, crabs removed all leaf litter and transported the leaves down their burrows within an hour. During September and October, when the crab aestivates, the standing crop of leaf litter increases on the forest floor (Fig. 14). The influence of mangrove crabs on litter dynamics has been described in other mangrove ecosystems with high geophysical energies and rates of litter turnover above 5 yr^{-1} (Malley 1978, Leh and Sasekumar 1985, Robertson and Daniel 1989). Thus, the use of geophysical forcing functions such as tides

to predict export of leaf litter is limited by consideration of biological factors within the ecosystem. In these examples, high rates of litter turnover do not reflect the coupling of mangrove to coastal waters, but the conservation of organic matter within the forest.

The levels of leaf litter during these two months are still much lower than expected based on daily rates of leaf fall suggesting that leaf export is significant. During the months when crab harvesting of leaf litter is negligible (July to October), the relative effects of decomposition and export on leaf litter dynamics can be analyzed (Fig. 17). The leaf litter standing crop is 5 g/m^2 in the M1 forest compared to 30 g/m^2 in the M3 site (Fig. 17). Decomposition is estimated at about 20 g m^{-2} mo^{-1} for each of the three sites (Fig. 15). Based on these assumptions, the estimated export of detritus from the M1 site is about 40 g m^{-2} mo^{-1}, compared to only 4 g m^{-2} mo^{-1} in site M3. Thus, the fate of litter in these mangrove forests depends on the relative effects of tides and crabs. If leaf litter falls when the forest floor is dry and crabs are seasonally active, then the leaf will remain within the forest in crab burrows. However, if the forest is inundated by tides or if crabs are inactive, then the leaf litter will most likely be transported to the estuary. The maximum rate of transport is about 1 g dry mass m^{-2} d^{-1} or about 0.5 gC m^{-2} d^{-1}, which is observed in the M1 sites. This is equivalent to about 200 gC m-2 yr-1, or about the mean value of carbon export found for mangrove forests around the world. This value is lower than expected for mangroves with tidal range and river discharge of this coastal region. This reduction is export is due to the effects of crabs preventing the loss of leaf litter from the forest floor.

Exchange of Nutrient and Detritus:

Methods

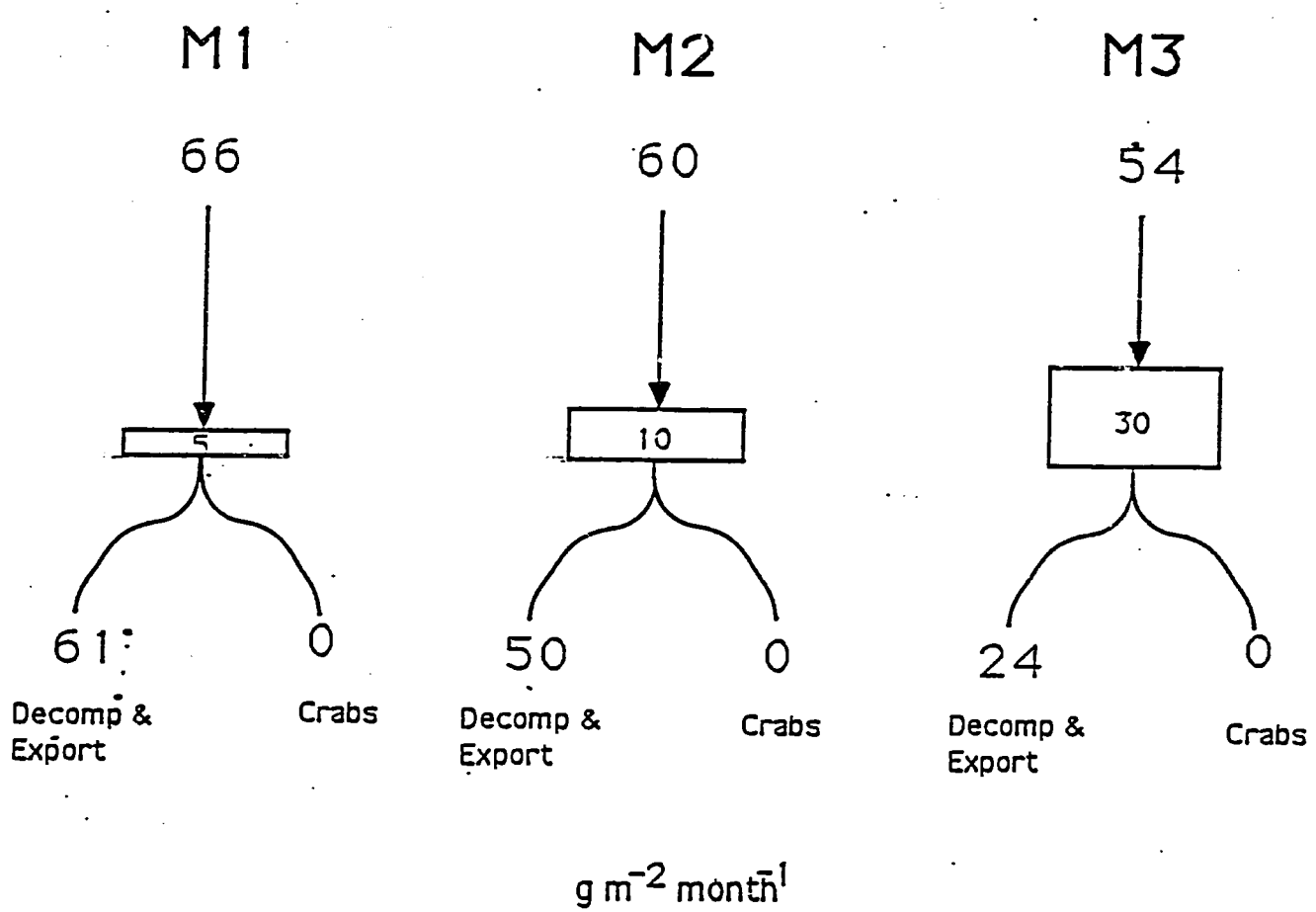
Fluxes of organic (TN, DON, PN) and inorganic nitrogen (NH_4, NO_3 + NO_2) were measured in Estero Pargo, Mexico, at the mangrove-tidal creek interface using the flume methodology (Wolaver et al. 1980, Wolaver et al. 1985). Tidal water in the flume was sampled monthly representing a range of lunar and diel periods over each season. Duplicate organic and inorganic nitrogen concentrations were determined every 2 hours at both ends of the flume over 1-3 tidal cycles. Comparing flux across the upstream (near tidal creek) end of the flume with the downstream end (inside the forest) indicates uptake by the wetland if the difference is positive and export if it is negative. Estimation of fluxes and their significance were determined using modifications to the flume technique (Childers and Day 1990a, 1990b).

Results

Ammonium concentrations ranged from 0 to 642 mg/m^3. The highest net aerial flux was during the Norte season when 2203 mg m^{-2} h^{-1} were imported to the mangrove (Fig. 18). This season is characterized by periodic rains and strong winds associated with frontal passages from October to February. There were only two occasions when export occurred during October (85 mg m^{-2} h^{-1}) and December (101 mg m^{-2} h^{-1}). Except for these two cases, all the nutrient exchange studies conducted in Estero Pargo indicate that there was a net removal of ammonium by the mangrove. This implies that mangroves are an efficient sink for ammonium, especially during times of high ammonium loading as in the Norte season.

Nitrate concentration ranged from 0 to 51.2 mg/m^3. There was high import of nitrate (60 mg m^{-2} h^{-1}) as the tidal water passed through the mangrove during the Norte season (Fig. 18). Export of nitrate was observed only in August and November 1990 (33.3 and 10.3 mg m^{-2} h^{-1}, respectively), and in April and July 1991 (6.4 and 3.5 mg m^{-2} h^{-1}). The high import of nitrate during the Norte season indicates that as observed for ammonium, mangroves play a significant role in removing inorganic nitrogen from tidal waters, especially when concentrations are high.

Concentrations of dissolved organic nitrogen (DON) and total nitrogen (TN) ranged from 123 to 759 mg/m^3 and 6.4 to 793 mg/m^3, respectively. DON concentrations account for a large percentage of all the nitrogen species present. Dissolved organic and total nitrogen were imported



(Decomp = 20 g m^{-2}month^{-1})

Figure 17. Estimates of the fate of leaf litter in the three mangrove forests of the Churute estuary including rates of litterfall and storage of litter on the forest floor. Losses are associated with decomposition and export, when crab harvesting of leaf litter is negligible.

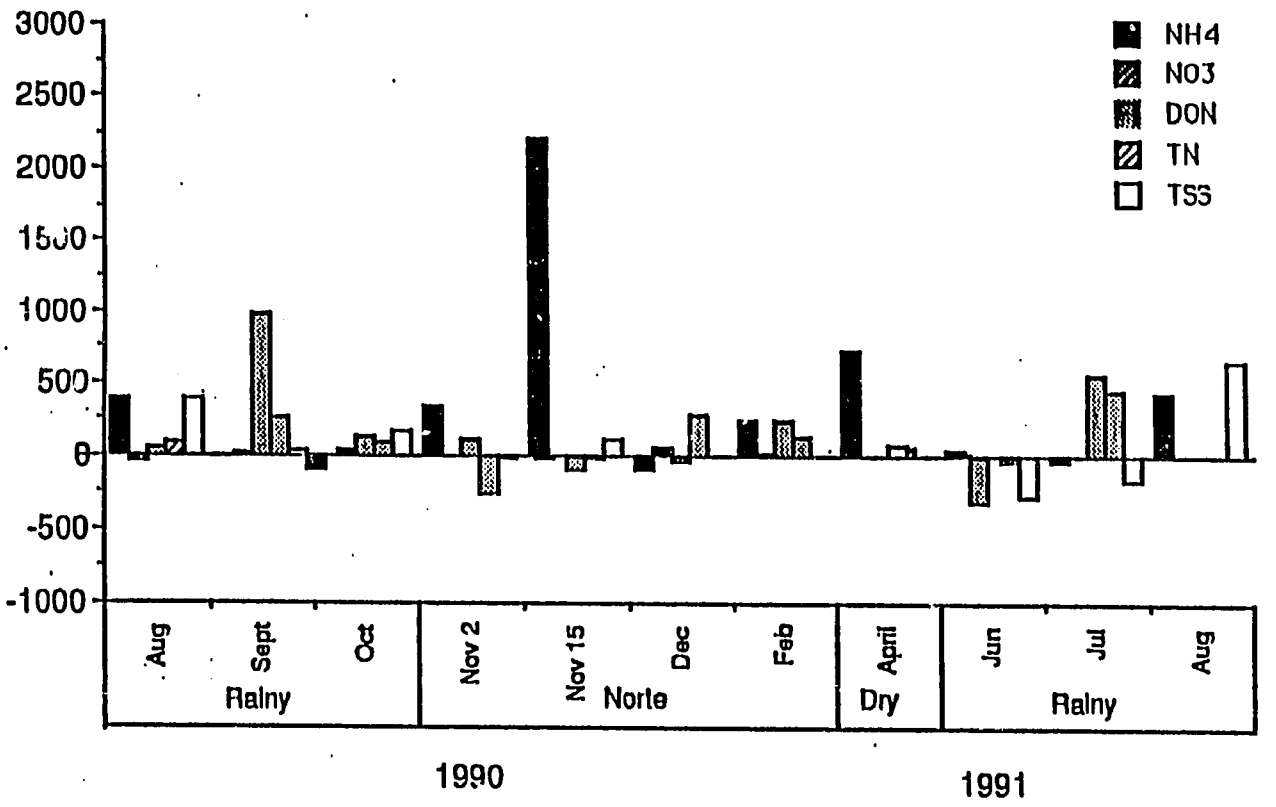


Figure 18. Seasonal net fluxes of total suspended sediments (g m^{-2} h^{-1}), organic and inorganic nitrogen (mg m^{-2} h^{-1}) in a fringe mangrove in Estero Pargo, Terminos Lagoon, Mexico. Positive flux is import to the mangrove surface; negative flux is export to the inundating water column.

in most of the flume experiments (Fig. 18). The highest uptake values were during the rainy season (June-October). The utilization of DON within the tidal water on the mangrove surface indicates that system does not contribute this constituent to the tidal creek.

Total suspended sediment values during the study were 8 to 610 g/m^3. High import during most of the rainy season (Fig. 18) indicates a significant transport of sediments associated with river discharge. This sediment input and the high in situ production within the mangrove forest in Estero Pargo (Day et al. 1987) suggest that vertical accretion rates might be high in this area.

Significant import of nitrogen constituents indicate that fringing mangroves in Estero Pargo act as a sink of nutrients. Wolaver et al. (1985) found a similar result in a mesohaline vegetated marsh using the flume technique. They suggest that a large non-tidal flux of these constituents off the marsh surface or other systems within marsh complex such as mudflats or creek bottoms have to supply the necessary nutrients. We have observed large amounts of organic matter in the bottom of Estero Pargo and other tidal creeks being resuspended in the water column. The origin of this material is mainly macrodetritus (leaves, propagules, flowers, and branches) from the mangrove that sink and accumulate on the bottom of the tidal creek where they decompose. Thus, mangroves in Estero Pargo are an indirect source of materials to the water column. Mangrove leaf production in Estero Pargo is 4.4 to 5.9 Mg ha^{-1} yr^{-1} (Day et al. 1987). Depending on tidal activity mangroves may export from 20 to 40 % of leaf productivity (Twilley et al. 1986).

Sedimentation:

Methods

Rates of sediment and nutrient accumulation were determined for mangrove forests in Churute River estuary, Ecuador, and Terminos Lagoon, Mexico. The fringe forests were dominated primarily by *Rhizophora mangle* L. and the basin forests by *R. mangle*, *Avicennia germinans* L. and *Laguncularia racemosa* Gaertn. f.

Cores were collected in Terminos Lagoon on January 1987, and in Churute Ecological Preserve on May 1990. 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 Terminos Lagoon at two sites: two cores were taken at 15 m and 100 m inland in Boca Chica near the mouth of the Palizada river; and two cores at 10 and 225 m inland of a tidal creek in Estero Pargo (Lynch et al. 1989). 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 all 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 (Allen et al. 1974). Total carbon and nitrogen were determined on a Perkin-Elmer Model 240, CHN elemental analyzer. Total phosphorus concentrations were determined by hydrochloric and nitric acid digestions on ashed samples followed by colorimetric analysis (Allen et al. 1974). Phosphate concentrations were determined by colorimetric analyses using the molybdate test (U.S. Environmental Protection Agency 1982).

The accretion rates in each forest were determined using ^{210}Pb dating techniques as described in Lynch et al. 1989; a representative estimate is given in Fig. 19. 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 concentration of materials (Cd, g/gdw), bulk density (D, gdw/cm^3) and the vertical accretion rate (R, cm/yr): $A = C_d \times R \times D \times 10^4$ (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 (Lynch et al. 1989). 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

Accretion rates based on ^{210}Pb analyses ranged from 1.6 to 4.4 mm yr^{-1} for Mexico, compared to about 5.8 mm yr^{-1} in Ecuador (Fig. 19). Average sedimentation rates (organic plus inorganic material) ranged from 300 to 2200 g m^{-2} yr^{-1} (Fig. 20). Accumulation of organic matter was similar among all sites while accumulation of inorganic matter was much higher in the forests influenced by river discharge. The accumulation of carbon (59-185 g m^{-2} yr^{-1}) and nitrogen (1.55-5.80 g m^{-2} yr^{-1}) were associated with deposition of organic matter among the sites as indicated by the similar range in rates among sites. Atomic carbon:nitrogen ratios of accumulated material at the riverine site were > 30, while sites with less riverine input had C:N ratios <20. Accumulation of phosphorus ranged from 0.11 to 0.78 g m^{-2} yr^{-1}; and the higher rates were associated with sites with high loading of inorganic matter. The riverine forests receive increased inputs of inorganic sediment and phosphorus from the Palizada river in Mexico and Guayas River in Ecuador, whereas sites dominated by tides in Terminos Lagoon and Rookery Bay accumulate greater proportion of organic matter and nitrogen. The elevated levels of phosphate input into riverine mangroves sites are associated with higher levels of litter productivity compared to tidal mangroves that have less phosphorus input and lower productivity.

Denitrification and Nitrogen Fixation:

Ecuador - Preliminary experiments on denitrification were performed in January 1990 in the M2 and M3 mangrove sites in Churute. These experiments were repeated in May 1990. The acetylene blockage technique was used with small intact cores to determine ambient denitrification rates. Nitrous oxide determinations were made on the January 1990 experiments with a HP 5890 GC.

Mexico - Mr. Victor Rivera-Monroy began studies of denitrification in mangroves in Terminos Lagoon during June 1990 using N-15 techniques to determine the coupling of nitrification and denitrification in mangrove sediments. Ambient rates of denitrification were measured in Estero Pargo with the acetylene blockage technique.

Results

The nitrogen-15 samples are still being assayed in Dr. Twilley's laboratory at USL. This component of the mangrove study is part of Mr. Rivera-Monroy's dissertation that should be complete in August of 1993.

Nutrient Cycling of a Tropical Estuary:

Methods

Nutrient surveys were conducted on monthly cruises from July 1989 to December 1990 in the three subsystems of the Guayas River estuary (Fig. 6). Measurements were made on selected chemical, physical and biological characteristics of the Guayas River estuary at the 21 stations described above. This survey allowed for comparison of water quality parameters between two systems - one that is naturally flushed by the Guayas River and surrounded mostly by natural wetlands; and another that is not flushed by river and is heavily impacted by urban and shrimp pond waste. Cruises were supported by INP aboard the RV Protero. Water samples were collected and filtered through GF/C filters and frozen on dry ice until returned to INP for chemical analyses.

Results

Suspended particulate material (SPM) exhibited strong seasonal patterns in Guayas River and Churute estuary stations with highest values during rain season from September to February (Fig. 21). Concentrations in these two systems ranged from 600 to 800 mg/L and 200 to 400 mg/L during rain season in the Guayas and Churute estuary, respectively. During the dry season, concentrations were about 50 mg/L in both systems. In Estero Salado, SPM concentrations were

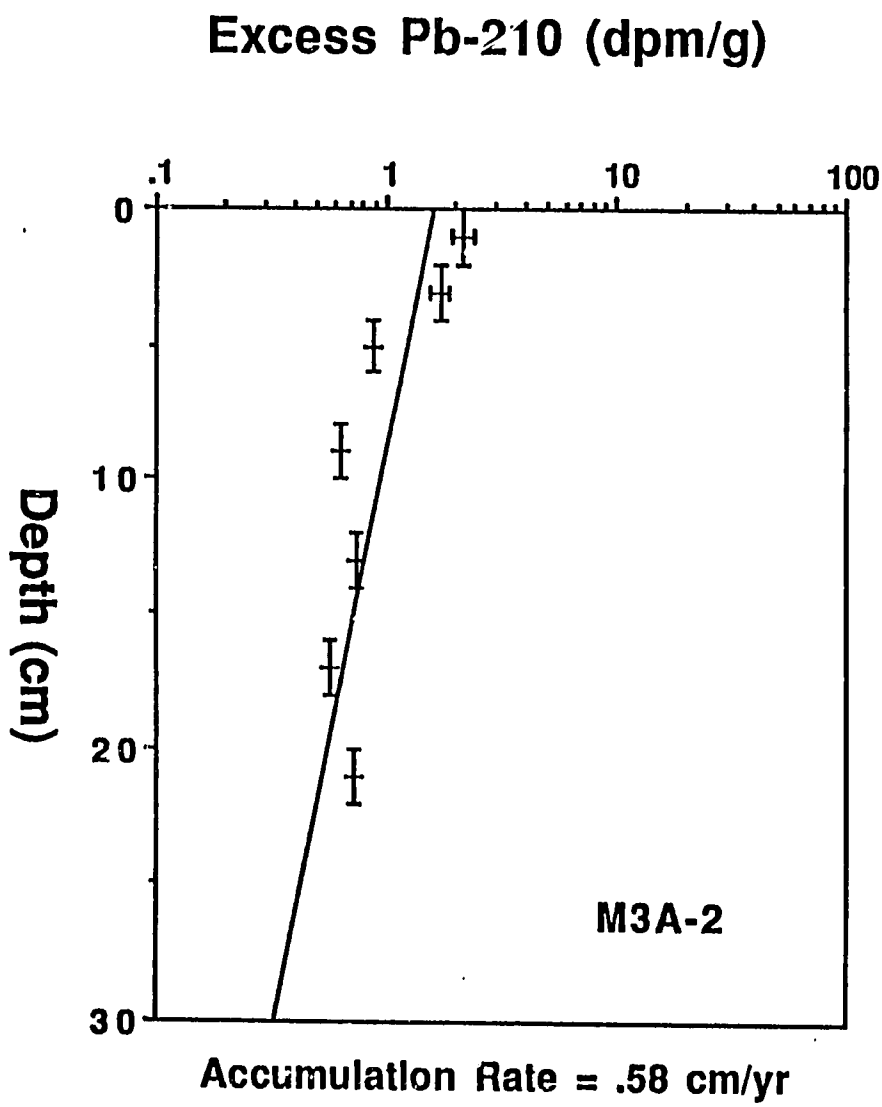


Figure 19. Representative distribution of lead-210 with depth in sediments in the M3 mangrove site in Churute estuary demonstrating the method used to calculate accumulation rates.

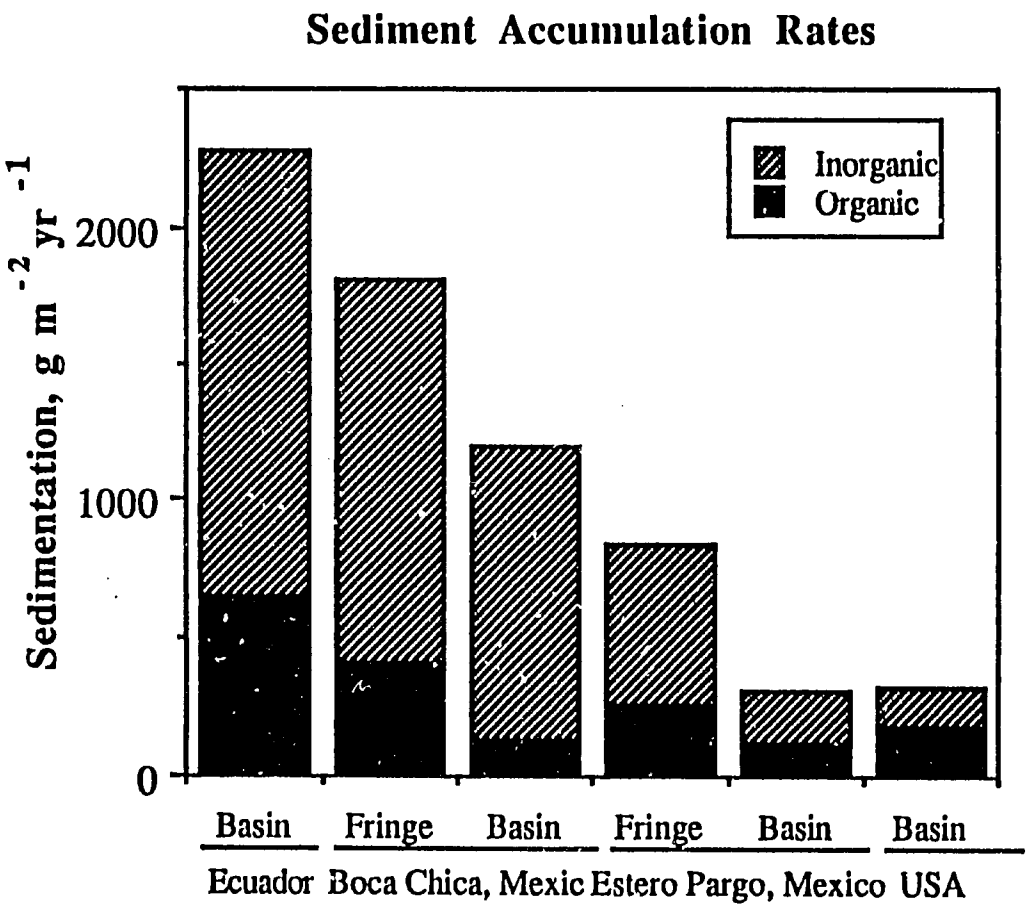


Figure 20. Comparison of sedimentation rates (g m^{-2} yr^{-1}) based on lead-210 estimates among the riverine mangroves in Ecuador with the riverine, fringe and basin sites in Mexico, and the basin forest in Rookery Bay, Florida. Rates are separated into inorganic (ash) and organic constituents to total sedimentation.

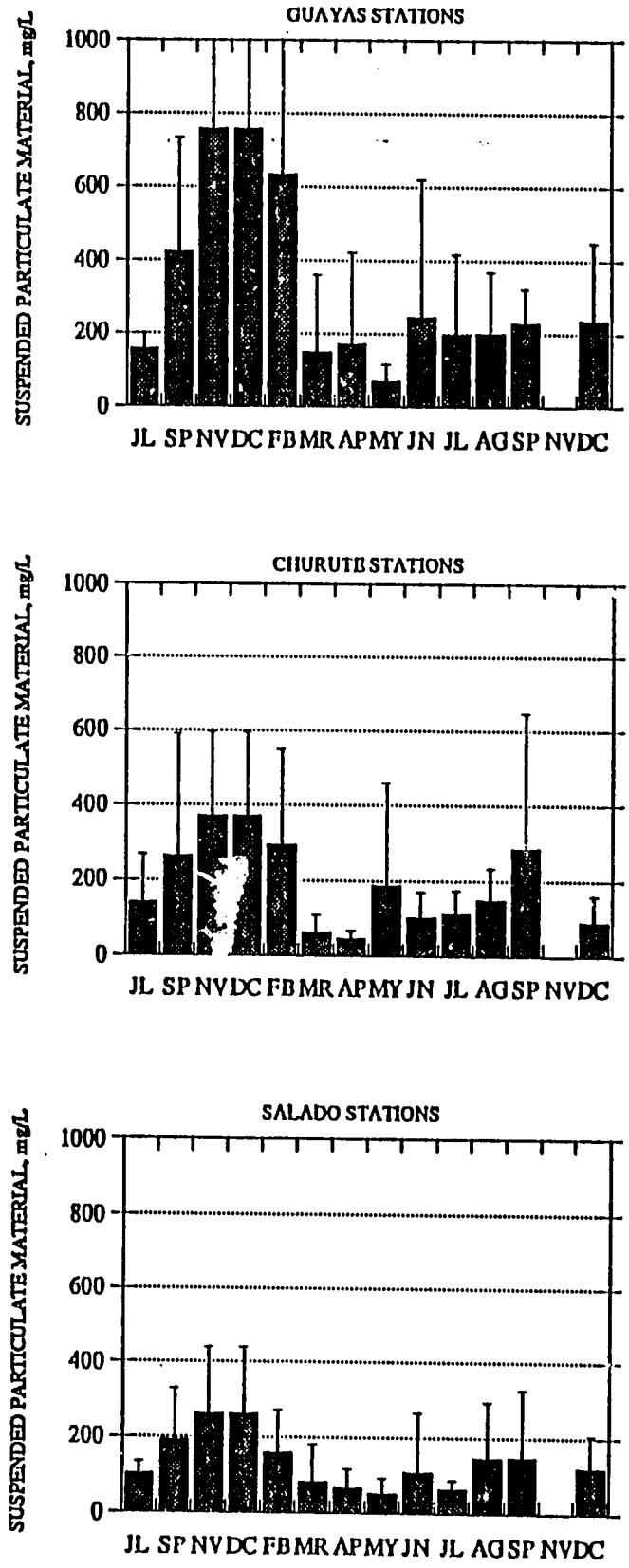


Figure 21. Seasonal patterns of suspended particulate material (mg/L) in the three subestuaries of the Guayas River estuary based on monthly sampling from July 1989 to December 1990. Means and standard error are for all stations in each subestuary for one sampling per month based on 0.5 m depth.

less than 250 mg/L during wet season, and generally less than 100 mg/L throughout the year (Fig. 21). Based on these values, production is light limited during the wet season in the Churute and Guayas River systems, however the light field is similar in all three systems during the dry season.

Chlorophyll concentrations were maximum in the Guayas River channel ranging from 10 to over 60 µg/L, compared to about 5 to 40 µg/L in Churute River estuary (Fig. 22). Concentrations were lower in Estero Salado, usually less than 10 ug/L and only twice just above 20 µg/L (Fig. 22). Chlorophyll was seasonal in the River Guayas channel and Churute River estuary with highest concentrations occurring just prior to peak river discharge in November. It is probable that the high turbidity of the Guayas and Churute estuaries during the dry season limits chlorophyll production, but levels of chlorophyll are even lower in Estero Salado where turbidity levels where less than half the more river dominated systems (Figs. 21 and 22).

Ammonium ranges from 1 to 6 ug-at/L in all three systems, whereas nitrate is less than 20 ug-at/L. There is no seasonal pulse in either nutrient in the three systems. Phosphate concentration remain at 2 to 3 ug-at/L and there is also no strong seasonal pulse. DIN:DIP ratios were generally less than 10 and in some cases less than 5 suggesting strong nitrogen limitation in all three systems (Fig. 23). There was a slight increase in DIN:DIP ratios with increased river discharge. Estero Salado had slightly lower DIN:DIP ratios, suggesting that this is a nitrogen limited system.

Silicate concentrations were much higher in the Guayas and Churute estuaries than in Estero Salado (Fig. 24). There was little seasonal pattern except that the highest concentration in all three systems occurred in March with values above 300 ug-at/L. Silicate concentrations were generally less than 50 ug-at/L in Estero Salado, compared to concentrations of 50 to 100 ug-at/L in the other systems. This nutrient may also be important to the primary productivity of estuarine waters. It is important to understand the relative role of light and nutrients in the control of phytoplankton productivity in these estuarine waters, since both are influenced by the shrimp ponds and mangrove composition of the intertidal zone.

Isotope Ecology of a Tropical Estuary

Methods

Suspended Particulate Matter (SPM) for stable carbon and nitrogen isotope analyses was collected by filtering between 5-10 l of water through a 4.7 cm GF/C filter. These were pumped onboard with a peristaltic pump and passed directly through the filter. Samples were taken below the surface to avoid including surface films. Filters were stored at -20°C prior to analysis. Samples for elemental analysis were collected by filtering the sample through 2.5 cm GF/C filters. Ten ml of the filtrate were sealed in glass ampoules and frozen at -20°C for dissolved organic carbon measurements. The ampoules had been pre-baked at 500°C for 2 hr. All glass-fiber filters were pre-baked at 480°C for more than 2 hr.

Acid-Precipitated Matter (APM) was recovered by precipitating about 5 l of the GF/C filtrate. After acidifying the filtrate to pH 2, the precipitate was recovered on a GF/C filter. The usual designation for this portion of the organic pool is humic acid (e. g.,Fox 1983). Instead, we have chosen to refer to this pool as APM to indicate that other dissolved organic matter (DOM), such as proteins, also precipitate out of solution at low pH.

Bacterial assays were conducted at selected stations (see Coffin et al. 1989). First, up to 18 L of sample were filtered through a 0.2 µm cartridge filter and placed in a 5 gallon cubitainer. The sample was then inoculated with a 1 µm filtrate of the same water and incubated in the dark for 48 hr. Then the sample was filtered through a GF/F glass-fiber filter to concentrate bacteria for isotopic analysis. This filter was frozen immediately and stored at -20°C.

Isotopic Analyses: Filters containing SPM, APM, and bacteria were dried at 60°C in an oven that was continually flushed with high-purity N_2 gas. Filters with SPM were placed in glass petri dishes and placed in a glass desiccator with concentrated HCl fumes to remove carbonates. These filters were then placed in the 60°C oven again to remove HCl without loss of labile nitrogen. When completely dry, the filters were carefully ground with a mortar and pestle.

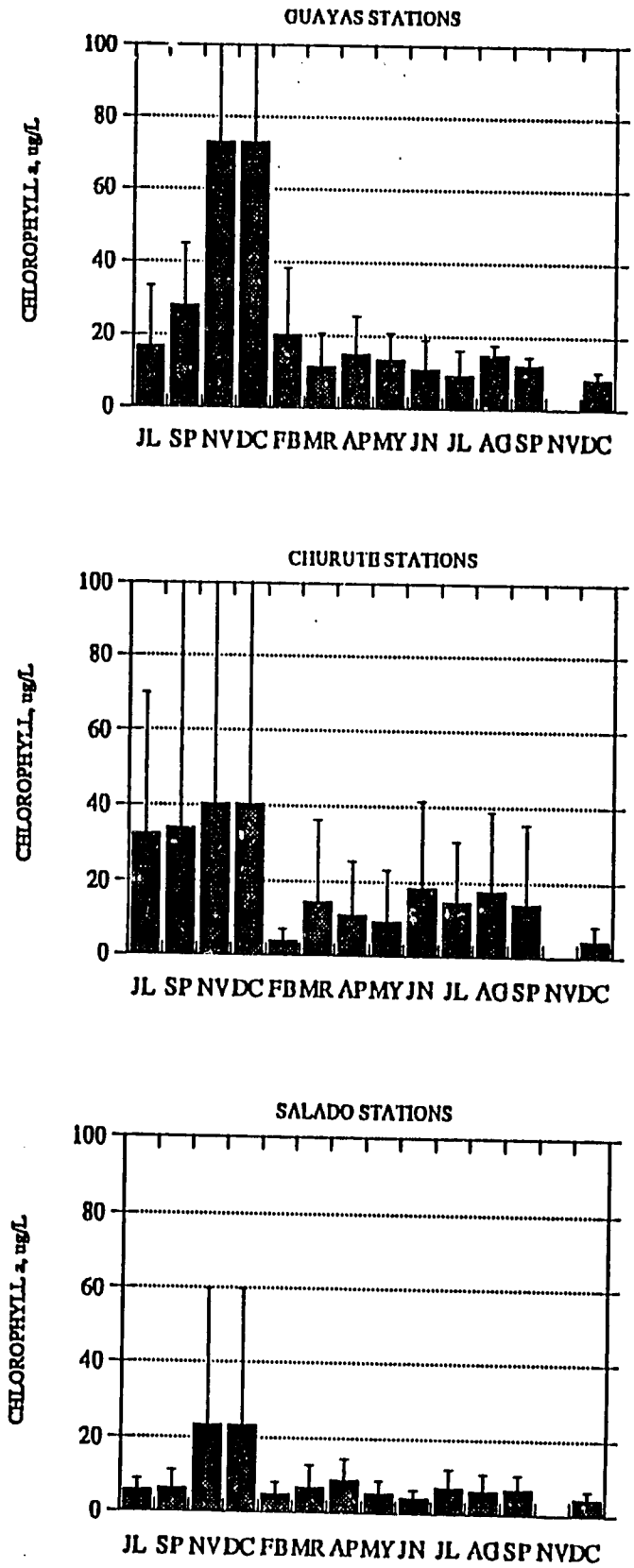


Figure 22. Seasonal patterns of chlorophyll a (µg/L) in the three subestuaries of the Guayas River estuary based on monthly sampling from July 1989 to December 1990. Means and standard error are for all stations in each subestuary for one sampling per month based on 0.5 m depth.

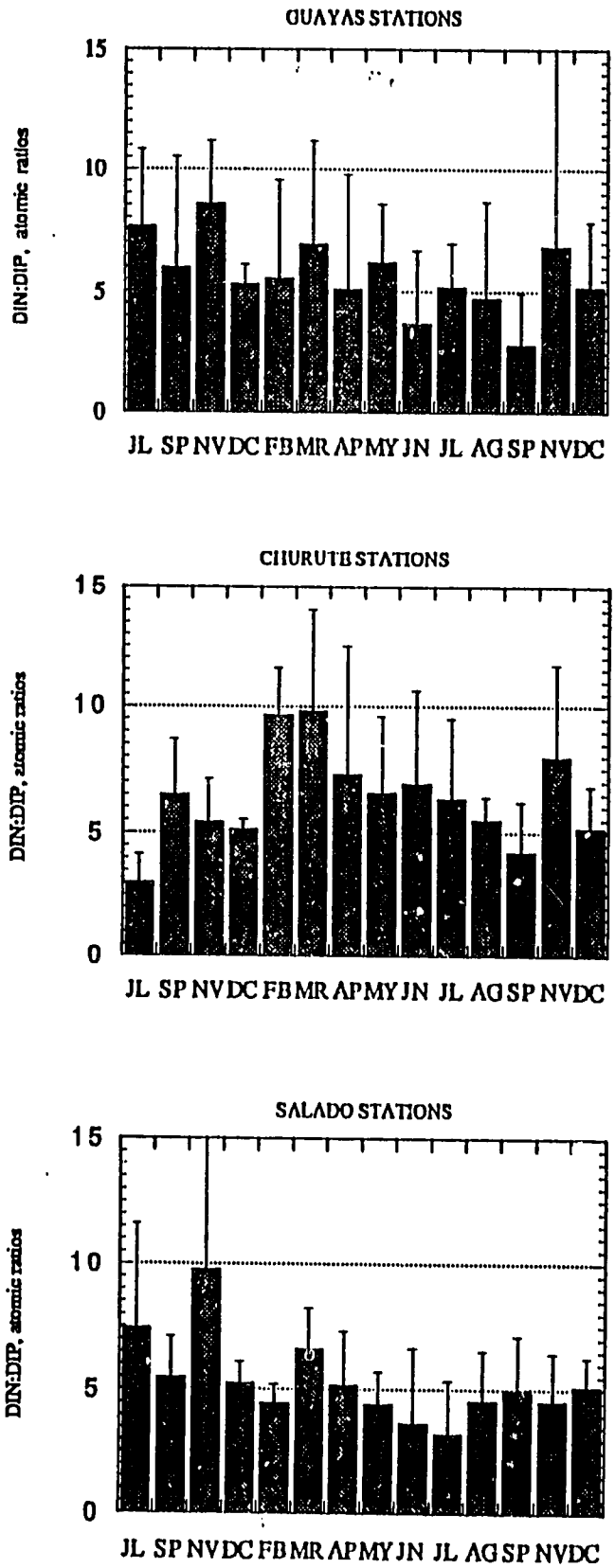


Figure 23. Seasonal patterns of atomic ratios of dissolved inorganic nitrogen to dissolved inorganic phosphorus (DIN:DIP) in the three subestuaries of the Guayas River estuary based on monthly sampling from July 1989 to December 1990. Means and standard error are for all stations in each subestuary for one sampling per month based on 0.5 m depth.

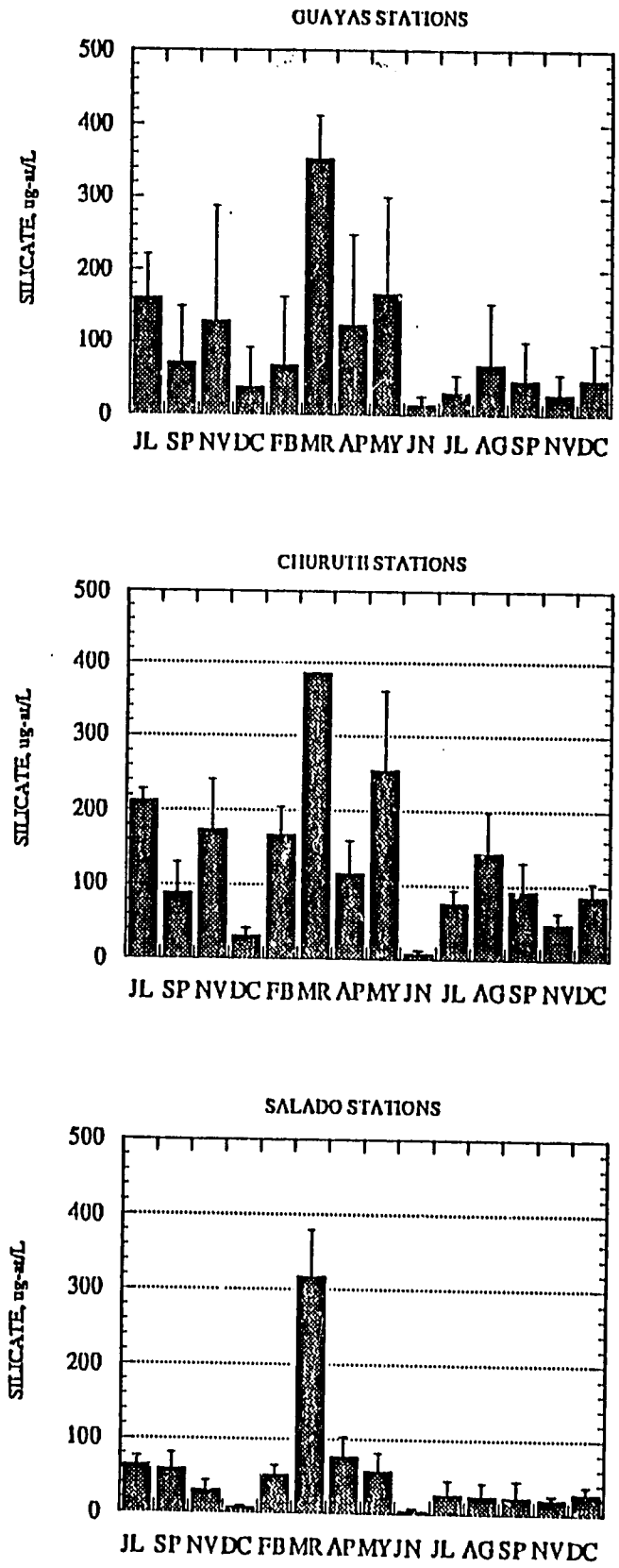


Figure 24. Seasonal patterns of silicate (mg/L) in the three subestuaries of the Guayas River estuary based on monthly sampling from July 1989 to December 1990. Means and standard error are for all stations in each subestuary for one sampling per month based on 0.5 m depth.

The ground filters and plant samples were analyzed isotopically by a modified Dumas combustion that converts organic carbon and organic nitrogen to CO_2 and N_2 gas for mass spectral analysis (Macko 1981). The samples were first placed in quartz tubes with Cu and CuO, which were evacuated and sealed. The quartz tubes were then heated to 850°C at a rate of 450°C h^{-1}, kept at 850°C for 2 h, and cooled to room temperature at a rate of 60°C·h^{-1}. The slow cooling cycle ensured that any oxides of nitrogen were decomposed to N_2. CO_2 gas was separated from N_2 gas by cryogenic distillation. N_2 gas was then analyzed on a Nuclide 3-60-RMS. CO2 gas was analyzed on a Finnigan MAT 251. Results are presented in standard notation. The standard for nitrogen was atmospheric N_2 and the standard for carbon was PeeDee Belemnite. For $d^{15}N$, the precision was ±0.3‰ for particulate samples, ±0.5‰ for NH_4^+, and ±0.8‰ for NO_3^-, respectively. The precision of the $d^{13}C$ measurement was ±0.2‰.

Other Analyses: Organic carbon and nitrogen concentrations of SPM, APM, and bacterial concentrates were measured on a Carlo-Erba CNS analyzer. Filters containing the particulate material were thawed and dried in a vacuum desiccator at 60°C. Dissolved organic carbon was measured by high temperature combustion at 680°C in the presence of Pt catalyst with a Shimadzu TOC-5000 analyzer. To remove dissolved inorganic carbon, 25 µl of Ultrex HCl was added to the samples followed by purging for 5 min with high purity N_2 gas. Salinity, suspended particulate matter, dissolved oxygen, and chlorophyll (fluorometric method) were measured by standard methods (Parsons et al. 1985). Bacterioplankton were counted by epifluorescence microscopy with the acridine orange direct count technique (Hobbie et al. 1977).

Results

We investigated spatial and temporal variations in elemental and isotopic ratios of suspended particulate matter (SPM) from a large, tropical estuary system. Our study area included three sub-estuaries of the Guayas River estuary system (GRES), which opens into the Gulf of Guayaquil, Ecuador. Much of the region has been transformed from pristine mangrove stands into shrimp farms. The stable carbon ($d^{13}C$) and nitrogen ($d^{15}N$) isotope data clustered closer to terrestrial mixing-members (e. g., rivers, mangrove detritus). Algae, sewage, and shrimp pond effluent were only important at selected sites. Atomic carbon to nitrogen ratios $(C:N)_a$ were at the upper end of the range reported for phytoplankton, but much lower than that of vascular plant material. We characterized mangrove detritus based on carbon to chlorophyll a ratios ($d^{13}C$ = -26.4±0.3, $d^{15}N$ = +4.8±0.2, and (C:N)a = 14.1±0.9). Bacterial bioassays (e. g. Coffin et al. 1989) were used to document potential sources of DOM in GRES. The isotopic similarity between these assays and SPM coupled with its relatively low (C:N)a led to the conclusion that bacteria were mobilizing nitrogen onto the detritus. Finally, the elemental and $d^{13}C$ data taken over a tidal cycle varied significantly. Based on these results, we caution that care must be taken when samples are taken for food-web studies in these types of systems.

Habitat Utilization

Methods

To determine recruitment and habitat utilization patterns of two species of *Penaeus*, we analyzed survey data from 1985 through 1988 collected as part of an OAS study of Estero Salado by R. Zimmerman and R. Jimenez. In addition, surveys of selected sites of the 21 site estuarine cruises during this study were sampled for estuarine nekton. Three tows were made at each site and samples stored until analyzed at INP. Selected samples were dried and preserved for latter assay of natural abundance of carbon and nitrogen isotopes.

Results

Five species of *Penaeus* co-occur in the Gulf of Guayaquil. Recruits of three species of *Penaeus*, *P. californiensis*, *P. vannamei*, and *P. stylirostris*, were abundant and shown to use nursery habitats associated with mangroves. Juveniles of the other two species, *P. occidentalis*

and *P. brevirostris*, occurred infrequently and their nursery habitats were not found in the estuary. Juveniles of the abundant species were each more numerous during wet than dry seasons, but the effect of rainfall varied significantly among species. The white shrimp, *P. vannamei*, was highly affected by greater rainfall and was most abundant during the El Niño year of 1987. By contrast, the brown shrimp, *P. californiensis*, was more abundant during the driest year (1985) and less affected by rainfall. Habitats in the lower estuary always had significantly more juveniles of all species than the upper estuary. However, in dry years, shrimp abundance increased in the upper estuary thus expanding the area of habitat utilization. These results demonstrate how tropical estuaries vary annually in habitat suitability as shrimp nurseries.

Habitat surveys indicate that the loss of mangroves from estuaries in Ecuador may influence the genetic resources of economically important fisheries, as well as many other less documented artisinal fisheries. Zimmerman and Minello (1986) have found that *P. vannamei* and *P. stylirostris* inhabit areas in the mangroves, but it is not known whether these habitats enhance the survival or growth of these and other marine organisms in the Estero Salado. During periods of warmer temperature of offshore waters, there is a significant increase in frequency of *Penaeus* sp. throughout the mangrove habitats. Zimmerman et al. (1991) found that recruits of three species, *P. californiensis*, *P. vannamei* and *P. stylirostris* were abundant and used the nursery habitats associated with mangroves, while juveniles of *P. occidentalis* and *P. brevirostris* occurred infrequently and were not associated with mangroves. *P. vannamei* was more abundant during years with higher rainfall, particularly during the 1987 El Niño event, while *P. californiensis* was more abundant during drier years. This multi-year study demonstrated that tropical estuaries vary annually in habitat suitability as shrimp nurseries, depending on the temporal pattern of oceanographic processes and available habitat.

Results of surveys during present AID study are for *P. vannamei* only in Churute estuary and Estero Salado (Fig. 25). Only channel sites were chosen in Churute, whereas sites up in the mangrove creeks were sampled in Estero Salado (Fig. 6). The highest frequency of *P. vannamei* was observed in February in Estero Salado and March in Churute (Fig. 25). This concurs with previous studies that have observed higher frequencies of *P. vannamei* during the wet season. The frequency was highest in the lower bay stations nearer the Gulf of Guayaquil at both systems, yet more abundant up in the mangrove tidal creeks than out in the channel. Abundance for *P. vannamei* is much higher in Estero Salado than in Churute estuary.

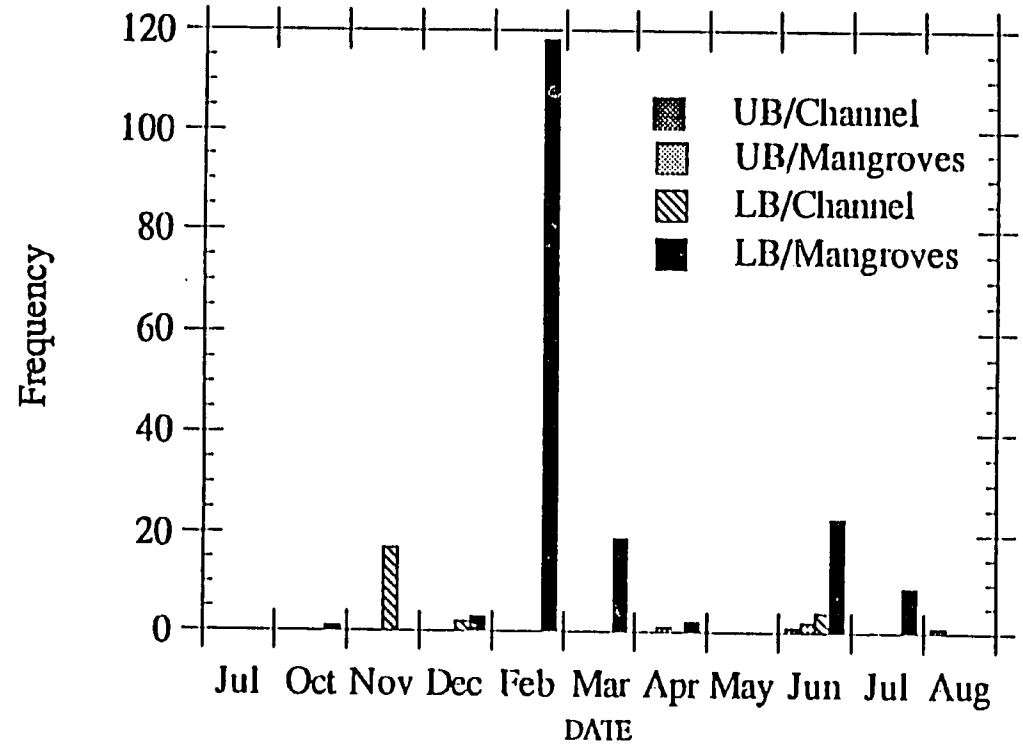
Detritus Utilization:

Methods

Representatives of the estuarine and mangrove food webs were collected on each of the monthly field trips as part of the estuary program in Ecuador described above. One trawl at each of the 21 stations was sampled for shrimp and detritus and dried for later assay of the isotopes of carbon, nitrogen and sulfur. In the mangroves, samples of leaves (green, senescent, and decaying leaves on forest floor), stems, and epiphytes were sampled along with sesarmid and *Ucides* crabs. In addition, all of the litter and decomposition samples from the litter study were ground and stored for possible assay. Samples have been selectively analyzed for sulfur and carbon to develop some of the strategies for future isotope assays. This report discusses the initial results of the sulfur analyses.

Results

Organisms that occur in freshwater habitats have lower $d^{34}S$ values compared to marine organisms that are range from 18 to 20 ‰ (Peterson and Howarth 1987). Macrophytes floating into the Churute estuary from the Guayas River had $d^{34}S$ values of -2.3 ‰, which indicates a depletion of the ^{34}S isotope (Fig. 26). Green leaves and stems of *Rhizophora* in the M3 site in the Churute estuary also had low $d^{34}S$ values of -1.2 and -0.3 ‰, respectively. During decomposition, mangrove detritus became enriched with ^{34}S, which is common in estuarine



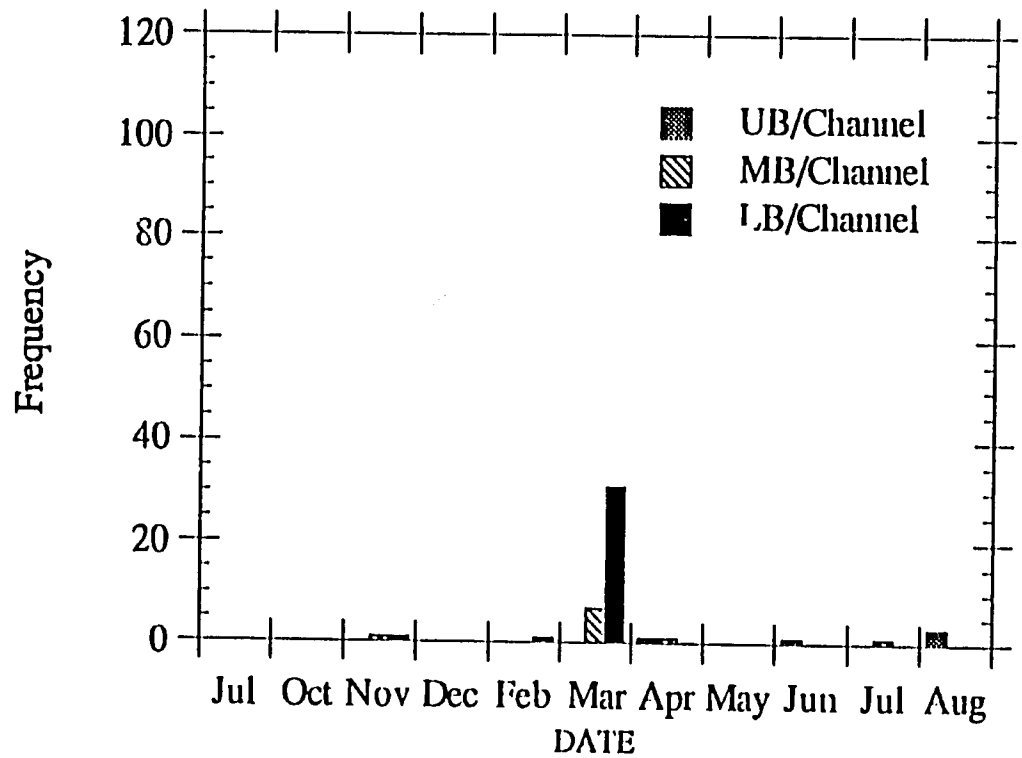


Figure 25. Seasonal and spatial frequency of the occurrence of *Penaues vannamei* in Estero Salado and Churute estuary from July 1989 to August 1990.

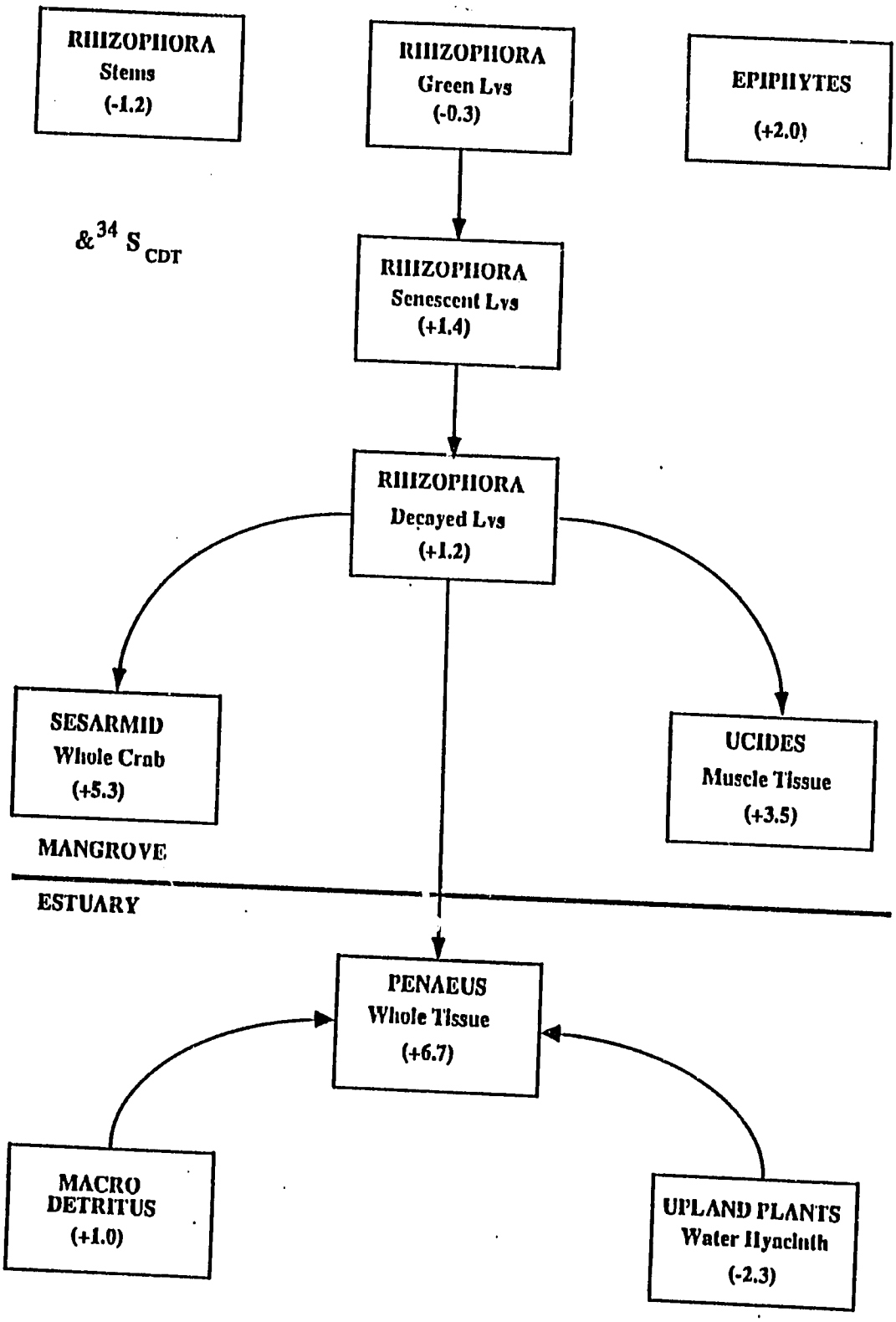


Figure 26. The distribution of del34 sulphur isotope amongr representative of food chains in the M3 mangrove in Churute and organisms in the Churute estuary.

wetland sediments. This may be due to sulfate oxidation processes that cause a fractionation of the sulfur isotopes by preferentially utilizing the lighter isotope. The tissue of two crabs in the forest, both detritus feeders, have enriched $d^{34}S$ values of +3.5 to +5.3 (Fig. 26). In the case of *Ucides*, a black ooze was found in the burrows that had remnants of mangrove tissue at advanced stages of decomposition. The higher values of the crabs could indicate the utilization of organic matter from sulfate reducers causing enriched values of $d^{34}S$. In the estuary, macro detritus had $d^{34}S$ values similar to the mangrove detritus. Yet samples of *Penaeus vannamei* had $d^{34}S$ values of +6.7‰, the highest values of selected samples of the food webs tested (Fig. 26). These enriched samples could indicate the utilization of enriched ^{34}S found in marine phytoplankton. This preliminary survey indicates that mangrove detritus may be an important component of the macro-detritus of the estuary, but that consumers such as shrimp also receive organic matter of a more enriched source of sulfur. More assays of the food webs sampled and preserved will have to be completed before better interpretations are warranted.

IMPACT, RELEVANCE AND TECHNOLOGY TRANSFER

Impact on Laboratories, Departments and Institutions:

The project helped with the procurement of equipment for field analyses of mangrove ecosystems and chemical analyses of ecological materials. Equipment in Ecuador was provided to University of Guayaquil and PMRC office that was used by the Mangrove Working Group to assist in the field studies of mangrove structure and biomass. Equipment was also provided to INP in Ecuador to assist in the chemical analyses of soil, plant and water samples. In Mexico, a nutrient laboratory facility was developed for the study of nutrient cycling in the mangroves at Laguna de Terminos.

Equipment for University of Guayaquil included: drying oven repair, triple beam balances, and field balances. Field equipment for PMRC, which was used by the students from University of Guayaquil included: DBH tapes (2), clinometer (1), compass (2), vernier calipers, 100 m transect tape, pore water sampler, filter holder and syringe, filters, soil thermometers, water level recorder, coolers (2), marking tape and tree tags, metal quadrats, lumber for litter baskets, pipe for groundwater wells, pH and redox probes and meter, decomposition bags and a textbook - WETLAND ECOLOGY by W. Mitsch and J. Gosselink. Contributions to the chemical laboratory of Dr. Lucia Solorzano of INP included: chemicals, glassware and gases for CHN analyzer, willey mill, refractometer, chemicals for nutrient analyses, glassware for nutrient analyses, sample bottles, filtration manifold, filters for water sampling, cooler, pH probes, support for RV Proteo. Support was also given to the Guayas District Forestry Office and the Churute Ecological Preserve in the form of fuel and repairs of boat for field study and personnel to support data collection of water levels in mangrove forests.

Equipment support in Mexico was for the development of techniques to support flume studies and denitrification assays in the mangroves in Terminos Lagoon. Support included: spectrophotometer, pressure cooker, chemicals for nutrient assays, glassware for nutrient assays, deionizer system for pure water, vacutainers, pH and redox probes and meter, distillation system for N15 studies, filtration system, nitrate/nitrite columns, centrifuge tubes.

Impact on Individuals:

Support of laboratories, departments and institutions include the training of individuals. Many of these activities are described below in the **Project Activities** section that describes the workshop and training activities of the mangrove project. Many of these workshops and field exercises were designed to foster research capabilities within the Mangrove Working Group to assess the mangrove resources of Ecuador, particularly around the Guayas River estuary. Other forms of impacts on individual resources of Ecuador include formal seminars, informal meetings and strategy sessions, and individual meetings with government and private sector of the shrimp farm industry. Many of these seminars and training activities were arranged in cooperation with

the ZEMs project of PMRC.

The mangrove project supported the graduate theses of two students as part of the research efforts in mangrove ecology. Victor Rivera-Monroy is from Mexico and is a student of Dr. Twilley in the Department of Oceanography and Coastal Science at LSU. Ramón Zambrano is employed by the Department of Forestry, Guayas District Office, and was in charge of field logistics during the mangrove project. His study of phenology of mangroves in the Churute Ecological Preserve was partially supported by the mangrove project.

Victor Rivera-Monroy, Ph.D., in progress, "Denitrification and nitrogen flux in a mangrove wetland in Mexico". Department of Oceanography and Coastal Science. Louisiana State University. Baton Rouge, Louisiana.

Ramón J. Zambrano Alcivar. 1991. Esudio Fenologico de Mangle Rhizophora harrisonii en la Reserva Ecologica Manglares Churute. Universidad Laica Vicente Rocafuerte de Guayaquil. Ingeniero Agronomo.

Several undergraduate students from the School of Natural Science at the University of Guayaquil worked on projects during the mangrove project. These students served as apprentice at the PMRC office or INP.

Mireya Pozo - PMRC - In charge of mangrove litter studies including litterfall, decomposition, and litter standing crop. Following project Mireya was hired by Fundacion Natura to assist in education program of coastal awareness.

Victor Garcia - PMRC - Assisted in the mangrove forest field program, responsible for hydrology and groundwater measurements.

Washington Cardenas - INP - In charge of nutrient sampling and chemical analysis in estuary program; also in charge of study of phytoplankton populations. Presently is a graduate student of Dr. Twilley at USL in coastal ecology.

Nikita Gaibor - INP - Assisted in both forestry and estuary programs of the mangrove project. Responsible for sampling of detritus in estuary and forest, and natural isotope abundance in nekton. Presently working for INP.

Jorge Espinoza - Assisted in estuary program analyzing samples of particulate material. Presently working at shrimp laboratory.

There is an urgent need for graduate training of coastal ecologists in Ecuador. Several attempts were made during this mangrove project to acquire fellowships for students from University of Guayaquil and INP to study coastal ecology and resource management abroad. Yet, while there may exists funding for graduate work in the more applied agriculture disciplines, there was a lack of initiative in the area of coastal resources. It is important that sources of funding are made available to train students in the ecology and resource management of coastal ecosystems. These opportunities would include classroom instruction and training abroad and field research in Ecuador. Such programs should include a commitment by the student to pursue research and management back in Ecuador.

Larger Scale Pilot Studies:

One of the key contributions of this mangrove project funded by AID is the development of information on the function of mangroves in the coastal zone of Ecuador. Few mangrove studies have been conducted in the New World in river dominated coastal zones near the equator with tidal amplitudes of nearly 3m. This information was used to further develop a conceptual framework to understand the properties of mangroves relative to the forcing functions of the coastal environment (see Twilley, in press, "Properties of mangrove ecosystems related to the energy signature of coastal environments"). The importance of this concept to the management of mangroves in Ecuador is described in two chapters resulting from this work: 1) "Mangrove ecosystem biodiversity and conservation: Case study of mangrove resources in Ecuador", and 2) "Management of mangrove resources in Ecuador". These two chapters develop the concept of integrative mangrove management for estuarine resources in Ecuador. This idea is to use the natural function of mangroves in habitat quality and water quality to enhance the productivity and sustainability of shrimp ponds (Fig. 28). The next step should be to establish pilot studies of these

type of mangrove/shrimp pond ecosystems to test the design of these engineered coastal ecosystems.

The development of further ecological studies of Churute Ecological Preserve and Estero Salado were described in a proposal to the World Bank as a component of the Guayas River Basin Study. This proposal included the development of a consortium for the research of coastal ecosystems. The interdisciplinary nature of mangrove and coastal resources limited the coordination of research among the university, government and NGO organizations in Guayaquil. The consortium would build upon the personnel training and resources of the mangrove project to continue studies of the estuary and forests. One focus would be on the ZEMS, where information on the ecosystem dynamics would be used in the development of integrative management schemes. The proposal relied heavily on the use of natural isotopes to determine the impact of chemicals from shrimp farm on the ecology of Guayas River estuary, and on modeling of mangrove ecosystem properties to assess the impacts of different levels of shrimp pond construction in estuarine watersheds.

During the AID mangrove project a proposal was submitted to Man and the Biosphere program to continue the research on ecology and management of mangrove resources. The proposal was entitled "Ecological and Economic Analyses of Mangrove Ecosystems in Ecuador: An Integrative Approach to Management of Marine Resources in the Tropics". The executive summary of this proposal follows and describes some of the research needs in the area of mangrove ecology and management by linking ecological and economic modeling approaches to resource management.

> Mangroves are one of the dominate features of coastal land margin ecosystems of the tropics. While ecologically they have been considered an important component of coastal watersheds, they are continually exploited for aquaculture, agriculture, charcoal, urban development and other economic usages. Attention has been focused on the utilization of mangrove habitat for the expansion of shrimp ponds, particularly in Ecuador, where in some watersheds such as Bahia de Caraques over 90% of the mangroves have been reclaimed for mariculture. The success of this economic activity in Ecuador is quickly spreading to other developing countries in Central and South America where there is concern for sustaining value of ecological and social systems. Assistance to these problems is limited because of the poor understanding of the various ecological functions natural resources such as mangroves provide, together with a methodology to evaluate these functions as economic value. We propose a study to develop an approach for the natural resource dilemma in Ecuador, which may have future implications for other management problems in the tropics.
>
> The goal of this study is to synthesize existing information on the properties of mangrove ecosystems into an ecological model that will describe the multiple functions of this natural resource. Outputs from this ecological model will serve as inputs to the economic evaluation of these ecosystems. Mangrove ecosystems will be evaluated as multiproduct assets relative to their contribution to the sustainability of shrimp mariculture. This information will be holistic in nature by not only considering the more popular function of mangroves as nursery, but by also taking into account the various functions such in timber and charcoal production, sediment control, and water quality in the design of best management practices for the coastal zone. Ecological analyses will be evaluated in terms of the loss of mangrove functions or "free services" from the estuary as a result of the conversion of forested land to shrimp ponds. In addition, analyses will also determine the impact of the new ecosystem, the shrimp pond, on the ecology of coastal waters. By evaluating both the ecological and economic consequences of mangrove loss and subsequent replacement with shrimp ponds in coastal watersheds, present management schemes can be evaluated relative to the issue of sustainability. This methodology will not only assist in the design of best management practices, but also foster a better understanding of the development implications of these practices.

Neither of the two proposals described above were funded to continue the efforts of the

AID mangrove project. Presently there is an effort through the International Development Bank to fund mangrove management plans in coastal Ecuador. Some of this will include silviculture of mangroves, it is uncertain how much ecosystem research will be included in the proposed program.

Technology Transfer:

Technology transfer for this project was largely restricted to several types of meetings: workshops and training sessions, lectures and seminars, informal strategy sessions, field exercises, and consultations. These activities are described below in PROJECT ACTIVITIES/OUTPUTS section below. This mangrove research project was coordinated through the PMRC office in Guayaquil, and was involved with many other government and academic institutions in Guayaquil (see Project Coordination above and Fig. 1). The focus of the mangrove research project was to provide information and technology to PMRC, INP, and ESPOL. Through PMRC, the mangrove project provided information and advise to the Mangrove Working Group and the various field ZEM offices. One of the most important contributions of this collaboration was the use of the ecosystem concept to integrate the complex issues of mangrove resources in Ecuador. The Mangrove Working Group and PMRC staff involved with mangrove resources were trained in forestry and resource management. Mangroves are unique in that they are intertidal forested wetlands that provide both timber related products and habitat for economically important fisheries. These can sometimes be competing users for coastal resources, as was the case for Ecuador. In addition, there was the use of the intertidal zone for mariculture. Accordingly, the different institutions interested in the research and management of mangroves had different agendas and interests. This mangrove project emphasized the integration of the ecological processes and functions of mangrove resources, and the importance in linkages in the institutions that are involved with the ecology and management of these resources. Simple ideas were implemented during the field research program, such as getting the forestry scientists to work on some of the estuarine cruises and consider the importance of tides in the exchange of materials between the forests and estuary. In addition, we had some of the scientists from INP work in the forests on some of the litter dynamic studies. All of the research and training activities were related back to the ecosystem approach of our study, and how each component complimented seemingly distantly related research objectives. The Mangrove Working Group was integrated with forestry and fishery research and management personnel to provide a broader forum for the exchange of information and ideas. Near the completion of this project, it was suggested that there should be the formation of an ECOSYSTEM WORKING GROUP to help integrate the information and technology of the various specific working groups.

Implications of Mangrove Ecology to Coastal Resource Management

The net production of coastal ecosystems, which depends on the forcing functions of the environmental setting, is utilized by human systems to support goods and services, such as fisheries (Fig. 3). There has been much recent effort to establish the value of ecological services that wetlands and other natural resources provide to human systems (Farber and Costanza 1987, Costanza et al. 1989, Dixon 1989). For mangroves, these services include indirect use such as providing food and habitat for economically important fisheries and water quality for aquaculture. Direct uses of mangroves include timber harvest and charcoal production, and non-use value functions of mangroves to maintain biodiversity (Fig. 3). These values and uses are linked to the functions of mangroves, and together with the cultural and economic characteristics of an area, determine the actual uses of mangroves that occur in a region. The link between ecological functions and human use of mangroves is fundamentally constrained by the forcing functions of an environmental setting. This link between the nature of an environmental setting with the ability of ecosystems to support human activities is an important concept in natural resource management. Valuation techniques and land use management schemes should identify those forcing functions that control the ecological functions of ecosystems that sustain the social and economic activities of human activities.

The use of mangroves by human social and economic systems in a watershed may generate negative feedback effects on the ecological processes of mangroves. One of the more common environmental impacts of human development in the tropics is the alteration in hydrology by construction of dams, levees, or alternate use of freshwater. Development of conceptual and ecological models of how river and tides control properties of mangroves is important to understanding how these alterations in hydrology will change the function or value of mangroves (Twilley 1985b). Twilley (in press) emphasized the importance of hydrology to many ecological processes in mangroves that support their function in the habitat and water quality of coastal ecosystems. Changes in hydrology can decrease the fertility of mangroves and limit litter productivity. The exchange of this litter with coastal waters will also decline and cause changes in the nutrient cycling of mangrove ecosystems. Decreases in outwelling of litter and accumulation of sediments and nutrients are ecological processes that are most sensitive to alterations of mangrove hydrology.

Shrimp farming in Ecuador is an excellent example of the coupling of ecosystem ecology with resource management. There are six key ecological functions of mangroves that maintain the habitat and water quality of coastal ecosystems (Fig. 27). The habitat and water quality of coastal ecosystems in Ecuador are important in sustaining the shrimp farm industry by providing wild stock of postlarvae, a productive pond environment, and minimum water quality problems such as turbidity and dissolved oxygen. Mangroves and tides provide the shrimp industry with clean water and important habitat that enhance wild PL supply and shrimp production in ponds. With the loss of these free services the cost of shrimp production increases such as in the cost of providing postlarvae by cperating hatcheries, increased dredging to remove sediment, and fuel for pumps to control dissolved oxygen (Fig. 28, upper panel). Thus negative feedbacks of the shrimp industry due to the loss of mangroves will influence the sustainability of the shrimp farm industry, which is so tightly coupled to the natural resources of estuarine ecosystems.

Understanding how forcing functions control the processes of ecosystems also allows for the design and engineering of ecological systems to sustain human socio-economic activities. Many mangrove functions are associated with the exchange of materials, such as organic matter and nutrients, at the boundary of these systems with coastal waters. These intrasystem mechanisms include the production, decomposition, and export of leaf litter and intrasystem nutrient cycling processes such as regeneration, accumulation, and denitrification. It is the balance of these processes that influence the exchange of nutrients at the mangrove/coastal water boundary. The net flux of materials across this boundary determines whether mangroves serve as a sink or source of nutrients. Information on these ecological processes in other wetlands has been used to design natural nutrient waste treatment facilities (Nichols 1983, Godfrey et al. 1985). Such ecological engineered systems using wetlands provide support to human societies, and provide a positive feedback to wetlands. There are some indications that mangroves can also be used as a nutrient sink and managed to remove excessive nutrients in coastal environments (Nedwell 1975, Sell 1977). In Ecuador, mangroves should be explored as natural filters of the excess nutrients released from shrimp ponds to coastal waters (Fig. 28, lower panel). This is a particularly important research agenda given the increased eutrophication of coastal waters in those estuaries where over half of the mangroves have been exploited for shrimp ponds.

Valuation techniques must use ecological information to identify the negative and positive feedbacks of human systems with the function of natural resources. This requires some sensitivity analysis of how ecosystems respond to different uses and associated impacts. We are presently developing models of these processes to more specifically predict the response of mangrove ecosystems to both natural and human alterations of coastal environments. The combination of these ecological models together with economic analyses of multiproduct functions of mangroves may provide better techniques that identify the role of ecological information in the valuation and management of mangrove resources. The clarification of this process will also help in identifying goals and priorities of research on the function of mangrove ecosystems.

Energy analysts utilize energy flows in natural systems as a measure of the total work performed by those systems. This holistic method is designed to account for the variety of functions that ecosystems provide to support goods and services. Scientists using this method

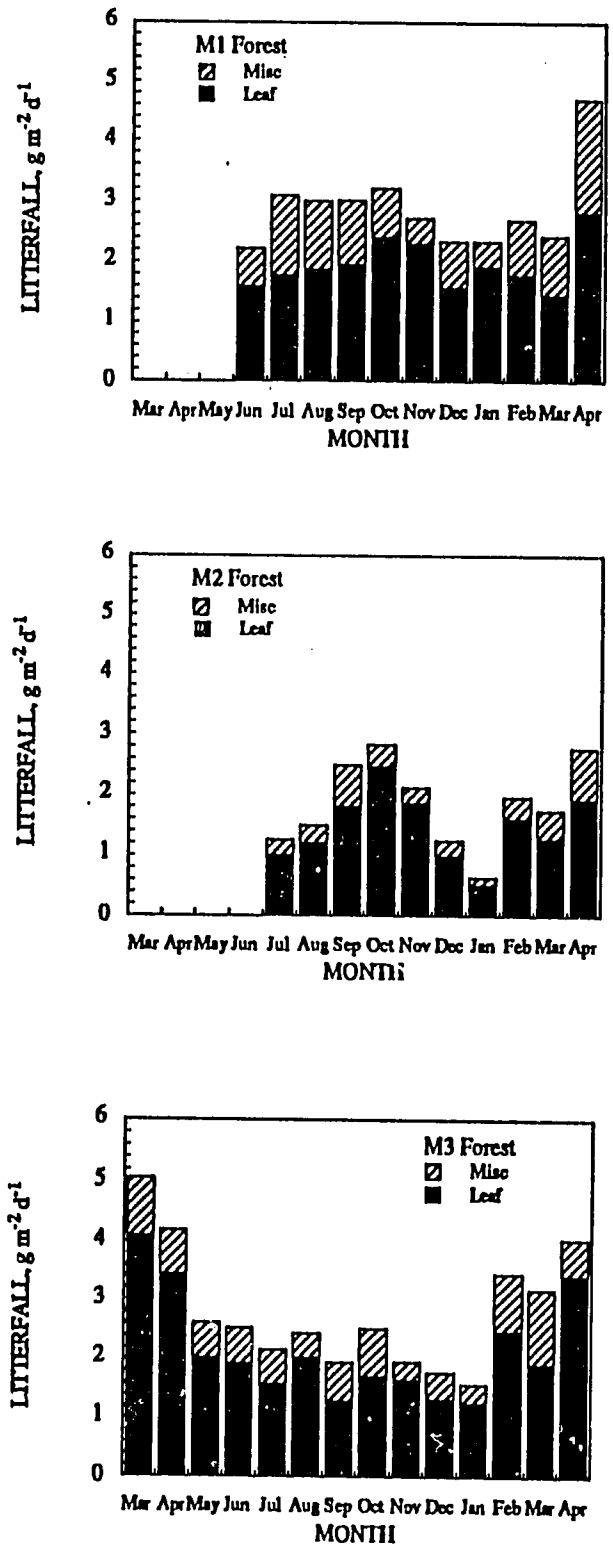


Figure 13. Litterfall (g dry mass m^{-2} d^{-1}) in three mangrove sites in Churute estuary from March 1989 to April 1990. Litterfall rates are separated among leaves and residual (wood, fruits, flowers, and miscellaneous).

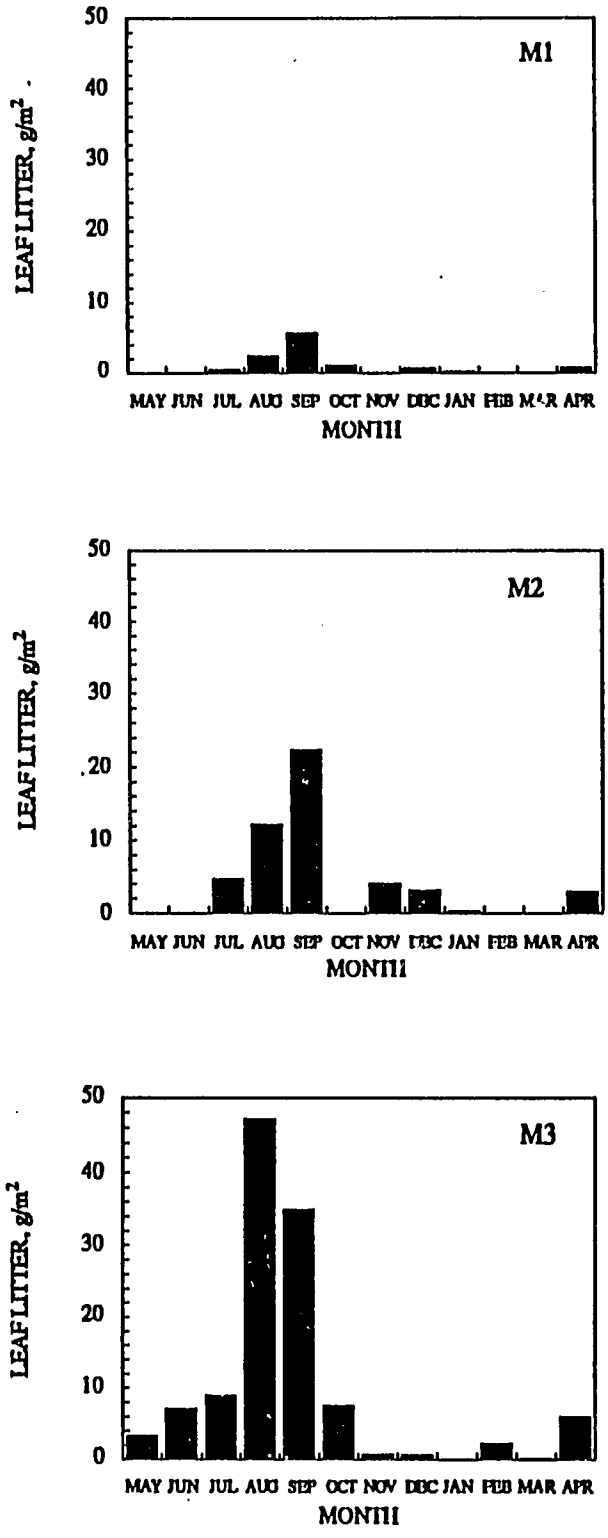


Figure 14. Litter on the forest floor (g dry mass m^{-2}) in three mangrove sites in Churute estuary from May 1989 to April 1990.

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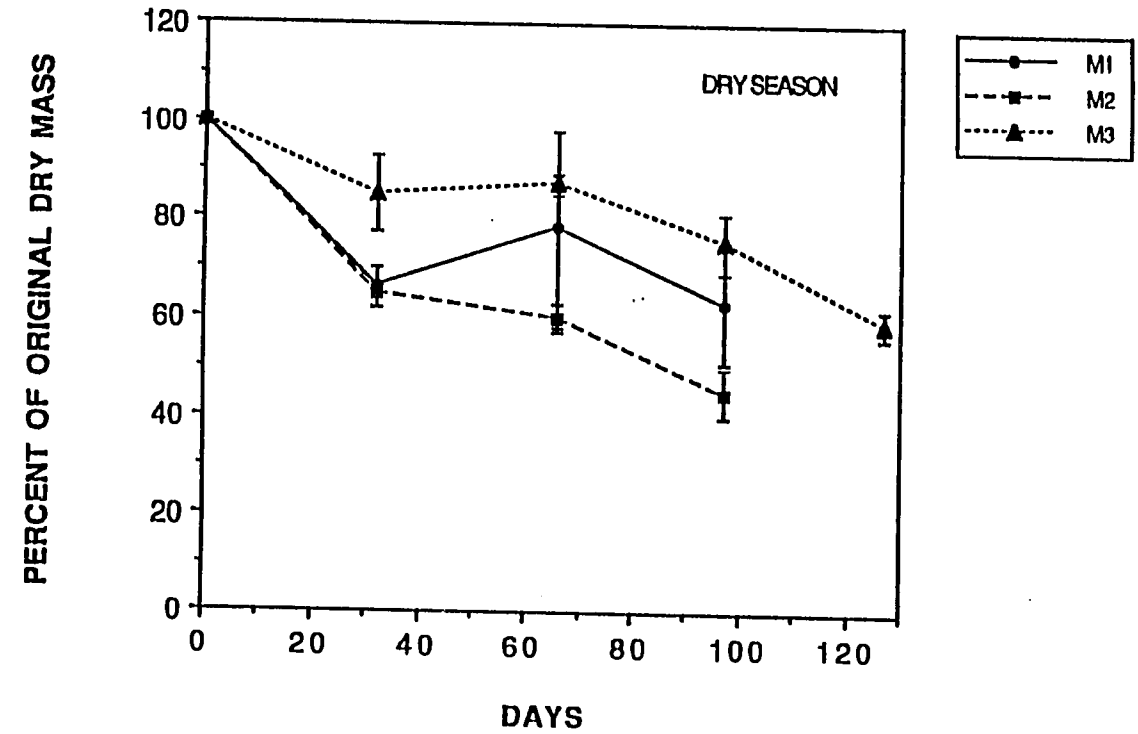

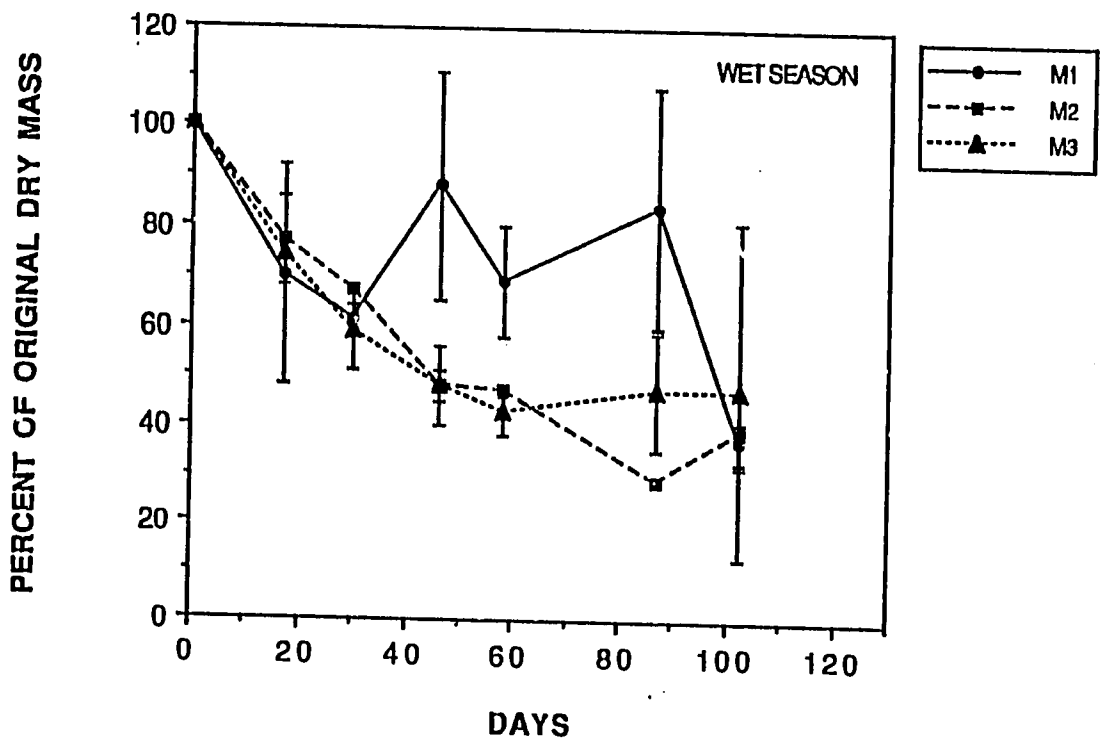

Figure 15. Decomposition of mangrove leaves (*Rhizophora mangle*) based on percent of original mass remaining in mesh bags following different time of incubation on the forest floor of the three mangrove sites in Churute estuary for two different seasons of the year.

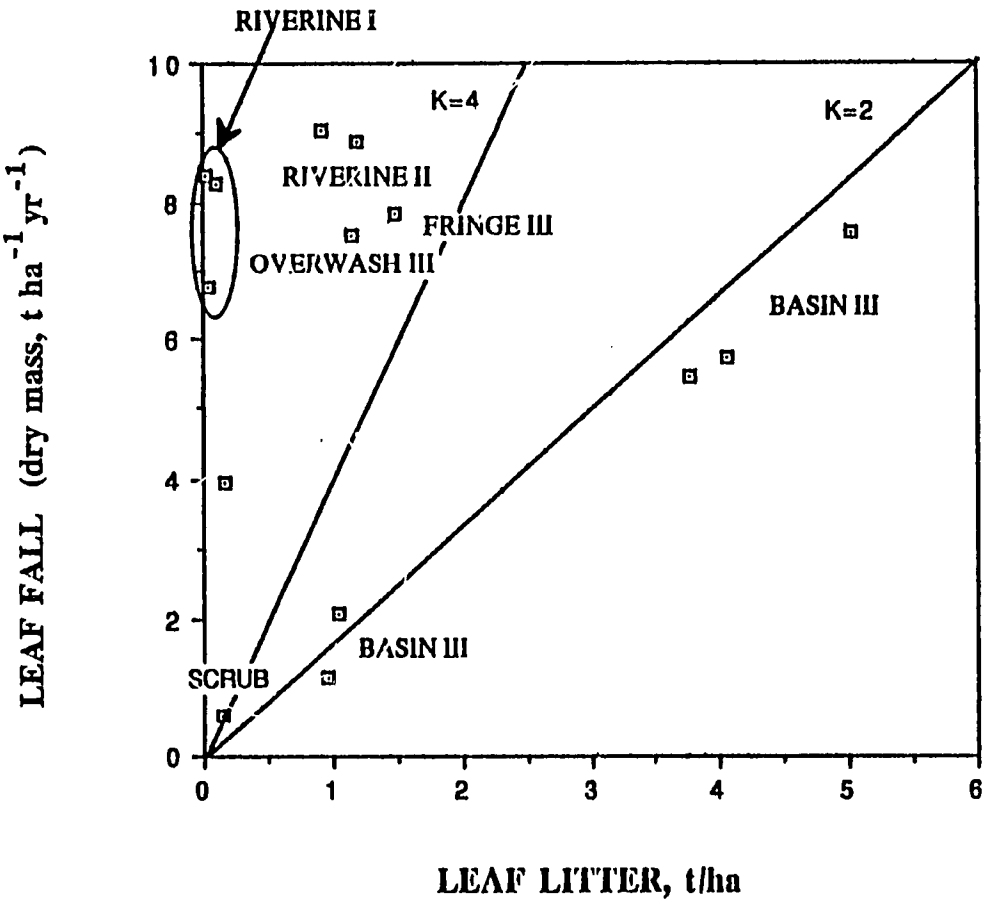

Figure 16. Comparison of litter dynamics of different mangrove forests with those on Churute estuary (Riverine I) using the turnover model of leaf fall vs leaf litter on the forest floor. The lines designate different turnover rates of litter on the forest floor.

convert energy flows to dollars by assuming proportionality between energy inputs and GNP (Gosselink et al. 1974, Farber and Costanza 1987, Costanza et al. 1989). H.T. Odum analyzed the ecological economics of shrimp pond industry in Ecuador to demonstrate the use of EMERGY method for evaluating environmental contributions to assist in natural resource management (Odum and Arding 1991). The emergy method is a scientific-based measure of wealth, which puts raw materials, commodities, goods, and services on a common basis. According to the theory, the pattern that maximizes EMERGY contributes more wealth. Designs and management alternatives can be evaluated by maximizing for EMERGY, which can generate wealth according to an area's potential. Evaluations of designs are based on comparing the EMERGY investment in purchased inputs to those that are provided free by the environment.

The analysis emphasizes the importance of feedback that encourages the sustainable use of the free services provided by the environment. The ratios indicate the huge investment of environmental inputs to support the international monetary exchange for Ecuador. Given the lack of feedback to support the genetic and environmental quality of the coastal systems that provide these environmental inputs, there will be some eventual shift in designs of the economic systems as these free services decrease. The total annual macroeconomic monetary value for the ecological processes of coastal ecosystems (out to the 100 m contour of the continental shelf) is about $21.4 billion/yr (Odum and Arding 1991). The costs of the degradation of these environmental resources is compared to the realized income from shrimp exports to Ecuador. The discounting of the contribution of environmental inputs and the loss of these natural resources to the subsidy of the shrimp farming industry can be remedied with the following recommendations: decrease channelization, return some of the *P. vannamei* produced in the shrimp ponds to the estuary to improve larval stocks; reforest mangrove areas; and manage the Daule-Peripa dam to allow for seasonal discharge. In addition, the report recommended that shrimp pond management be less intensive, shift some ponds to other more artisinal fisheries, and discontinue exchange of shrimp with developed countries. These latter recommendations are to keep more of the wealth generated from environmental inputs within the country. Information on the ecology of mangrove ecosystems produced from our study used within the context of the EMERGY analysis provides a methodology for the linkage of ecosystem ecology and economics for the development of best management plans of coastal resources.

PROJECT ACTIVITIES/OUTPUTS

Publications:

Twilley, R.R., R.H. Chen, and T. Hargis. **1992.** Carbon sinks in mangroves and their implications to carbon budget of tropical coastal ecosystems. Water, Air and Soil Pollution.

Twilley, R.R. **in press.** Properties of mangrove ecosystems related to the energy signature of coastal environments. IN: C.A.S. Hall, (ed.), Maximum Power. University of North Carolina, Chapel Hill.

Twilley, R.R., A. Bodero, D. Robadue. **in press.** Mangrove ecosystem biodiversity and conservation: Case study of mangrove resources in Ecuador. In: J. Cohen and C. Potter (eds.), Case studies of genetic resource conservation in natural habitats: Biological and Socioeconomic Dimensions. AAAS Press, Washington, D.C.

Twilley, R.R. and J. W. Day, Jr. **in press.** The productivity and nutrient cycling of mangrove ecosystems. In: A. Yáñez-Arancibia (ed.), Management and Research of Mangrove Ecosystems.

Cifuentes, L.A., R.B. Coffin, R.R. Twilley and L. Solarzano. **submitted.** Isotopic and elemental variations of carbon and nitrogen in a mangrove estuary. Limnology and Oceanography

Barbier, E.B., R. Costanza, and R. R. Twilley. **1991.** Guidelines for Tropical Wetland Evaluation. Report of "Taller internacional de Trabajo para la Elaboracion de un Manual de Evaluacion Economica de los Bienes y Servicios de los Humedales Tropicales", CATIE, Turrialba, Costa Rica.

Presentations (Abstracts):

Twilley, R.R., L. Solorzano, W. Cardenas, N. Gaibor, R. Garcia, R. Zimmerman and L. Cifuentes. 1991. Ecology of the Guayas River Estuary: Patterns in chemical, physical, and biological properties of a river-dominated tropical estuary in Ecuador. Estuarine Research Federation, November, San Francisco.

Rivera-Monroy, V.H. and R.R. Twilley. 1991. Comparison of potential denitrification rates of mangrove soils in Twin Cays, Belize; Laguna de Terminos, Mexico; and Guayas River estuary, Ecuador. Coastal Wetland Ecology and Management Symposium, 3-6 December, New Orleans.

Rivera-Monroy, V.H., R.R.Twilley, J.W. Day. 1991. Nutrient cycling in mangroves in Mexico. Estuarine Research Federation, November, San Francisco.

Twilley, R.R.. Production, transport and utilization of detritus in the Guayas River estuary, Ecuador. International Ecology Conference, Yokohama, Japan. August 1990.

Twilley, R.R. 1990. Ecosystem analysis of mangroves and shrimp mariculture in Ecuador. Invited paper to symposium on "Shrimp Aquaculture: Impacts on Latin American Economics, Environments, and Social Structures". AAAS Annual Meeting, January, New Orleans, LA.

Twilley, R.R. 1990. Cycling of nutrients in coastal zone associated with the ecology of mangroves. Invited paper to symposium "Ecossistemas da Costa sul e Sudeste Brasileira: Estrutura, Funcao e Manejo (Ecosystems of the southern coast of Brazil: Structure, Function and Management)", Lindoia, Brazil. 6-11 April.

Seminars by Dr. Robert R. Twilley:

United States:

Zoology and Botany Departments, Louisiana State University, November 1991
Marine Environment Science Consortium, Dauphin Island Sea Lab, November 1991
National Research Council/World Bank, October 1990
Gulf Breeze Environmental Laboratory, September 1990
University of Rhode Island, October 1989
Agency for International Development, Washington, D.C., October 1989.
University of North Carolina-Chapel Hill, September 1989
Dauphin Island Sea Laboratory, August 1989

International

Escuela Superior Politecnica del Litoral (ESPOL), Guayaquil, Ecuador. 18 August 1988.
University of Guayaquil, Guayaquil, Ecuador. February 1989.
Fundacion Natura, Guayaquil, Ecuador. February 1989.
Instituto Nacional de Pesca, Guayaquil, Ecuador. May 1989.
Institute of Oceanography, University of Sao Paulo, Brazil, April 1990
University of Carmen, Carmen, Mexico. August 1990.
Universidad Laica Vicente Rocafuerte de Guayaquil, Guayaquil, Ecuador. May 1990.
Zona Especial de Manejo de Bahia San Vicente, Bahia de Caraquez. May 1990.
Universidad Tecnica de Manabi, Escuela de Ingenieria Forestal. May 1990.
Zona Especial de Manejo de Machala, Machala, Ecuador. May 1991.

Seminars - Invited Speakers

Dr. Luis Cifuentes, Department of Oceanography, Texas A&M University, College Station, TX. USA.
Dr. Richard Coffin, US Environmental Protection Agency, GBERL Sabine Island, FL
Dr. Alejandro Yáñez-Arancibia, Director. EPOMEX
Mr. Gilberto Cintrón, Department of Natural Resources, Puerto Rico.
Mr. Victor Rivera-Monroy, Louisiana State University.

Workshops/Training

Mangrove Training Course. Institute of Tropical Forestry, Rio Piedras, Puerto Rico. 9-14 August 1988. Drs. Ariel Lugo and Alejandro Yáñez-Arancibia, and Robert Twilley, and Mr. Gilberto Cintrón.

Forest Ecology of Mangroves. PMRC. February 1989. Dr. Robert Twilley, MS. Gilberto Cintrón, MS. Victor Rivera-Monroy. Participants included government personnel from DIGEMA, CLIRSEN, DINAF, University of Guayaquil, and INP. Purpose of course was training in techniques to determine structure and biomass of mangrove forests.

Forest Ecology of Mangroves. PMRC. January 1990. Dr. Robert Twilley, MS. Gilbert Cintrón, MS. Victor Rivera-Monroy. Participants included government personnel from DIGEMA, CLIRSEN, DINAF, University of Guayaquil, and INP. Purpose of course was training in techniques to determine structure and biomass of mangrove forests.

Fishery statistics. National Marine Fisheries Service, Galveston Laboratory. August 1990. Rosa Garcia from INP traveled to the NMFS to work under the direction of Dr. Roger Zimmerman on the statistical analysis of data collected on the abundance of post larvae in the Guayas River estuary.

Mangrove Working Group. PMRC. May 1991. Drs. Robert Twilley and Alejandro Yáñez-Arancibia gave a series of seminars in Guayaquil and at three of the ZEMs on the importance of mangroves to fish ecology of tropical estuaries. Participants included government, shrimp growers, students, and the public interested in the management of shrimp resources.

Mangrove Working Group. INP. May 1990. Established series of lectures by Drs. Luis Cifuentes and Rick Coffin at INP to describe the use of natural isotope in the study of the ecology of estuaries.

Mangrove Working Group. PMRC. June 1992. Dr. Francis Putz, University of Florida. Established visit of Dr. Putz to PMRC effort for mangrove reforestation in coastal Ecuador.

Water Quality Working Group. USL. Dr. Mariano Montano from ESPOL spent three months of his one-year sabbatical to the United States in Dr. Robert Twilley's laboratory working at USL studying techniques in water quality of estuarine resources. 15 May to 15 August 1992.

PROJECT PRODUCTIVITY

The ecosystem analysis of mangroves in the Guayas River estuary provided much needed basic information on the function these forested wetlands. The training and technology transfer products of this project are described in other sections. A summary follows of the five objectives in this study to describe the ecological functions of mangroves in Ecuador and Mexico. *Objective One*: Litter produced in the canopy of mangrove forests represents a major source of organic matter and nutrients for outwelling to adjacent coastal waters. Thus the dynamics of mangrove litter including productivity, decomposition, and export influence the coupling of mangroves to coastal ecosystems. Mangroves in Churute Ecological Preserve (CEP) produce about 10 Mg ha^{-1} yr^{-1} of detritus. Very little of this litter accumulates on the forest floor except for the months of September and October, resulting in some of the highest litter turnover rates for mangroves in the world (>10 yr^{-1}). Given rates of leaf decomposition in the three mangrove sites, most of the loss of litter is via tidal export. However, leaf litter was harvested by the mangrove crab, *Ucides occidentalis*, and burrowed within the forest. Thus the level of detritus export depends on tidal and crab activity. It is estimated that detritus export from mangroves in CEP is average at about 200 gC m-2 yr^{-1}, although high litter productivity and large tidal range would suggest more contribution of organic matter to the estuary. Detritus export to estuarine food webs is limited due to the activity of the mangrove crab, which results in more direct utilization of organic matter within the mangrove.

Objective Two: There is evidence that sedimentation and nutrient accumulation along with denitrification are important sinks of sediments and nutrients in estuaries. The relative influence of

these ecological processes on the fate of sediments and nutrients depends on the geomorphological characteristics of the coastal zone. The Churute Ecological Preserve represented an opportunity to compare these processes in riverine mangroves with much greater river discharge and tidal amplitude than in other mangrove studies. Sedimentation rates of 2200 g m-2 yr-1 for mangroves in CEP are higher than for mangroves other riverine mangroves, and much higher than basin mangroves in lagoons. Denitrification studies are incomplete, but indicate that together with sedimentation, these systems are an important nutrient sink in coastal margin ecosystems.

Objective Three: The fact that mangroves provide a source of organic detritus to coastal waters contradicts the idea that they also serve as a nutrient sink. The key to understanding the function of mangroves in food webs and nutrient cycles of coastal waters is to compare the different form of nutrients in estuarine waters that are exchanged with mangroves. A fringe mangrove in Estero Pargo, Mexico, demonstrates the effect of mangroves on removing inorganic nutrients transported during flood tide, to organic detritus on the ebb tide. The net flux of inorganic nutrients into mangroves may be associated with sedimentation and/or denitrification, and these fluxes are higher than net release of organic nutrients from the forests. The net flux of total nutrients is into mangroves supporting their function as a nutrient sink. The net export of organic nutrients are associated with the function of mangroves in providing detritus to coastal food webs.

Objective Four: There are very few studies on the ecology of tropical estuaries, and most of our understanding comes from comparisons with much different temperate systems. Seasonality in the tropics is controlled in many cases by the presence and absence of precipitation, and in the Guayas River estuary there were also strong seasonal patterns of salinity associated with seasonal river discharge. Other physical, chemical and biological characteristics of this natural estuary were linked to seasonal patterns in river flow such as turbidity, total suspended sediments, nutrients (particularly silicate) and phytoplankton. Differences between natural (Churute) and altered (Salado) systems were salinity, light, and silicate concentrations, and the utilization of mangrove habitat by estuarine fauna.

Objective Five: The habitat quality of mangroves are a function of both the detritus that support the mixed tropic food webs of estuaries, and refugia that provide nekton protection from predators. Recruits of three species of *Penaeus*, *P. californiensis*, *P. vannamei*, and *P. stylirostris*, were abundant and shown to use nursery habitats associated with mangroves. Juveniles of the other two species, *P. occidentalis* and *P. brevirostris*, occurred infrequently and their nursery habitats were not found in the estuary. Juveniles of the abundant species were each more numerous during wet than dry seasons, but the effect of rainfall varied significantly among species. The white shrimp, *P. vannamei*, was highly affected by greater rainfall and was most abundant during the El Niño year of 1987. The use of natural isotope abundance to discern the utilization of mangrove detritus in estuarine food webs is masked by the complex flow of energy in tropical estuaries. Bacteria may be mobilizing nitrogen onto organic detritus changing the nature of nitrogen poor detritus from mangroves, suggesting that care must be taken when interpreting natural isotope abundance samples for food-web studies in these types of systems.

There are six key ecological functions of mangroves that maintain the habitat and water quality of coastal ecosystems. Mangroves are important in sustaining the shrimp farm industry by providing wild stock of postlarvae, a productive pond environment, and minimum water quality problems. Negative feedbacks of the shrimp industry are associated with the loss of mangroves, and the associated free services they provide to sustaining farm production. In addition, negative feedback results from the replacement of these natural intertidal systems with those that are nutrient sources and provide no refugia for estuarine fauna. Integrated shrimp pond management is recommended that utilizes the habitat quality and nutrient sinks of mangroves. Systems should be design that use mangroves to improve the quality of water that is exported from shrimp ponds. The habitat quality of ponds could be utilized by returning a portion (10%) of the shrimp stock to the estuary to sustain the PL supply. In addition, estuarine food webs of mangroves in Ecuador include the mangrove crab, *Ucides occidentalis*, which is harvested for 10 months and is sold locally. There are no reports of the value of this fishery to the local economy, but it is listed as an important management issue in the Esmeraldas, Manabi, and Guayas provinces.

FUTURE WORK

Book

The work described in this project is presently in various forms of peer review publication as described below. It is proposed that these works be collectively published in a book in Spanish for distribution throughout Ecuador and Latin America. Preliminary discussions for such document has been proposed to Fundacion Natura a couple of years ago. The distribution of this ecological work needs to be accompanied with the management issues of coastal Ecuador. The outline of the proposed book follows with an indication of the present progress of each chapter (article). The proposed title of the book is 'Ecosystem Analysis of the Guayas River Estuary: Significance of Mangroves to Sustaining Fisheries and Controlling Water Quality in Coastal Ecuador'.

ECOSYSTEM ANALYSIS OF THE GUAYAS RIVER ESTUARY: SIGNIFICANCE OF MANGROVES TO SUSTAINING FISHERIES AND CONTROLLING WATER QUALITY IN COASTAL ECUADOR

edited by
Robert R. Twilley and Alejandro Bodero

Chapter One:	Properties of mangrove ecosystems related to the energy signature of coastal environments. Twilley, R.R. **in press.** IN: C.A.S. Hall, (ed.), Maximum Power. University of North Carolina, Chapel Hill.
Chapter Two:	The productivity and nutrient cycling of mangrove ecosystems. Twilley, R.R. and J. W. Day, Jr. **in press.** In: A. Yáñez-Arancibia (ed.), Management and Research of Mangrove Ecosystems.
Chapter Three:	Environmental Quality of Coastal Systems in Ecuador: Implications for the Sustainability of Shrimp Mariculture. Twilley, R.R., M.M. Armijos, and J. M. Valdivieso. **in press.** In: A. Yáñez-Arancibia (ed.), Management and Research of Mangrove Ecosystems.
Chapter Four	Litter Dynamics in Riverine Mangrove Forests in the Churute Ecological Preserve, Ecuador. Twilley, R.R., M. Pozo, V. Garcia, A. Bodero, V. Rivera-Monroy, R. Zambrano, and N. Gaibor. **final preparation.** Estuaries.
Chapter Five	Comparison of Sedimentation and Nutrient Accumulation in Mangrove Ecosystems. Twilley, R.R., J.C. Lynch, V. Garcia, N. Gaibor, R. Zambrano, and B. McKee. **final preparation.** Limnology and Oceanography.
Chapter Six.	Biomass, Phenology and Regeneration of Mangrove Forests in Churute Ecological Preserve, Ecuador. Zambrano, R., G. Tazán, K. Loor, A. Bodero, and V. Rivera-Monroy. **in preparation.** Biotropica.
Chapter Seven	Denitrification and Nitrogen Fixation in Riverine Mangroves in the Churute Ecological Preserve, Ecuador. Rivera-Monroy, V., N. Gaibor, and R.R. Twilley. **in preparation.** Biogeochemistry.

Chapter Eight:	Seasonal Patterns of Nutrient Dynamics in a Tropical Estuary in Ecuador. Twilley, R.R., W. Cardenas, J. Espinoza, and L. Solorzano. **in preparation.** Marine Ecology Progress Series.
Chapter Nine:	Utilization of Mangroves as Habitat in the Guayas River Estuary, Ecuador. Zimmerman, R., R. Garcia, N. Gaibor, and R.R. Twilley. **in preparation.**
Chapter Ten:	Utilization of Mangrove Detritus in Food Webs of the Guayas River Estuary, Ecuador. Twilley, R.R., N. Gaibor, R. Garcia, W. Cardenas, J. Espinoza, L. Cifuentes. **in preparation.** Limnology and Oceanography.
Chapter Eleven:	Patterns of Phytoplankton Distribution and Abundance in Guayas River Estuary, Ecuador. Cardenas, W., J. Espinoza, L. Solarzano, and R.R. Twilley. **in preparation.** Marine Ecology Progress Series.
Chapter Twelve	Isotopic and Elemental Variations of Carbon and Nitrogen in a Mangrove Estuary. Cifuentes, L.A., R.B. Coffin, R.R. Twilley and L. Solarzano. **submitted.** Limnology and Oceanography
Chapter Thirteen	Mangrove Ecosystem Biodiversity and Conservation: Case Study of Mangrove Resources in Ecuador. Twilley, R.R., A. Bodero, D. Robadue. **in press.** In: J. Cohen and C. Potter (eds.), Case studies of genetic resource conservation in natural habitats: Biological and Socioeconomic Dimensions. AAAS Publishers.
Chapter Fourteen:	Ecology and Management of Mangrove Ecosystems in Ecuador. Twilley, R.R. **in press.** In: A. Yáñez-Arancibia (ed.), Management and Research of Mangrove Ecosystems.

Training

Academic fellowships are needed for students interested in ecology and management of coastal resources of Ecuador. Specific funding is needed to complete the statistical analyses of data that were collected during this mangrove study. This is the present limiting factor to getting the results published in peer review journals. Several of these chapters could be post baccalaureate training for students on data analyses and writing skills that are critically needed within the scientific community in Guayaquil. The proposed book would be the focus of these activities including publishing the works in Spanish, and presentation of results to groups in Ecuador. Seldom is data analyses and publication adequately funded in research projects. And for international studies it is very important that there exists resources to involve in country collaborators the training to participate in this part of the study. This is critically needed to protect the initial progress and investment in this study of mangrove resources in Ecuador.

Ecological Analyses

There are additional analyses of ecological materials that are needed to complete specific components of this ecosystem study. Most of the funding for this project went into labor and field logistics to collect samples. The analytical costs of this study were underestimated and supplemented with other research projects in Ecuador (eg. at INP) and USA. A good example of this is the budgeting for radionuclide and natural isotope abundance analyses. Priority was placed within the existing budget on assay of lead-210 samples for estimates of mangrove sedimentation rates. Second, natural abundance was determined on food web samples in the mangroves and during an intense study of a tidal creek to test the validity of these methods to analyze utilization of mangrove detritus in tropical estuaries. One particular area of the project that needs further

assistance is the natural abundance of isotopes in samples of the estuarine food webs. Samples were collected during the estuary survey on various components of the food web throughout the year. Carbon, nitrogen and sulfur assays are needed on these samples to separate out the mangrove signature in the estuarine food web.

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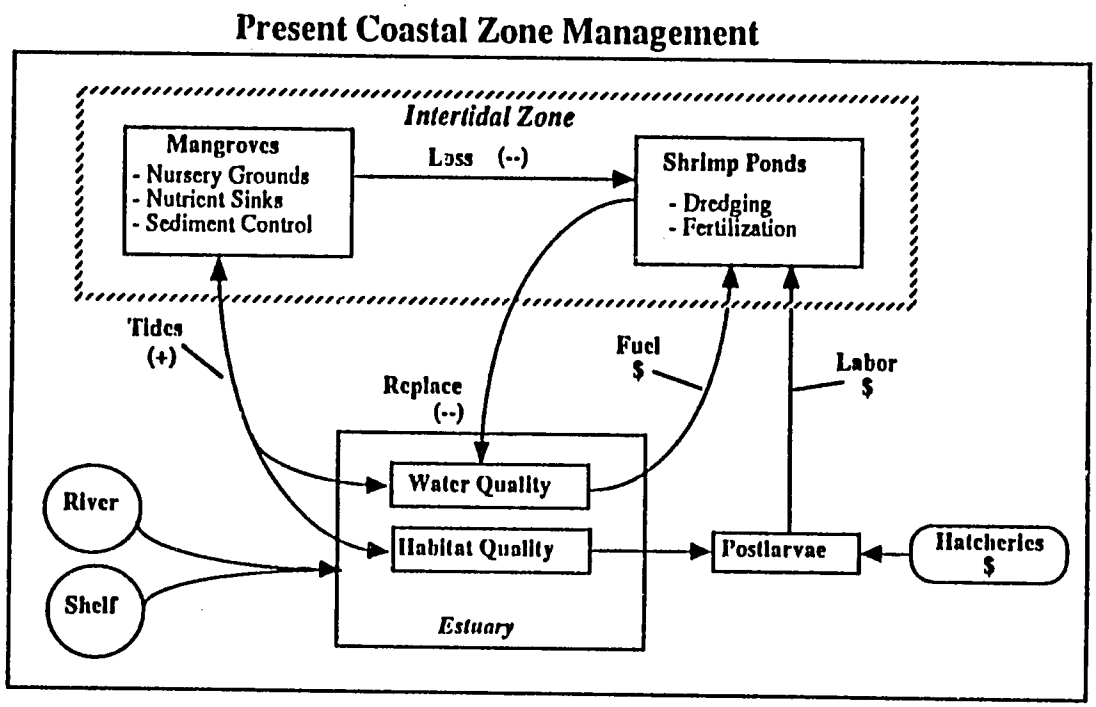

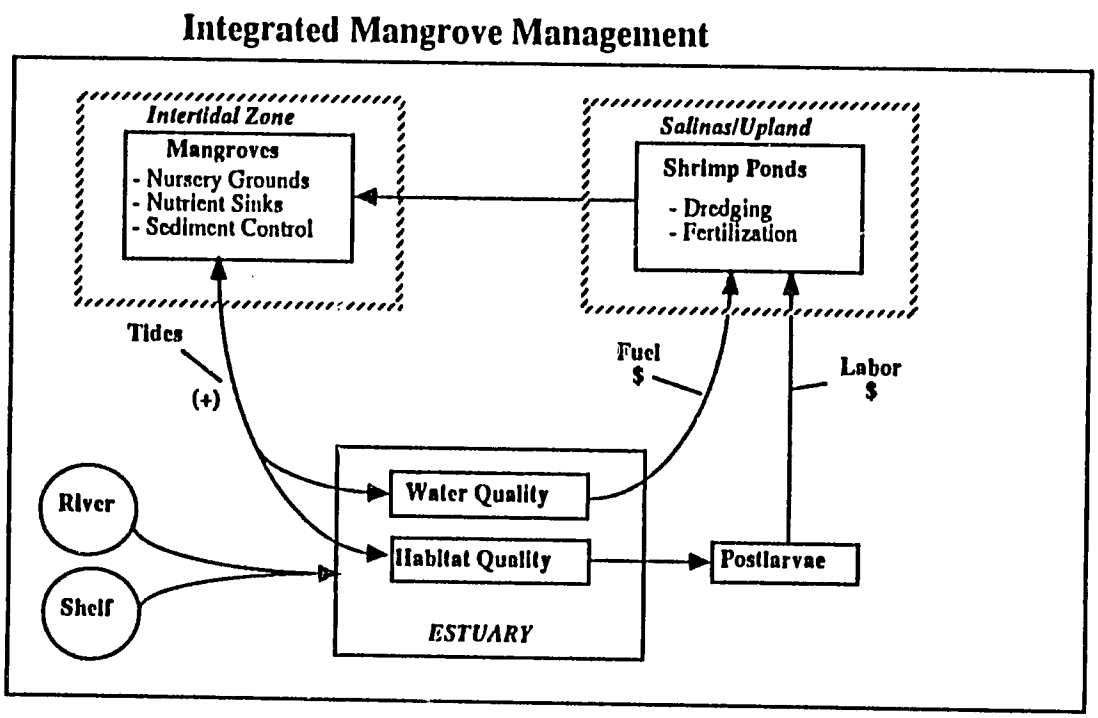

Figure 28. Comparison of present practices in coastal zone management (upper panel) with recommended strategies for integrated mangrove management based on the ecological function of mangroves in the coastal zone (lower panel).

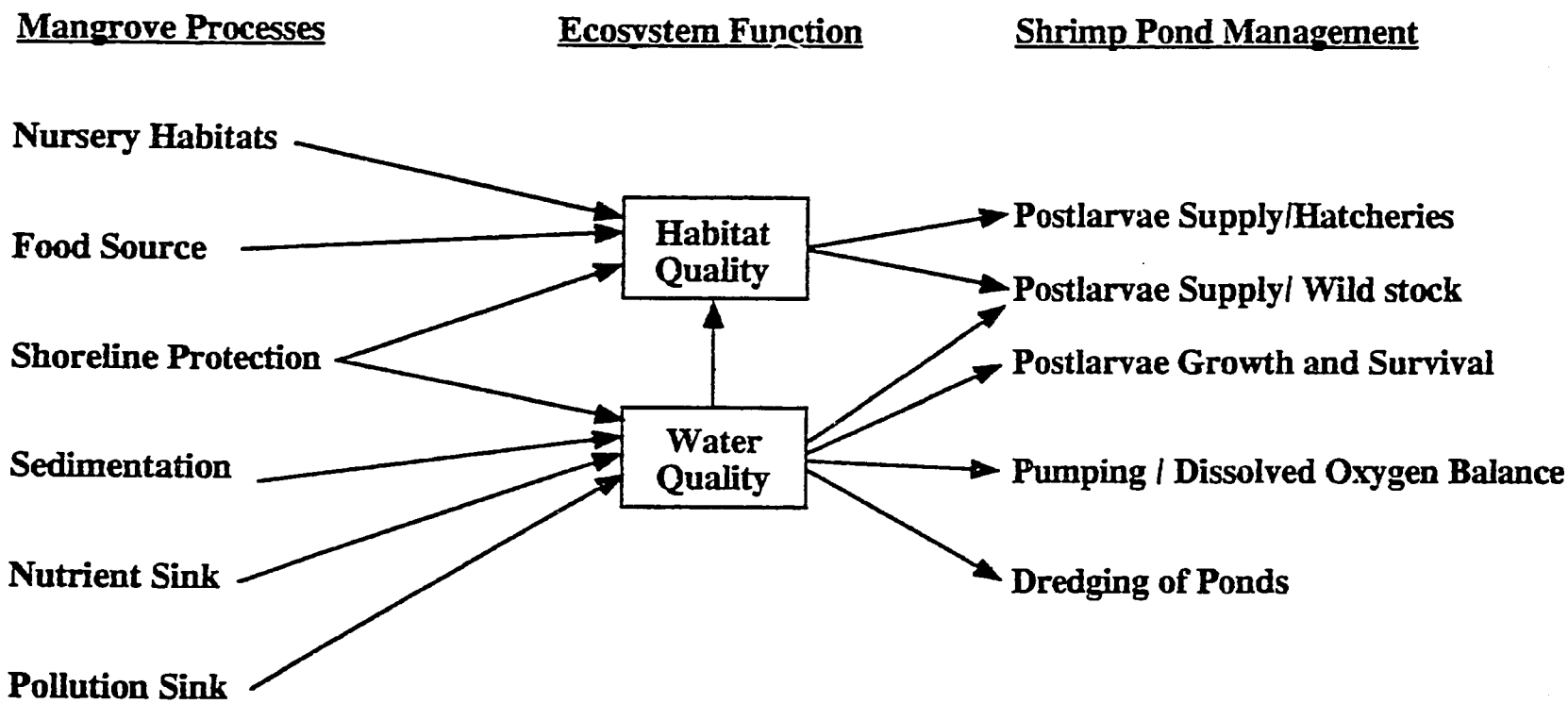

Figure 27. The linkage in mangrove processes with ecosystem function and the processes of shrimp pond management.