COASTS

Coastal Publication No. 3

Renewable Resources Information Series

JOHN R. CLARK, Editor
RESEARCH PLANNING INSTITUTE, INC.

In cooperation with NATIONAL PARK SERVICE — USDI, and U.S. AGENCY FOR INTERNATIONAL DEVELOPMENT

Renewable Resources Information Series
Coastal Management Publication No. 3

COASTAL RESOURCES MANAGEMENT: DEVELOPMENT CASE STUDIES

JOHN R. CLARK, Editor
National Park Service
Washington, D.C.

Prepared by
Research Planning Institute, Inc.
Columbia, South Carolina

for

NATIONAL PARK SERVICE
U.S. Department of the Interior
and
U.S. Agency for International Development

March 1985

The opinions, findings, conclusions, or recommendations expressed in this report are those of the authors and do not necessarily reflect the official view of the National Park Service or Agency for International Development.

Coastal resources management.

(Renewable resources information series. Coastal management publication; No. 3.)
"Prepared by Research Planning Institute, Inc., Columbia, South Carolina, for National Park Service, U.S. Department of the Interior, and U.S. Agency for International Development."
"March 1985."

Includes bibliographies.
1) Coastal zone management--Developing countries--Case studies.
2) Shore protection--Developing countries--Case studies.
3) Coastal engineering--Developing countries--Case studies.

I. Clark, John R., 1927-
II. Research Planning Institute (Columbia, S.C.)
III. United States. National Park Service.
IV. United States. Agency for International Development.
V. Series.

HT395.D44C63 1985 333.91'7'091724 85-60819
ISBN 0-931531-02-0 (pbk.)

Available from: Research Planning Institute, Inc.
925 Gervais Street
Columbia, SC, USA 29201

FOREWORD

Most countries recognize their coastal zones as distinct regions with resources that require special attention. Many have taken specific actions to conserve coastal resources and to manage coastal development. A few have created comprehensive nationwide coastal zone management programs that are fully integrated with other resource conservation and economic sector programs. There is a current trend to move toward more comprehensive and integrated coastal programs. But comprehensive programs must, nevertheless, be organized to address specific development projects and specific conservation needs in a real world context. This context can best be understood from real experience, as illustrated in the collected case studies presented in this book. While every type of coastal development is not illustrated, the authors of the various case studies have done an excellent job in reporting on fisheries, aquaculture, upland and river development, beach erosion, islands, marine mining, and mangrove conversion and providing guidance for managing future development projects that affect coastal resources.

This casebook is one in a series of publications being produced for the Agency for International Development (AID) by the National Park Service (NPS). It's purpose is to provide expert guidance in planning and management for sustainable coastal development and for the conservation of coastal resources. In addition to this book, compiled by the Research Planning Institute (Contract No. CX-0001-3-0050), the coastal series includes a comprehensive coastal development guidebook, a report on institutional arrangements for coastal resources management, and a condensed design aids booklet.

This coastal series is part of a wider publication and training partnership between AID and NPS under the "Natural Resources Expanded Information Base" project commenced in 1980 in response to a worldwide need for improved approaches to integrated regional planning and project design. The project is producing publications on arid and semi-arid rangelands and humid tropic systems as well as on coastal zones. The publications and training components are dedicated to strengthening the technical and institutional capabilities of developing countries in natural resources and environmental protection and to providing other international development assistance donors with ready access to practical information.

In a world of rapid population growth and diminishing natural resources, countries that fail to plan their economic development strategy in concert with resource conservation and environmental management may not be able to sustain progress in health, food, housing, energy, and other critical national needs. Each developing country needs to have a realistic plan for accomodating its share of the 100 million people per year being added to the world's population. Such basic resources as fuel, water, fertile land, and fish stocks are already in short supply in many countries and their future prospects are in grave doubt.

While the presence of integrated planning and comprehensive management alone may not assure a sustained and ample yield from the coastal natural resources of any country, its absence will lead to their depletion. The opportunities for development based on excessive exploitation of coastal natural resources are rapidly fading. The future depends on development closely linked to resource conservation. In the coastal zone, the need for an enlightened approach is urgent.

In producing the coastal publication series for AID we realize that we have, at best, provided a foothold for natural resources aspects of the new and rapidly expanding field of coastal resources management. Much important work lies ahead in many of the technical areas. We particularly recognize the need to provide specific natural resources working materials for regional planners and economic development planners. Also, there is a need for advice on protection of life and property against storms and other coastal natural hazards. Equally important is advice to planners on the role for designated protected areas--reserves, parks, sanctuaries--in tourism enhancement, fish stock management, and critical area and species conservation. We hope the present series will provide a springboard for studies on these important matters.

Hugh Bell Muller and Jeffrey Tschirley directed the implementation of the "Expanded Information Base" project and John Clark managed the coastal components. We thank AID for supporting the project. We are especially grateful to Mr. William Feldman, and Ms. Molly Kux, and Mr. William D. Roseborough of the Office of Forestry, Environment, and Natural Resources of the Bureau of Science and Technology, for their continuing encouragement and their patience.

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Case Study One

MARICULTURE DEVELOPMENT IN MANGROVES: A CASE STUDY OF THE PHILIPPINES, ECUADOR AND PANAMA

Scott E. Siddall, Joseph A. Atchue, III,

and Robert L. Murray, Jr.

SUMMARY

The purpose of this project was to investigate how the Philippines, Ecuador and Panama deal with the problem of balancing mariculture expansion with the protection of mangrove resources. These countries were visited during July and August of 1983. During the visits literature and data were obtained which were not readily available in the U.S. and interviews were conducted with officials involved in resource management and aquaculture, with mariculturists and with others involved in exploitation of the resource, such as coastal fishermen and fry gatherers. All of the countries evidenced some understanding of the need to protect the mangrove resource, and had administrative structures to protect it, but in the Philippines and Ecuador pressure to remove mangroves was high. It appears that all three countries would benefit from a more intensive approach to mariculture. Guidelines with regard to mariculture development and mangrove conservation are presented.

1. INTRODUCTION

In several areas of the world, valuable and ecologically sensitive coastal habitats--mangrove swamps--are being destroyed in the construction of ponds used to rear fish and shrimp. The objective of this case study is to summarize existing information and document current trends in mangrove management and development. Before intelligent discussion can proceed, several definitions of concepts are required.

Aquaculture is a general term describing man's efforts to manipulate natural cycles of aquatic organisms in order to enhance production of aquatic resources for his benefit. Approximately 15% of the 60-million-metric-ton world fishing harvest is derived from aquaculture. Mariculture, actually a subset of aquaculture, is a more specific term referring to the manipulation of marine plants and animals for man's benefit. This case study concerns mariculture developments in coastal and estuarine habitats where mangroves are found.

The scale of mariculture ranges from subtle manipulations of unconfined, natural populations to technologically oriented, highly controlled production of plants or animals in artificial environments. Typically, intensive mariculture systems have higher yields of product per unit space, but the greater yields require more money, more energy and more technology. Intensive mariculture does not, however, require a great deal of space. Less intensive systems achieve profitable yields by virtue of being extensive in area. While many costs are reduced, space requirements are much greater. Yields per unit area are lower, but this is offset by having more extensive areas under production.

These comparisons are not unique to mariculture, but they are an important aspect of this study (Table 1).

Table 1. Tradeoffs for intensive vs. extensive mariculture.

Mariculture Approach	Yield Per Unit Area	Costs in Money, Energy	Technology	Space Requirement
Intensive	High	High	High	Low
Extensive	Low	Low	Low	High

Therefore, to a greater or lesser degree, extensive and intensive mariculture require space. The space required for an extensive system may be reduced if the operation is "intensified." Intensification of a mariculture system achieves greater yields of fish or shrimp per unit area by increasing material and labor input (fertilizers, locally available supplemental foods, greater water flow, more advanced handling methods).

Selection of a location for any mariculture operation is the most important determinant of the operation's potential for success. From the mariculturist's viewpoint, the most appropriate sites are those nearest the natural habitat of the species being cultured, in this case, fish or shrimp. Coastal sites within or near the mangrove forests provide sources of clean seawater and abundant stocks of juveniles which may be collected and reared to market size.

Mangroves, of which there are at least 55 species, are tropical hardwoods adapted for growth in marine intertidal, estuarine, river and other coastal habitats. Mangrove swamps receive nutrients from tidal flushing and river runoff. Their adaptation to these habitats results in very rapid growth. Thriving in unstable coastal environments, mangrove forests are subject to destruction by natural forces -- hurricanes, diversion of freshwater runoff, and shifts in patterns of tidal flushing. Different species of mangrove grow in different areas depending upon salinity, tides and soil types. Mangroves are generally categorized as fringe, riverine, overwash and basin forests (Lugo and Snedaker, 1974).

The productivity of mangrove swamps is well known with litter production ranging from 3.6 to 9.7 metric tons per ha (Golley et al., 1962; Heald, 1971; Lugo and Snedaker, 1974; Christensen, 1978; Aksornkoae and Khemnark, 1980; Goulter and Allaway, 1980; Steinke, 1980). Leaf litter undergoes microbial transformations which causes an increase in the amount of protein available (Odum and Heald, 1975) thus making the litter a prime food source for both juvenile and larval fish or crustaceans (Odum and Heald, 1972; Prince Jeyaseelan and Krishnamurthy, 1980; Macnae, 1974; Martosubroto and Naamin, 1977; Daugherty, 1975). An excellent review of the importance of mangroves to fisheries and aquaculture has recently been written by MacIntosh (1983). In it he suggests that half of the productivity of mangrove swamps ends up being transported to the waters adjacent to the swamps where it is utilized by the nearshore fish and crustacean communities.

This dependence of economically important species on intact and productive mangrove systems further complicates the issues of coastal mariculture development. While incontrovertible scientific data illustrating links between mangroves and coastal productivity does not exist, it is clear that the existence of many natural fish and shrimp stocks is related to mangrove production. The basis for productivity in mangroves, coastal waters and mariculture ponds are all part of the same ecosystem; alterations to any component of the system may lead to changes in others.

Specifically, mariculture operations remove postlarvae and juvenile fish and shrimp from the mangrove ecosystem for rearing in ponds sited nearby. However, larvae of other commercially exploited species also depend upon the mangrove swamps for refuge and development. While the removal of larvae and juveniles is targeted at specific species of fish and shrimp, other species are either directly or indirectly affected. Conclusive data on the effects of large-scale harvests of juveniles on coastal productivity (landings in traditional and nearshore catch fisheries, in particular) are wanting. Motoh (1981) has pointed out that many shrimp fry collectors discard less desirable fry rather than replacing them in the water. Futhermore, in many areas grow-out ponds have been placed directly in mangroves which have been clearcut and excavated. These grow-out ponds generally range in size from 1 to 20 ha and are used to grow juvenile fish and shrimp to marketable size. Where extensive areas of mangroves have been removed for mariculture operations, landings in adjacent catch fisheries appear to have declined, but again there is little evidence to "prove" these as cause and effect relationships.

Based on these concepts, we can refine the definition of this study's objectives:

1) To describe economic pressures which promote extensive mariculture developments in and around environmentally sensitive and important mangrove ecosystems.
2) To summarize estimates of the rate at which mangrove areas are being destroyed for sites of fish and shrimp production ponds.
3) To describe the short- and long-term costs and benefits of such development.
4) To integrate this information into guidelines to promote the economic benefits of mariculture production while conserving mangroves. Three countries were chosen for this study: The Philippines, with a long history of extensive mariculture of milkfish (Chanos chanos), Ecuador, where cultured shrimp (principally Penaeus vannamei) has become the second most important export product of the nation, and Panama, where recent development of extensive shrimp culture has succeeded.

The methods used in this study are detailed in Appendix I. Two Two University of Miami researchers with extensive experience in Philippine milkfish culture (J. A. Atchue, III) and Panamanian shrimp operations (R. L. Murray, Jr.) traveled to these countries to conduct interviews, collect data and update earlier information. Mr. Murray also traveled briefly to Ecuador; his new material is supplemented by contributions to the study by Dr. Joshua Dickinson (Gainesville, Florida). Dr. Bruce Austin (South Atlantic Fisheries Management Council) performed the economic evaluations. Discussion of the findings and analyses will follow geographical and historical descriptions of mariculture development and mangrove management in the three nations.

Collation of new and existing data made apparent a number of lessons learned in each of the case study nations. Critical analysis of these lessons in terms of resource management, mariculture production and the political and economic needs of developing coastal nations led to the formation of more generic or global guidelines addressing mariculture development in tropical coastal habitats.

The work presented here was supported by the National Park Service (NPS) (contract CX-001-3-49). We wish to thank the following people for their assistance: J. Clark, S. McCreary, NPS; M. Kux, I. Asher, M. Hatziolas, U.S. Agency for International Development (USAID); J. Dickinson, Environmental Management; B. Austin, South Atlantic Fishery Management Council; R. Edwards, S. Berkley, S. Snedaker, S. Hersh (drafting) and K. Seykora (typing), Rosenstiel School of Marine and Atmospheric Science (RSMAS). Supplemental funding was supplied by Dean Alan Berman, RSMAS. Finally, several anonymous reviewers were also very helpful.

2. GEOGRAPHIC COMPARISONS

The Philippines is an archipelago of more that 7,000 islands formed by a combination of tectonic and reef-building processes. The four climate types covered throughout the Philippines are all dominated to one extent or another by monsoons. Additionally, Luzon is hit by several typhoons each year. Both Panama and Ecuador are much closer to the equator than the Philippines and their climates are truly tropical. Ecuador, with 284,000 square km, is not much smaller than the Philippines (294,000 square km), while Panama (83,000 square km) is the smallest nation in the study. The population density of the Philippines (163 people per square km) is however more than seven times greater than that of either Ecuador (29 people per square km) or Panama (24 people per square km). The populations of all three nations are growing. The Philippines leads with a 3% increase per year.

The relationship between extent of coastline to the total area, is different for each country. The Philippines has more that 18,000 km of coastline by virtue of being an island nation; Ecuador has less that 700 km of shore. Panama's Pacific coast is approximately 1,200 km long.

Although a large number of mangrove species are found in the Philippines, the coastlines are dominated by *Rhizophora apiculata*,

R. mucronata and Avicennia marina (Chapman, 1974). The coasts of both Ecuador and Panama are dominated by Rhizophora mangle, R. brevistyla, Avicennia marina and Laguncularia racemosa (Chapman, 1974; Garibaldi, 1982).

For purposes of this case study, Ecuador and Panama have common features of geographical importance, while the Philippines represent a different suite of characteristics. This offers the study opportunity for comparisons and contrasts.

3. HISTORY OF DEVELOPMENT

3.1 Philippines

Mariculture in coastal areas of the Philippines has a long history, perhaps as long as 500 years. The earliest recorded fishpond was established in 1863 in Rizal Province (Census of the Philippines, 1921). For the most part coastal mariculture relied on natural embayments which could be easily blocked for control of water flow. Little if any pond construction went on, and other than the actual harvest, management was not practiced.

By the beginning of this century, mariculture practices had changed. Although by today's standard, Philippine mariculture of 80 years ago could not be called intensive, there was nevertheless a much larger input of money and other resources. One of the major changes was a movement away from the use of natural embayments to construction of ponds for producing milkfish. Such pond-based mariculture demands more management input than does casual stocking of embayments.

For the first half of this century, most mariculture production was centered in embayments in and adjacent to mangrove swamps. Initially, preferred sites for the new ponds were also in the mangrove habitat. Although accurate records do not exist, we conservatively estimate that, prior to the early 1950's, not more than 85,000 ha of mangroves were removed for fishpond development.

After the 1950's, mariculture production was perceived, by both the government and the fishing industry, as an important adjunct to the catch fisheries in the Philippines. Additionally, prices demanded by milkfish (the principal product of Philippine mariculture throughout this century)

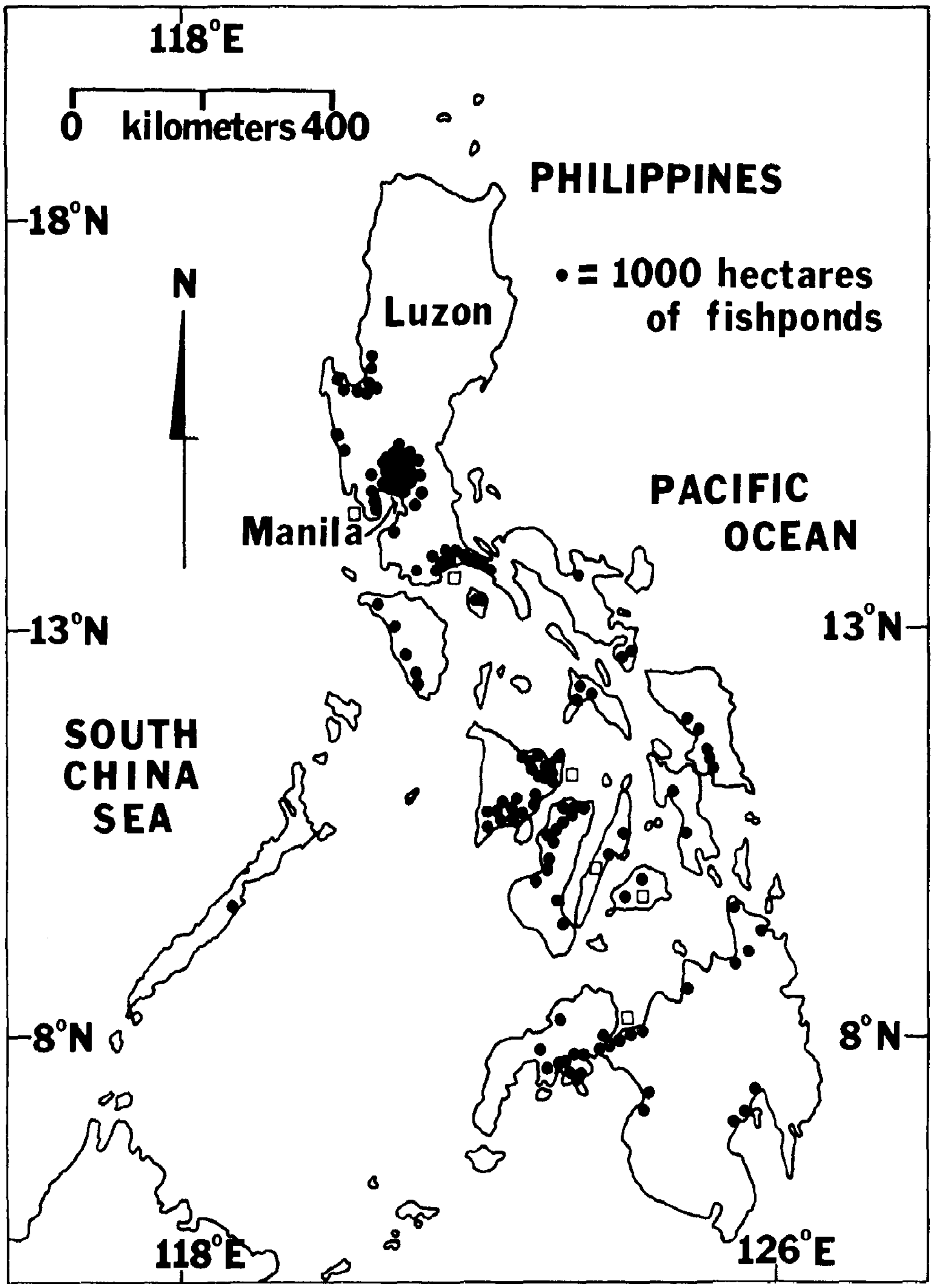

Figure 1. Map of the Philippines showing areas of fishpond concentration (redrawn from Oshima, 1973).

Figure 2. This complex of fishponds has grown up over the past 7 years in Cebu province (Philippines). The ponds are leased by a number of private investors. Note canal, at lower left, for inlet of water. Their average area is 5-10 ha. Unlike Ecuadorian and Panamanian facilities, Philippine fishponds rely almost entirely on tidal flushing (photo by J. Atchue).

were making investment in the industry more attractive. As an example, five towns in Pangasinan Province had a total of 940 ha of fishponds in 1953, but by 1976, the total area was 3,940 ha with a probable increase of several hundred hectares since that time (M. Rice, pers. comm.). This pattern is typical throughout the Philippines. A large number of small to medium scale entrepreneurs, mostly from the middle and upper-middle class, have continued to build fishponds almost exclusively at the expense of mangrove resources. The fishpond industry in some regions though (e.g., Iloilo) is operated for the most part by wealthy individuals (Oshima, 1973). Figure 2 shows a concentration of fishponds in Cebu, while Figure 1 shows current mariculture operations in the Philippines.

Apparently, there was little motivation to regulate mariculture development until the early 1950's when what is now the Bureau of Fisheries and Aquatic Resources (BFAR) was formed. Through the early 1970's, clearance from the Bureau of Forestry Development (BFD) and a Fish Pond Permit were all that was needed to convert an area of mangrove into fishpond. The granting of these clearances and permits were in essence pro forma.

With the advent of martial law in 1972, mangrove swamps passed from private ownership to public trust (Presidential Decree 704) administered jointly by BFD and BFAR. People who owned fishponds at the time of the decree were encouraged to apply for Fishpond Lease Agreements (initially of 10-years' term but later increased to 25 years). The granting of these agreements (FLA's) became more restricted primarily because most new fishponds were built with money from the Development Bank of the Philippines (DBP). However, at this time the official policy of BFAR is still the continued expansion of fishpond area.

These policies encouraging extensive mariculture development promulgated by BFAR appear to have been caused by two factors. The first was the genuine belief that mangrove swamps served little function in Philippine coastal fisheries production. The second factor was the 23.6 million dollars made available by the International Bank for Reconstruction and Development specifically for fishpond production. Very few developing countries can afford to turn down large sums of international development money and the Philippines has not been an exception. Responsibility for loss of mangrove swamps can be attributed at least partially to economic assistance from the Western world.

By the mid-1970's when more than 170,000 ha of mangroves had been removed for mariculture development, a number of scientists, both in the Philippines and abroad, had begun to voice concern about the loss of the resource. Since research in mangrove ecosystems was in its infancy, there was little evidence to present to the government, only a growing uneasiness that a problem was developing. Figure 3 C shows the expansion of fishpond areas during the twentieth century with respect to the 1967 estimate of mangrove area, while Figure 4 shows yields of fishpond production since 1952. Based on these estimates, fishponds now occupy approximately 45% of the original mangrove forests.

There is considerable variability in the field data on which these estimates are based, however, and not all mangrove conversions or alterations may be attributed to mariculture development. Other very important uses of mangroves include clearcut logging principally for charcoal production and also for construction purposes. Sustained-yield management of mangrove forests for lumber production is not widely practiced in any of the case-study nations, yet successful models of such management do exist in Asia (Matang Mangrove Forest Reserve, Peninsular Malaysia; Ong, 1983).

The government did respond to mounting concerns by forming the Land Classification Teams (LCT's, under Special Order No. 3). These LCT's function through regional government agencies and are composed of personnel from BFAR, BFD and the Bureau of Lands. Their purpose is to certify which areas of mangrove swamps may be utilized for fishpond construction, lumbering activities or conservation purposes. In their early actions, the LCT's did little to change the tendencies of governmental policies to support extensive mariculture. However, after Presidential Decrees 2151 and 2152, they adopted a more conservation-oriented approach.

The Ministry of Natural Resources, of which BFAR and BFD are agencies, is under direct order of the President to accelerate the rate at which mangrove areas are declared either refuges or conservation areas (Deputy

(A)

(B)

(C)

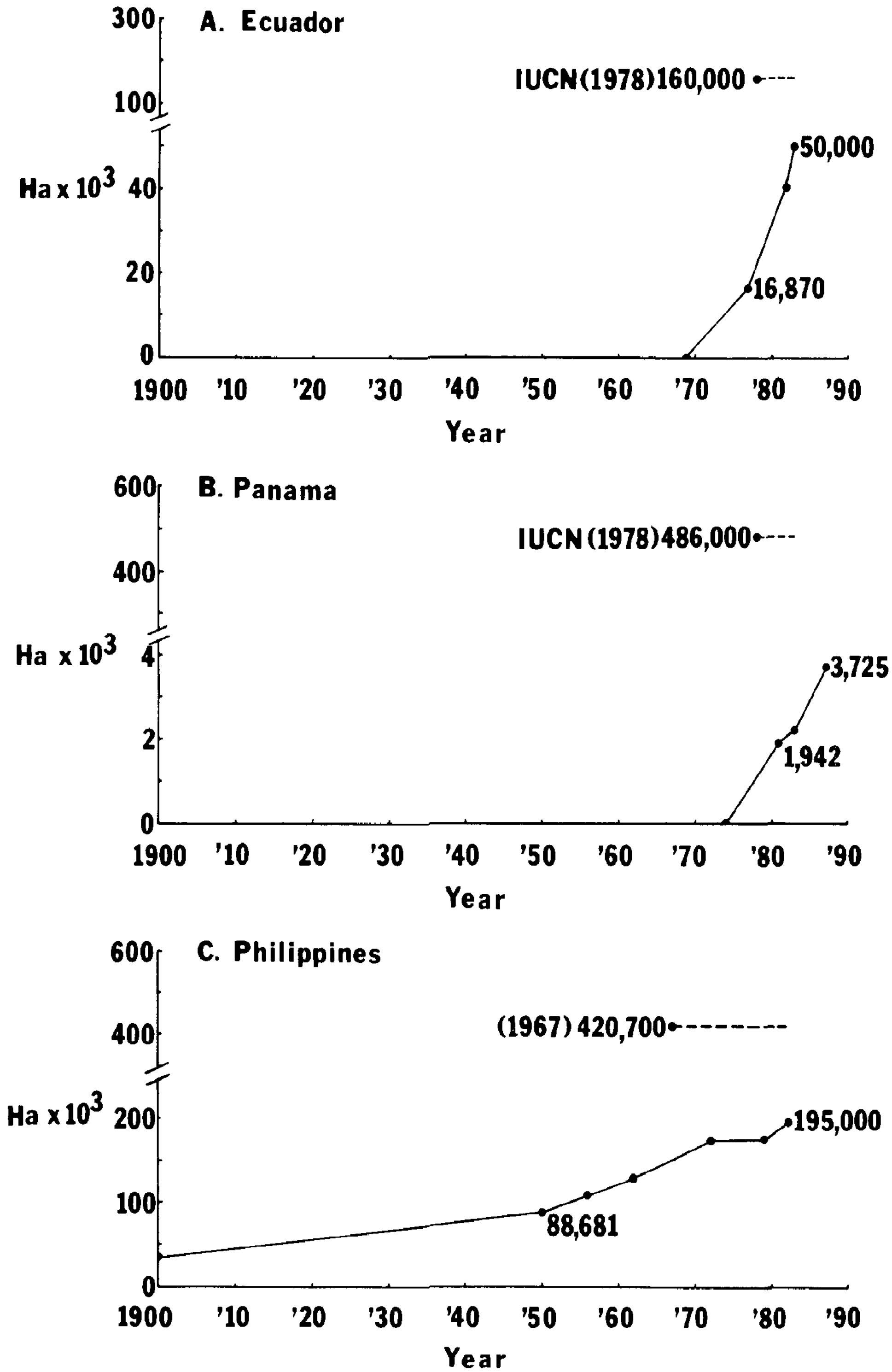

Figure 3. This graph shows the relative amounts of fish or shrimp pond areas in each country. The upper lines represent various estimates of the areal extent of mangroves. Note horizontal scale adjustments.

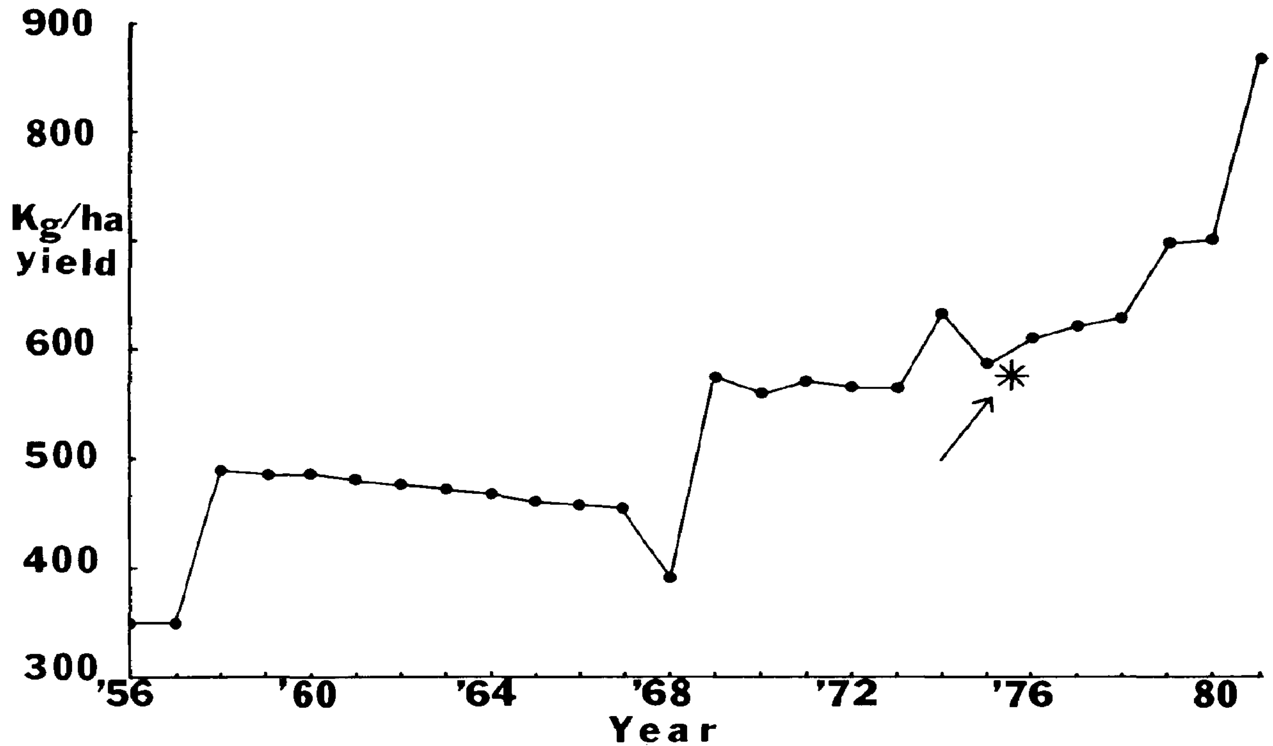

Figure 4. This figure shows the yield of milkfish in the Philippines. The relatively large increase since 1979 shows that high-quality extension services can increase pond yields. (*The Bureau claimed that no fishpond development took place between 1975 and 1981. We felt it was more realistic to assume an increase of approximately 2,300 ha per year for that period rather than the 19,000 reported between 1981 and 1982. This leads to a difference between our yield figures and those published by BFAR in their Fisheries Statistics for 1982). (Source: Fisheries Statistics of the Philippines, 1981).

Minister Caoili, pers. comm.). Through Presidential Decrees 704 (Forestry Reform Code), the emphasis of policies of the Ministry is to concentrate on increasing yields of existing ponds rather than the creation of new ones. Additionally, Presidential Decree 950 was intended to promote conservation by requiring the holder of any fishpond lease to plant or leave untouched a 20-meter border of mangroves around ponds, and to leave intact larger borders of mangroves adjacent to rivers or the sea (PD 705). The value of the narrow borders as tools in management of the mangrove resource is questionable. They do partially protect pond constructions and adjacent areas from storm damage, but they almost certainly do not function either biologically or economically as intact mangrove swamps. The size at which these these borders might actually fill the role of intact swamps has not been determined.

BFAR requires potential fishpond lessees to complete a project feasibility study on development of the area and projected fishpond productivity. Current 25-year leases may be renewed for an additional 25 years and require the leasee to develop at least 50% of the pond to commercial scale in five years. The remainder must be developed to commercial scale within another five years or undeveloped leased areas automatically revert back to the Bureau for disposition. Abandoned ponds also revert to BFAR for reassignment.

The National Mangrove Committee (NMC) of the Natural Resources Management Center (NRMC) was also established in 1976 (Special Order 309). Both levels of this organization are attempting to halt fishpond construction, at least until better data are available on the interactions and dependencies of mangrove swamps and coastal productivity. This type of supportive data is now being gathered principally by the University of the Philippines and the Forestry Research Institute (FORI), at a research station for mangrove ecosystems which was established in the mid-1970's in Quezon Province. The National Mangrove Committee has developed guidelines for selecting mangrove areas for conservation or preservation (see Appendix II).

The coastal zone management plan of the Philippines as described by Zamora (1979) has as its objectives to assess the status and use of coastal resources, formulate a master plan for use and conservation, initiate projects for best use of coastal resources, and recommend policies to the National Environmental Protection Council (NEPC). The coastal zone task force is comprised of 22 government agencies. The World Bank has sponsored a coastal zone management program in the Central Visayas for implementation in 1984 which will attempt to promote use of mangrove swamps as renewable, multi-use resources rather than as objects of one-time-only resource mining. USAID is also addressing coastal zone management through its Rainfed Resources Project. The latter project is attempting to link uplands, coastal plains and coastal fisheries in a comprehensive program which addresses specific problems in each area.

The current interest in mangrove conservation notwithstanding, there are still many issues to resolve. The major threat to mangrove conservation lies at the provincial and regional levels where the number of staff is limited while the number of tasks, in addition to monitoring mangrove usage, is great. As a result, opportunities for mangrove resource management are often lost.

3.2 Ecuador

The Incas farmed shrimp in Ecuador as long as 400 years ago by closing off lagoons temporarily flooded with seawater and penaeid shrimp larvae (Shayne, pers. com.). Modern shrimp farming began in 1962 by accident when high tides destroyed a levee around a coconut plantation, flooding the area with shrimp-laden seawater. By the time repairs were made, the shrimp postlarvae had grown to market size (Hirono, 1983). The first commercial operations began in 1969; heavy investment in shrimp pond operations began in 1977 after some of the early farms were proven to be economically sound. The 1982 shrimp harvest from ponds accounted for 44% of Ecuador's fish product exports, making fish the second most important export of the nation after petroleum. Such large-scale development of the Ecuadorian shrimp farming industry has provided as many as 19,000 new jobs by some estimates.

The impact of pond production can be seen in Tables 2 and 3 which show the relatively large increases in shrimp exported by Ecuador to the U.S.

Table 2. Shrimp exports to the United States from Ecuador, Panama and Mexico (1977-1982) in millions of pounds.

	1977	1978	1979	1980	1981	1982	% Change 1977-1982
Ecuador	8.61	10.95	13.70	20.19	24.73	36.12	320%
Panama	10.07	9.15	12.20	13.73	15.92	17.62	75%
Mexico	76.25	72.45	71.89	76.06	70.87	80.17	5%

Table 3. Value of shrimp exports to the United States from Ecuador, Panama and Mexico (1977-1982) in millions of dollars.

	1977	1978	1979	1980	1981	1982	% Change 1977-1982
Ecuador	24.00	30.03	54.48	68.08	80.30	136.51	+469%
Panama	27.55	27.54	49.80	46.20	55.41	61.22	+122%
Mexico	187.92	170.49	294.61	316.84	290.31	374.73	+99%

(Source: Current fishery statistics series, fisheries of the United States, U.S. Dept. of Commerce, NOAA National Marine Fisheries Service.)

Although the preferred sites for ponds are salt flats (salitralis or albinas, in Spanish) devoid of vegetation, estimates of the removal of mangroves for ponds from Ecuador's total mangrove resource of approximately 200,000 ha range from 5% (National Fisheries Institute, J. Dickinson, pers. comm.) to 29% (based on a study of aerial photographs from 1966, 1977 and 1982 of 8,500 ha in the Machala area, CLIRSEN, 1983). Samuel Bellentini, a shrimp producer in Manabi, estimated that 50% of the mangroves in the Bahia de Caraquez have been lost to shrimp ponds (FAO Mangrove Symposium, Guayaquil, July 1983). Figure 3 A depicts this rapid increase in total area of shrimp ponds relative to estimates of the mangrove resource, while Figure 5 shows the extent of mangroves in the country. As in the Philippines and Panama, mangroves are exploited by users other than in shrimp mariculture. Charcoal production and logging for construction timbers are important economic activities which remove mangrove forests.

Estimates of areal extent of Ecuador's mangroves vary from 160,000 ha

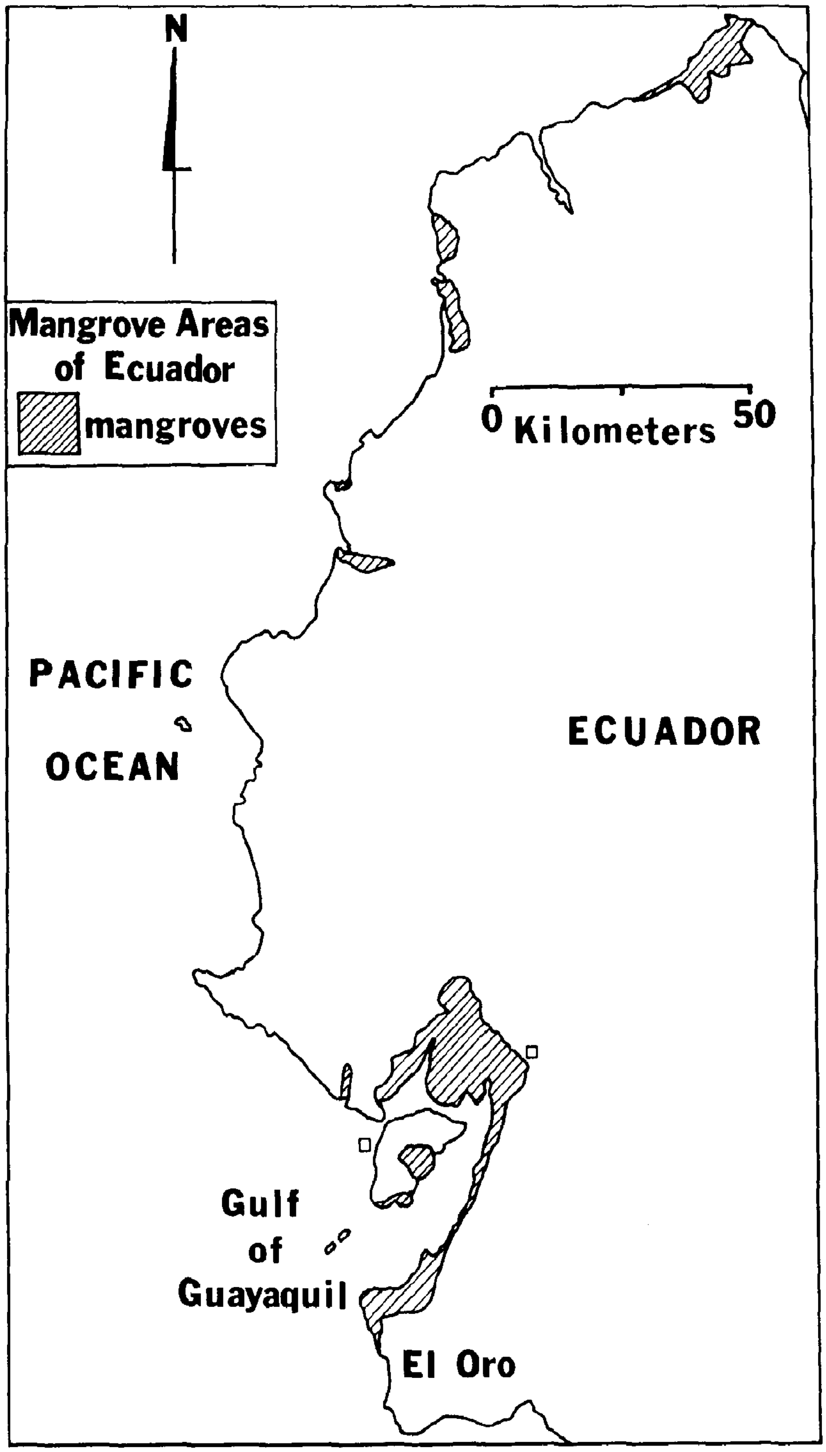

Figure 5. Map of the major mangrove areas in Ecuador. (Source: Anonymous)

(G. Clintron, pers. comm.) to 316,800 ha (R. Horna, pers. comm.; Yoong and Reinoso, 1982). Coastal zone maps recently published by the National Program of Agrarian Regionalization (PRONAREG) based on 1982 CLIRSEN (Ecuadorian Center for Integrated Resource Inventory using Remote Sensing) aerial photography should update these variable estimates.

Several Ecuadorian institutions are involved in coastal resource management and development. The Association of Cultivators of Bioaquatic Species (ACEBA) headed by Mr. F. Orellana represents a group of 35 shrimp producers who appear to be most interested in rational, productive management of shrimp ponds, mangrove protection and control of export licensing. This Association represents shrimp farming interests in lobbying efforts and exerts a measure of leadership over the industry. The Ministry of Defense has jurisdiction over the coastal zone in the interests of national security while the Merchant Marine grants concession for shrimp ponds. A permit from the Navy is needed to undertake any construction in areas up to 8 m above the high tide, and areas subject to tidal inundation. The concessions are renewable and usually last 10 years, however, they are not supposed to be given in mangrove areas. Public protests have resulted from blatant mangrove removal and the Ministry of Defense appears to be aware of the need to enforce these policies.

The Subsecretaria de Pesca of the Ministry of Natural Resources has overall responsibility for fisheries and mariculture while the Forestry Program, within the Ministry of Agriculture, oversees mangrove forests and associated fauna and the National Parks. Research and teaching activities related to both mangroves and shrimp production are conducted by ESPOL, the Polytechnic Institute of the Littoral. The Oceanographic Institute of the Navy also conducts research.

3.3 Panama

Panamanian exports of shrimp (caught and cultured) to the U.S. were valued at US$61 million in 1982, representing 80% of all fishery exports (see Table 3). While fishery products (primarily shrimp) are the second most important export item in Ecuador, shrimp (as shown in Figure 6) alone is the second most valuable export of Panama, after bananas. Landings from

Figure 6. These shrimp (Penaeus vannamei) are part of a crop from a typical Panamanian shrimp pond facility. (Photo by R. Murray).

traditional shrimp catch fisheries have varied from 5,000-7,000 metric tons per year with a fleet of 280 vessels involved (McCoy, 1981). Borema (1961) estimated that penaeid shrimp capture fisheries in Panama would reach a maximum catch per unit effort (CPUE) if 150 to 200 vessels were active in this Pacific coast fishery, and the maximum sustainable yield would be reached with 230 vessels. These estimates indicate offshore stocks of shrimp in Panama are over-fished. Clearly, increased exports of shrimp based on increased mariculture production might offset this overfishing while meeting lucrative market demands. Figure 3 B shows the recent history of shrimp pond development in Panama.

The institutional framework for managing mangrove resources and mariculture development is somewhat simpler in Panama than in Ecuador or the Philippines. The Ministerio de Desarrollo Agropecuario (MIDA) was established in 1973 to plan, organize, coordinate, and promote policies in the agricultural sector. The 1981 budget for MIDA totalled US$72.6 million. DINAAC, or the Dirección Nacional de Acuicultura, was created in 1979 as a part of MIDA with headquarters in Santiago. Dr. Richard Pretto, Director of DINAAC, is a specialist in mariculture.

The other relevant directorate within MIDA is the Direccion General de Recursos Renovables, or RENARE, which was established along with the Ministry in 1973. Until 1978, when USAID loaned Panama US$10 million (principally for protection of forests in the Panama Canal watershed), there were only four to five people involved in RENARE's activities. The current RENARE staff of more than 100 is responsible for inventory of the country's forests, regulation and supervision of forest exploitation and reforestation of areas which have been over-exploited. Its jurisdiction also extends to the littoral zone, including management of mangrove forests and superficial waters which enter the estuaries. Figure 7 shows the estimated extent of mangroves in Panama.

As in Ecuador, the preferred sites for shrimp ponds in Panama are salt flats (locally called albinas, Figures 8 and 9). Salt production, which also takes place in tidally flooded salt flats, has a much longer history on Panama's coast, and in fact there is almost as much hectarage involved in salt production (1,565 ha) as there is in shrimp farming (2,200 ha in

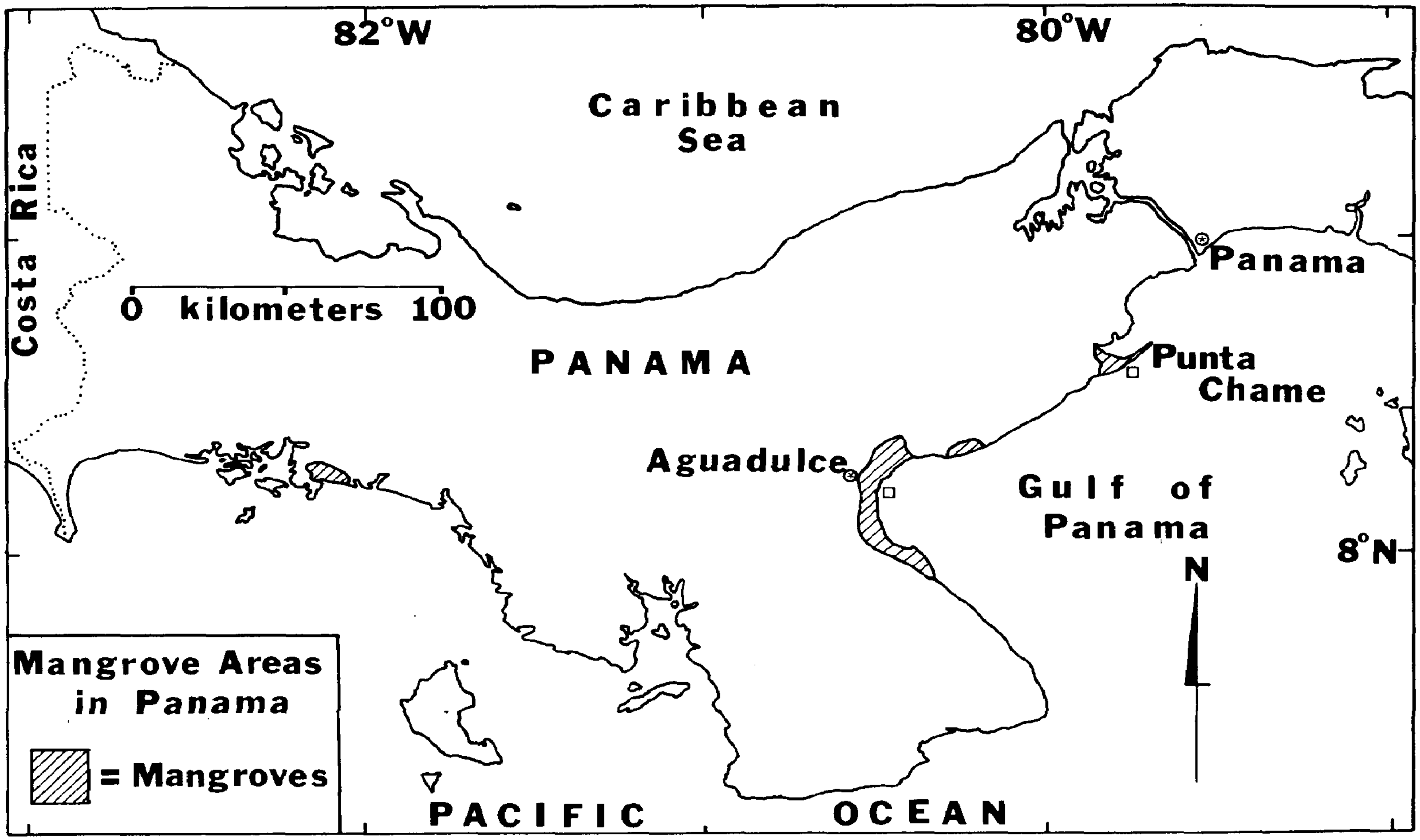

Figure 7. Map of the major mangrove areas in Panama. (Redrawn from FAO Investment Ctr.)

Figure 8. Portion of a shrimp pond constructed in a former albina area. The dikes extend to the mangrove line in background. (Photo by R. Murray).

Figure 9. Extensive albina converted to a salt gathering operation in Agudulce, Panama. (Photo by R. Murray).

1983; Pretto, pers. comm.). In spite of the fact that the salt producers, or salineros, occupy less than 10% of the available salt flats in Panama (14,000 ha according to McCoy, 1981; 19,845 ha according to Food and Agriculture Organization, 1981, government policies favor the participation of the Comision de Salineros in granting concessions for shrimp production.

The cadastral registry (an agency for land taxation) of the Ministry of Housing and Finance formally grants concessions (fees of US$20-25/ha are levied) once the MIDA directorates of RENARE and DINAAC, along with the Comision de Salineros and the Port Authority (of the Ministry of Commerce and Industry) have given approval. The cadastral registry is authorized only to grant concessions less than 2.5 ha in salt flats; Cabinet approval is required for larger concessions, although legislation is pending (1983) to permit the registry to grant concessions up to 200 ha.

While salt flats are preferred sites for shrimp ponds and salterns for salt production, the mangroves are most frequently removed for urban expansion and other agricultural purposes. Production of charcoal and construction poles called muletillas also account for a major depletion of mangrove resources (Garibaldi, 1982; Figure 10). In the Bejuco-Punta Chame area alone, more than 70 people are employed in charcoal production. Each 100 pounds of mangrove yields 50 pounds of charcoal after eight days of burning. With manual labor, one person can harvest sufficient wood to produce 20 fifty pound sacks of charcoal per day realizing US$1 per sack in earnings. Chainsaws have increased rates of harvest to as much as 100 sacks per person per day. This represents the clearance of a maximum 1.4 ha of mangroves per person per working day based on weight per area estimates from other studies (Golley et al., 1962). Straight lengths of mangrove growth are harvested for poles at the rate of 75 to 100 poles (10-18 feet long) per person per day for which the worker can receive as much as US$55 per day. Canoes are used to enter the mangroves on high tides for cutting. It should be noted that this work is normally done only a few days per month. There are several large storage areas in the Punta Chame area for both charcoal and muletillas ready for shipment to Panama City.

Figure 10. These Rhizophora trunks are being readied for conversion to charcoal in the Bejuco region of Panama. (Photo by R. Murray).

Still another major use of mangrove wood is to supply bark for production of tannin used in Costa Rica's leather industry. While Costa Rica bans the harvest of mangroves, a cooperative which harvests bark from Panama's red mangroves has supplied a leather tanning cooperative in Costa Rica for at least six years. More than 700,000 kg of red mangrove bark were exported to Costa Rica in 1981; however, current recessionary trends have reduced the demand for bark in Costa Rica since the peak year of 1979. Again, based on Golley et al. (1962) 700,000 kg of bark represents the destruction of as much as 250 ha of mangrove forest. Clearly, shrimp pond development is not the only, or even most extensive, cause of mangrove alteration in Panama.

Panama's involvement in the mariculture of penaeid shrimp began 10 years ago. Early in 1974, the U.S. firm of Ralston Purina established a Panamanian company, Agromarina de Panama, S.A., with a pilot scale shrimp grow-out facility of 48 ha in Aguadulce and a hatchery in Veracruz. Research and development continued through 1977 when Agromarina expanded to a commercial production scale on its 4,500-ha 20-year concession. Through 1982, more then US$6.8 million were spent in developing the company's hatchery (15 million postlarvae per month) and grow-out ponds of which there are currently 620 ha.

A second concession of 124 ha was granted the firm of Palangosta in 1979, this time for only 10 years. Economic returns from these operations encouraged investment in Panamanian shrimp farming; between November 1979 and August 1980, the Port Authority had received 23 requests for private concessions in salt flats. The central problem in this rapid growth was the premature, illegal development activities which, in some cases, preceded evaluation and approval by the government. Mangroves, rather than salt flats, were frequently altered or destroyed while applications to legitimize the concessions were ongoing according to the Port Authority. Policies of other governmental institutions were not coordinated or applied at that time. The Directorate of Marine Resources favored a limit on capture of wild shrimp postlarvae needed by pond operators. RENARE did not claim jurisdiction in the issue. While DINAAC promoted mariculture development, the Port Authority recommended a ban on all mariculture programs.

Federal legislation has been enacted (1959-1973) for protection of mangroves, regulation of water use and management of fishing activities. However, the parts of this legislation addressing concerns over mangrove alteration or destruction were not retroactive and could not be applied to landowners whose title to the property predated the laws. Eventually in 1980, an intergovernmental committee recommended unified policies for the problem. Under these policies, all current (1980) illegal operations are not permitted to expand. Companies with more than 100 ha in ponds must meet their needs for postlarvae or juveniles from hatchery production rather than collection of wild stocks, and the Port Authority will coordinate future concessions.

4. CURRENT SITUATION

4.1 Philippines

The Philippines has the longest involvement in aquaculture of the three countries surveyed and hence has exerted the heaviest pressure on mangrove resources. Until the early 1970's there was relatively little concern about the loss of the resource even as there was little concern about the loss of saltmarshes in the U.S. Both ecosystems, especially the mangroves, were viewed as noisome areas which begged to be utilized in a "constructive" manner.

Since 1972 the Philippines has built an admirable structure of administrative and legal constraints with regard to fishponds and mangrove resources. The early laws were designed to retard poorly planned fishpond construction which often resulted in poorly producing or unfinished ponds. (Figure 11 shows the secondary mangrove growth in a fishpond.) As far as they went these laws had little effect on the rate of fishpond construction, although they probably acted to discourage people with little capital or those who wished to build small fishponds (less than 5 ha in areas). Laws that were enacted after 1976 had a different complexion. These were written with the intent of establishing a conservation ethic with regard to mangroves.

Figure 11. This second growth mangrove in Mindanao is coming back after the area was cleared for a fish pond. (Photo by J. Atchue).

Unfortunately, there are several constraints associated with enforcement of the many existing laws. These constraints can be broken down into several areas. They are: lack of a data base on the resource, lack of manpower for implementation, and finally, lack of personnel at the regional and provincial levels educated in a conservation ethic. These problems point to a realization that is sometimes lost on planners and legislators alike: no matter how good or well intentioned a law is, it is almost impossible to implement without adequate data and manpower. The Philippines has a unique opportunity to deal with two of the three constraints.

The first constraint, although still serious, has begun to be dealt with by personnel from the NRMC and the NMC. They have already made many advances in mangrove resource identification using LANDSAT images (J.A., pers. obs.). The major obstacles preventing an accurate assesment of the current extent of both fishponds and mangroves are 1) lack of current images from LANDSAT and 2) lack of manpower to "ground truth" the areas. The addition of a relatively modest number of properly trained personnel and amounts of money would enable the Philippines to have access to a much more accurate and complete data base with regard to both mangroves and fishponds.

The other constraint, of lack of education in the "conservation ethic" at the regional and provincial levels, may be dealt with directly. New educational programs would, most appropriately, take the form of in-service seminars for both regional and provincial personnel. During these seminars, fundamental ecological principles can be used to illustrate to the personnel why it is impossible to alter a portion of an ecosystem without causing a shift in the overall balance. Associated with such regional and provincial seminars should be an effort to re-educate Bureau personnel on current policies favoring intensification rather than expansion of fishponds. Many people interviewed in both supervisory and extension roles in the Bureau were able to state the current government stance favoring intensive aquaculture while simultaneously endorsing the need for more fishpond areas to increase productivity.

The last constraint is the one least easy to remove. The government has been able to decrease the number of approved fishponds by involving the National Mangrove Committee in the Fishpond Lease Agreement process. This has had the admirable effect in our opinion of slowing fishpond development. The increase of production by the intensification of aquaculture effort is, however, not as large as planned. This can only begin to occur when the number of extension agents has increased. Almost every regional and provincial office is undermanned in the extension divisions. We understand that these are budgetary problems, on which we are unable to comment. We submit, though, that an effort to put trained extension agents in the field will yield a "rapid" increase in production by fishponds. The FIDC (1983) in their 10-year plan predict a 50% per year increase in fishpond production. Unless there are extension agents in the field to assist the operators we do not believe such targets can be met.

A related area of concern involves coordination and planning of coastal zone management. Two ministries (Ministry of Human Settlements, MHS and Ministry of Natural Resources, MNR) and at least three councils (Fishery Industry Development Council, FIDC, NRMC, NEPC) appear to have some regulatory interest in coastal zone management in addition to the Coastal Zone Management Task Force. This promotes confusion with regard to operational planning and overall goals in coastal zone management. We recommend that a single ministry be charged with the authority to manage all planning with regard to the coastal zone. Further we recommend that projects such as USAID's Rainfed Resources and World Bank's Central Visayas Resource Management Project be integrated with the overall Philippine coastal zone management plan.

4.2 Ecuador

The attitude of most governmental agencies and pond operators in Ecuador toward preserving mangroves has been generally favorable in the past. Most of the owners of ponds built in the last two or three years have shown an awareness of the importance of mangroves to the continued existence of their operations. They recognize mangroves as the most important source of postlarvae for stocking their ponds. The increased cost of construction in mangrove areas is also frequently mentioned as a constraint. Site visits to several of the newer shrimp farms in the Guayas region in the first part of 1983 indicated that very little destruction of mangroves had occurred in that area. These ponds were built landward of the mangrove line, with removal of small portions (1-2 ha) of mangroves for pump sites, construction of reservoirs and for access to salt water (Figure 12).

More recently, however, there have been several reports of extensive destruction of mangroves. In the newspaper El Universo (August 5, 1983) there appeared a front page photograph of mangroves being burned in Bahia de Caraquez. An accompanying article explained that this was done in order to clear the land for shrimp ponds. According to the author 1,000 ha of mangroves have already been cleared and another 1,000 ha are being dried up preparatory to clearing. An explanation of the importance of mangroves to shrimp farming is given, and the article concludes with a request for action by the Merchant Marine in order to stop the "illegal activity."

Reports of similar activities recently occuring in the Guayas region have also been personally communicated (M. Hatziolas, USAID). Apparently a new system of pond construction has evolved which is suited for exploiting mangroves. A single perimeter ditch and dike are first built so that the planned pond area will not be inundated by tidal action as it would normally. After drying for a sufficient period of time to support heavy equipment, the area is then cleared of vegetation and the ponds are constructed.

This type of construction has apparently been brought about by a lack of salitralis (salt flats) due to the rapid expansion of shrimp farming in Ecuador the past few years. Whatever the cause, the pattern in Ecuador seems to be going from the initial wholesale destruction of mangroves in Machala to a period of moderation, with a recent return to mangrove exploitation.

The economic impact of pond-reared shrimp is easily discernible in Ecuador. In 1975 the total catch for the country was 5,800 metric tons. By 1980 10,200 metric tons worth $66.4 million were exported, and in 1981 the harvest again doubled to 20,100 metric tons. This increase is almost entirely due to the proliferation of shrimp ponds, which provided 70% of the total export in 1981.

Figure 12. The high profitability of shrimp in Ecuador allows the use of high volume diesel pumps such as the one pictured. Very few ponds in the Philippines are capable of supporting this sort of energy intensive management practice. (Photo by R. Murray).

An allied industry which is expected to rapidly increase in the next 2 to 3 years is shrimp feed manufacturing. Six firms produced 17,000 tons of feed in 1982 with less than 20% of the shrimp farmers using a program of supplemental feeding. If more pond owners begin using pelletized diets, and new pond construction coutinues, it is estimated that 300,000 tons would be needed by 1986. (Chauvin, 1983). Another estimate places the future total value of the Ecuadorian shrimp feed industry as in excess of $40 million (S.P. Meyers, pers. comm.).

Interest in starting new ventures in shrimp farming is still high. Advertisements are seen almost every week in Ecuadorian newspapers in which as much as 500 ha of land suitable for shrimp ponds is sought. Such pressure, combined with the unavailability of salt flats for expansion, would seem to indicate that a critical point has been reached in Ecuador. If mangrove resources are to be preserved both as a source of postlarvae for the shrimp farming industry, and as a part of the coastal ecosystem, steps will have to be taken in the near future.

If a majority of the farmers can be convinced that better management practices will double or triple their yields from existing ponds, it would certainly help to alleviate the immediate problem. Since most of the farms in Ecuador are now operated on an extensive basis, conversion to a more intensive system seems to be the most practical first step.

The current practice is to stock ponds at very low densities with small postlarvae, on the order of 10,000-20,000 per ha. Seawater is either pumped into the ponds or exchanged through tidal action in some older operations. Since all food for the shrimp is provided by natural production in the ponds, there is usually no filtration of incoming water to remove possible competitors or predators. Without supplemental feeding the growth of the shrimp is slow, with increases in body weight averaging approximately 0.5 g/week. The slower growth in turn causes an extension of the time needed to reach a marketable size, so the number of crops is limited to 1 to 1.5 per year. Estimates of shrimp production from ponds operated in this manner range from 100 to 400 kg of tails (shrimp with the head removed) per hectare per year.

What could be termed a semi-extensive system would allow much higher production with only two or three procedural changes. Chief among these are a higher stocking density (50,000 to 60,000/ha) and a supplemental feeding program. A nursery system could also be employed so that shrimp are stocked in the grow-out ponds at 1 to 2 g. The combination of larger stocking size and a feeding program result in growth rates averaging 1 g per week or better, so that as many as two crops per year are obtained. Production in this system, depending on water quality, mortality and other factors, is in the range of 450 to 1,000 kg of tails/ha/year.

Using other management techniques which have been successfully employed elsewhere leads to an even more productive semi-intensive system. This system employs even higher stocking densities of juvenile shrimp (100,000/ha). Ponds are fertilized prior to stocking to increase natural production and feed is supplied throughout the grow-out period. Water quality is monitored closely in this system and water exchange rates in the ponds are usually higher than in extensive or semi-extensive production in this case, again depending on a number of factors, is in the range of 1,000 to 1,800 kg/ha/year.

Since only 20% of the shrimp farms in Ecuador are now using a feeding program, the potential for increased production from existing farms is extremely high. One feed company has issued its own technical bulletin with guidelines for feeding and examples of the increase in profits at different stocking densities. This sort of private initiative is probably one of the most effective means of disseminating this type of information. ACEBA, the shrimp farmers association, would also be an excellent conduit for the exchange of technical methods to improve production. Simple manuals on using different cultivation practices could be made available to all members and to others involved with raising shrimp.

These steps should satisfy those persons who are presently engaged in shrimp farming. However, pressure for expansion into mangroves could still come from new investors who do not yet have their "piece of the pie." As indicated earlier, suitable areas for shrimp pond construction (salt flats) which do not adversely affect mangroves apparently have been fully utilized. If the rate of increase of ponds in the past few years continues, there will be a critical need for enforcement by governmental agencies if Ecuador is going to maintain this new industry. Although two hatcheries have been built and three or four more are under construction, they will not be able to meet the demand for postlarvae if the wild stock should decrease significantly because of habitat loss or expansion of the industry continues. It is estimated that extant hatcheries can produce as many as 200 million postlarvae per year while the need for postlarvae will exceed 8 billion in 1985 if current trends in supply and demand continue.

The logical first step in a comprehensive program of mangrove protection would be to identify and classify the existing resources and at the same time obtain a more accurate estimate of what damage has been done. At present there is no detailed information on the actual locations and extent of mangroves nor on the actual area and rate of increase in ponds. Some workers have estimated as many as 80,000 ha of shrimp ponds in Ecuador when ponds built without authorization are included (Pires, 1983).

A proposal entitled Shrimp Pond Siting and Management Alternatives in Mangrove Ecosystems in Ecuador has been submitted to USAID, and has received funding (pers. comm., J. Dickinson).

The major goals of this project are to:

1) Determine the areal extent of mangroves and classify the communities according to major type.
2) Inventory existing shrimp ponds and determine what sort of area they are located in (mangrove forest, salina, saltera).
3) Detect and map patterns of stress on mangrove communities that may be related to shrimp pond construction or operation.
4) Correlate differences in shrimp pond signatures with physical or biological parameters and report yields.
5) Develop and test different techniques for measuring shrimp pond production and mangrove stress which can be used in Ecuador or in other developing countries with a minimum of "ground truthing."

With this type of information available the appropriate agencies within the Ministry of Defense should be able to increase their regulatory effectiveness. Accurate information on existing ponds would lead to better monitoring of future construction, especially that undertaken without authorization. Periodic coastal flyovers, or part-time ground observers in sensitive areas, may be used in such a program. The results of this important field research program should be followed closely as a model for mangrove resource monitoring.

4.3 Panama

Compared to the Philippines and Ecuador, the mangrove resources of Panama have suffered little from aquaculture operations and do not appear to be in any immediate danger. Demands on mangroves for urban expansion, and as sources of tannin and charcoal presently appear to be greater threats. This situation seems to be attributable to a number of factors which have made some contribution to a greater or lesser degree.

One of these factors is undoubtedly the existence of agencies concerned with mangroves in one way or another which have been able to function effectively. RENARE, which has primary responsibility for protection and enforcement, has sponsored a seminar on mangrove management presented by FAO. RENARE has also conducted a brief study on the ecological impact of shrimp culture in albinas and mangroves and has fined owners of several farms which were built in mangrove areas. They also have reportedly put a temporary halt to the cutting of red mangrove for its bark until the problem can be evaluated (S. Castillo, pers. comm.).

DINAAC has been able to help the situation in several ways. Articles have been published which point out the disadvantages of building shrimp ponds in mangroves (including greater cost, poor water quality and off-color, less valuable shrimp), the overall risks involved in investing in shrimp culture and the possibility of encountering acid sulfate soils in mangrove zones. A training program for biologists and technicians is being conducted at the marine station, and several personnel are already involved in working with private shrimp farms. Prior to the loan application made to the Inter-American Development Bank, DINAAC also conducted an assessment of the number of hectares of albinas available for shrimp pond construction. Estimates ranged between 10,000 and 19,000 ha, which should comfortably accomodate the total planned expansion of 2,500 ha allowed by the amount of monies provided through this loan.

There was some initial concern (R.M., pers. obs.) that visits to ponds after construction would not allow an accurate estimate of the amount of mangrove destruction involved. In Panama, however, there did turn out to be an effective means of comparison using aerial photos (1:40,000 scale) taken prior to pond construction. These are available at a nominal cost from the Instituto Nacional de Geografía in Panama City. Two of these photographs covering the Punta Chame area showed that four of the five farms located there were built on existing albinas, with little or no mangrove involvement (Figure 13).

Management practices in Panama also tend to differ dramatically from Ecuador. Here the majority of farms are using semi-extensive or semi-intensive operations, with 5% or less using an extensive system. This is probably primarily due to the influence of the Ralston Purina operation, Agromarina, S.A. Production here for the past year has exceeded 2,100 kg of tails/ha/year. The operation has earned the nickname Universidad del Camarón, or Shrimp University, because of the number of former biologists and technicians who are now working for Panamanian shrimp farms. DINAAC has also served as a source of trained personnel and information for farms in Panama. This is in contrast to Ecuador where the extensive system was historically practiced and there were no local people with expertise in shrimp culture.

5. LESSONS LEARNED AND SITE COMPARISONS

The status of shrimp production in Ecuador and Panama for export markets is similar; Philippine milkfish production represents an older system meeting the needs of local consumption in a nation of much higher population density.

Important areas of contrast are summarized in Table 4. The fact that most smaller fishponds (less than 2 ha) in the Philippines are not profitable (Chong, Lizarondo, Holarzo and Smith, 1982) is not a particularly grave economic concern. Operators produce food for themselves and defray their cost of living by selling off the remaining production.

Figure 13. Location of two shrimp farms in Punta Chame. The albina area on which the forms were built is outlined and indicated by arrows. Dark areas on the coast are mangrove forests. (scale 1:40,000 photo by Panamanian Government).

Table 4. Areas of contrast in the three target countries with regard to resource use and aquaculture economics.[1]

Country	Preferred Site	Approximate % Mangroves Converted	Typical Mariculture Approach	First Pond	Major Expansion	Economic Pressure	Population Density	Relative Profitability	Potential economic benefits from Improved methods	Potential economic benefits from Hatchery
Philippines	mangrove	45	extensive	1863	1950-70	local consumption	$163/km^2$	low	great	moderate
Ecuador	salt flat	25	extensive (some semi-extensive)	1969	1977-pres.	export	$29km^2$	moderate to high	moderate	great
Panama	salt flat	5	semi-intensive	1974	1981-pres	export	$24/km^2$	moderate	moderate	great

1. Sources of data are discussed in the history of development section. Estimates of profitability and economic benefits are authors inferences.

There is little incentive to improve yields. Larger operations (greater than 10-ha farms) such as those in Iloilo, Pangasinan and Quezon provinces are profitable and in many cases have achieved much greater yields per unit area, in some instances as much as 2,000 kg/ha/yr (J.A., pers.obs.). The many small fishponds produce far less than the few larger operations where profit motivation has led to improved operations. Futhermore, there are a number of important economies of scale which are achieved only by larger pond operations. These include higher stocking densities, polyculture with shrimp, food preparation and feeding, and improved water circulation from better sluice gates installed in the larger ponds.

If mangrove conservation is to be accomplished while permitting mariculture production (both fish and shrimp) to continue, improvements in yield per unit area of ponds must be pursued. In fact this is the stated goal of many government agencies. Legislation exists in all three countries studied which, if effectively enforced, would preclude mangrove conversions and encourage intensification of existing pond production. However, achieving overall improvement in yields is quite difficult in any agriculture or aquaculture endeavor.

According to figures from BFAR, each hectare of milkfish pond in the Philippines provides employment for one person, or approximately 190,000 people nationwide. The socioeconomic characteristics of milkfish culture have been established over many years and involve many people. The structure of the industry will complicate efforts to achieve higher yield by combining adjacent small and medium scale operations into a few larger scale operations. Yet to minimize continued mangrove conversions, the pressures to create new ponds must be relieved by improving yields of the established ponds.

It may be possible to improve yields per unit area by putting a greater emphasis on manual labor in the production process. The addition of a few people per facility could be used in such never-ending tasks as dike and gate repair, organic (or inorganic) fertilizer application and preparation and addition of locally available foods (such as rice bran). These personnel could be added at a relatively low cost to the pond operator especially in areas where large labor pools tend to shrink daily wages. In this way manual labor avoids an obligation for expensive technology while improving the local employment picture. Taking greater care in the overall culture as suggested above will result in a greater yield per unit area both in product and cash.

Aquaculture advisory service through government extension agents has not been useful in accomplishing this task in most countries; the Philippines, Ecuador and Panama are no exceptions. Typically, there is a critical shortage of properly trained extension agents (Ecuador, Panama) Their effectiveness is compromised by pond operators whose actual production is often greater than their officially reported, taxable production (Ecuador). Often the extension agent's status is considered low in view of the modest salary and the excessive amount of challenging field work required (the Philippines). The net result is poor transfer of technical information to small-scale mariculture operators on issues such as pond siting and design, maintenance of water quality, or pond management and harvest.

Product quality is excellent but high yields using unskilled labor is difficult or variable at best. The participation of a limited number of foreign technicians and mariculture specialists has been important in the development of shrimp mariculture in Ecuador and Panama. Increased yields appear to be unlikely unless there is an increase in qualified local technicians. Part of the Panamanian program funded by the Inter-American Development Bank addresses this need for training.

Low yields of both shrimp and fish can be achieved with very little input of labor, energy and money; however, this is the most extensive approach. The greatest input is land, mangroves in the Philippines, or dwindling areas of salt flats, and more recently, mangroves in Ecuador. Panama's young shrimp mariculture industry has yet to exert significant pressure on their mangroves, and therefore Panama has the best opportunity to review and react to these pressures before they become an environmental problem.

Production of milkfish fry depends on the productivity of the mangrove ecosystem as does natural production of shrimp postlarvae in Ecuador and Panama. However, to date the availability of juvenile milkfish has not limited fish production. Milkfish fry remain numerous in spite of the loss of as much as 45% of original mangrove areas. Milkfish are highly fecund, as are shrimp. They grow rapidly either in the wild or in captivity and are easily held (stunted) in nursery ponds until required. Shrimp postlarvae move into the mangrove ecosystem only temporarily and are much more sensitive to handling and grow-out procedures. In Panama and especially in Ecuador, the availability of shrimp postlarvae could become a major obstacle to further mariculture development.

Milkfish are produced in ponds located in mangrove habitats from which the trees have been removed, often for charcoal and lumber. On the other hand, preferred sites for shrimp ponds (in Panama and Ecuador) are salt flats, tidally flooded salt-soil areas devoid of vegetation behind the mangrove forests. For successful operation, milkfish ponds must be located in mangroves. Therefore each hectare of pond represents the removal of one hectare of mangrove. Ecuador shrimp farming has been expanding since 1969 with ponds in salt flats where construction costs are lower and there are fewer production problems. But as fewer desirable salt flats remain in Ecuador, there has been an increase in the illegal removal of mangrove areas. Panamanian shrimp farming is a more recent development, and extensive areas of salt flats are available for development. While some mangroves have been removed for shrimp ponds, current economic pressures appear to have reduced the rush to develop new ponds. This is clearly evident from the lack of participation in the Inter-American Development Bank loan program of US$15.3 million. US$10.3 million are available for development of 1,525 hectares of shrimp ponds in Panama, but applications for less than US$1.1 million have been processed (R. Pretto, pers. comm.)

6. GUIDELINES

This case study has focused on the Philippines, Panama and Ecuador as premier examples of successful, coastal mariculture in the developing world. For the most part, the successes of these nations in fish and shellfish mariculture continue to take place in environments where mangrove forests are often found. We have reviewed specific histories of mariculture development in these nations, examined current situations and discussed lessons learned from the proper and improper management of both mariculture projects and mangrove resources. The constraints upon the opportunities for natural resource management discussed in this study are widely applicable in nations where aquaculture developments may have serious impacts on other coastal resources. In countries where ecological and economic conditions are favorable, mariculture can rapidly take on considerable socioeconomic importance in a relatively short period of time. In less than two decades, shrimp mariculture has expanded to account for 40% to 80% of all exports in Panama and Ecuador. Once proven successful, mariculture production becomes a traditional activity over the course of many years, as in the Philippines where nearly 200,000 people rely on the industry for all or part of their living. Given the important socioeconomic basis of coastal mariculture, it becomes imperative that planners and administrators work to promote the prosperity of the industry while expanding and refining their efforts to manage, conserve and, in some areas, preserve mangrove systems. To that end, we present the following generic recommendations which are intended to guide decision-makers dealing with mariculture developments in coastal habitats harboring important natural resources. These guidelines are subdivided into four broad categories: technical measures, information transfer, funding practices and administration.

6.1 Technical measures

(1) Existing mariculture production should be intensified to increase yields without the need to convert new coastal habitats.

Intensification is the most important strategy, and one likely to be successful in many countries for most species under cultivation. From a technical standpoint, intensive or semi-intensive mariculture production is based on proven methods involving higher stocking densities of postlarvae or juveniles, improved maintenance of water quality, better design engineering and siting of grow-out ponds, and use of supplemental foods. These improvements need not be technologically oriented or prohibitively expensive but the mariculturists must be aware of the methods and the need for their use. Even small pond operations can have yields per unit area increased (by use of simple fertilizers, supplemental feeding, more frequent exchange of water, etc.). Intensification of larger scale operations requires more inputs (money, labor, supplies) to achieve greater production, higher product quality and dependability of supply, all of which lead to greater profits and a more stable market for the mariculture product. To some extent, these improvements in operations are a result of several economies of scale which are achieved only in large, technically oriented facilities (e.g., many problems of water quality may be solved in a large-scale operation while small-scale grow-out ponds cannot yield sufficient products to justify the expense of technical solutions). It is important to recognize, however, that profitability is a less important criterion in areas where mariculture production is consumed locally rather than by national or international markets. Successful intensification can improve profit margins but it can also increase supplies of protein without increasing the areal extent of grow-out ponds at the expense of mangrove forests. This is particularly true in nations of high population density where the need for food is not always met. In such areas where the labor force is a large and unemployment high, increased labor input may lead to improved production per unit area without the involvement of expensive technologies.

(2) Accurate baseline environmental and economic data and periodically updated assessments of mangrove resources must be collected. It is not possible to judge the biological or economic problems or evaluate the merits or constraints of any solution without sufficient and accurate data. Very little data exist on the relationship between intact mangrove forests and the productivity of coastal waters and hence we cannot evaluate the impact of mangrove conversions on nearshore fisheries, although there appears to be a relationship. The economic value of intact mangroves, or mangroves managed for sustained yields of tannin, charcoal and lumber, is not generally known, so again we cannot evaluate mariculture conversions relative to other land-based activities. Even such data as the areal extent and temporal variation of production in mangroves is not routinely and accurately collected. For example, it has been suggested (IUCN,1981)

that one unit of mangrove may be converted to mariculture ponds for every four units of intact mangrove before coastal fisheries will suffer from the loss of the mangrove habitat and productivity. Ecological data to test this hypothesis are lacking; accurate or unbiased economic data are unavailable for evaluations of such resource development strategies on different socioeconomic groups (catch fishermen, mariculturists, local consumers, exporters).

In the absence of useful data or other properly validated conversion ratios, the most prudent course of action would involve a moratorium on conversion of new mangrove areas. Such restrictions must be enacted only as interim measures while necessary data are collected and formulated into management guidelines.

It is beyond the scope of this study to outline specific types of data required for proper biological and environmental analyses and assessments of the status of mangrove forests. In any event, what would be considered appropriate data generally varies from one coastal system to another.

In general, however, satellite imagery supported by aerial and ground truth surveys appear to be one of the most appropriate means to accumulate the data needed for ongoing evaluation of mangrove forests in areas of mariculture activity. Results from current and proposed research programs at the University of Panama, the University of Miami and the FORI, mangrove research station in Quezon Province, Philippines, should be critically reviewed as potential models for routine collection of the biological and ecological data needed in periodic assessments.

Economic data to integrate with biological and ecological findings are also required; data suitable for the evaluation of mariculture and the quantification of tradeoffs between short- and long-term development strategies are not available. In most areas, mangrove forests provide lumber for human habitation, are a source of charcoal, lumber and tannin for man's use, and cycle nutrients into highly productive coastal waters in addition to serving as sites for mariculture ponds. In spite of this biological and economic importance of the mangrove system, we lack data on which to base management decisions for balancing uses of mangroves or for sustaining the resource.

this study suggests the complexity of the required data (e.g., what information is needed to establish a value of the discount rate for mangroves?).

(3) Siting of new mariculture facilities in mangroves must be discouraged while reclamation of abandoned ponds should be encouraged. In most areas, conversion of mangroves to ponds is not an absolute requirement for successful mariculture production, and in fact such pond siting can be disadvantageous. Ponds built in mangrove areas cost more to prepare, as much as 20% more in Ecuador (E. Heald, pers. comm.) and frequently have poor water quality resulting from acid sulphate conditions caused by decaying mangrove matter. Because soils in mangroves often cannot be adequately compacted, pond dikes rupture more frequently. Planners and decision-makers should favor siting of ponds in areas other than intact mangrove forests, and only after a sufficient financial commitment has been made for plans which reflect proper design engineering of the facility. Programs of pond reclamation should be supported in instances where economic failures have led to pond abandonment. Poorly sited or engineered ponds should be breached to promote eventual recolonization.

6.2 Information transfer

(4) Programs must be established to train more extension or advisory agents and to mandate continuing education for current agency staff involved in extension services for mariculture. Greater commitments must be made to the support of extension services; key personnel must be trained and retained through improvements in the agent's status and salary. Well trained and respected extension agents may prove to be the most effective communicators of improved mariculture practices. Key personnel should be drawn to responsible positions from areas of relevant experience. Training of extension agents and advisory personnel is often insufficient and inappropriate and must be improved if even minor technical advances toward intensification of mariculture are to be made. Promotion of simple improvements through effective extension services is likely to result in the most rapid intensification of small production

operations.

Current successes in coastally sited mariculture are based predominantly on methods rooted in tradition and difficult to change. The transfer of technology upon which intensification depends faces opposition from this traditional, grass-roots outlook. Therefore to be effective, extension agents must gain the confidence of the industry. But this role of the agent is made difficult through his or her association with the bureaucracy which regulates and taxes the mariculture industry. The following guideline addresses this concern.

(5) Private, non-governmental organizations (NGO's) such as shrimp and fish farmers associations must be involved in programs to promote improvements in production. These associations are local in character, are not involved in procedures of regulation and taxation, and generally are well regarded. While association members may be reluctant to share successful methods among themselves, the associations do provide a forum for the extension service to promote proven methods of intensification extracted from successful foreign operations, international specialists and published reports.

(6) Large, expatriot companies should be required to gradually transfer production technology to local producers as part of their land concession permit. Foreign-based firms usually have made a significant commitment of capital to establish production operations which take advantage of local labor and natural resources, often to meet demands of a lucrative export market. Such foreign investment offers a number of obvious benefits to local economies in terms of employment, export trade and tax bases. However, once initial research and development costs have been recovered, expatriot companies should not retain exclusive privileges to exploit local natural resources by virtue of proprietary technologies. Foreign investors must be offered a definite period of time in which to establish the profitability of production and recover development costs. After that period (we recommend 10 years as a reasonable figure) continued operation would require a well-defined program of technology transfer. In return for this information, the term of the original land concessions would have to be extended beyond current standards (e.g., a 10-year proprietary development period followed by 20 years of continued operation for a total

term of 30 years).

(7) Specific mechanisms must be established for the timely transfer of research results and recommendations in appropriate form for application by regulatory agencies and user groups. Publication of technical reports in the scientific literature does not address the need for transfer of information from research projects to decision-makers. Publication is frequently slow and presentations are in highly technical terms. Governments, international development organizations and user associations should continue to support more frequent gatherings of specialists to produce and circulate non-technical syntheses of results from research programs on both mangrove resources and mariculture developments.

6.3 Funding practices

(8) International funding agencies must carefully structure their mariculture development programs to encourage improved yields in existing facilities rather than the creation of additional coastal sites. In the past, loan programs for capital expenses have increased pressures on mangrove resources by encouraging the entry of new operators into the mariculture industry. Loan funds for operating expenses should be made available for improving and sustaining existing mariculture operations. Restrictions on use of current loan money for operating expenses should be removed. Discounted interest rates or tax advantages may be given on loans used to reclaim abandoned ponds. New development programs should represent a balance of financial support for capital and operating expenses and training programs.

6.4 Administration

(9) We strongly recommend that single agencies or departments be charged with the coordinated administration of coastal resources and mariculture development, and that this agency effectively communicate governmental policies to all parties concerned. Interagency conflicts should be minimal; policy statements and research programs should be unified. While shifting jurisdiction within existing departments or ministries may be difficult, such changes are needed.

Bureaucratic processes tend to become more complex and resistant to change over the long term. This tendency toward bureaucratic entrenchment and inflexibility is complicated in the administration of multidisciplinary issues. Responsibilities are typically partitioned into many management units, which increases the complexity of the system to the outsider. The "outsiders" in the instance of mangroves and coastal mariculture are for the most part shrimp and fish farmers, lumbermen, and rural families producing charcoal and tannin. (Sophisticated entrepreneurs who, from time to time, may promote urban development of mangrove tracts are not, in this sense at least, "outsiders" to the system.) Of particular concern to the ministry administering coastal resources and development should be the effective communication of policies to everyone involved in the development or management of coastal resources regardless of their sophistication in natural resource issues or the apparent degree of their involvement from passive concern to daily participation. Feedback should be part of this communication. Thus, administrative policies and legislation which allocate common property resources, such as shrimp postlarvae, milkfish fry or mangrove tracts, should be assessed and adjusted periodically by all interested or affected groups if resources which permit successful mariculture are to be sustained.

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APPENDICES

Appendix I - Methods: Itinerary
Part 1

Mr. Joseph Atchue traveled throughout the Philippines from 4 July through 12 August 83. In addition to visiting Manila, he spent time in Pangasinan, Ilolio, Cebu, Bohol and Cagayan Provinces.

Mr. Robert Murray traveled throughout Panama from 15 August through 26 August 83. In addition to spending time in Panama City, he visited pond operations and mangrove sites in Punta Chame, Aguadulce and Chitre. In Ecuador he was able to tour several shrimp farms on the Guayas River.

Appendix I - Methods: Interview Guidelines
Part 2

Uniform Reporting Guidelines

These guidelines provided a basis for comparison of data collected during interviews. In the following lists, topics with asterisks are considered most important.

1. Persons Interviewed

A. Aquaculturist -	Owner Operator Employee Processor
B. Private Interests -	Association administrator Consultant
C. Governmental -	Local Provincial Federal US AID Mission
D. Financier - Lawyer -	Banker Attorneys Venture capitalist
E. Alternate User - (of mangrove coast)	Catch fishermen Home owner, developer Boating interests Salt pond facilities

2. Areas of inquiry:

    Biology - Mariculture
    Environment
    Economic
    Social

Appendix I - Methods: Interview guidelines
Part 2

AQUACULTURE - Owner, operator, employee, processor

* Production levels per unit area
* Area in production, harvests per year
* Favored habitat, climate, specifics of suitability
* Expand vs increase yield?
* Value of extension agents, if any
* Planned expansion, timetable, where
* Value of mangroves - esthetics, habitat for postlarvae and juveniles, other roles

Pond designs, innovations, alternatives
Pond failures, flaws, time to construct
Constraints to increased yield per unit area
History of availability of postlarvae (not from hatchery)
History of facility development, personal involvement
Perceived (or measured) impact on habitat, history
Freshwater difficulties
Extent of vertical integration
Any local conflicts - officials, neighbors, fishermen, laws
Number of employees, wages
Hierachy of expense
Marketing methods
Estimates of market demand
Price returned to producer
Profit margin, profit sharing incentives
Cost of money (interest rate), accessibility

PRIVATE INTERESTS - Consultant, association administration, scientist

* Mean production levels per unit area
* Estimate of total area in production
* Favored habitat, climate
* Perceived (or measured) impact on habitat, history
* Planned expansion, timetable, where
* Value of mangroves - esthetics, habitat for PL and juveniles, other roles
* Areal extent of mangrove habitat, by province
* Estimates of natural productivity of mangrove

Pond design, innovations, alternatives
Pond failures, flaws
Constraints to increased yield per unit area
History of availability of postlarvae (not from hatchery)
History of aquaculture industry
Specifics of suitability

Freshwater difficulties
Most pressing regional problem
Expand vs. increase yield
Extent of conflict with fishermen
Hierarchy of expenses
Role of extension agents, consultants
Percentage population employed by aquaculture
Marketing methods
Price returned to producer
Estimate of market demand

GOVERNMENT - local, provincial, federal, AID mission

* Value of mangrove - esthetics, habitat for PL and juveniles, other roles
* Extent of failures of aquaculture operations
* Most pressing regional problem
* Percentage of population employed by aquaculture
* Planned expansion, timetable, where
* Government policy to ecnourage/discourage expansion
* Areal extent of mangrove habitat, by province

Nature of legislation to manage coastal resources
Nature of legislation to promote/regulate aquaculture
Role of extension agents
Estimate of economic benefits of aquaculture
Percentage of population employed by catch fisheries
Any local conflicts - officials, fishermen, laws
Quality of intragovernmental relations

FINANCE/LAWYER - attorney, banker, venture capitalist

* Estimate of economic benefit of aquaculture
* Extent of failures of aquaculture operations
* Planned expansion (participation), timetable, where
* Government policy to encourage/discourage expansion
* Value of mangroves - esthetics, habitat for marine life, other roles

Outline of aquaculture involvement, service provided
Favored habitat, climate
Cost of money (interest rate), accessibility
Marketing methods
Price returned to producer
Estimate of market demand
Percentage of population employed by aquaculture
Perceived (or measured) impact on habitat
Most pressing regional problem

In loans to aquaculture, what is failure rate
Time from loan to cash flow

ALTERNATE USER - catch fishermen, home owner, developer, boating

interests, salt pond facilities

* Estimate of economic benefit of aquaculture
* Value of mangroves - esthetics, habitat for marine life, other roles
* Planned expansion (non - aquaculture), timetable, where
* Estimate economic benefits of alternate use
Percentage of population employed by catch fisheries
Favored habitat, climate, specifics of suitability
Total area in alternative use
Any local conflicts - officials, neighbors fishermen, laws
Freshwater difficulties

Appendix I Methods: Persons Contacted
Part 3

The following individuals were personally contacted during the course of this study.

CASE STUDY CONTACTS: PHILIPPINES

Ministry of Natural Resources (MNR)

Arnol Caoili, Deputy Minister

Bureau of Fisheries and Aquatic Resources (BFAR)
at the national level.

Joe Marie Gerochie, Assistant Director
Abe Gaduang, Chief Extension Division
Myrna Capati, Officer in Charge, International Liaison
Lourdes De Mesa, Head Librarian
Lulu Bautista, Acting Chief, Statistics Division
Natividad M. Lagua, Chief, Plans and Management Division (PMD)
Aurora B. Reyes, PMD

Region I:

BFAR:
Primitivo Clave, Regional Director
Romulo Rasing, Extension Agent
Michael Rice, Peace Corps Volunteer

Part 3 con't.

Region VI:

BFAR:
Jose Garrido, Regional Director
Fred Telarma, Assistant Regional Director
Cesar Matulac, Chief, Extension Division
Donnie Boquieren, Chief, Gear Technology
May Abdua, Chief, Management Information Staff
Development Bank of the Philippines:
Ramon Buenaflor, Manager, Iloilo
Personal contact:
Mr. Danila, Western Visayas Fish Farmers Federation

Region VII:

BFAR:
Mr. Avesado, Regional Director
Boy Bernardino, Assistant Regional Director
Corazon Coralles, Chief, Extension Division
Rafael Bojos, Chief, Plans and Management Division
Myrna Reyes, Plans and Management Division
Condring Gustador, Chief of Calape Demonstration Fish Farm
Rolando Obispo, Chief of Vis. Fisheries Training Center
Gerry Loquellano, District Fishery Officer, Bojol
Development Bank of the Philippines:
Ben Tapedor, Manager of DBP, Cebu
Wilfredo Oredina, Chief, Aquaculture and Agriculture Div.

Region X:

BFAR:
Arlene Pantanosas, Chief, Plans and Management Division

Manila

Development Bank of the Philippines:
N. Chave, DBP Aquaculture Section

University of the Philippines (Marine Sciences Research Center (UP/MSRC)

Edgardo Gomez, Professor

National Environmental Protection Council (NEPC):

Ella S. Deocadiz, Chief, Coastal Zone Management Planning Section

Southeast Asian Fisheries Development Council (SEAFDEC):

Rogelio Fortez, Manila Office
Angelito Vizcarra, Aquaculture Engineering
Mr. Torrez, Aquaculture Engineering
Sylvia San Juan, Administrative Assistant, Training Programs

International Center for Living Aquatic Resources Management (ICLARM)

John L. Munro, Director, Research Division

National Resources Management Council (NRMC)

Celso Roque, Director General
Ricardo Umali, Deputy Director General (also Chairman, National Mangrove Council)

Fisheries Industry Development Council (FIDC)

Elizabeth Samson, Chief

Silliman University; World Bank

Fred Vandevuuse

USAID:

Jaime Correa, Agricultural Project Officer, ORAD
David Alverson, Director, Policy and Planning, ORAD
Noel Ruiz, ORAD
Jeremy Edwards, Chief, ORAD

CASE STUDY CONTACTS: ECUADOR

Mr. Mark Newman, Chief Biologist
Camaronero Lebama, Islas Las Canoas

Dr. Joshua Dickinson, III
Consultant to project, environmental management
Gainesville, Florida

Mr. Rafael Horna

Eric Heald
NMFS; farm partner in shrimp (Ecuador)

Dr. Gilberto Cintron
Assoc. Prof. Univ. Puerto Rico

Ricardo Torres
ACEBA, Guayaquil

Part 3 con't.

CASE STUDY CONTACTS: PANAMA

RENARE:

Dr. Sergio Castillo M., Director
Directorate of Renewable Natural Resources (RENARE)

Lic. Cristina Garibaldi E.
Biologist, RENARE

Ing. Manual Hurtado
Chief, Forest Service

Ing. Cecilio Estribi, Provincial Coordinator,
(Chiriqui)

University of Panama:

Prof. Luis D'Croz
Marine Biologist

Bogdan Kwiecinski
School of Biology

DINAAC:

Dr. Richard Pretto M., Director
National Directorate of Aquaculture

Ing. Luis Hooper, Chief
Shrimp Culture Section

Lic. Vielka M. De Ruiz, Chief
Vacamonte and Carrasquilla Labs

Tec. Miguel de Leon, Chief
Marine Station "Enrique Ensenat"

Arnulfo Luis Franco R.
Marine Biologist, Marine Station "Enrique Ensenat"

Azael Torres Diaz
Marine Biologist, Marine Station "Enrique Ensenat"

Eyda Smith, Economist
Carrasquilla laboratory

Production operations:

Victor Ruben Espano, Manager
Palangosta, S.A. (Aguadulce)

Ramon Morales, Administrator
Agromarina de Panama (Aguadulce)

Javier Perez
Grupo Ganadera, S.A. (Granjas Marinas, Punta Chame)

Ing. Eduardo Perez, Field Manager
Aquachame, S.A. (Punta Chame)

USAID:

Mr. Gale Rozelle

Mr. Jesus Saiz

Others:

Dr. Len Lovshin: AID/DINAAC (Santiago)

Dr. David Hughes: AID/DINAAC (Santiago)

Carlos A.Becerra: Banco Nacional de Panama
Director, Aquaculture Program for IDB-BNP-MIDA

Armando Solicas: Manager, Cooperativa Salineros Marin
Campos, R.L. (Aguadulce)

Mr. Enrique Diaz, US Army Engineering Division

Appendix II

Philippine National Mangrove Committee guidelines:

The Philippine National Mangrove Committee was reorganized to its present form by the (then) Ministry of Natural Resources under Special Order No. 178, 1980.

Areas to be recommended for preservation or conservation or to be declared as mangrove forest reserves:

1). mangrove areas adjoining the mouth of major river systems, covering at least 3 km distance along both sides of the river fronting the sea,
2). mangrove areas near or adjacent to traditional productive fry and fishing grounds, areas of importance as breeding, spawning and nursery waters for fish and shellfish,
3). mangrove areas near populated areas or urban centers, for use by people dependent on mangrove forest products,
4). mangrove areas of significant hazard if developed because of storms, erosion, floods,
5). mangrove forests which are primary or pristine and have dense young growth, in view of their important roles in local ecosystems, and
6). mangrove forests on small islands, forests which are important components in such small ecosystems.

Appendix III

Recommendations of participants at the FAO seminar on management and regulation of mangroves held in Panama in July 1-6, 1983.

1). The technical assistance offered by international bodies, in material for the regulation of mangroves, should have a specific and practical character for field application. Suitable Panamanian personnel should be sent to Southeast Asia to receive practical training in mangrove management, as well as forestry aspects.

2). Recommendations of the missions on mangrove management already received by the Forest Service should be put in effect as far as possible.

3). Mangrove forest inventories already produced should be made current and processed on corresponding maps. Perhaps technical assistance would be required for this during the entire period.

4). Establish a small pilot level unit of mangrove forest management. This could be 45 to 100 hectares, including a charcoal oven (50 m^3), which implies an investment of some $US10,000 for the first year. For the management of said unit the identification of a market for the products to be obtained is indispensable. This unit is of total importance to demonstrate the feasibility of mangrove forest management, without affecting the other resources derived from it.

5). An area of forest reserve should be selected and created for the mangroves in Panama.

6). The corresponding laws should be regulated for more orderly use of mangroves.

7). Due to the large number of entities which in one form or another are related to this resource, it is very important to quickly form a Comision Nacional del Mangle (COMAN) integrated by representatives of public as well as private institutions which are concerned with the conservation, use, administration and investigation of the mangrove zones. This model functions sucessfully in S.E. Asia.

8). Mangrove investigation programs should be reinforced and coordinated through the proposed "Comision Nacional del Mangle." This should channel the corresponding funds for investigations such as the management projects.

9). At the level of said comission, they should coordinate information and extension workers on the value of the mangrove resource with a target of a better understanding on the part of the users and the general public.

Case Study Two

BEACH EROSION

Miles O. Hayes

"We have learned that even works executed for coastal protection sometimes accelerate severe beach erosion. It should be deeply engraved in our minds that any development project must be examined from a broad view of both positive effects and negative results."

Watanabe and Horikawa
(1983)

SUMMARY

Assessment of beach erosion problems on a global scale indicates that eroding beaches are a common phenomenon. Serious erosion problems in developed areas are usually the result of the activities of man, such as unwise construction practices or the development of harbors or hydroelectric dams. Case studies from different parts of the world provide guidelines for sound planning and management of beaches in developing countries. Most of the pitfalls of beach erosion can be avoided if the following "golden rules for combating beach erosion" are adhered to:

1) Understand the natural beach system before it is altered. Site-specific studies may be required at many localities to insure wise planning decisions.
2) Develop a setback line before construction begins.
3) Where a major obstruction to longshore transport is built, such as a large harbor, allow for an adequate sand-bypassing system.
4) Where possible, use soft solutions, such as sand nourishment or diversion of channels, rather than hard solutions, such as revetments or seawalls, to solve beach erosion problems.
5) Maintain a prominent foredune ridge.
6) If a beach is valuable for tourism, recreation, or wildlife habitat, do not mine the sand from dune, beach, or nearshore bars.
7) Do not panic after a storm and drastically alter the beach. Wherever possible, let the normal beach cycle return the sand.

Lone observer on an eroded beach in Western Australia.

1. INTRODUCTION

Erosion is a common phenomenon on many of the shorelines of the world. In fact, almost no coastal area of the world that has been developed by man is free of problems caused by beach erosion.

An average erosion rate of between 30 centimeters (cm) and 1 meter (m) per year has been determined for the shoreline of the United States (Dean and Walton, 1975). The National Shoreline Study, which was conducted by the U.S. Army Corps of Engineers (1971), concluded that there are 32,000 kilometers (km) of eroding shoreline in the United States, 4,800 km of which are classified as critically eroding, with nearly 43 percent of the shoreline of the United States undergoing significant erosion.

The erosion or accretion of any coastline is ultimately controlled by the natural forces responsible for the motion of wind and water along the beach and in the nearshore zone. Under the action of nearshore currents, waves, or winds, sediments are moved on, off, and along the beaches. This mass transport of sand (the primary sediment type found on beaches) results in the net erosion or accretion of a particular segment of the coastline (Hayes and Kana, 1976).

The following discussion outlines the causes of erosion and reviews man's effort to combat it, emphasizing specific case studies. What becomes evident in this discourse is the conclusion that man himself has caused most of his own beach erosion problems. That being the case, perhaps he can do something to solve them. Lessons learned from the mistakes of the past should be applied in the planning phases of every new development in the coastal zone. The costs involved in preventing erosion by wise planning are orders of magnitude less than those required to solve an erosion problem once the structures are in place.

2. THE NATURE OF BEACHES

2.1 Definition

A beach is an accumulation of unconsolidated sediment that is transported and molded into characteristic forms by wave-generated water motion. The landward limit of the beach is the highest level reached by average storm waves, exclusive of catastrophic storm surges, and the seaward limit is the lowest level of the tide (Davis, 1982). The beach's landward limit is usually marked by an abrupt change in slope at a coastal cliff, a foredune ridge, or a man-made structure.

Most of the discussion in this case study concentrates on the erosion of beaches, although the cliffs, dunes, and man-made structures of adjacent coastal areas are commonly affected by wave erosion. Furthermore, it is important to realize that changes on a beach are responses to processes acting far outside the limits of the beach itself. Offshore shoals and currents as well as inshore dune systems exert important controls on the erosional and depositional cycles of beaches.

2.2 Beach Sediments

Sediments on beaches range from coarse-grained fragments of rocks to fine-grained sand. Quartz sand is the most common constituent of beach sediments because of its relative abundance in the earth's crust, as well as its chemical stability and resistance to abrasion. Carbonate sand beaches are common in tropical regions. Gravel beaches are most common in areas subjected to Pleistocene and Holocene glaciation (polar and subpolar regions), but they also occur in warmer climates near eroding bedrock cliffs and near some river mouths. The texture and composition of beach sediment roughly parallels the distribution found for the nearshore shelf sediments of the world (shown in Figure 1). Approximate distributions of beach sediments on a global scale are summarized further in Table 1. In effect, the waves will build a beach from whatever material is available.

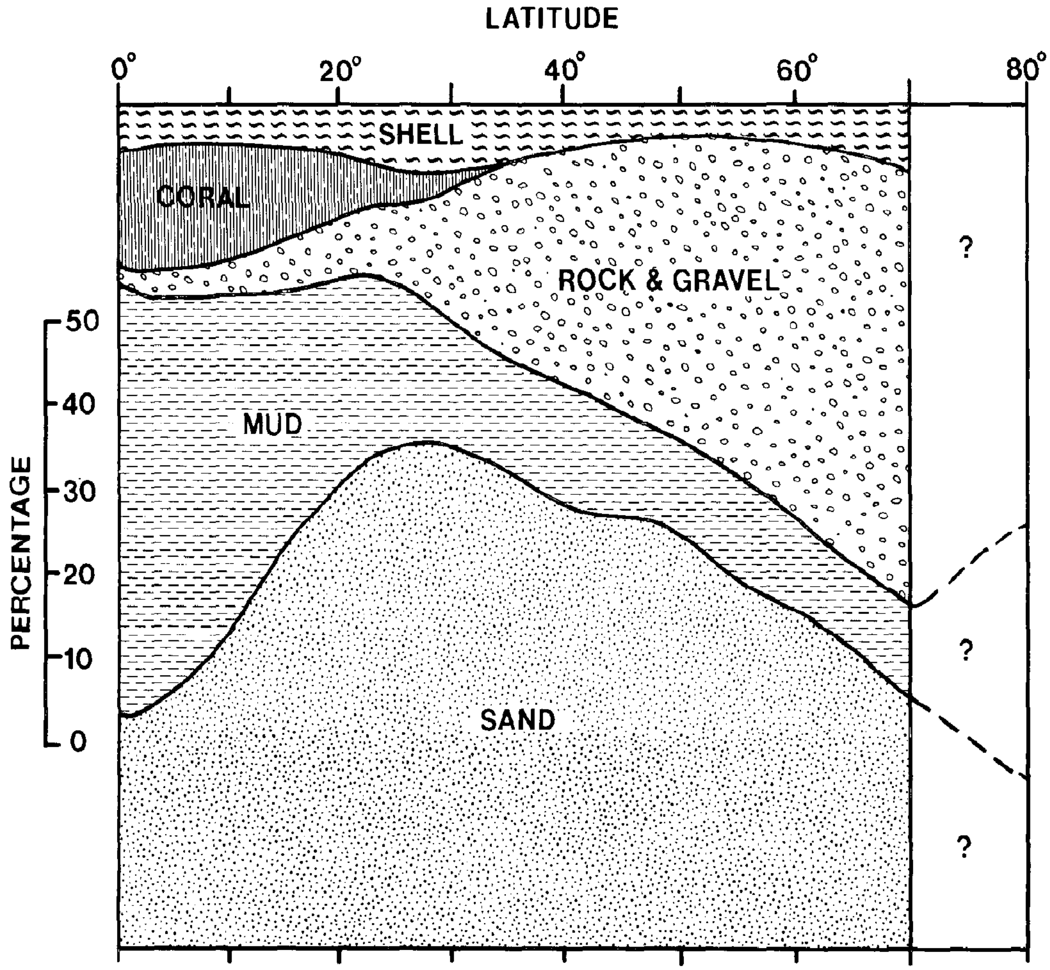

Figure 1. Relative frequency of occurrence of sediment types on the inner continental shelves of the world (from Hayes, 1967b). Beach sediments show a similar trend, except for mud, which is winnowed from beach sediments. "Coral," a general term used on nautical charts, presumably encompasses other types of carbonate sediments besides coral.

TABLE 1

Generalized global occurrence of beach sediment

Tropical regions	Carbonate sand composed of coral and algal fragments, shell, and carbonate precipitates abundant; quartz and rock fragments common in sand, especially in areas of eroding bedrock and near river mouths
Temperate regions	Quartz sand dominant; rock fragments and feldspar abundant in sand near river mouths and along coasts with eroding bedrock
Subpolar and polar regions	Gravel beaches abundant; pure sand present on long, exposed beaches; quartz and rock fragments common in sand
Oceanic islands	Volcanic sands (normally black in color) and carbonate sands common

2.3 Waves on Beaches

Most of the wave energy arriving at the shoreline is contained in progressive waves generated by winds blowing over the water. They are termed progressive because they move in the general direction the wind is blowing. These waves have two common forms: seas and swell.

2.3.1 Seas

Seas are highly irregular waves with pointed crests which are produced and influenced directly by the wind blowing over the water. They generally include a wide range of wave lengths and periods, making it difficult to describe the average wave. The height of waves at a given water depth depends on three factors: wind velocity, fetch (the waterway distance over which the wind blows), and wind duration (length of time a given wind velocity occurs). As each of these factors increases, wave heights increase.

2.3.2 Swell

When the wind stops blowing, seas become more rounded and smooth in appearance, approaching a sinusoidal shape. Such waves are called swell. Because the velocity depends on the period or wave length, swell waves tend to sort themselves out naturally at sea, traveling in groups with approximately equal velocity. Typically, the sea surface contains a complex pattern of locally generated seas interacting with swell from another part of the ocean.

2.3.3 Waves at the Shoreline

Seas and swell are transformed as they approach the coast because of the effect of friction as the depth of water decreases. If waves approach at an angle to the shore, they will bend (refract) toward the shore. Also, they will generally decrease in height because of shoaling and friction with the sea floor. Waves break when the depth of water is approximately equal to the height of the wave. So, a wave one meter high will usually break in about one meter of water.

2.3.4 Breaking Wave Types

There are three basic types of breakers which occur on beaches, mainly depending on beach slope. Along gently sloping beaches, spilling waves are most common. These waves have a broad foam area at the wave crest as they approach the beach, expending their energy over a relatively wide surf zone. As a rule, they tend to move sand onto the beach. Plunging waves occur as beach slope increases. They have curling breakers which entrain a vortex of air as they break. They are more violent than spilling waves and expend their energy rapidly over a narrow width of the surf zone. As a rule, they entrain more sediment than spilling waves and commonly tend to move beach sand offshore to the limit of the outer breaker line. Surging waves occur on steep slopes and are characterized by a sloshing up and down the beach. The three breaker types are illustrated in Figure 2.

2.3.5 Wave Erosion

Steep, plunging waves generally cause shoreline erosion and retreat. A schematic representation of storm waves eroding a beach is given in Figure 3. Beaches typically erode during storms and recover to near-original profiles during intervening periods.

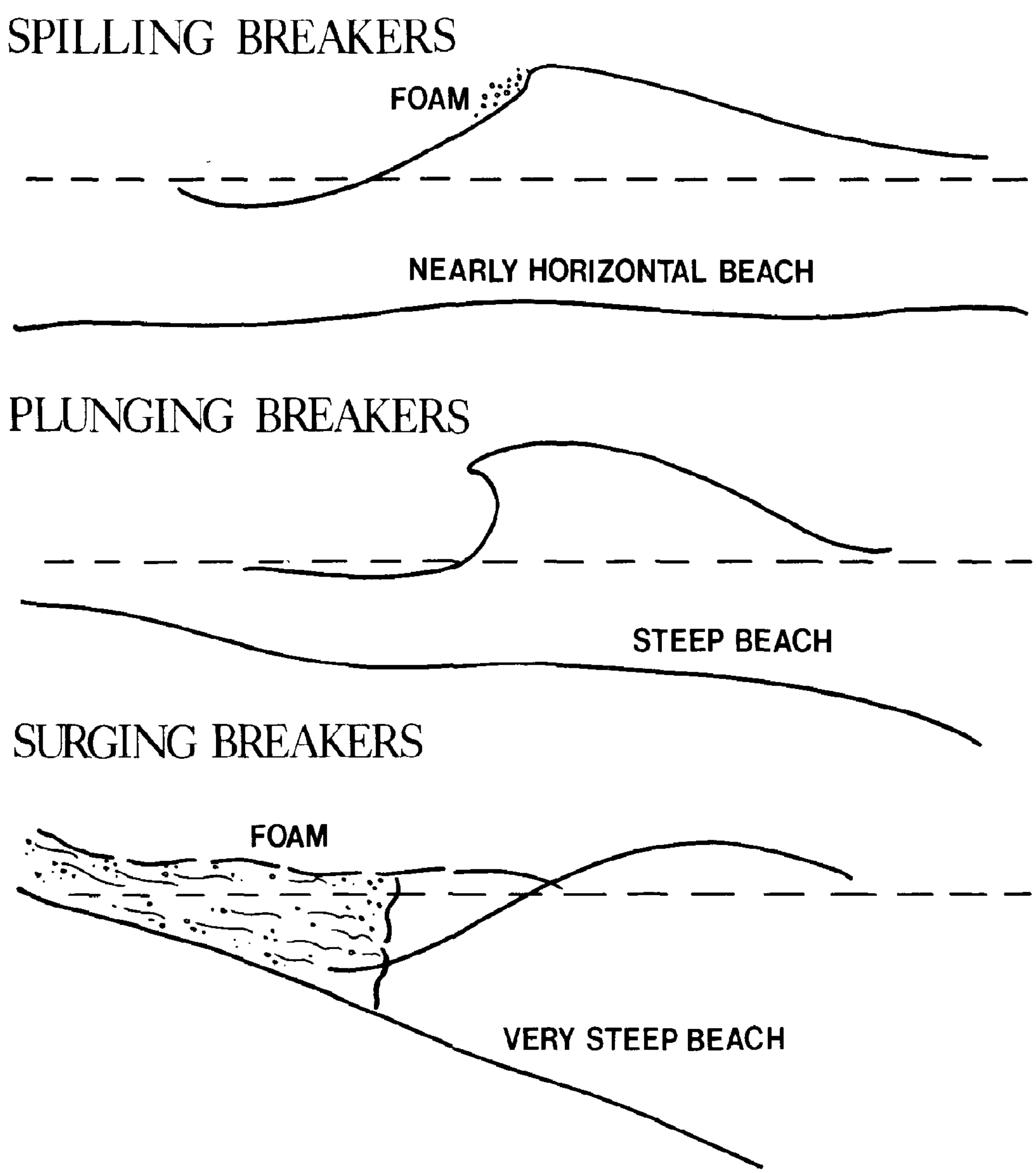

Figure 2. The three principal types of breaking waves that occur on the beach (from Komar, 1976, Figure 4-17).

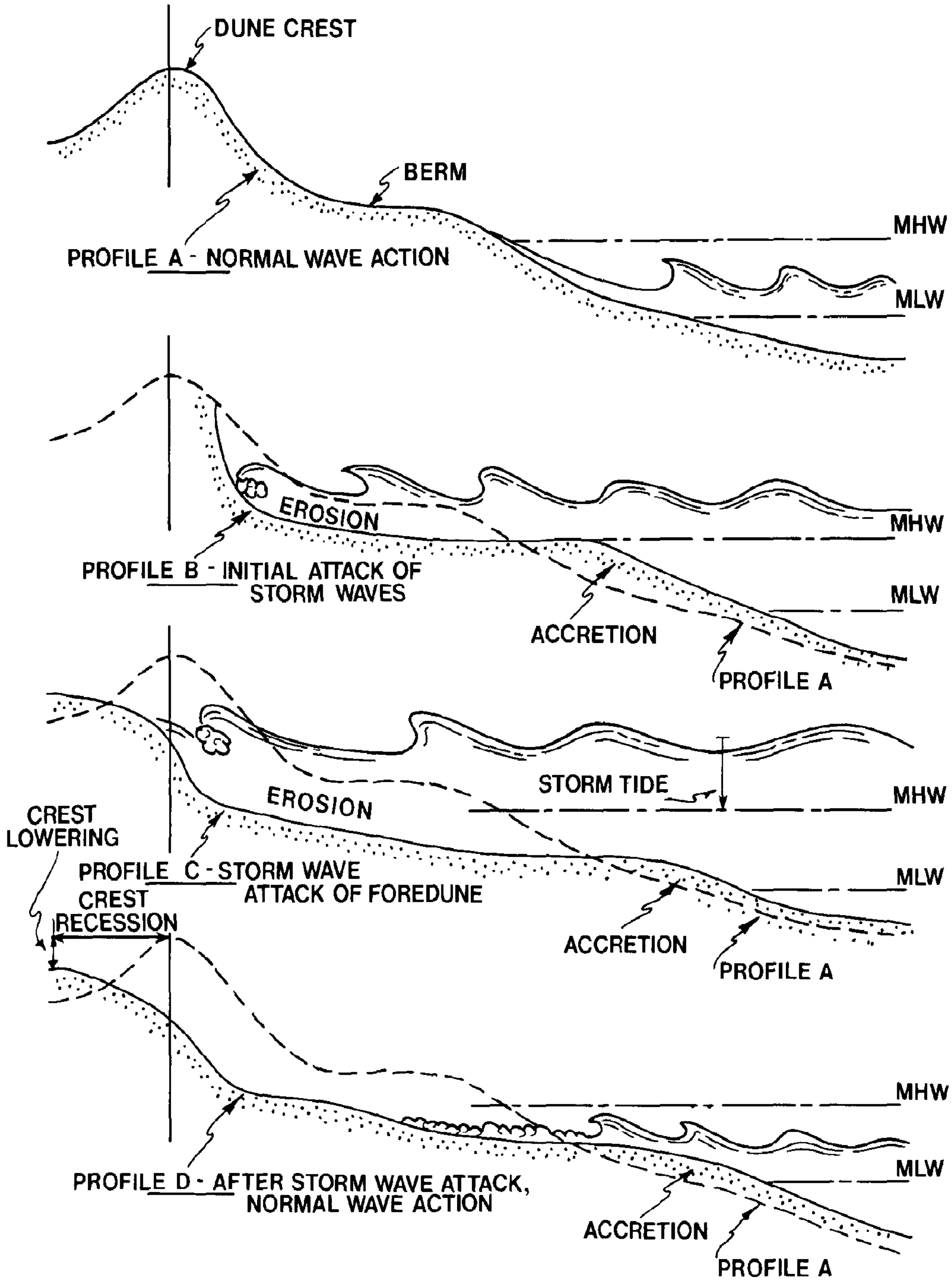

Figure 3. Schematic diagram of storm wave attack on beaches (from U.S. Army Coastal Engineering Research Center, 1973, Figure 1-7).

2.4 Currents

There are several categories of currents in the ocean, including tidal currents, ocean currents, and wave-generated currents. Of these, wave-generated currents have the most important influence on open coast beaches. Tidal currents are important in modifying sediment transport near inlets, but have little effect on uninterrupted straight shorelines, except in areas with very large tidal ranges (greater than 4 m). Ocean currents only rarely affect nearshore sand transport. A notable example is the Guyana Current, a branch of the North Equatorial Current, which moves large quantities of fine-grained sediment discharged from the Amazon River along the shoreline of northeastern South America.

Wave-generated currents include longshore currents and rip currents. Longshore currents are discussed in the section on sand transport. Rip currents flow from the beach seaward and are generally part of a well-defined nearshore cell circulation such as is illustrated in Figure 4. The most commonly held theory for the origin of rip currents is that they result from interactions between incoming waves and edge waves trapped within the nearshore system (Komar, 1976). Edge waves are free-wave motions introduced by a coast in its interaction with surges or lower-period oscillations (Bowen and Inman, 1971). They are generally standing waves with crests normal to the shoreline and wave lengths from crest to crest parallel to the shoreline (Komar, 1976, p. 176). Bowen and Inman (1969) demonstrated that longshore variations in wave setup caused by periodic longshore variation in wave height generate lateral flow, with rip currents flowing seaward at the positions of lowest wave heights. Wave heights are least where the edge wave and incoming wave are 180 degrees out of phase (see Figure 5; from Komar, 1976).

2.5 Local Variations in Wave Energy

Wave energy is not distributed evenly along some shorelines. Usually, this is the result of wave refraction around an offshore island or rocks, over submerged bathymetric highs or lows, or as the result of a variable orientation of the coast.

The uneven distribution of wave energy along local shorelines (scale of few kilometers) has been demonstrated in many areas. Two well-known

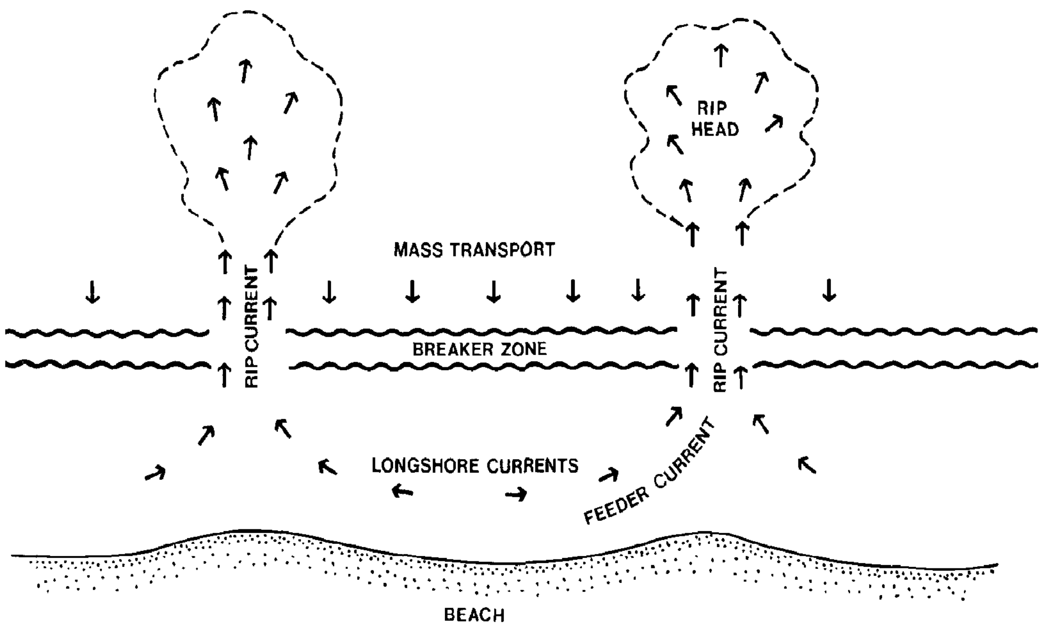

Figure 4. Nearshore cell circulation consisting of (1) feeder longshore currents, (2) rip currents, and (3) a slow mass transport returning water to the surf zone (after Shepard and Inman, 1950).

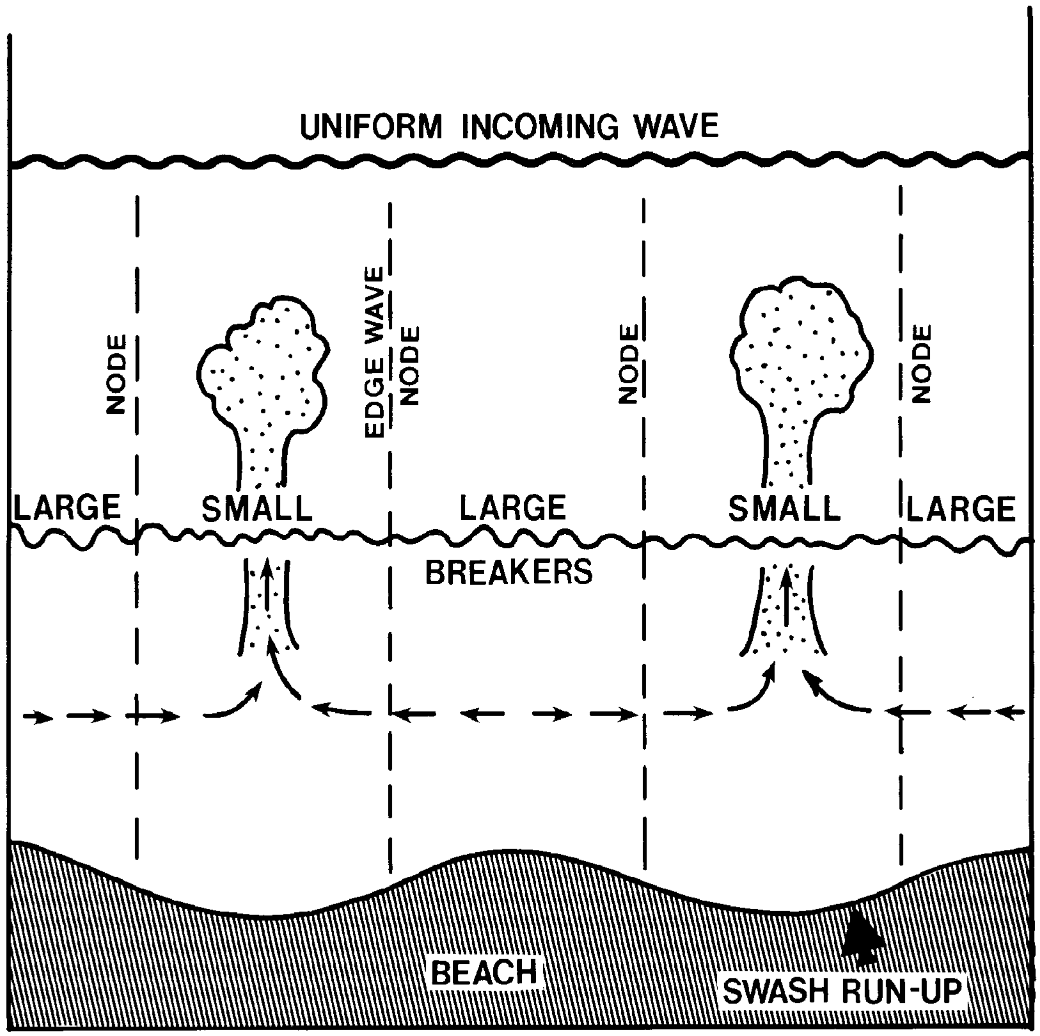

Figure 5. Illustration of nearshore rip currents. Note the positioning of the currents where the breaker height is smallest--that is, where edge waves and incoming waves are 180 degrees out of phase (from Komar, 1976, Figure 7-8).

examples, the coast of southern California (U.S.) and the Delmarva Peninsula (U.S.), illustrate this principle. In southern California, submarine canyons occur close to the shoreline. Waves tend to refract away from the canyon openings, creating areas of decreased wave energy at the shoreline adjacent to the canyon heads. On the Delmarva Peninsula, submerged linear ridges project away from shore in a northeasterly direction. Waves passing over these ridges are focused by wave refraction near the points of intersection of the ridges with the shoreface. In both regions, beach erosion is most critical in areas where wave energy is focused by wave refraction.

2.6 Transport of Beach Sediment

2.6.1 Introduction

Sand transport on beaches is primarily caused by currents generated by breaking waves. It is estimated that over 90 percent of nearshore sand transport takes place between the shoreline and the outer line of breaking waves. This portion of the nearshore area is known as the surf zone and can vary in width from less than ten to many hundreds of meters.

2.6.2 Longshore Sediment Transport

Sand is moved alongshore on beaches by two mechanisms. Under oblique wave approach, the paths of moving sand grains on the beach face follow a sawtooth pattern as the wave uprush pushes the grains obliquely up the beach and they roll straight down the slope as gravity pulls back the backwash. Also, the continuous action of the oblique waves induces a longshore current which carries sediment parallel to shore. Both processes are illustrated in Figure 6. In many instances, complex sediment circulation patterns are set up in the nearshore zone in response to complicated bar and rip systems (Figures 4 and 5).

The amount of sand that is transported along a beach by natural processes depends essentially on two parameters: (1) wave height and (2) breaker angle (the angle between wave crest and shoreline). It is possible to estimate the amount of sand transported at any place on the coastline by measuring these two parameters each day or during representative periods during the year. Sand transport is generally measured over a period of one

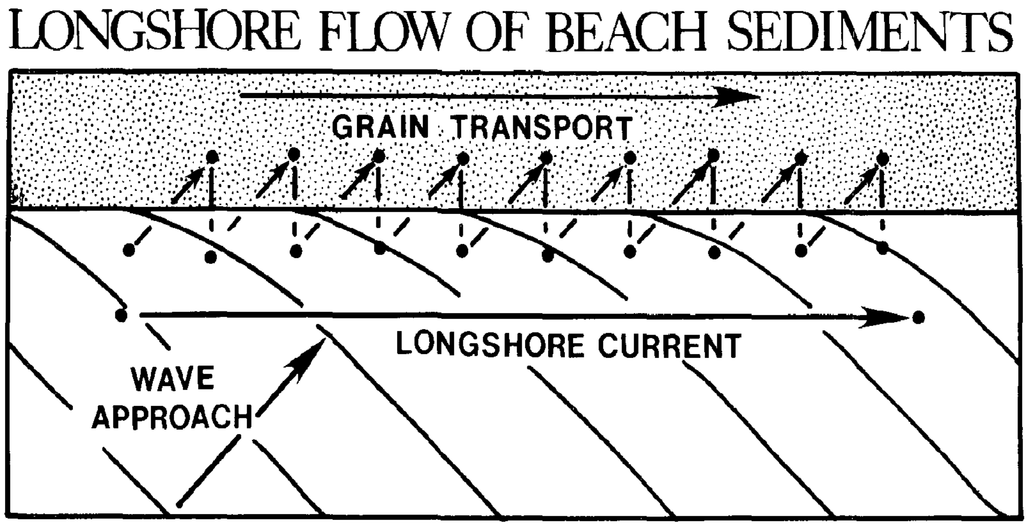

Figure 6. Longshore flow of beach sediment produced by wave and current action when waves approach the shoreline at an angle (from Bird, 1968).

year and given as a volume of sand moved past a shore station in units of cubic meters of sand per year (m^3/yr).

2.6.3 Relation of Sediment Supply to Longshore Transport Capacity

Waves have a finite capacity to move sand alongshore depending on wave height and breaker angle. If more sand is supplied to the coast than can be moved by waves, the shoreline will accrete (for example, near the mouths of rivers). When an approximate balance is maintained between the sediment supply and longshore transport capacity, the shoreline will remain relatively constant.

2.7 The Sediment Budget

Inasmuch as shoreline changes are primarily a matter of gaining, retaining, or losing beach sand, an erosion problem can be explained by the concept of a sediment budget. This budget accounts for gains and losses to the beach as explained below:

> The budget of sediments is nothing more than an application of the principle of continuity of conservation of mass to the littoral sediments .... The budget involves assessing the sedimentary contribution (credits) and losses (debits) and equating these to the net gain or

loss (balance of sediments) in a given sedimentary compartment (Bowen and Inman, 1966). (Komar, 1976, p. 227)

The application of this concept provides useful information for dealing with beach erosion problems, because once the source of sediment loss is determined, remedial measures can be taken. The concept of the sand budget has been applied to the California coast by Inman and associates at Scripps Institution of Oceanography in California (U.S.) (Bowen and Inman, 1966; Inman and Frautschy, 1966). Bowen and Inman's budget of littoral sediments for the California coast is given in Table 2. Inman and Frautschy (1966) divided the southern California coast into a series of littoral cells, which are shown in Figure 7.

TABLE 2

The budget of littoral sediments for the California coast (after Bowen and Inman, 1966)

CREDIT	DEBIT	BALANCE
Longshore transport into area	Longshore transport out of area	Beach deposition or erosion
River transport	Wind transport out	
Sea cliff erosion	Offshore transport	
Onshore transport	Deposition in submarine canyons	
Biogenous deposition	Solution and abrasion	
Hydrogenous deposition	Mining	
Wind transport onto beach		
Beach nourishment		

A sediment budget analysis was used by Everts (1980) to deduce the human influence on the sediment budget of a barrier island. He defined a "fixed reference frame" within which to work (illustrated in Figure 8). As a result of the study, several means were suggested in which "human processes can be introduced to mitigate a shoreline retreat problem."

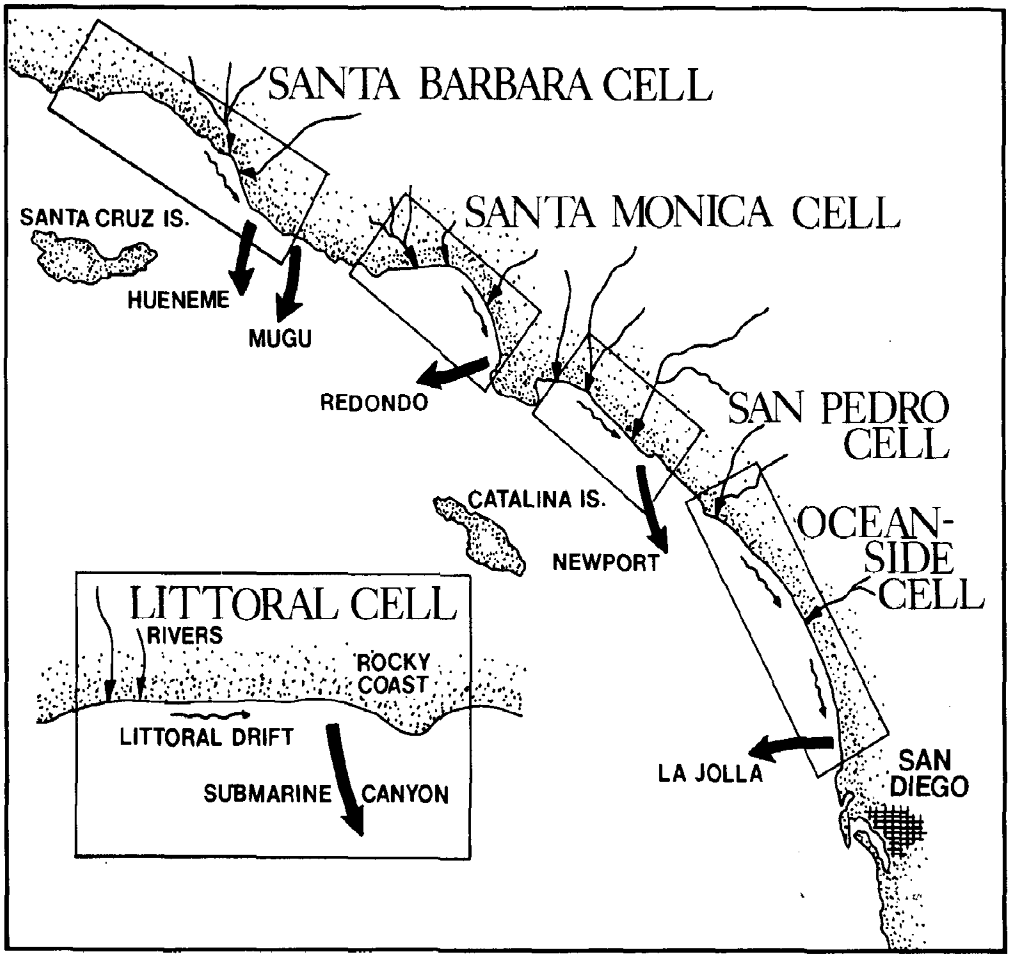

Figure 7. The southern California coast divided into a series of cells, each cell being a system where rivers add sand to the beaches and the sand moves south as littoral drift to be trapped within submarine canyons and lost offshore to deep water (after Inman and Frautschy, 1966; from Komar, 1976, Figure 9-1).

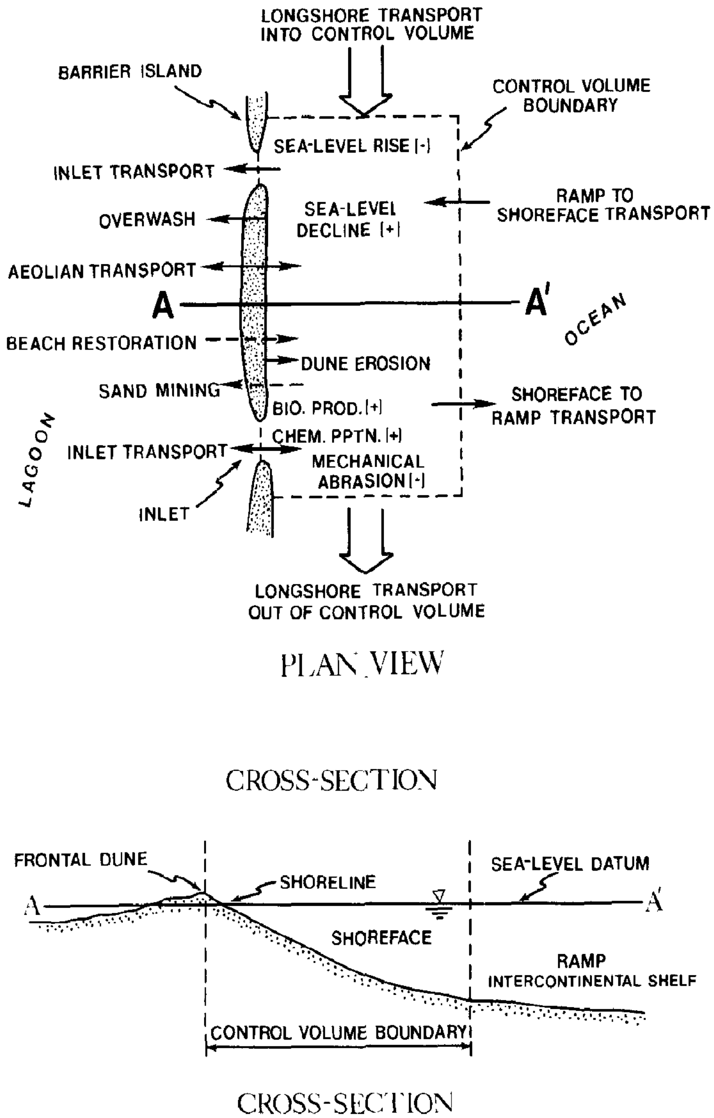

Figure 8. Sediment budget concept used by the U.S. Army Corps of Engineers to deduce man's impact on barrier-island erosion. The suggested control volume is shown below and transport mechanisms are shown above. Seaward control volume boundary is depth of reworking of sediment by normal storm waves (from Everts, 1980, Figure 1).

2.8 Coastal Dunes

An integral part of the natural transport of sand along many shorelines is the storage of sand in primary foredune ridges. This naturally stored sand serves two important functions: (1) protects landward areas from erosion during storms and (2) feeds sediment back into the natural system during periods of erosion. It is very important to protect the natural foredune ridge from destruction by man's activities, as it serves as the first line of defense during storms.

2.9 The Beach Profile

No single beach profile or morphology can be used to characterize beaches. Based on the writer's field experience in numerous parts of the world, the morphology of beaches varies greatly from place to place depending upon such factors as:

1) Type of sediment.
2) Overall wave climate, including relative predominance of storm wave or swell conditions.
3) Tidal range.
4) Nature and intensity of storms in the area.
5) Degree of exposure to wave attack.
6) Orientation of shoreline relative to storm passage and prevailing winds.
7) Local variations in reflection and dissipation of waves, such as in spiral bay systems (discussed by Wright, 1980).
8) Local fluctuations in sediment supply, such as occurs around tidal inlets.
9) Slope and depth of nearshore zone.
10) Angle of wave attack and rate and volume of longshore sediment transport.
11) Presence of reflective man-made structures, such as seawalls and revetments.

Some examples of model, or typical, beach profiles, gleaned from the literature and from the writer's experience, are presented in Figures 9 and 10.

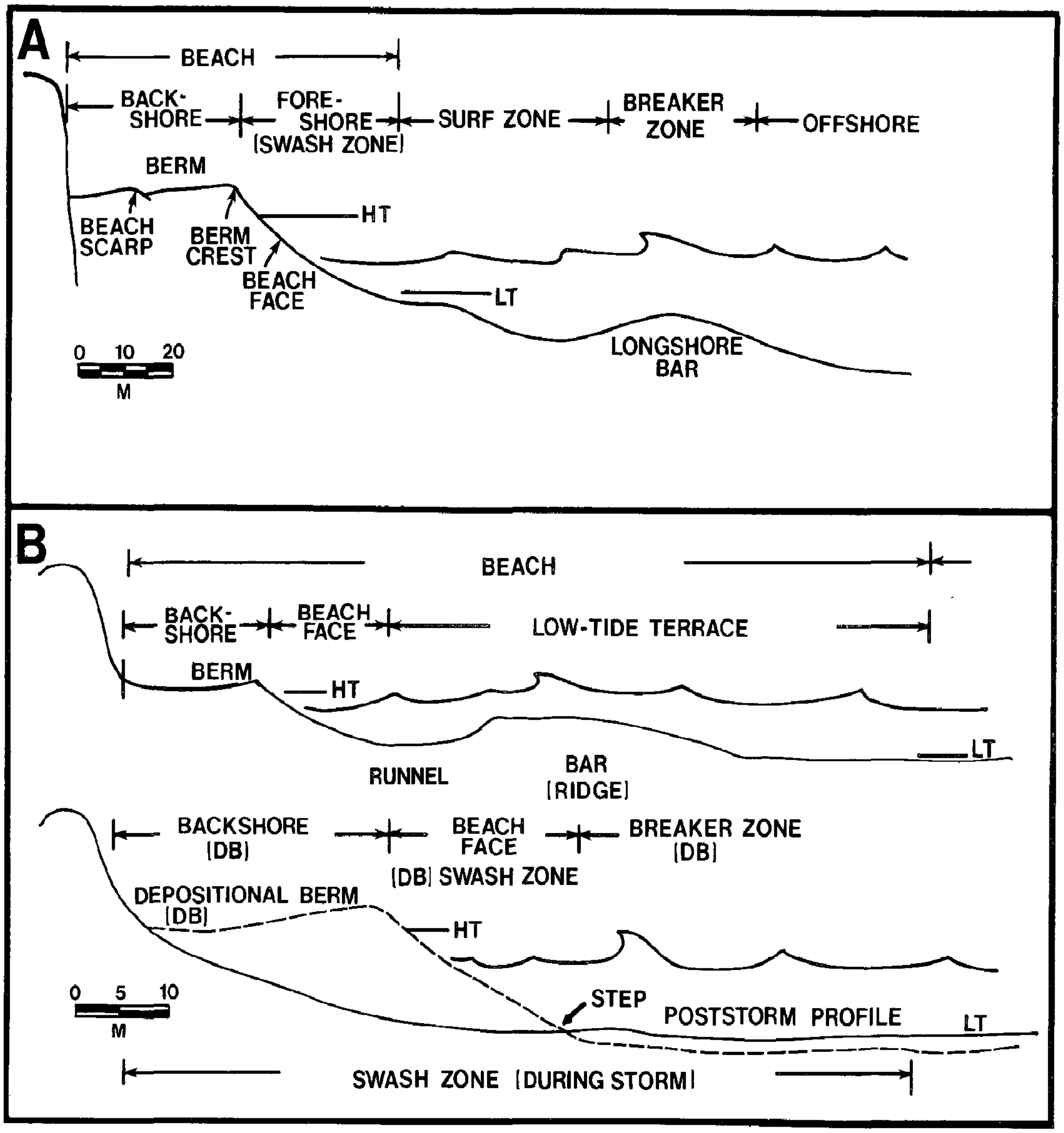

Figure 9. Examples of representative beach profiles from the west (A) and east (B) coasts of North America. The California profile (A) develops on a windward shore dominated by ocean swell, whereas the New England and South Carolina profiles (B) develop on a leeward shore dominated by storm waves. Tides are somewhat larger at the two east coast sites (mesotidal; tidal range = 2-4 m).

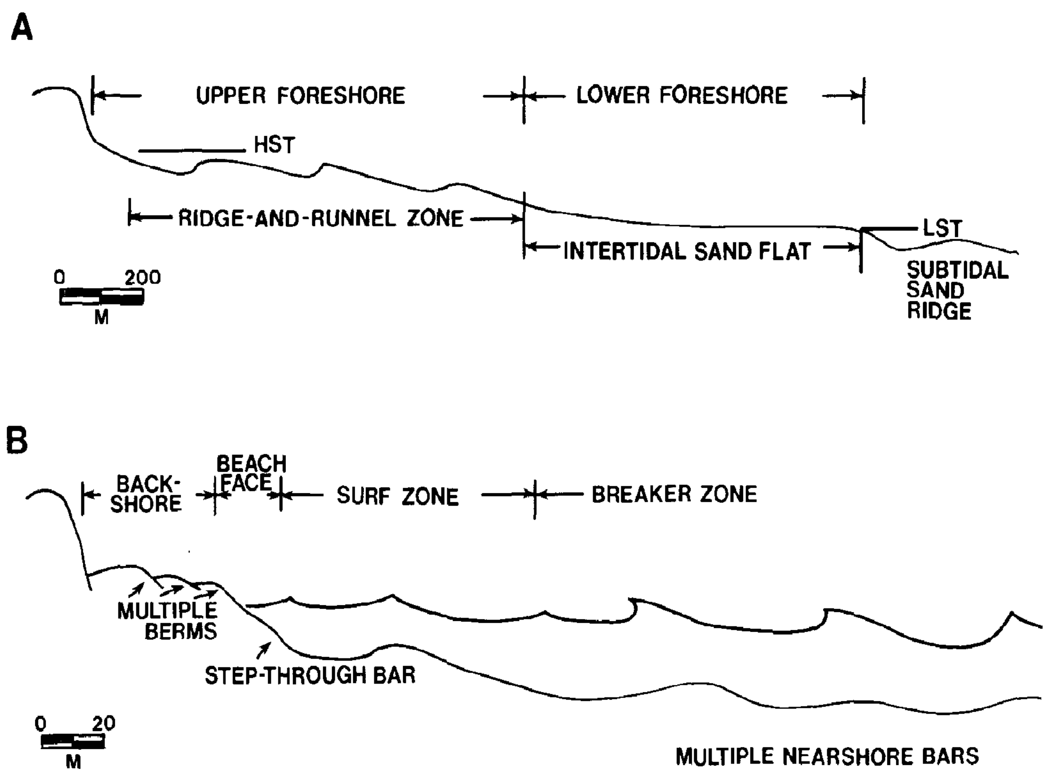

Figure 10. Examples of representative beach profiles from an exposed macrotidal coast (A) and a microtidal, or lake, shoreline with moderate waves and mixed sediment grain size (B). Example A (after Parker, 1975) is from the United Kingdom, but similar examples occur in other macrotidal settings in western Europe, Alaska, and elsewhere. Profiles like the one shown in B have been observed by the writer in the Gulf of Mexico and the Great Lakes. The ridge-and-runnel systems of A and the nearshore bar in B move landward during accretionary cycles, whereas the multiple nearshore bars in B are relatively stable.

These profiles are examples of sand beaches exposed to moderate-to-high wave action. Gravel beaches are typically steeper, more cuspate, and prone to having multiple berms.

Beach profiles can show considerable differences within similar geological and oceanographic settings. Examples from South Carolina (Figure 11) and south-central Alaska (Figure 12) illustrate this point. The differences in the South Carolina profiles are a function of differences in erosion rates, sediment types, and presence of seawalls and revetments. Differences in the Alaskan profiles are controlled by differences in grain size, exposure to waves, and proximity to tidal inlets.

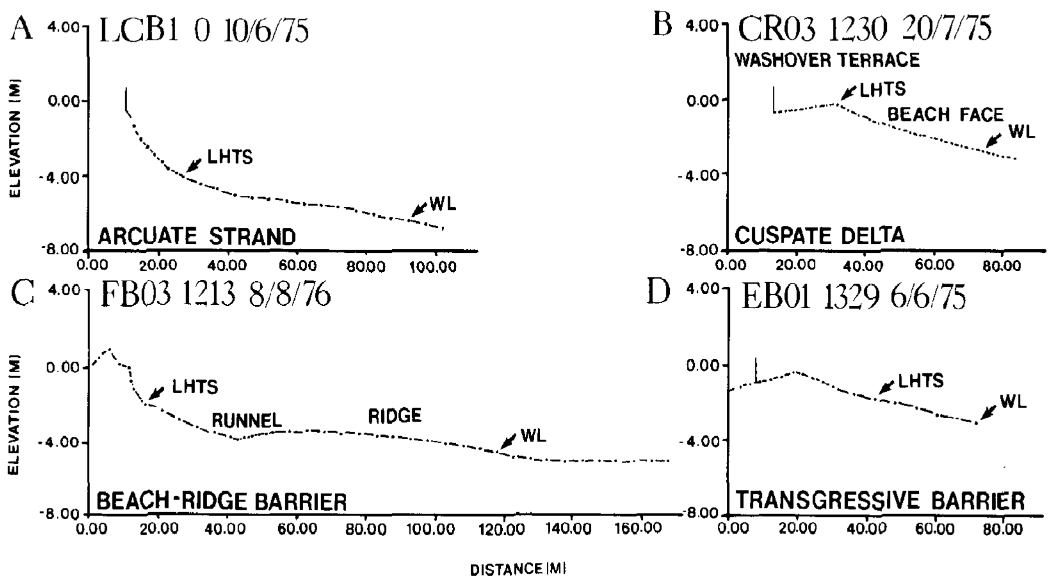

Figure 11. Representative beach profiles for four morphological provinces on the South Carolina coast. Profile A is in front of a seawall; profiles B and D, which contain abundant oyster shells, are on shoreward-retreating barrier islands; and profile C is in the middle of a fine-grained, prograding barrier island. LHTS = last high-tide swash line, WL = water level. Profiles were measured at low tide (from Hubbard et al., 1977a, Figure 4). Letters and numbers at top of each diagram indicate profile location and time and date of measurement.

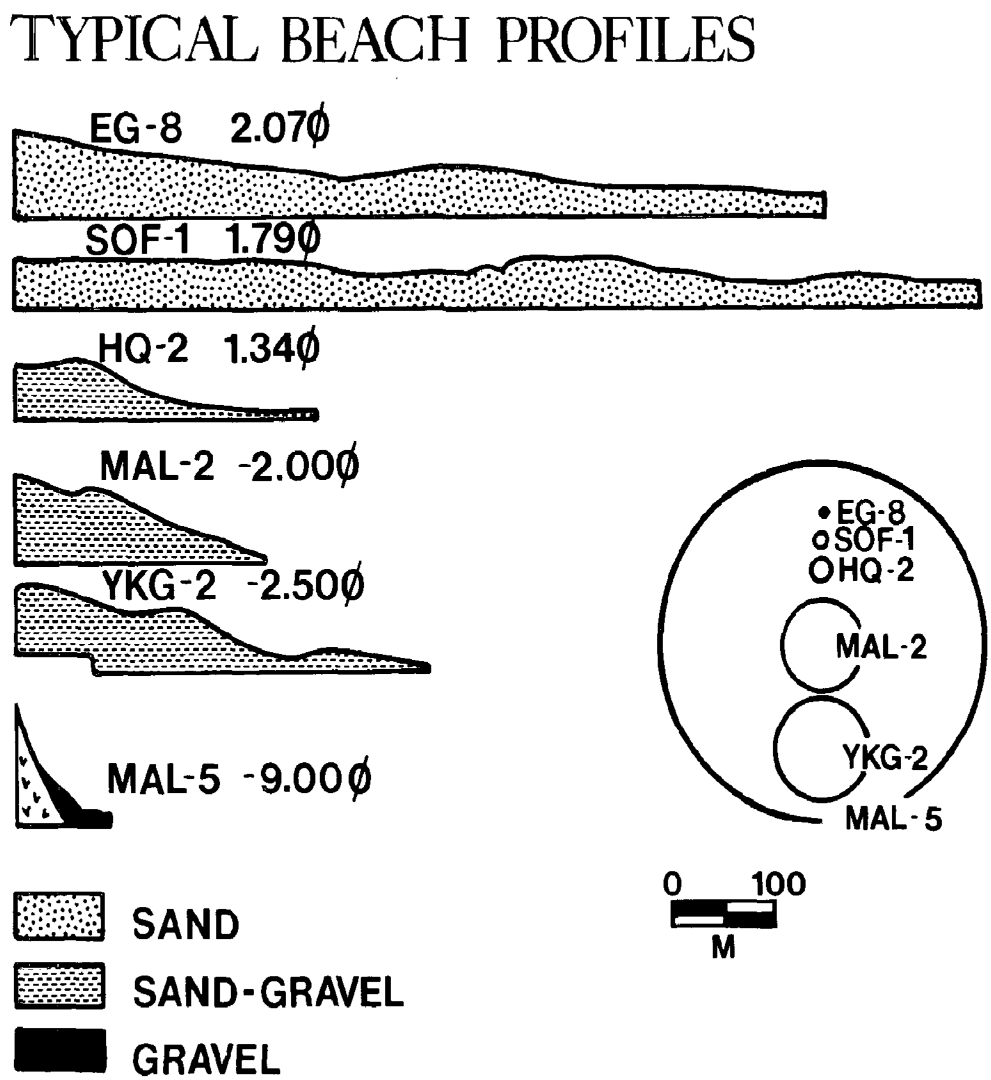

Figure 12. Typical representatives of intertidal beach profiles measured at over 100 stations along 600 km of glacial outwash plain shoreline in south-central Alaska. Note the correlation between beach width and mean grain size of the beach sediment (-2.0 ϕ = 4.0 mm; +2.0 ϕ = 0.25 mm). Profiles plotted at 5:1 vertical exaggeration. The circles in the lower right are ratio comparisons of the sizes of the sediments at each profile (using phi scale) (from Hayes et al., 1973, Figure 6). These differences in beach morphology within a single geographic area result from differences in exposure to waves and proximity to tidal inlets, as well as grain size of the beach sediment.

The slope of the beach face in a given area will attain an equilibrium profile under steady conditions. The profile attained is controlled principally by sediment grain size and wave height (Komar, 1976). Several field studies (Bascom, 1951; Wiegel, 1946; McLean and Kirk, 1969; DuBois, 1972) and wave tank experiments (Bagnold, 1940; Rector, 1954) show that coarser beaches have steeper slopes. Komar (1976, p. 303) explained why:

> Due to water percolation into the beach face and frictional drag on the swash, the return backwash tends to be weaker than the forward uprush. This moves sediment onshore until a slope is built up in which gravity supports the backwash and offshore sand transport.

He explained further that coarser beaches allow greater percolation, thus reducing the strength of the return backwash. Consequently, a steeper beach face is required to maintain an equilibrium profile on coarse-grained beaches. Beaches with poorly-sorted sediment tend to be somewhat flatter than those with well-sorted sediment, because of reduced percolation rates (McLean and Kirk, 1969). On beaches of comparable grain size, high-energy, exposed beaches have flatter slopes than low-energy, sheltered beaches, because larger waves produce stronger backwash which tends to flatten the profile (King, 1972; Komar, 1976). The relationship of beach slope to grain size and degree of exposure is illustrated in Figure 13.

2.10 The Beach Cycle

The concept of the cyclical change of beaches from a flat, erosional profile in winter to a wide, depositional berm in summer is well ingrained in both the popular and scientific literature. The concept originated from detailed studies on the west coast of the United States (Shepard, 1950; Bascom, 1954). Bascom's data are illustrated in Figure 14. Generally speaking, erosional storm waves are more common in the winter, and flatter, depositional swell waves are more common in the summer on the California coast--hence the terms summer and winter profiles. Galvin and Hayes (1969) observed a striking contrast between beach cycles on the U.S. east coast and those on the west coast. Eroded winter profiles are sometimes absent on northern Atlantic beaches, particularly in the New England area. This appears to reflect less severe wave climate and relatively smaller seasonal changes on the northern Atlantic coast. Mean wave heights and periods are 48 cm and 6.9 seconds along the northern Atlantic and 72 cm and

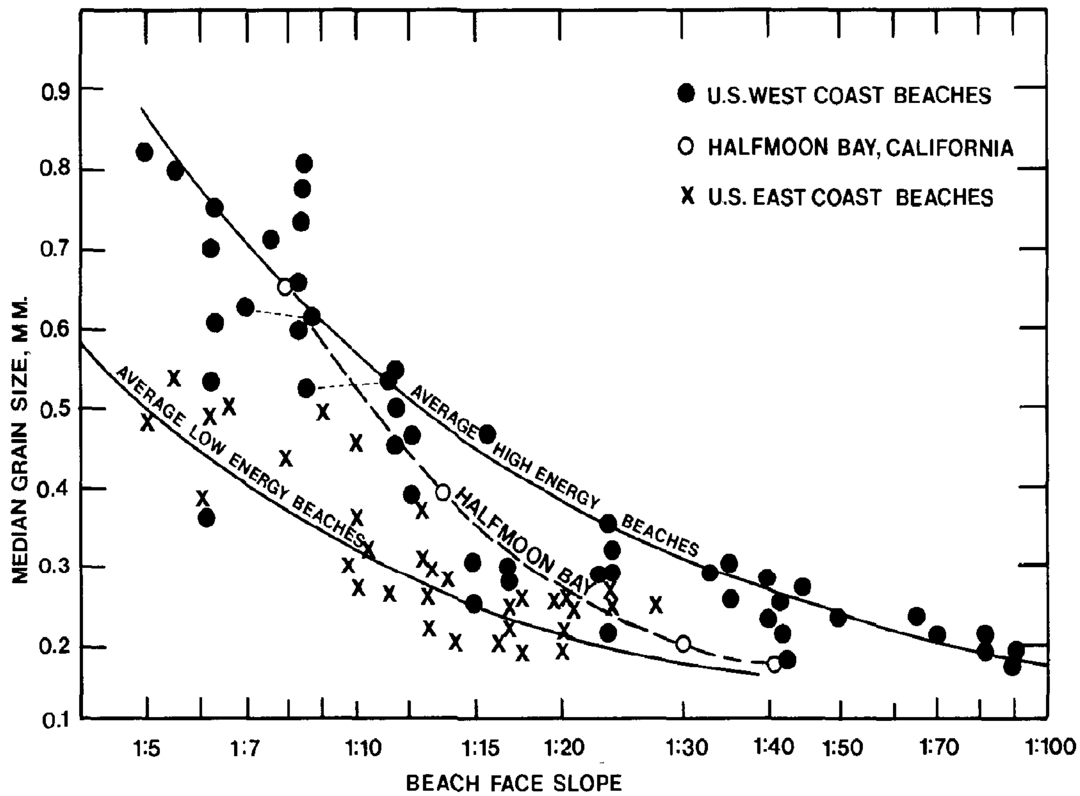

Figure 13. Relationship of beach grain size to beach-face slope on the east and west coasts of North America. The more exposed beaches of the west coast tend to have flatter slopes because of the large volumes of backwash produced by the larger waves. Halfmoon Bay, California, is partially sheltered by a headland, so its data points fall between the two extremes (from Komar, 1976, Figure 11-8; based on data of Bascom, 1951, and Wiegel, 1946).

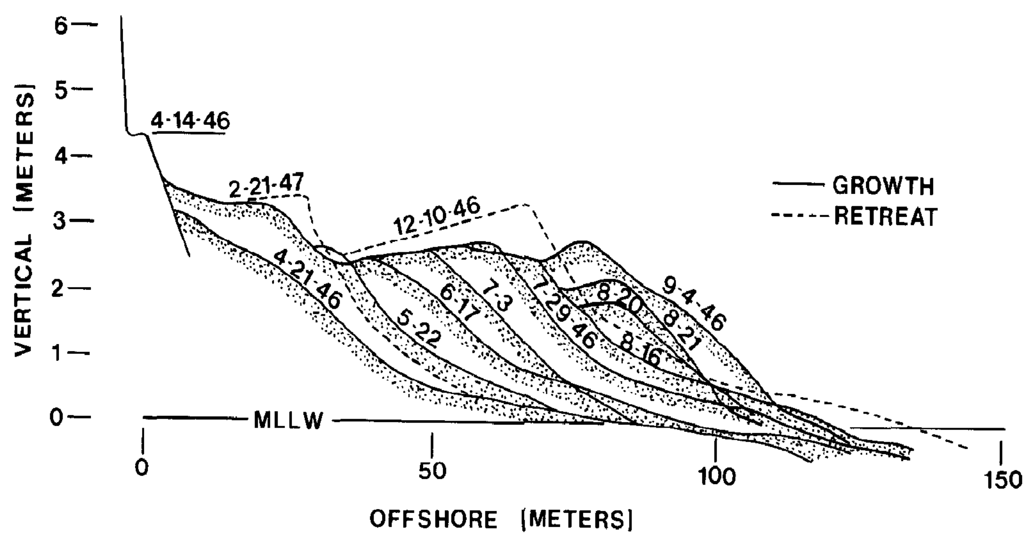

Figure 14. Growth and retreat of beach berm of Carmel, California, for dates ranging from 14 April 1946 to 21 February 1947 (after Bascom, 1954). These and other observations on the California coast gave birth to the concept of winter and summer beach profiles.

12.5 seconds along the California coast. These differences in wave climate result from differences in location on western and eastern edges of oceans with predominantly westerly winds.

The general consensus today is that the terms winter beach and summer beach should not be used with reference to erosional and depositional cycles on beaches. Hayes and Boothroyd (1969) used the terms early poststorm profile and late accretional profile, and Komar (1976) suggested storm profile and swell profile. Further comments on this concept follow:

> Davies (1973, p. 117): "On beaches where big storm waves are common, cut profiles tend to be present at all times: on those where they are rare, fill profiles become almost permanent features."
>
> Davis and Schwartz (1982, p. 144): "Some regions experience less coastal energy during the winter than during the summer (e.g., Queensland, Australia). Further, it is not uncommon to have an accretional profile in winter and an erosional or storm profile during the summer."
>
> Short (1978, p. 1159): "Application of these terms . . . (winter cut and summer fill) . . . to other wave environments including southern hemisphere west coast swell coast is often inappropriate and has led to much confusion and misunderstanding."

On the northern New England coast, northeasterly storms play a dominant role in the generation of cycles of erosion and deposition. Observations at 40 beach profiles covering most of the New England coast over a six-year period revealed the following stages of low-tide beach morphology relative to storm occurrences (Hayes and Boothroyd, 1969):

> Early poststorm (up to 3 or 4 days after storm) - Profile is flat to concave upward and beach surface is generally smooth and uniformly medium- to fine-grained. Severest storms leave erosional dune scarps.
>
> Early accretional, or constructional (usually 2 days to 6 weeks after storm) - Small berms, beach cusps, and ridge-and-runnel systems are quick to form.
>
> Late accretional, or maturity (6 weeks or more after storm) - Landward-migrating ridges weld onto the backbeach to form broad, convex berms. On some beaches, welding does not occur and gigantic ridges (up to 1.2 m in height) lie between the backbeach and the low-tide terrace.

Some typical examples of northern New England beach profiles are given in Figure 9.

There are some similarities between the New England beach cycle and that described for Nags Head, North Carolina, by Sonu (1968), who found that after passage of storm waves, a shallow inshore (subtidal) bar quickly migrated back to the intertidal beach zone and welded to the backshore on the North Carolina beaches. Work on the South Carolina coast (Hubbard et al., 1977a) shows that the South Carolina beaches follow a cycle similar to the New England and North Carolina cycles in the vicinity of inlets. In mid-barrier areas away from inlets, the beaches are usually flat or contain low-amplitude intertidal ridges that migrate very slowly in comparison with the areas near the inlets.

The rates of migration and final welding of the ridges (or bars) vary greatly from locality to locality. The bars in the Nags Head example (Sonu, 1968) took only two days to weld, and similar bars in Lake Michigan took nine days (Davis et al., 1971). At Plum Island, Massachusetts, a large berm was constructed over a two-week period. In contrast, it took an entire summer for the ridge at Crane Beach, Massachusetts, the barrier beach that adjoins Plum Island to the south, to migrate two-thirds of the way across the intertidal profile. Crane Beach is flat and fine-grained (average mean grain size around 0.25 mm), and the waves break on large, offshore bars. The Plum Island beach, on the other hand, is coarse-grained (average mean grain size around 0.4 mm) and steep, and the offshore bar is quite deep. Therefore, it is logical to conclude that differences in rates of migration of ridge-and-runnel systems are determined by:

1) Average wave height.
2) Slope of beach and adjacent offshore areas.
3) Grain size.
4) Length of time waves can work at a single level. Note that in areas where the tidal range is small (e.g., Lake Michigan), the migration rate is rapid (Davis et al., 1971).

As more and more data accumulate, it is becoming clear that simple, two-dimensional beach profiles do not adequately express the dynamic behavior of beaches. Analysis of 4,400 beach profiles collected over a ten-year period along three New Jersey barrier islands (Everts and Czerniak, 1977) did show that two out of three of the islands have seasonal erosional/

depositional trends (Figure 15). However, one island showed no seasonal pattern and "storm changes were highly variable between islands and between profile lines on the same island. Often changes on profile lines less than 0.8 km apart were opposite in sign" (p. 444). These findings indicate that changes alongshore may be as important as onshore/offshore changes. Thus, understanding beach morphology is a three-dimensional problem.

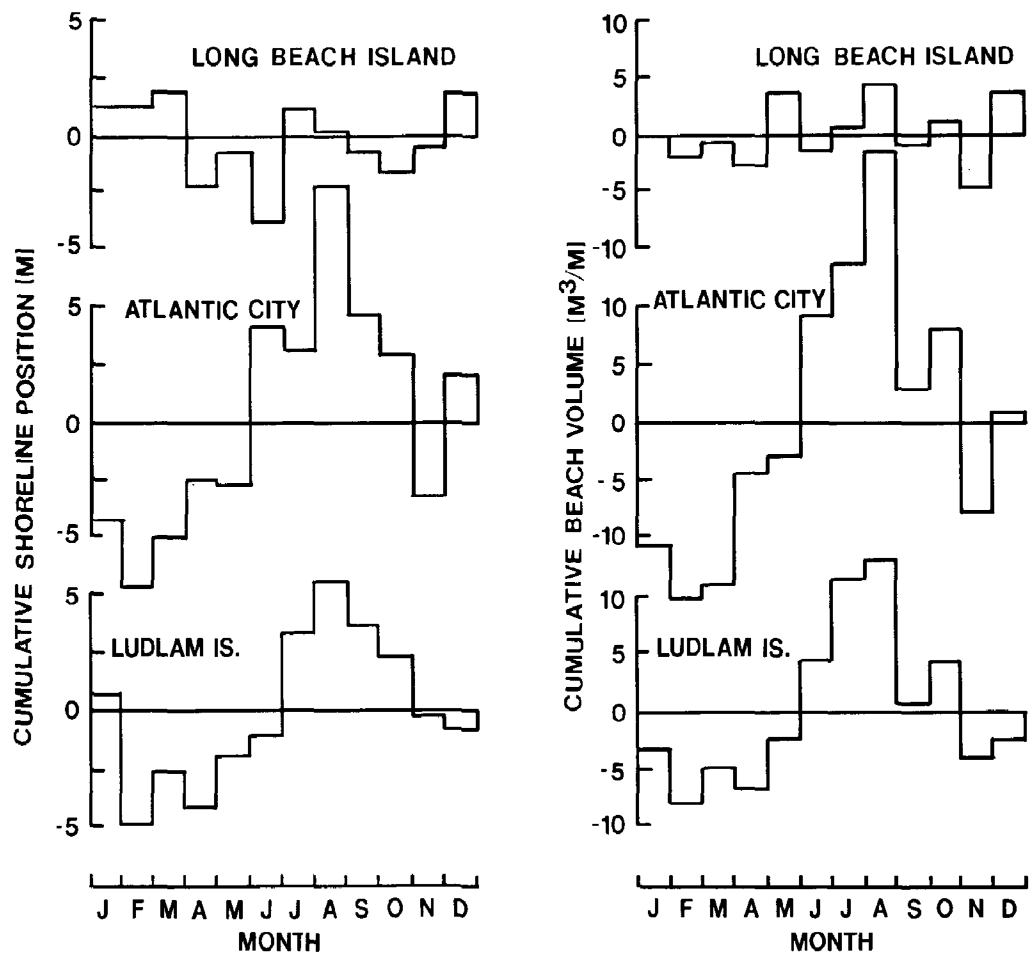

Figure 15. Beach changes on three barrier islands in New Jersey in terms of cumulative shoreline position and relative volume of sand in storage on the beach above MSL. Note that two islands show seasonal patterns of change, whereas one (Long Beach) does not. Based on 4,400 profile measurements (after Everts and Czerniak, 1977, Figure 4).

2.11 The Three-Dimensional Beach

The beach is a three-dimensional body of sediment made from material carried to the site by wave-generated currents which flow both parallel and perpendicular to the shore. On many sandy shorelines, a type of rhythmic beach topography (Hom-ma and Sonu, 1962) develops. This topography has been described from the coasts of the Netherlands (Bruun, 1954; Bakker, 1968), North Carolina (Dolan, 1971; Dolan and Ferm, 1968), the Great Lakes (Evans, 1939), Cape Cod (Goldsmith and Colonell, 1970), and several other localities. Sonu (1968), who termed the features "cusp-type sand waves," discussed them in detail. He stated (p. 383) that Evans (1939) was probably the first to describe their formation. The total system of rhythmic topography migrates parallel with the shore in the direction of longshore drift at different rates, depending upon the size of the features, the local wave climate, and probably the grain size of the sediment. In the process of formation of rhythmic topography, depositional berms assume cusp-like shapes; however, these cuspate forms are considerably larger than normal beach cusps. The wave lengths of most of the cusp-type sand waves at Cape Hatteras, North Carolina, ranged between 500 and 600 m, and they migrated at rates averaging between 100 and 200 m per month (Dolan, 1971, p. 177). The most important implication of the recognition of the abundance of rhythmic topography, according to Dolan (1971, p. 178), is the fact that "sand beaches cannot be considered in terms of stationary straight lines or simple angles, but must be treated as nonstationary sinuous forms." A sketch of the type of rhythmic topography described by Sonu (1968; 1973) is given in Figure 16.

Studies in recent years on the microtidal, sandy beaches of the swell-dominated southeastern coast of Australia have provided a more detailed accounting of the three-dimensional variability of high-energy beaches (Short, 1978, 1979; Wright et al., 1979; Wright, 1980). Short (1978, p. 1,146) proposed a time series of wave and beach conditions separated into ten beach stages, four erosional, four accretional, and the two end stages of fully eroded and fully accreted profiles (see Figure 17).

The combined work of Short, Wright, and their colleagues on the southeastern coast of Australia gave birth to the concept of morphodynamics, which is defined as the "combination of beach-surfzone morphology and wave-

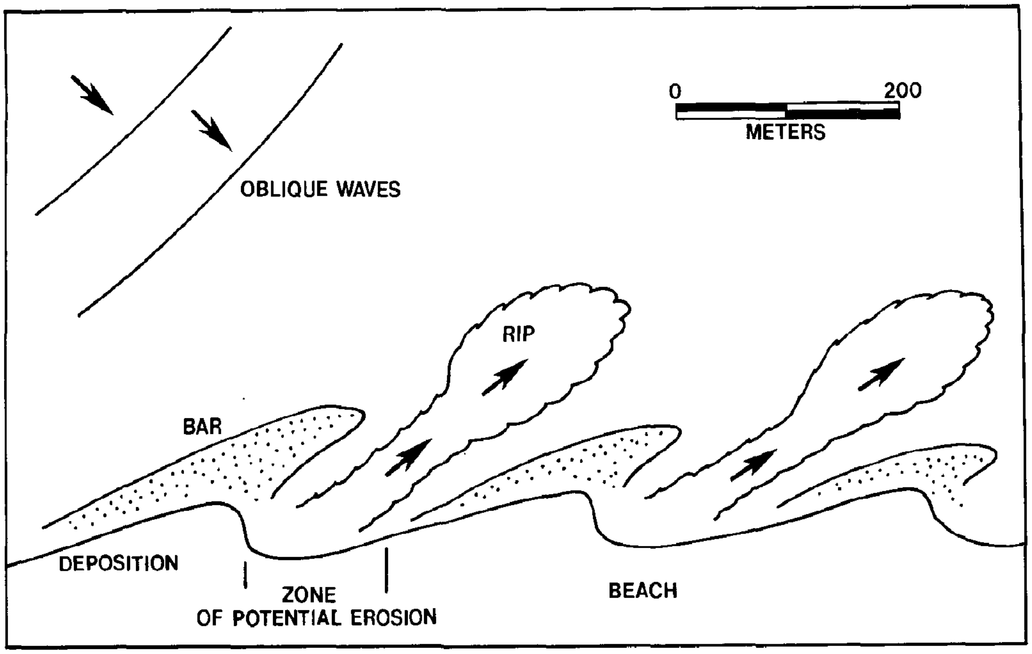

Figure 16. Rhythmic beach topography as described by Sonu (1973). The shoreline bulges move in the direction of longshore sediment transport at rates of up to hundreds of meters per year.

current dynamics" (Short, 1979, p. 553). Short (1979, p. 567) stated that "breaker wave power provides the energy to move a beach through various beach stages" (shown in Figure 17). Wright et al. (1979) placed emphasis on the reflective and dissipative nature of beaches, based on extensive field measurements of surf and inshore current spectra and inshore circulation patterns.

According to Wright et al. (1979, p. 105), reflective beaches are characterized by steep, linear beach faces, well-developed berms and beach cusps, and surging breakers with high runup and minimum setup; rip cells and associated three-dimensional inshore topography are absent. Dissipative beaches are typically found on open coasts and are characterized by concave-upward nearshore profiles and wide, flat surf zones which may contain multiple bars. Waves break tens of meters seaward of the beach and dissipate much of their energy before reaching it. Typical reflective and dissipative beach profiles are shown in Figure 18.

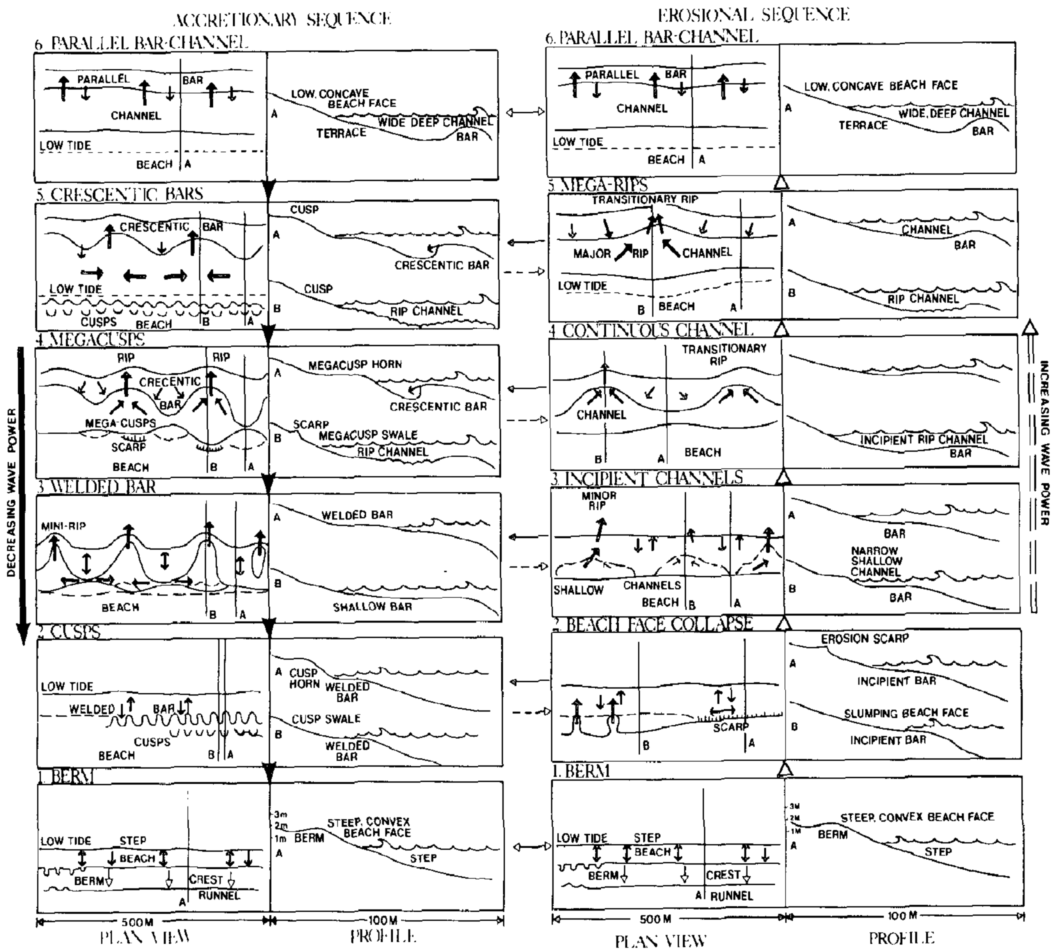

Figure 17. Three-dimensional beach-stage model proposed by Short (1978, 1979) for the microtidal, high-energy beaches of southeastern Australia: (a) accretionary sequence (6 → 5 → 3 → 2 → 1) during decreasing wave power (a function of wave height) (solid arrows); (b) erosional sequence (1 → 2' → 3' → 4' → 5' → 6) during increasing wave power (clear arrows). Arrows within stages indicate the direction of surf-zone currents, small arrows at incident frequency, large arrows at lower (infragravity) frequencies. Arrows between adjacent stages show the direction of movement accompanying a rise or fall in wave power. Note movement can occur within and between the two sequences. Positive transition within stages 1, 2, 2', 3, 3', and 4 is represented by the variation in morphology from left to right (from Short, 1979, Figure 3).

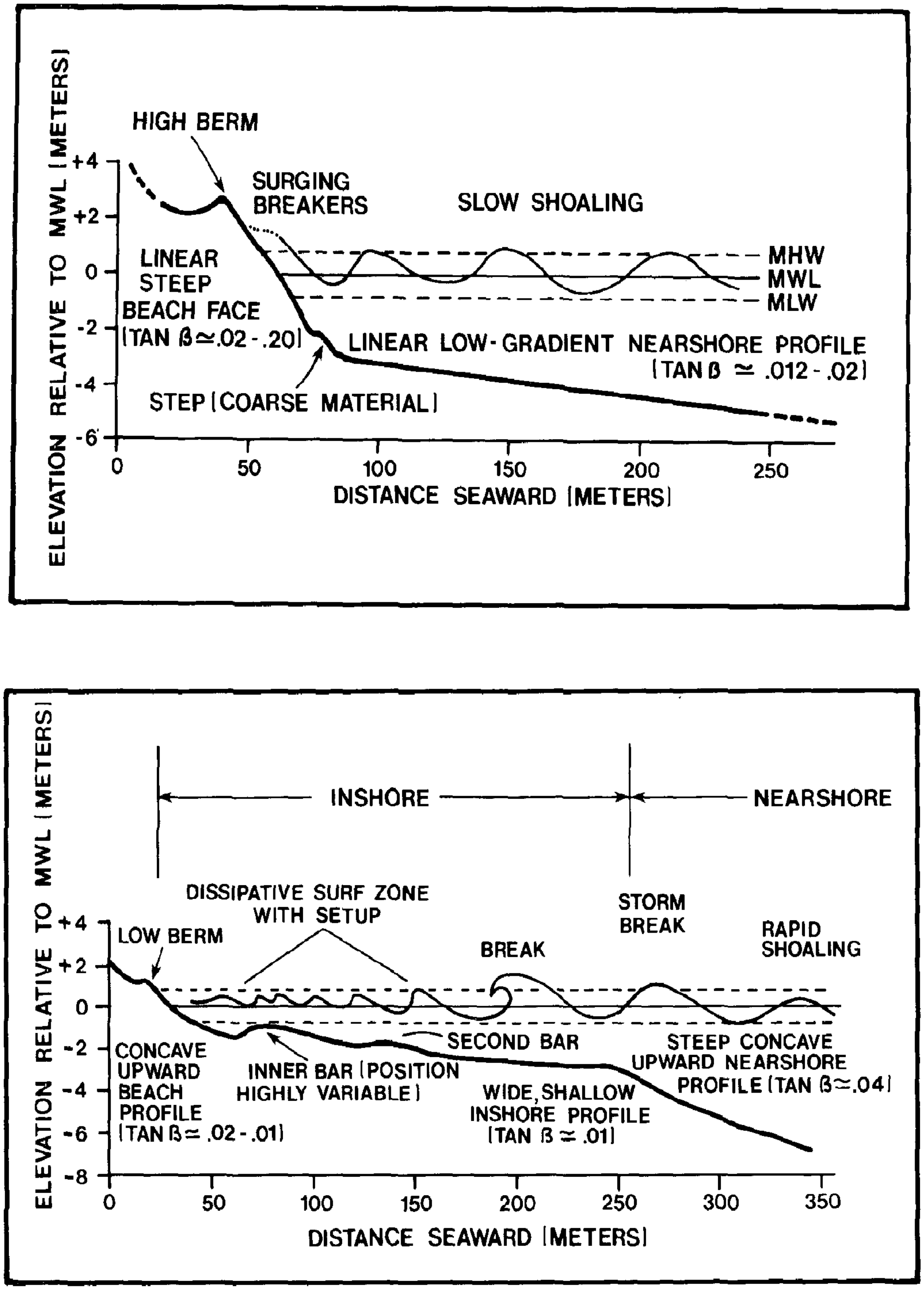

Figure 18. Typical cross-section profiles of reflective (top) and dissipative (bottom) beach profiles (from Wright et al., 1979, Figures 3 and 6).

In a later paper, Wright (1980) related beach cut, or beach erosion, to the morphodynamic state of the beach with respect to its reflective or dissipative character. He envisioned three modes of beach cut in relation to beach state which are outlined in Table 3. Wright defined six stages of beach development, five of which are dissipative. The intermediate classes, which contain complex nearshore topography, show the greatest mobility and "relative hazard" of potential beach erosion. However, steep, reflective beaches are more susceptible to erosion by smaller waves than the other types. The most energy is required to erode flat, dissipative beaches.

TABLE 3

Modes of beach erosion (cut) in relation to morphodynamic beach state (after Wright, 1980, Table 1)

MODE OF BEACH EROSION	CAUSE	ASSOCIATED BEACH AND SURF-ZONE CONDITIONS	RELATIVE ENERGY REQUIRED TO INDUCE BEACH EROSION
1) Accentuated runup and berm overtopping, formation of erosional cusps	Strong subharmonic resonance	REFLECTIVE	LOWEST
2) Backshore scarping by bores superimposed on long period setup oscillations	Strong infragravity oscillations	DISSIPATIVE	HIGHEST
3) Beach scarping in embayments of arrested rip cells	Radiation stress gradients induced by irregular surf-zone topography	INTERMEDIATE-RHYTHMIC Surf-zone topography in regions adjacent to shoreline protrusions, inlets, or river mouths	INTERMEDIATE

Many of the beaches studied by Wright and Short occur in spiral embayments. Short (1978) showed the variation of breaker wave power within such embayments, and Wright (1980) showed the variation of beach reflection/dissipation as well as modes of beach erosion (see Figure 19). These studies add a new dimension to dealing with beach erosion problems. Wright (1980, p. 993) concluded:

> Since the physical processes responsible for cut are different, different beach protection strategies may be required for different morphodynamic states. For purposes of long-term advance planning, it is the modal beach states and/or normal range of states that are important. These may be recognized from sets of long-term ground or remotely-sensed observations.

2.12 Nearshore Bars

Bar systems develop off beaches in a vast array of forms and numbers, ranging from a single parallel bar to up to 40 multiple bars. They are important to beach erosion in that they act as storage systems during storms, affect sediment transport perpendicular and parallel to shore, and influence wave behavior. A classification of common nearshore bar types is given in Table 4. The formation of nearshore bars is not well understood. Some of the more commonly proposed mechanisms are given in Table 5.

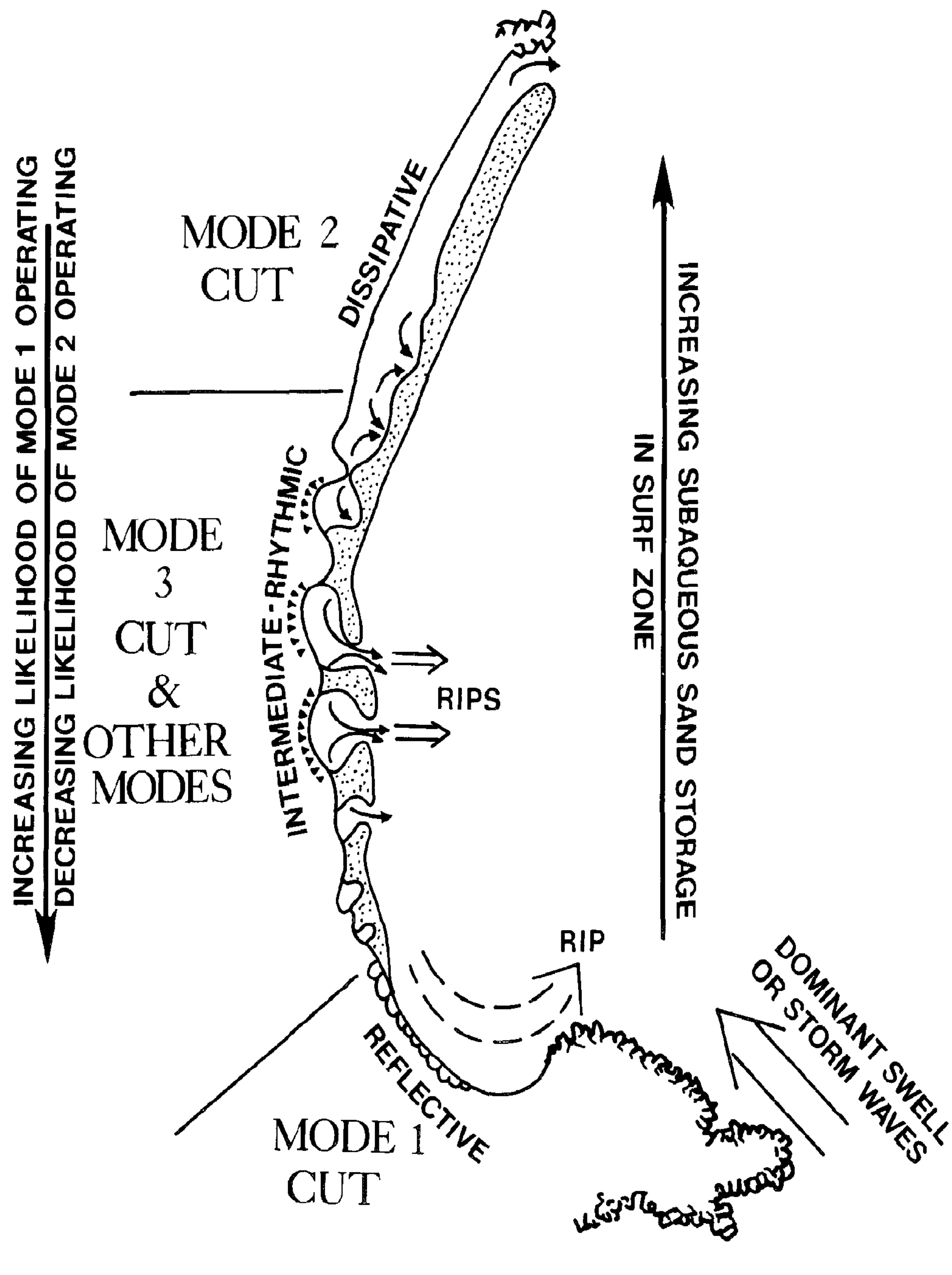

Figure 19. Distribution of modal beach state and associated modes of beach erosion (cut) within a typical spiral embayment in southeastern Australia (from Wright, 1980, Figure 12).

TABLE 4

Bar classification (slightly modified after Greenwood and Davidson-Arnott, 1979)

Name	Definitive Description	MORPHOLOGY					PHYSICAL CONTROLS			
		Size	Planform	Profile	Number Seaward	Location	Wave Energy	Wave Processes	Near-shore Slope	Inter-tidal Slope
Ridge and runnel	King (1972)	$h \sim 0.2\text{-}1.5$ m $\ell \sim 10^3$ m	Straight, shore parallel	Asymmetric landward	1-4	Intertidal	Low to moderate	Surf-swash, beach drainage	-	<0.01
Cusp- or bar-type sand wave	Sonu (1968) Davis and Fox (1972)	$h \sim 0.2\text{-}1.5$ m $\ell \sim 10^2$ m	Straight to spit-shaped, shore parallel	Asymmetric landward	1-2	Intertidal and low-tide terrace	Moderate	Breakers, surf-swash	-	>0.01
Multiple parallel	Zenkovich (1967)	$h \sim 0.2\text{-}0.75$ m $\ell \sim 10^3$ m	Straight to sinuous, shore parallel	Near symmetric	4-30 or more	Nearshore and intertidal	Low to moderate	Spilling breakers, surf	<0.01	-
Transverse	Niedoroda (1973)	$h \sim 0.2\text{-}0.75$ m $\ell \sim 10^2$ m	Straight, shore normal	Symmetric and asymmetric landward	1	Nearshore and intertidal	Low	Surf-swash, spilling breakers	<0.01	-
Nearshore I	Shepard (1950)	$h \sim 0.25\text{-}1.0$ m $\ell \sim 10^2$ m(?)	Straight, shore parallel	Asymmetric landward	1-2	Nearshore	Moderate to high	Plunging breakers	<0.1	-
Nearshore II	Evans (1940) Hom-ma and Sonu (1962)	$h \sim 0.25\text{-}3.0$ m $\ell \sim 10^3$ m	Straight, sinuous to crescentic, shore parallel	Asymmetric landward	1-4	Nearshore	Moderate	Spilling breakers	<0.01	-

h = bar height; ℓ = bar length

TABLE 5

Mechanisms controlling types of nearshore bars.

Bar Type	Mechanism	Reference
Nearshore I (see Table 4)	Vortices under plunging waves	Miller (1976)
Multiple parallel bars	Mass transport velocities under reflected standing waves	Suhayda (1974)
Nearshore II (see Table 4)	Standing edge waves	Bowen and Inman (1971)

3. CAUSES OF BEACH EROSION

Beaches erode when waves remove sediment that is not returned or otherwise replaced. This can occur aperiodically as a result of storms or as a relatively steady, ongoing process. A specific site has its own individual response to erosive processes which are affected by a number of variables, some of which are discussed below.

3.1 Coastal Morphology

3.1.1 Introduction

The morphology, or shape, of the coast exerts a strong influence on coastal erosion as well as on the disposition of coastal environments and habitats. Larger scale features such as continental shelf width, the occurrence of headlands, and the presence of tidal inlets, as well as smaller scale features such as the presence of rhythmic topography and hard ground, may play important roles in the erosion process.

3.1.2 Shelf Width

The continental shelf is generally defined as that zone between the shoreline and the position where the break in shelf slope begins. A narrow shelf allows waves to arrive at the coast at greater heights and at a greater angle than on a wider shelf because the waves do not shoal or refract as much. Also, it is possible that nearshore sediment is more readily lost to the offshore zone of narrow shelves during periods of high wave activity because of the relatively steep slope.

3.1.3 Effect of Headlands

Headlands tend to focus waves and serve as protection of shorelines downdrift. In some places, the headlands act as natural groins. For example, rock promontories located at various points along the coast of West Africa give rise to the formation of embayments on their downdrift sides, such as Cape Saint-Paul east of the Volta, the bay of Pointe-Noire, and the bay of Mayumba. The amount of recession of these bays depends upon the degree of protection provided against the swell by the rock promontories.

3.1.4 Effect of Tidal Inlets

Natural tidal inlets are breaks in barrier beaches that occur at the entrances to estuaries or lagoons. The tidal inlet allows the daily or semidaily exchange of water generated by changes in tidal levels and river runoff. Inlets are generally unstable, moving downdrift at rates that vary from less than one meter to tens of meters per year depending upon such factors as rate of longshore sediment transport and inlet depth. A shoal usually develops seaward of the inlet (called an ebb-tidal delta) which affects the behavior of waves in the vicinity of the inlet. The size of the ebb-tidal delta is a function of tidal range, tidal prism, and wave conditions. Generally speaking, large tides create extensive ebb-tidal deltas because of the larger tidal prism (volume of water passing through the inlet) created by the tide. Large waves tend to erode away ebb-tidal deltas; hence, they are smaller in areas of high wave activity.

Studies of a number of tidal inlets on the east coast of the United States show that erosional/depositional patterns of adjacent beaches are controlled closely by morphological changes of the inlets (Hayes et al., 1974). For example, waves refracting around the ebb-tidal deltas create a zone of deposition downdrift of the inlet. Sand bars affiliated with the tidal delta also create local zones of erosion and deposition by focusing wave energy through wave refraction. As the inlet changes, and the bars shift position, loci of the focused wave energy will change. And, of course, as the inlet migrates, the shoreline downdrift is eroded away. An example of a rapidly migrating tidal inlet is given in Figure 20.

3.1.5 Rhythmic Topography

Shoreline rhythms migrate along the shore at rates of several hundred meters to a kilometer or so per year. As the system migrates, zones of erosion, which occur in the embayments, migrate at the same rate (Figure 17). Dolan (1971) emphasized the importance of shifting rhythmic topography on local beach erosion at Bodie Island, North Carolina (U.S.) by demonstrating that the regular spacing of dune breaching during the Ash Wednesday storm of March 1962 matched the rhythmic topography. Dolan also showed that intense beach erosion at Cape Hatteras, North Carolina (U.S.) corresponds to the embayments of rhythmic topography.

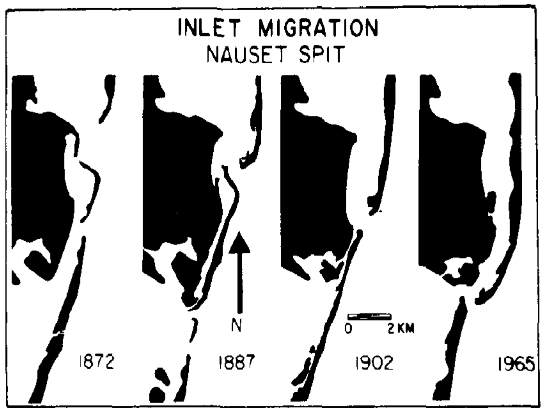

Figure 20. Example of a rapidly migrating tidal inlet, Nauset Inlet, Massachusetts. Note the continuous southerly migration of the inlet since 1872. Such migration is accompanied by dramatic changes in the beaches on either side of the inlet (from Hine, 1972, Figure 4).

3.1.6 Hard Ground

The existence of wave-resistant material, such as rock, beach rock, or coral reefs, on or near a beach can slow down coastal erosion considerably. Barrier reefs act to absorb most of the wave energy before it reaches the beach; therefore, sand movement is usually low behind such reefs.

3.2 Vegetation

Vegetation is helpful in trapping sediment in motion. This is especially true for windblown sand at the high-tide line, where a foredune ridge commonly forms as a result of this process. However, in the writer's opinion, the importance of coastal vegetation in stopping beach erosion is overrated considerably. A breaking wave has no difficulty eroding sprigs of grass. While planting vegetation will help build up a dune line, greater measures are usually required to deal with serious erosion problems.

Vegetation in the nearshore zone can act directly to reduce erosion somewhat by physically binding the sediment and reducing turbulence near the sediment surface. In certain lagoons and bays, mangroves and marsh grass accelerate sedimentation of silt and clay (Williams and Harvey, 1983).

3.3 Sea-Level Changes

Sea level has been rising since the end of the last glacial epoch, approximately 14,000 to 18,000 years before present (BP). Between 14,000 and 7,000 BP, the sea rose rapidly, and the shoreline retreated across the continental shelf (Milliman and Emery, 1968). According to Kraft (1971), sea level rose at a rate of about 30 cm per century between 7,000 and 3,000 BP along the east coast of the United States.

Caution must be exercised in applying sea-level curves from one area to another, as can be seen in Figure 21, a plot of Holocene sea-level curves from 11 places around the world. The fact that a relative still-stand of sea level began around 5,000-4,000 BP (Figure 21) is of great importance to the problem of beach erosion. It is during this period of relative still-stand that most of the sandy beaches and barrier islands of the world were formed.

Detailed studies on the east coast of the United States show that sea level rose as much as 10 cm between 1964 and 1971 (Figure 22). This recent and relatively rapid rate of sea-level rise of roughly 15 cm per decade is probably only a short-term fluctuation. Some experts believe that this recent, rapid sea-level rise may be responsible for an increased occurrence of erosion problems during the last two decades (O. H. Pilkey, pers. comm.). Others predict that sea level will continue to rise fairly rapidly in the future due to atmospheric heating (Hoffman, 1983). If this is so, beach erosion problems will increase.

The theory that a rising sea level brought about by melting ice sheets is the major cause of beach erosion worldwide prevails in both scientific and popular literature (Concerned Coastal Geologists, 1981). This widely held notion is illustrated in Figure 23. A careful analysis of beach erosion in a variety of settings casts considerable doubt on this assumption, particularly with regard to problems of concern in the near future (±50 years from now). In fact, this writer is of the opinion that, in most cases, man's impact on sediment supplies and unwise construction practices cause most beach erosion problems. However, the opinions of the experts differ markedly on this topic, as the following discussion shows.

Russell (1967) hypothesized that the present "still-stand" of the last 5,000 years or so (Figure 21) has, in fact, caused erosion by bringing

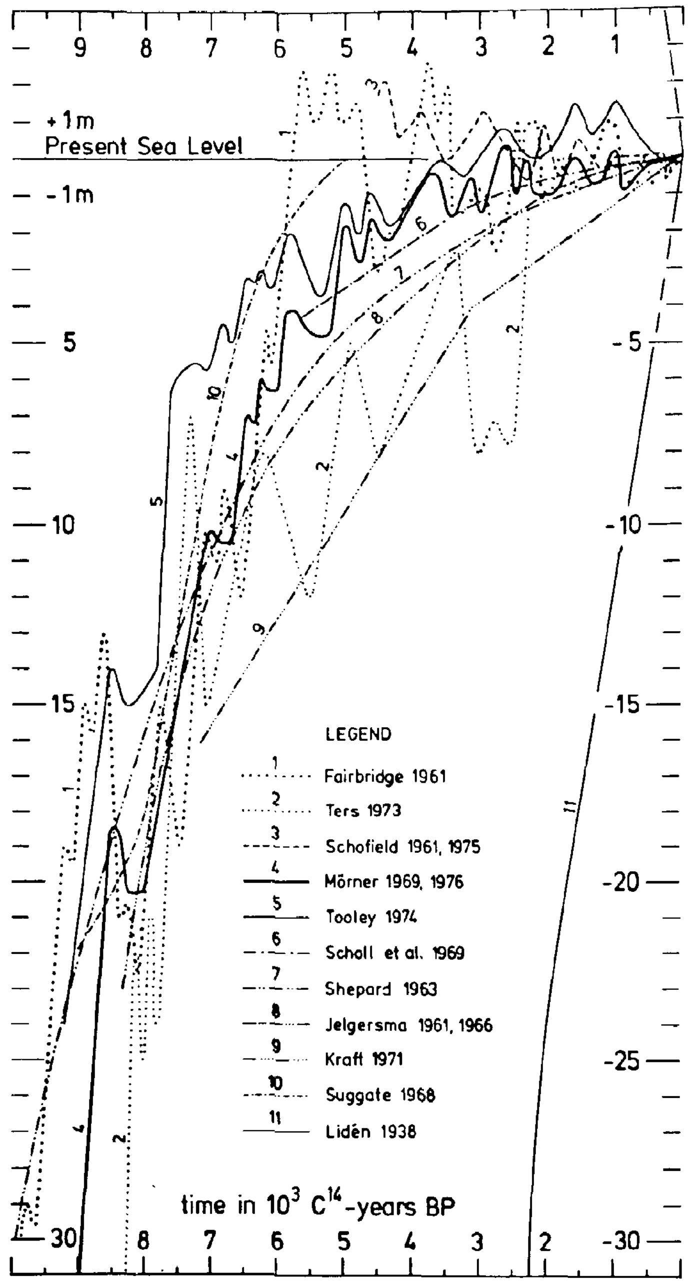

Figure 21. Eleven Holocene sea-level curves representing different parts of the globe. Curves 1-4, 6-7, and 10 are supposed to be eustatic (absolute sea-level) curves. The others are relative sea-level curves (with curve 11 being plotted with changed sign) (from Mörner, 1982, Figure 1). The great differences among these curves stress two factors: (a) the differences in tectonic conditions around the world's coastline, and (b) the imperfection of the techniques used for sampling and age dating of Holocene sediments.

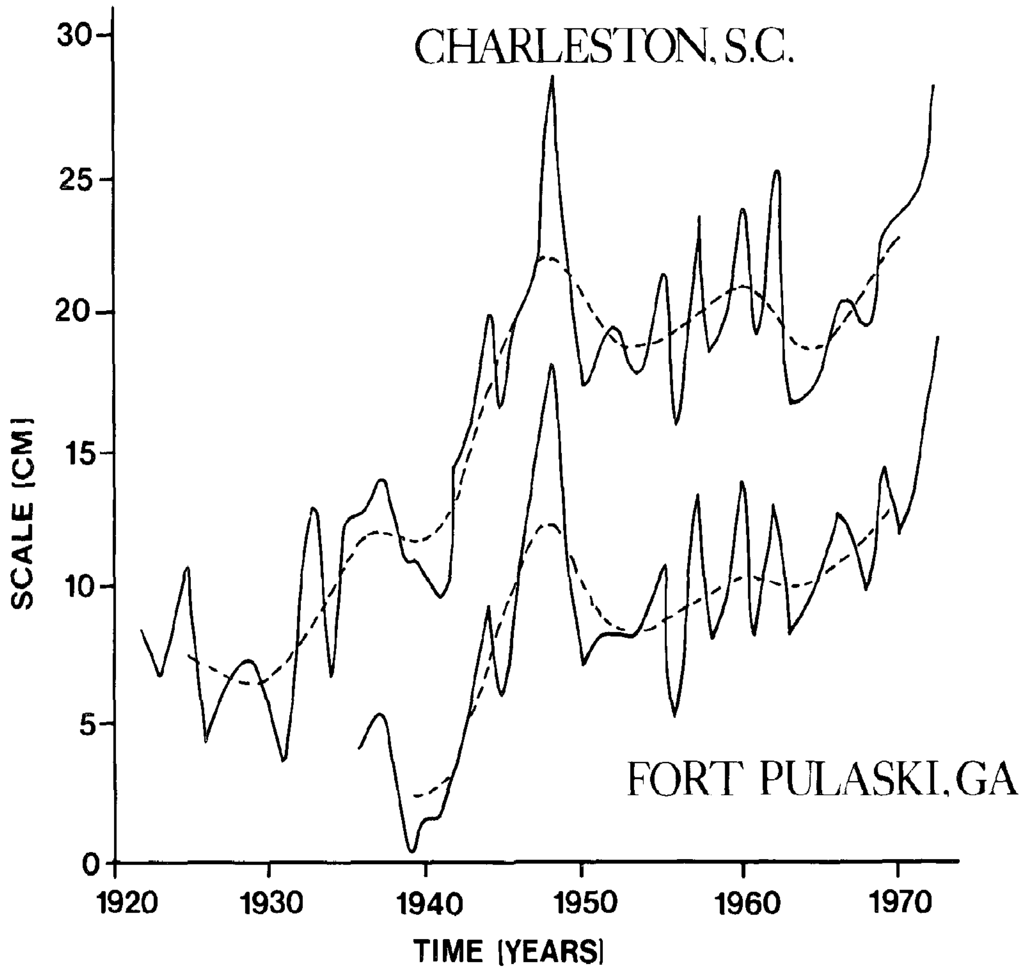

Figure 22. Changes in sea level with respect to the adjacent land at Charleston, South Carolina, and Pulaski, Georgia (from Hicks and Crosby, 1974). These curves illustrate a rapid increase in rate of sea-level rise over the past 50 years.

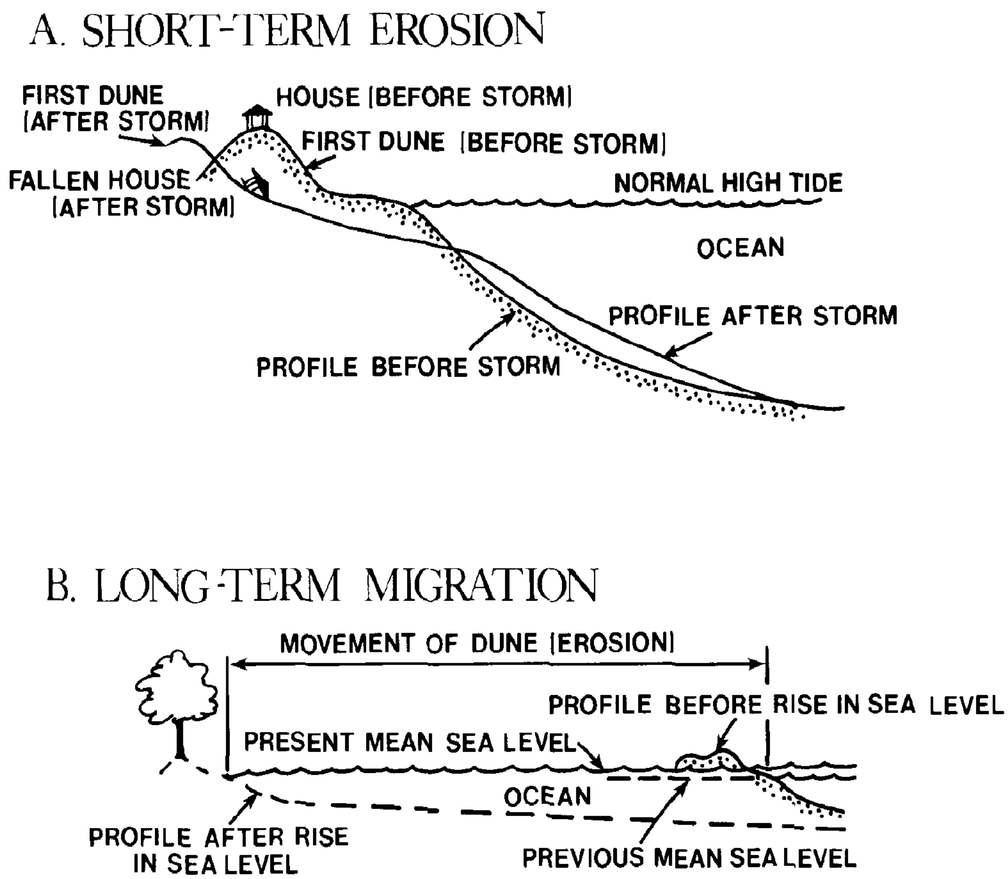

Figure 23. Beach and dune changes resulting from storms and the relative rise of sea level (modified after Pilkey et al., 1975). Note that, according to this idea, the catastrophic event (storm) and the slow change (sea-level rise) work together to achieve shoreline retreat.

about a period of disequilibrium in which sand lost is not replaced by new supplies. He assumed that the rapidly rising sea of earlier times had somehow brought large volumes of sediment to the shore zone.

Galvin (1983, p. 2,084), in challenging a report by Concerned Coastal Geologists (1981), asserted that "sea-level change has negligible effect on shore erosion, compared to fluctuation in longshore transport rate." On a site-specific basis, Galvin's assertion is demonstrably true. In South Carolina, for example, beaches that are eroding tens of meters per year are located within a few kilometers of shorelines accreting tens of meters per year. The differences are usually related to sediment bypassing at major tidal inlets. On the other hand, changes in water level clearly impact shoreline erosion in the Great Lakes (Hands, 1977), which show 11-year cycles of major water-level changes. Hands concluded (p. 162):

> Extrapolation from studies on Lake Michigan suggests that even modest rates of submergence can have measurable effects on shore erosion and profile development. Profile response on the lakes is evident across a 500 m wide zone, to a depth of about 9 m. The relationship between submergence and recession is nonlinear and time-dependent. Complete profile adjustment lags years behind changes in water level. Greater retreat is observed in areas where recession supplies a smaller volume of material per unit of retreat. This is in keeping with the sediment budget concept of profile response.

For any given coastal area not unduly influenced by man, it is the interaction of sediment supply and water-level changes that controls beach erosion. In some areas, fluctuations in sediment supply prevail, and in others, rapid changes in water level are most important. The most serious erosion problems occur either where man interferes with sediment supply or where some unusual phenomenon causes unusually rapid changes in water level e.g., in Lake Michigan and around sinking abandoned delta lobes on the Mississippi delta).

3.4 Storms

The most dramatic erosion of shorelines occurs during major storms, which usually result from the passage of tropical or extratropical cyclones. Much of the eastern and southern shoreline of the United States is affected by a tropical cyclone, or hurricane, every few years (Figure 24). Shepard and Wanless (1971) in their book Our Changing Coastlines described

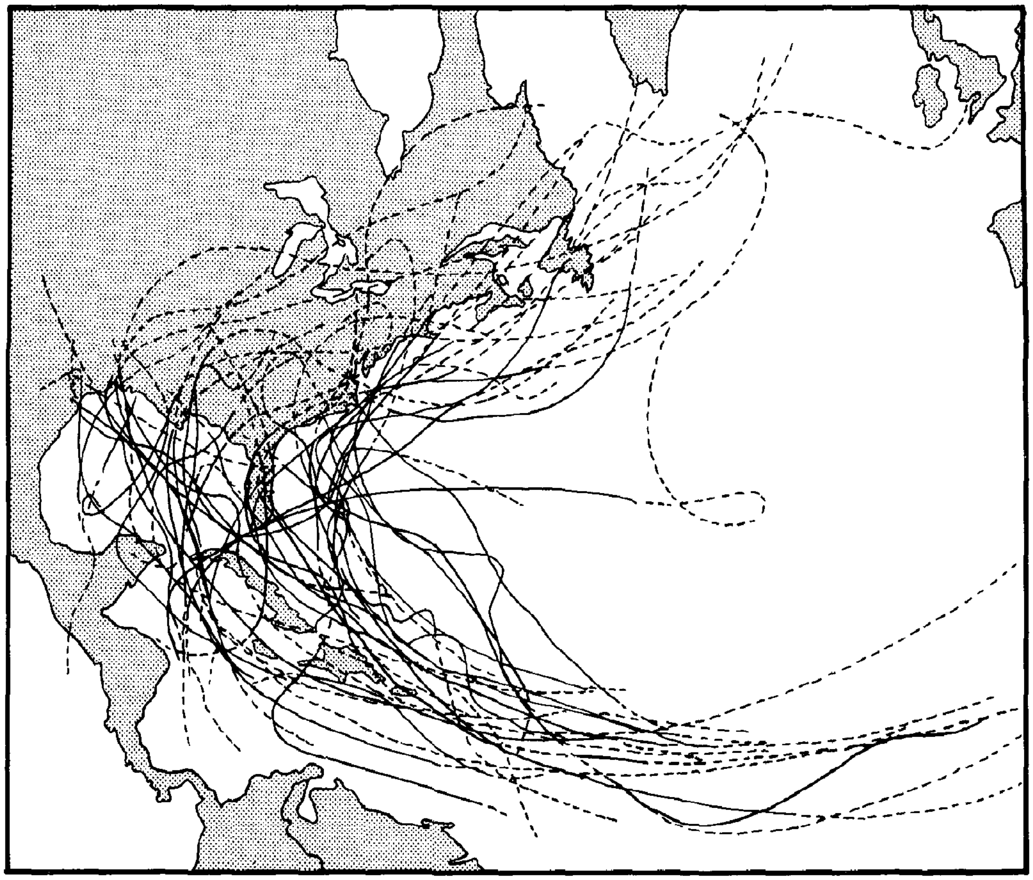

Figure 24. Computer plot showing the tracks of a selected number of Atlantic tropical cyclones, 1886 through 1969 (from Neumann and Hill, 1976).

hurricane-related changes on the east and Gulf coasts of the United States on the basis of aerial photographic interpretations. Notable among their many discussions of hurricane effects are the descriptions of the impact of Hurricanes HAZEL (1954) and HELENE (1958) on the Outer Banks of North Carolina. During these storms, many houses and hotels were washed away and a series of new tidal inlets were formed.

Extratropical cyclones are the dominant force in initiating beach cycles on the east coast of North America (previously discussed). The effectiveness of these storms, which occur several times a year, is determined by (1) size of storm, (2) speed of storm movement, (3) tidal phase and stage, (4) storm path, and (5) time interval between storms (Hayes and Boothroyd, 1969).

Hayes (1978) summarized geological studies conducted on erosion during 14 separate hurricanes that occurred mostly between 1957 and 1975. Table 6 is a brief accounting of the results of those studies. For purposes of conciseness, this discussion of storms will focus on hurricanes in North America, but the principles learned apply elsewhere.

3.4.1 Hurricanes

Technically, a hurricane is a storm of tropical origin with a cyclonic wind circulation (counterclockwise in the Northern Hemisphere) of 74 miles per hour or higher (Dunn and Miller, 1960, p. 9). The hurricane is the North Atlantic member of the tropical cyclone family that includes the typhoon of the western North Pacific, the cyclone of the northern Indian Ocean, and the willy-willy of Australia (Tannehill, 1956). Tropical cyclones are the most powerful and destructive of all storms (Dunn and Miller, 1960; Tannehill, 1956). Tornadoes have higher wind velocities (central axis velocities may attain 640-800 km/hr), but tropical cyclones are also intense (winds may reach 250-300 km/hr) and cover a much larger area. At one stage, Hurricane CARLA's (1961) circulation enveloped the entire Gulf of Mexico, and fringe effects were felt by all Gulf Coast states (Cooperman and Sumner, 1962).

Tropical cyclones occur in the North Atlantic with a frequency of approximately 7.5 per year and occur most often during the months of August, September, and October. The season of maximum occurrence of tropical cyclones corresponds roughly to the time when the ITC (intertropical convergence zone, or equatorial trough) has its maximum divergence from the equator (Hayes, 1967a, p. 4).

3.4.2 Storm Surge

The storm surge is the rise or fall of the sea level caused by a meteorological disturbance (Pore, 1961, p. 151). As used here, it refers to the hurricane surge, or a rapid rise in the water produced by hurricane winds and falling barometric pressure, and other factors (Dunn and Miller, 1960, p. 207).

Not only is the storm surge or storm tide the primary cause of death and property damage in a hurricane (Freeman et al., 1957, p. 12), it is

TABLE 6

Effects of a selected group of hurricanes (from Hayes, 1978, Table 1)

Hurricane (Date)	*Landfall*	*Characteristics*	*Documented Effects*	*References*
Sept. 1938	Long Island; Connecticut	**Large**; max. surge 4 m; winds 200 km/hr; heavy rains	Extreme shore erosion; formation of inlets and washovers; record flooding	Nichols and Marston (1939)
Audrey (1957)	Texas-Louisiana border	**Medium**; max. surge 4 m; winds to 130 km/hr	Shoreline retreat (25-30 m) in chenier plain area; mud deposition; shell berms deposited over marsh; numerous breaches through barriers and cheniers; mud flats not modified	Morgan, Nichols, and Wright (1958)
Donna (1960)	Florida Keys; southwest Florida	**Medium**; max. surge of 3 m; winds to 200 km/hr	Erosion of platform-edge reefs; mud layers deposited on supratidal flats; spillover lobes of coarse sediment deposited in breaks through reef fronts; beach erosion and inlet breaching in SW Florida	Ball, Shinn, and Stockman (1967); Perkins and Enos (1968); Tanner (1961)
Carla (1961)	Central Texas	**Large**; max. surge of 7 m; huge waves; winds to 200 km/hr	Eroded beaches; breached barrier islands; washover fans reactivated; mud layers and shell layers on tidal flats; sed. layer on inner shelf	Hayes (1967)
Hattie (1961)	British Honduras	**Large**; max. surge of 4 m; winds to 200 km/hr	Heavy destruction of reef corals; island overtopping and erosion; destruction of plant communities	Stoddart (1963, 1965)
Cindy (1963)	East Texas	**Small**; max. surge of 1 m	Only beach changes (mostly depositional)	Hayes (1967)
Betsy (1965)	Bahamas; Florida Keys	**Medium**; max. surge 3 m; winds 200 km/hr	Erosion of spillover lobes on Bahamas; deposition of spillover lobes at Cape Sable, Fla.; beach erosion in NW Florida; generally minor effects	Perkins and Enos (1968); Pray (1966); Warnke *et al.* (1966)
Beulah (1967)	Texas-Mexico border	**Medium**; max. surge of 3 m; winds to 240 km/hr; heavy rains	Opened storm and tidal channels; deposited washovers; deltas formed on bay margins	Scott, Hoover, and McGowen (1969); McGowen (1970); McGowen and Scott (1975)
Camille (1969)	Louisiana; Mississippi border	**Large**; record storm surges >7 m; heavy rains; winds 200 km/hr	Spit eroded at Miss. river mouth; islands eroded and washed over; sand washovers deposited on peats; deposition on natural levees	Wright, Swaye, and Coleman (1970); Sonu (1970)
Celia (1970)	Central Texas	**Medium**; max. surge 3 m; highly destructive winds to 150 km/hr; little rain; very fast moving	Minor breaching of barriers; minor beach erosion; heavy wind damage	McGowen *et al.* (1970)
Ginger (1971)	Outer Banks, N.C.	**Medium**; max. surges of 2.5 m; winds to 120 km/hr; heavy rains	Dune recession in man-modified areas; overwash processes and overwash deposition elsewhere	Dolan and Godfrey (1973)
Fern (1971)	Louisiana; south Texas	**Small**; slow moving; heavy rains	Mostly excessive rain and flooding	McGowen and Scott (1975)
Agnes (1972)	Northwest Florida; New York	**Medium**; winds to 120 km/hr; max. surge 2 m (in Fla.); large circulation; extremely heavy rains	Runoff produced by storm introduced as much sediment into upper 40 km of Chesapeake Bay in one week as would be normally deposited in fifty years	Schubel (1974); Zabawa and Schubel (1974)
Eloise (1975)	Northwest Florida	**Medium**; max. surge 5 m; winds to 210 km/hr; rains variable; fast moving	Mostly erosion related to storm surge and wave set up; wind damage and flooding minimal	Morton (1976)

also the characteristic of hurricanes most responsible for making them important erosive agents. The rise in water level brought about by hurricanes inundates vast areas of low-lying coastal regions, producing widespread erosion and deposition of formerly subaerial sediments.

The two most important factors in the generation of storm surges are the stress of wind on the sea surface (sometimes called wind setup) and reduction of atmospheric pressure, or inverted barometer effect. Winds of North Atlantic hurricanes have frequently reached velocities of 130 to 200 km/hr, and a few have attained 300 km/hr (Dunn and Miller, 1960). The width of the path of a single storm may extend 300 to 500 km. These factors, combined with the fact that a storm may last for several days, give hurricanes the ability to pile up tremendous quantities of water against the coastline. Several other factors, such as shoreline configuration and shape and slope of continental shelf, may also tend to accentuate, or modify, the storm surge. Two hurricanes, CARLA (1961) and CAMILLE (1969), have generated surges on the order of 7 m on the Gulf Coast of North America.

3.4.3 Waves

Probably the most spectacular geological effect of hurricanes is the erosion produced by breaking waves on an exposed shoreline--a cubic yard of water weighs about three-fourths of a ton, and a breaking wave may move forward at speeds up to 80-100 km/hr (Dunn and Miller, 1960). The erosive effects of waves are greatly increased when they ride the crest of a large storm surge, because much greater land areas are exposed to erosion. Some hurricane waves attain tremendous heights. Twelve- to fourteen-meter waves were reported by Coast Guard stations in New England during Hurricanes CAROL and EDNA of 1954 (Pore, 1957).

3.4.4 Currents

Although current measurements made during the passage of hurricanes are scarce to nonexistent, some indirect evidence indicates that the strong winds associated with hurricanes set up appreciable nearshore currents. Tannehill (1956, p. 34) described the effects of currents generated by the Texas hurricane of 1915 as follows: ". . . the current set up by the storm carried Trinity Shoals gas and whistling buoy nearly ten miles to the westward. This buoy weighed 21,000 pounds and was anchored in 42 feet of water with a 6,500 pound sinker and 252 feet of anchor chain weighing 3,250 pounds." Numerical and analytical models by Forristall (1974) and Sloss (1972) indicate that strong currents flow parallel to the coast during the approach and landfall of a hurricane, inasmuch as winds pile up water against the land to the right of the storm and push water offshore to the left of the storm.

Breaking waves, especially those breaking obliquely to the shoreline, generate strong longshore currents during hurricanes. Timbers and pilings from Bob Hall fishing pier on northern Padre Island, Texas, which was completely destroyed by Hurricane CARLA (1961), were found for tens of miles south along the beach after the storm (Hayes, 1967a, p. 7). Murray (1970) measured currents up to 160 cm/sec in 6.3 m of water off the coast of northwest Florida during the passage of Hurricane CAMILLE (1969).

Strong currents flow in hurricane channels cut into Texas coast barrier islands during the high-water stage of the hurricane surge (Hayes, 1967a; Scott et al., 1969; McGowen et al., 1970). Ball et al. (1967) also made this observation in the passes between the Florida Keys during Hurricane DONNA (1960), when currents washed out the interisland bridges and broke the pipeline supplying fresh water to the islands where the pipe crossed the bridges.

3.4.5 Life and Death of a Storm

Introduction. A succession of papers, including those of Price (1956), Hayes (1967a), Scott et al. (1969), and McGowen et al. (1970), have outlined the various changes in storm effects that take place during the approach, landfall, and dissipation of hurricanes. All of these papers have dealt with storms striking the Texas coast. For purposes of discussion, the life and death of a Texas coastal hurricane can be divided into four stages: (1) approach (or storm-surge flood), (2) landfall, (3) early aftermath (or storm-surge ebb), and (4) late aftermath.

Approach. This is a period of rising tides, increased wind velocities, and increased wave heights. The slower the storm moves, the larger the storm surge. Some important effects during this period include erosion of shelf and shoreface, shore erosion, breaching of barrier islands and formation of washover fans, and mud deposition on supratidal flats (Hayes, 1967a). During this phase, longshore currents are generated that flow from north to south (on the Texas coast).

Landfall. As the storm passes over the shore, the pattern of current and wave attack shifts into compliance with the direct influence of the counterclockwise winds of the hurricane (McGowen et al., 1970, p. 5). Water and sediment are pumped out of the bays on the south side of the storm, whereas water is still being pushed shoreward on the north side. This is the time of most severe coastal winds.

Early aftermath. As the storm moves inland, it becomes more diffuse and weaker. Winds blow either offshore or from south to north. This shift in wind direction and sudden rise in barometric pressure cause strong storm-surge ebb currents to flow seaward which scour out the hurricane channels and inlets and deposit bay and nearshore sediments on the barrier shoreface and inner continental shelf (Hayes, 1967a). Wave erosion gradually diminishes with the falling water levels, and longshore currents flow from south to north (McGowen et al., 1970).

As the storm moves further inland, it may be accompanied by tornadoes and heavy rains which produce large-scale runoff of flood proportions, inundating low-lying areas along stream courses and bay margins (Scott et al., 1969). Differences in the tracks of storms after landfall greatly influence the extent of flooding and deltaic deposition [in the bays] (McGowen and Scott, 1975, p. 27). For example, Hurricane BEULAH (1967) stalled and went up the Rio Grande valley, producing rains in excess of 40 cm at many stations in south Texas (Scott et al., 1969).

Late aftermath. During the weeks and months following the storm, longshore currents build bars across the mouths of the tidal passes cut by the storm (Hayes, 1967a), waves restore the normal beach profile (Sonu, 1970; Morton, 1976), mud settles from suspension in the bays and in stranded ponds (Hayes, 1967a), exposed fine-grained deposits are reworked by rain, desiccation, and wind (McGowen et al., 1970), and the wind blows some of the sand left exposed on the washover fans by the storm either back to sea or further into the bay (Andrews, 1970).

3.5 Tidal and Seasonal Water-Level Changes

The tides follow a cycle which is controlled by the position of the sun and moon relative to the earth. When the sun and moon are in syzygy (i.e., in line with each other), the tidal range is greatest (spring tides), and when they are in quadrative (i.e., at right angles to each other), the tidal range is least (neap tides). Spring and neap tides occur twice each lunar month.

The most severe erosion of the beach occurs at high tide. During spring tides, higher levels of the beach are exposed to wave action than during neaps, so erosion is at a maximum. Observations on the east coast of the United States by university researchers and the U.S. Army Corps of Engineers show that storms do their greatest damage when they cross the coast during a high spring tide. Observations on the southeastern U.S. coast show that the beach may be erosional during spring tides and depositional during neaps under similar wave conditions. Erosion occurs at spring tide because (1) the dune ridge is exposed to wave action, and (2) the beach sediment is water-saturated because of the higher level of the sea.

Water-level changes also show seasonal variations. On the coast of the United States, sea level is generally lowest in the spring and highest in the fall (Figure 25). This fact is well known by east coast developers who have built too close to the beach, as the high tides in the fall commonly cause them problems. According to Komar (1976, p. 148), these annual sea-level changes can be attributed primarily to seasonal variations in climate and ocean water properties. However, much is yet to be learned about the causes of annual changes in water level.

3.6 Natural Changes in Sand Supply

Beach erosion may be accelerated in places where the sand supply is decreased abruptly by natural processes. Two of the more common ways this can happen are: (1) switching of river mouths on major river deltas, and (2) tidal inlet migration or bar-bypassing (previously discussed; Figure 26).

The modern Mississippi delta complex is composed of an array of abandoned delta lobes (Frazier, 1967; Figure 27). A birdfoot or lobate delta

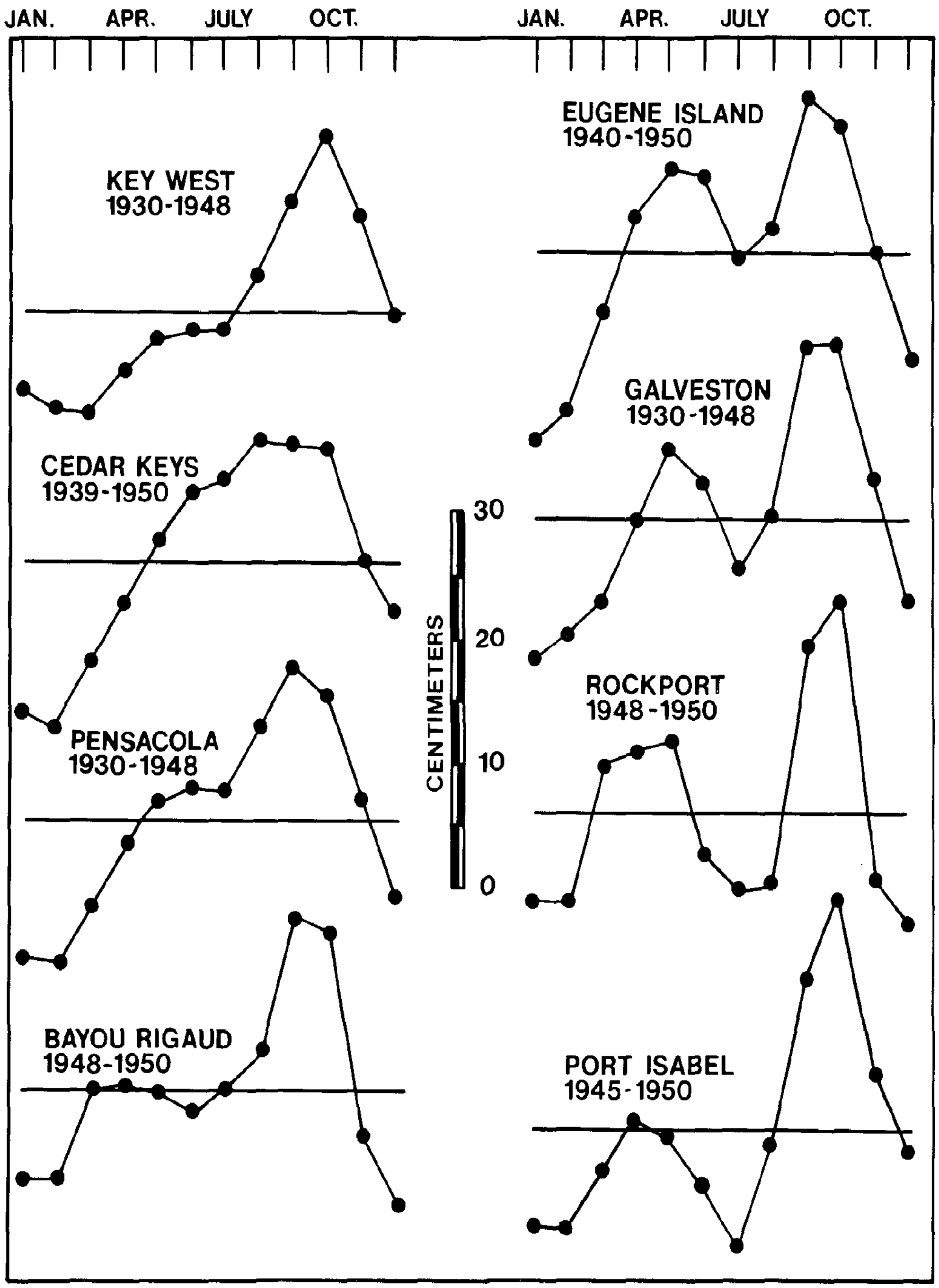

Figure 25. Seasonal variations in sea level along the Gulf coast of the United States, determined from tide observations (after Marmer, 1952; from Komar, 1976, Figure 6-1).

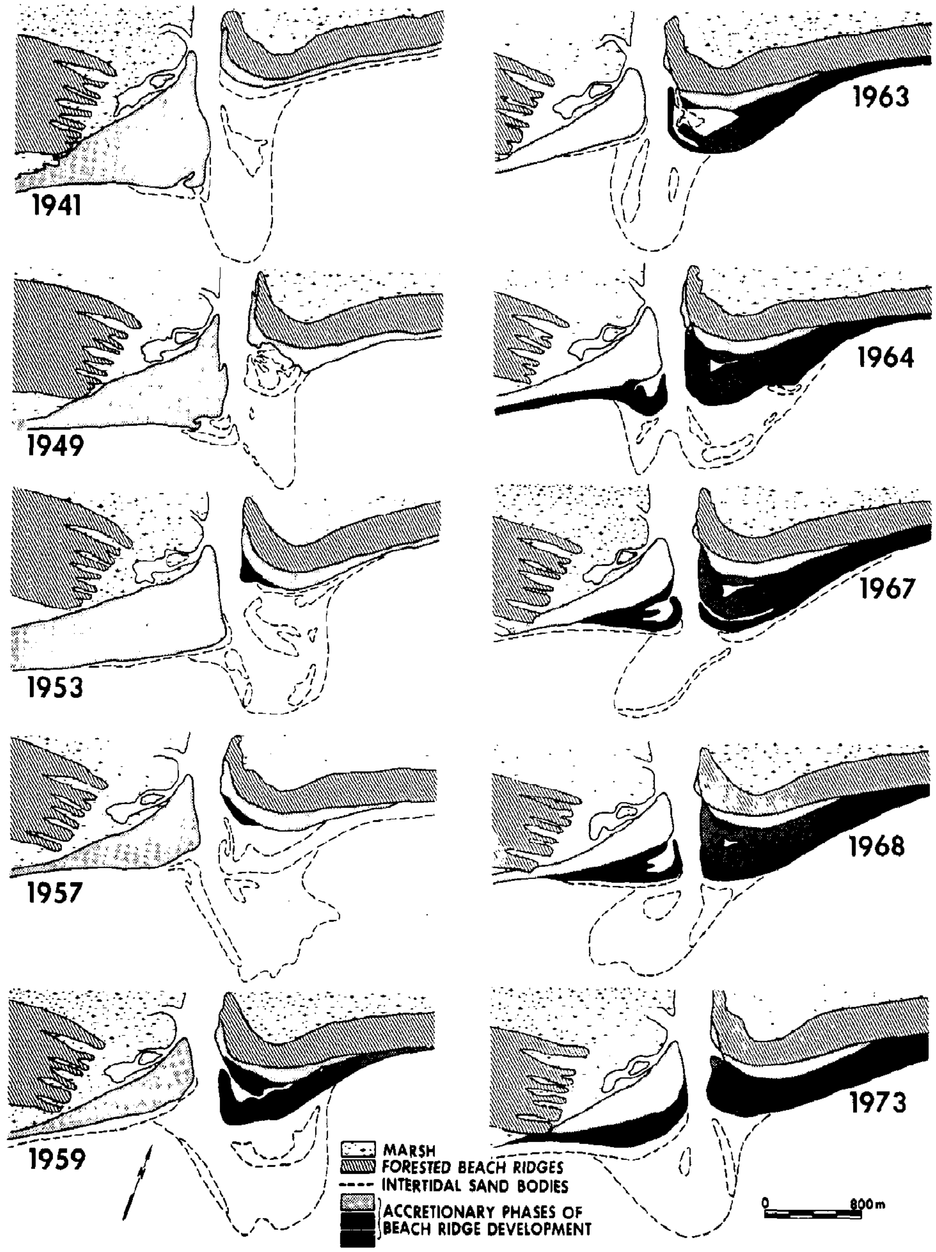

Figure 26. Shoreline changes of Price Inlet, South Carolina, between 1941 and 1973, as determined from vertical aerial photographs. On the southwestern side of the inlet, shoreline progradation has been a product of bar migrations around the inlet. Accretion on the opposite side of the inlet is due to bar migrations and spit growth. Erosion to either side of the inlet occurs when the ebb-tidal delta (offshore shoal) is asymmetric to one side of the inlet, exposing the other side to storm wave attack (from FitzGerald and Hayes, 1980, Figure 11).

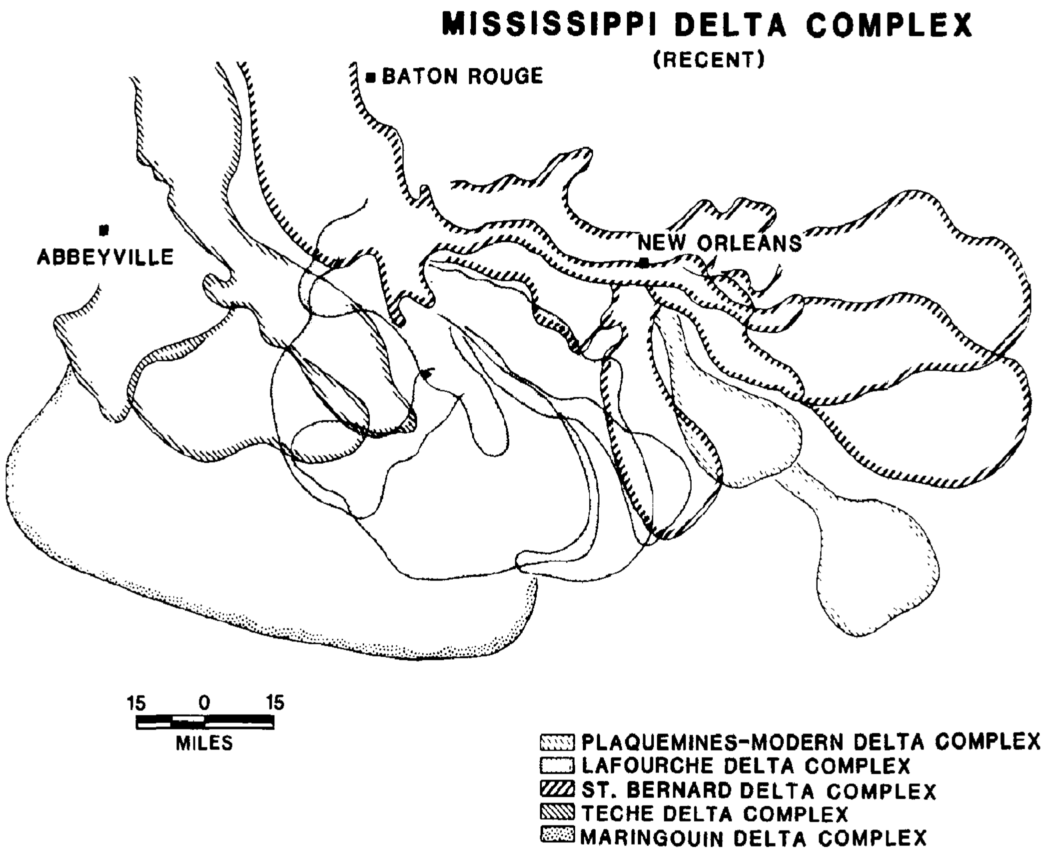

Figure 27. Principal delta lobes that have developed on the Mississippi delta during the past 5,000 years. Once a lobe is abandoned, its margin is eroded rapidly (after Frazier, 1967)

builds seaward until the main distributary channel loses its gradient advantage. Then, the river chooses a shorter, steeper avenue to the sea, abandoning the protruding delta lobe. Once abandoned, the lobe begins to sink, the sea transgresses over it, and waves erode its margin and create narrow barrier islands that migrate rapidly landward.

3.7 Man-Induced Changes in Sand Supply

There are many ways in which the activities of man have changed the supply of sediments to beaches. If these activities result in significant loss in sand, the beach will probably erode. Some examples of these activities are given below.

3.7.1 Dams on Rivers

Sediment contribution of any river discharging on the coast is of great importance to the sediment budget of that coast. If a dam is built on the river in order to create a reservoir for storage of water, the current velocities in the river are reduced to such an extent that practically all sediment carried by the river settles in the reservoir. The water discharged by the spillway has a very low sediment content and, therefore, a high erosive capacity. In the first years after construction of the dam, degradation of the river bed immediately below the dam may be expected. Later, a new equilibrium will be established, generally with much lower sediment transport due to reduction of sediment supply from upstream.

3.7.2 Diversion of Rivers

Some engineering structures call for the diversion of river systems from their original channels. This has the same effect as the natural switching of river channels (discussed above)--namely, increased erosion due to diminished sand supply. The diversion of 90 percent of the flow of the Santee River, South Carolina (U.S.), in 1940 essentially cut off the sediment supply to the coast (Stephen et al., 1975). The beaches at the river mouth have eroded hundreds of meters since the diversion.

3.7.3 Sand Mining

River sand and gravel are important sources of building and fill aggregate in many parts of the world. In areas where large seasonal variations in river flow occur, the reduced water level in streams during periods of low river flow makes it easy to mine sand and gravel directly from the river bed. Such extraction of river sediment can have a direct impact on coastal erosion in that it will result in either a decrease in the volume of sediment brought to the shoreline or an increase in river erosion downstream, or both. If the sediment mining occurs in the lower reaches of the river system, it is unlikely that erosion downstream will replenish the volume of sediment lost by extraction. In this case, there will be a net deficit in the volume of sediment brought to the coast.

Mining beaches for construction material is a common practice on many shorelines. In areas of strong longshore drift or high wave energy, this can result in local coastal erosion, because removing sand from a beach reduces the sediment supply available to the longshore transport system. In many areas of Europe and Africa, intensive beach mining has resulted in severe beach and coastal erosion problems, particularly where there is no fluvial (riverine) sand input to replenish the mined sand.

Offshore sand mining influences coastal erosion if it is done on shoals which act as partial breakwaters. Dredging these shoals has two effects:

1) Alteration of depth contours, which changes wave refraction patterns and may cause a focusing of wave energy at the shore, and
2) Elimination of a natural breakwater, which acts to reduce wave energy arriving at the shoreline.

Offshore mining in water deeper than about 15 m has little effect on shoreline erosion since it is rarely extensive enough to alter wave refraction patterns and will not cause a significant change in wave heights.

3.7.4 Modification of Inlets

Inlets along coasts are influenced by tidal action as well as by the littoral drift. From the studies made by O'Brien (1931) it is well known that the stability of the inlet is governed by the relative strength of the littoral drift and the tidal prism volume. Sand bypasses the inlet by bar migration or by tidal current transport of individual grains. On coasts with large littoral drift, there is a tendency for the inlet to migrate due to the infilling of the mouth on the updrift side.

Modifications to a tidal inlet, therefore, can have significant influence on the erosional/depositional patterns on adjacent beaches. Artificial deepening of an inlet for development of harbors, for example, could change the bar-bypassing nature of the inlet, depriving the downdrift coast of its supply of sediment and thus leading to erosion. Where inlets serve as the only outlet to the sea for a coastal lagoon, they are commonly "cut open" artificially in order to maintain a given level of water quality within the lagoon. Such a cut interferes with longshore sand transport. A similar effect would be felt by constructing jetties for artificial stabilization of the inlets. A large number of sand-bypassing plants, which move the littoral drift past jettied inlets, have been built in the United States in order to prevent coastal erosion on the downdrift sides of the inlets.

3.7.5 Construction of Shore-Perpendicular Structures

Jetties, piers, groins, and outfalls are structures built more or less perpendicular to the shore. Their functions may differ, but they all have a common effect on the shoreline: their blockage of sediment transport causes erosion on their downdrift sides.

Jetties are built at a river mouth or a tidal inlet in order to stabilize the channel, to prevent shoaling by littoral drift, and to protect the channel entrance from storm waves. Jetties direct or confine the flow to help in the channel's self-scouring capacity. Jetties extend through the entire nearshore to beyond the breaker zone in order to prevent the entry of littoral sediment into the channel. The jetties act as barriers to the longshore drift, causing the sediment to accumulate on the updrift side. At the same time, on the downdrift side of the jetties, the sand transport processes continue to operate and cause the sand to move away from the jetties, resulting in the erosion of the shoreline.

Groins are structures built perpendicular to the shoreline to help beach buildup by trapping a portion of the littoral drift. They are relatively narrow in width and may vary in length from 10 m to about 200 m.

Though their function differs from the jetties, they are also barriers to littoral drift. Groins may be used in a series--groin fields--to protect a large area, but the zone of erosion will shift downcoast through time. Once a groin is filled, some littoral drift may pass by its seaward end. While sand is accumulating between the updrift groins, the sand is prevented from reaching the downdrift groins, enhancing erosion there. To prevent such damages, groins may be filled by artificial nourishment. Poorly designed groins may deflect sand past their ends into deeper water, resulting in its loss to the littoral drift system.

Outfall structures built to carry storm sewers may also cause buildup on their updrift sides and erosion on their downdrift sides. The erosion downdrift can be minimized by building the outfalls on piles.

Examples illustrating the effect of the structures mentioned above are shown in Figures 28 and 29. The jetties built in 1935 to stabilize the inlet south of Ocean City, Maryland, on the Atlantic Coast of North America trapped the southerly littoral drift, causing the beach to erode on the south side by 450 m in 20 years. By 1961, the south beach had eroded to the point where it actually separated from the inner end of the south jetty, leaving a gap of almost 240 m of open water. The situation had to be controlled by dredging and filling the eroded area. The construction of a pier in 1875 at Madras, India, created serious problems of erosion just north of it due to accumulation of sand on the south side, because that coast is influenced by very strong littoral transport from south to north. The erosion on the north side extended to as much as 5 km and had to be checked by use of seawalls and bypassing of dredged sand.

3.7.6 Construction of Seawalls and Revetments

In areas experiencing severe erosion, it is sometimes necessary to construct vertical seawalls and revetments to protect valuable property. Thousands of examples could be cited to demonstrate the effectiveness of such structures in saving property. However, erosion of the beach itself is usually accelerated in front of these features because of wave reflection from the hard, vertical structures. According to Silvester (1977, p. 639), when waves are obliquely reflected from such walls, energy is applied

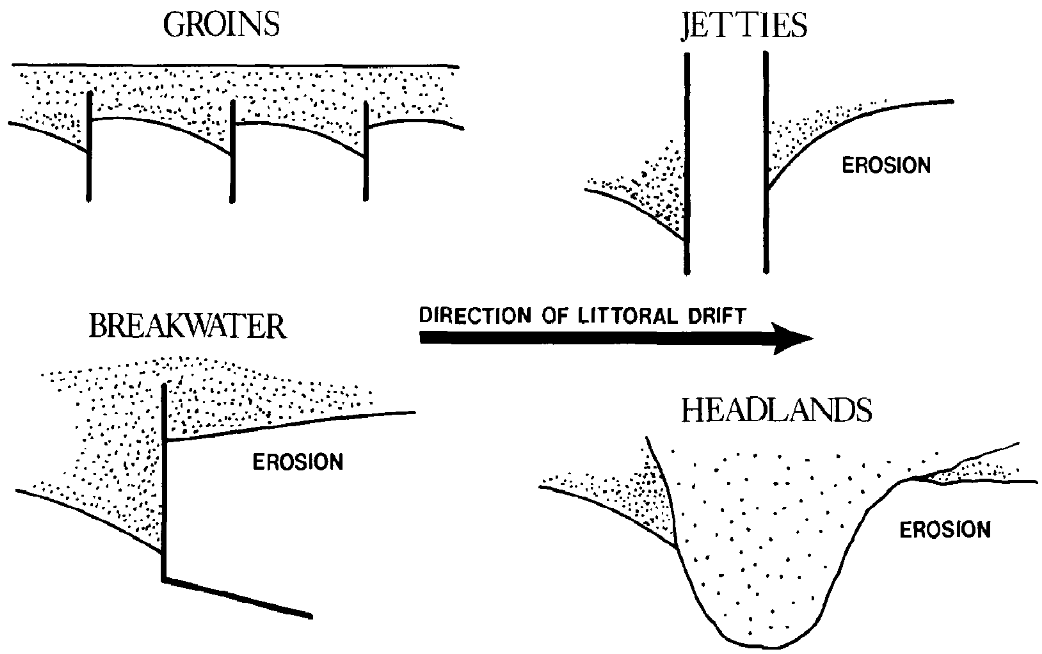

Figure 28. Examples of shore-perpendicular features which block longshore transport, causing erosion on their downdrift side (modified after Komar 1976, Figure 9-7).

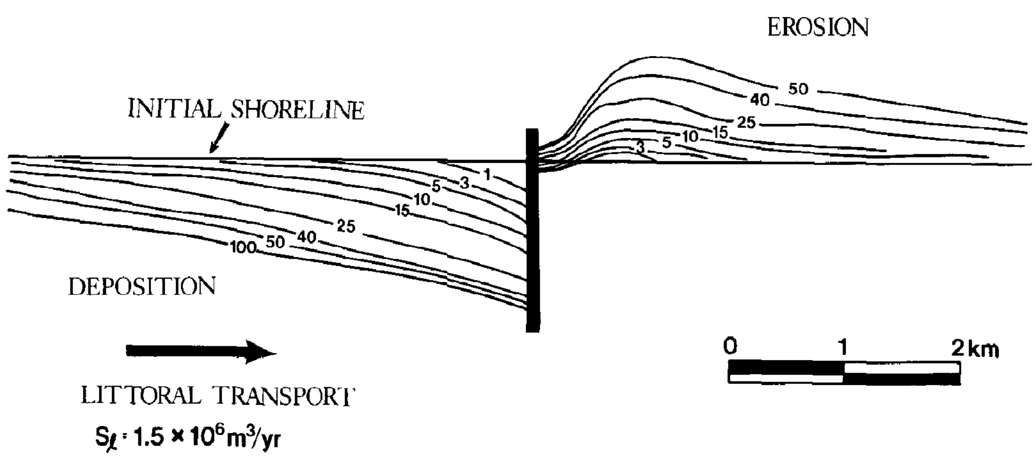

Figure 29. Illustration of the blockage of littoral sand transport by the emplacement of a breakwater or groin transverse to the drift. This example is from a physical laboratory model of a proposed breakwater at Cotonou, Benin; included are the shoreline changes, given in years, as well as the drift rate pertaining to the prototype. Twenty minutes of model operation is equivalent to a year of prototype conditions according to the model (after Sireyjol, 1965; from Komar 1976, Figure 8-1). Field conditions mimicked the model.

"doubly" to the sediment bed and "hence expedites the transmission of material downcoast." This process is illustrated in Figure 30.

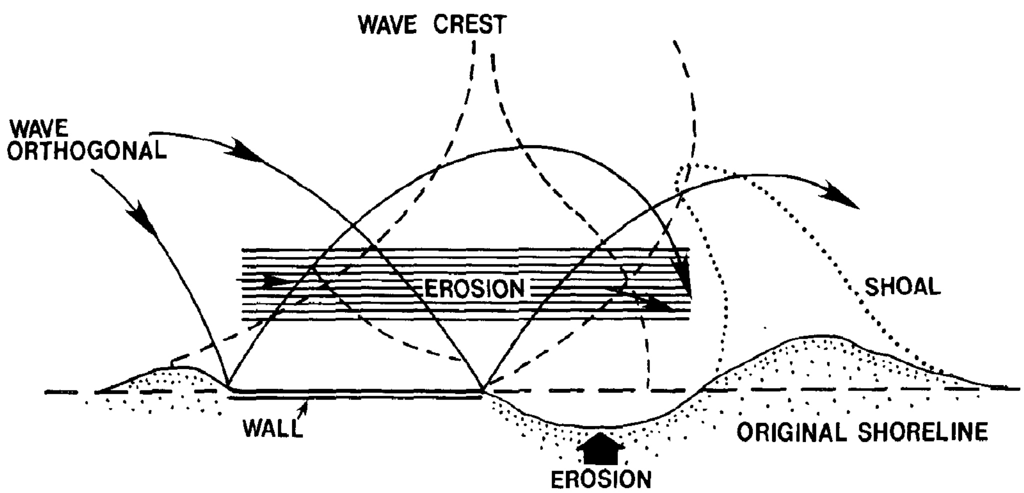

Figure 30. Illustration of erosion in front of and on downdrift side of seawall (modified after Silvester, 1977, Figure 8). The approaching wave crests meet the reflecting wave crests at approximately right angles, generating a flow parallel with the shore in a downdrift direction. This current scours a channel a few meters seaward of the wall. Wave orthogonol--line drawn perpendicular to wave crest.

4. METHODS USED TO PREVENT BEACH EROSION

4.1 Introduction

Engineers have attempted to curtail beach erosion for centuries. Their success ratio is variable, depending upon the vagaries of the sediment supply, storm-wave conditions, and water-level changes in the erosion zone. A list of the commonly used methods is given in Figure 31 and definitions of some of the structures used are given in Table 7.

In determining what kind of structure to erect to stop erosion in a given area, engineers usually apply a set of criteria to the site. These normally include the following (Kana et al., 1980):

1) Definition of a need to protect the critically eroding, or flood-prone, area.
2) The desirability to achieve continuity in structure design (including type, crest elevation, and position) within communities.
3) The requirement of the design to be compatible with some predetermined, combined wave-and-water level (usually 50- to 200-year levels).
4) The need for structure designs to have a design life of a given number of years (usually at least 50).
5) The most cost-effective method that will achieve long-term protection.

A brief discussion of some of the methods proposed is given below.

4.2. "Hard" Engineering Solutions

4.2.1 Introduction

Engineers usually deal with beach erosion by building resistant, permanent features which reflect or dissipate incoming waves. These are referred to as "hard" solutions in this discussion.

4.2.2 Seawalls, Revetments, and Bulkheads

In places where fixed property (such as highways, cottages, and hotels) is threatened by erosion, seawalls, revetments, and bulkheads are usually constructed. Examples of these types of structures are shown in Figures 32 and 33. Seawalls are massive, concrete structures designed to hold a line against storm-wave erosion. Reflecting waves tend to set up scour in front of such walls, as shown in Figure 30. Usually, the end result is that the fixed property is saved for some period of time and beach sand in front of

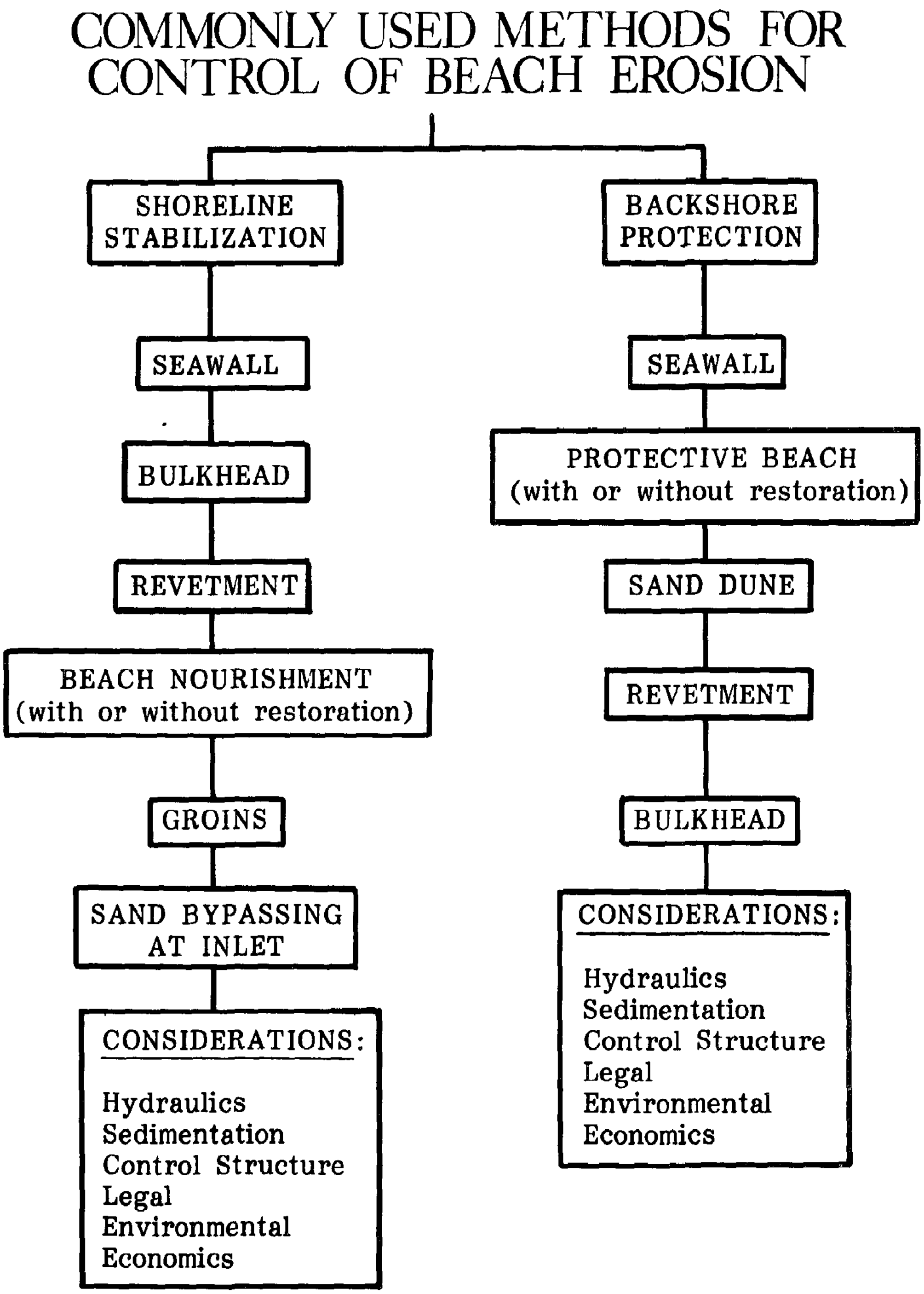

Figure 31. Some commonly used methods for controlling beach erosion (modified after U.S. Army Coastal Engineering Research Center, 1973).

TABLE 7

Coastal structure definitions [revised from Coastal Engineering Research Center (1973) with additions; from Kana et al. (1980), Table 7].

BREAKWATER	A structure protecting a shore area, harbor, anchorage, or basin from waves.
BULKHEAD	A structure or partition to retain or prevent sliding of the land. Generally used in areas of quiet water.
GABION	Wire cages, filled with loose stone, tied together in an orderly arrangement to construct seawall, groins, or other shore-protection structures.
GROIN	A structure built to trap littoral drift or retard erosion, generally placed perpendicular to shore. Generally not associated with inlets.
JETTY	A structure extending into water, designed to prevent channel shoaling and direct flow. Generally associated with inlets.
PIER	A structure usually of open construction serving as a landing place.
REVETMENT	A facing of stone, concrete, etc., built to protect a scarp, embankment, or shore structure against erosion by wave action or currents.
REVETTED SEAWALL	Generally a seawall which is protected on the seaward side by a revetment of stones.
ROCK CRIB	A cage of wire and pipe or wood, filled with gravel and used for shore protection.
SEAWALL	A structure separating land and water areas, designed to prevent erosion by keeping waves and wave overtopping from reaching the land behind the wall.

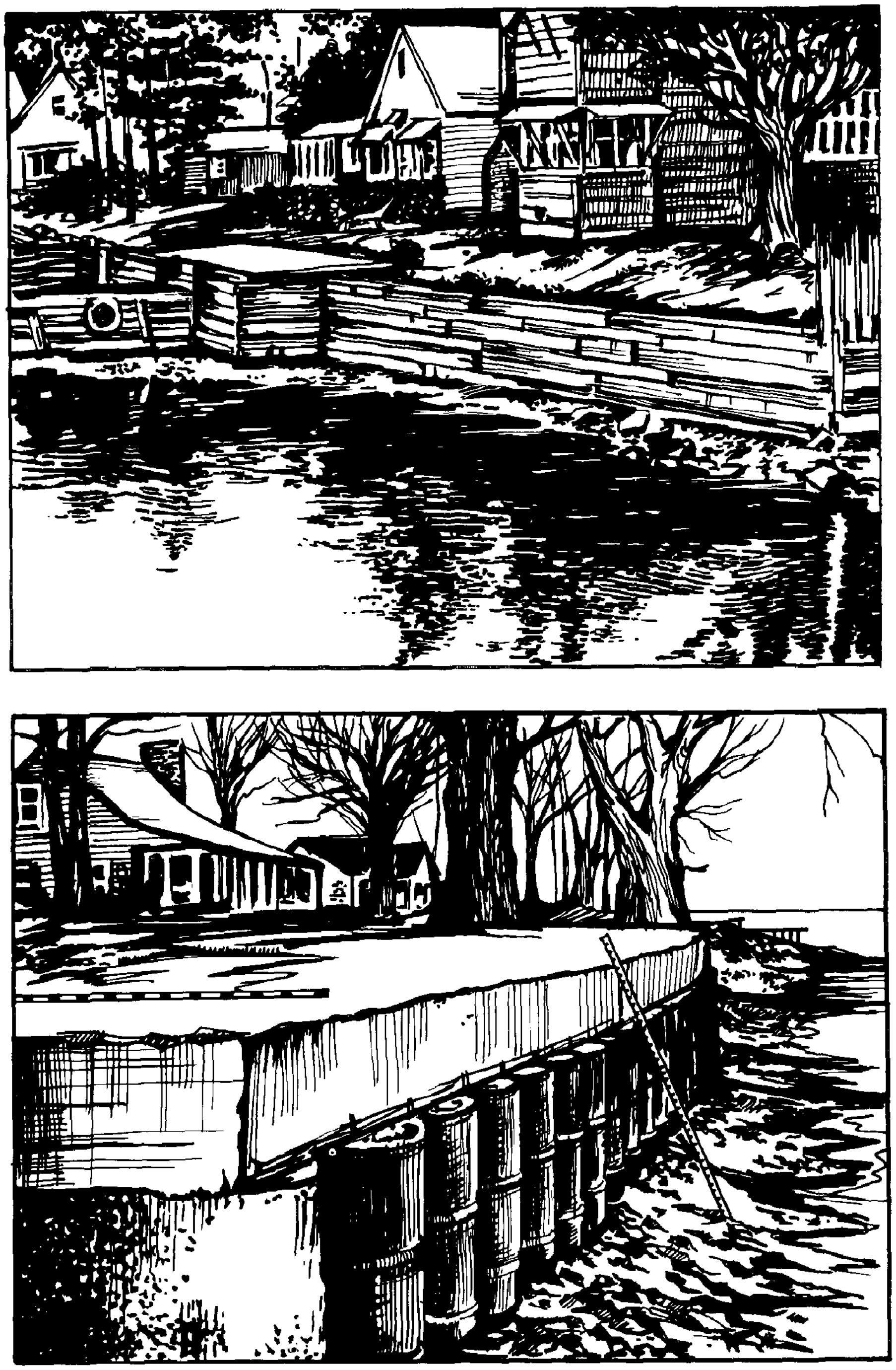

Figure 32. Examples of shore-protection structures at Lake Ontario, U.S. (from Kana et al., 1980). [Upper] Wood bulkhead composed of horizontally laid railroad ties (Sodus Bay). [Lower] Composite structure composed of concrete slab built on concrete-filled oil drums (Henderson Bay).

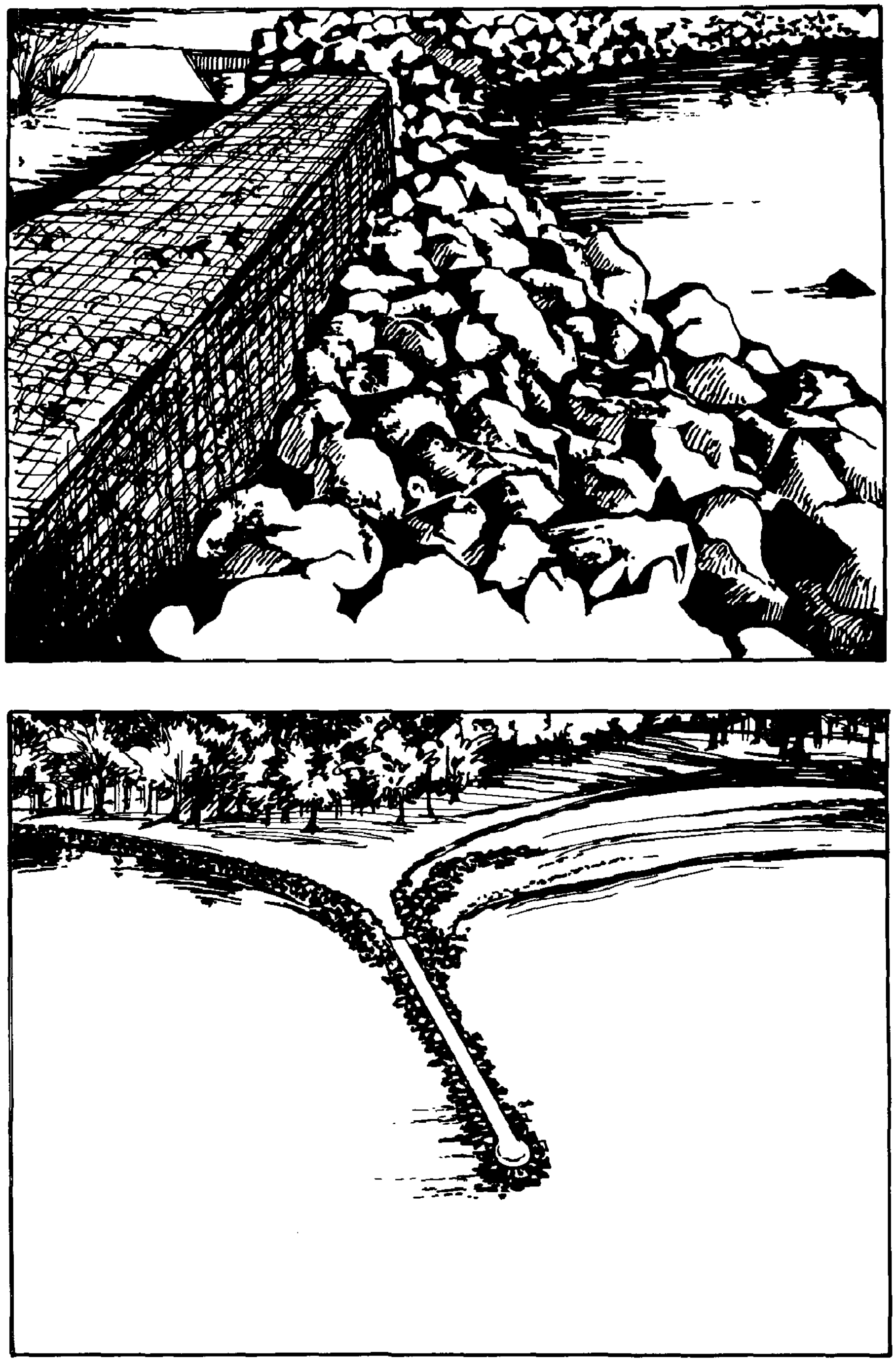

Figure 33. Examples of shore-protection structures at Lake Ontario, U.S. (from Kana et al., 1980). [Upper] Revetted gabion seawall (near Rochester). [Lower] Revetted concrete groin at Hamlin Beach State Park. Sediment transport is right to left.

the wall is lost. A bulkhead is made of pilings, composed of a wide range of materials (Figure 32 upper), driven into the ground. They are usually built in areas of moderate waves. Revetments (Figure 32 lower) are constructed by armoring the sloping face of a dune or bluff with one or more layers of rock, concrete, or asphalt (U.S. Army Coastal Engineering Research Center, 1973). The armor stones of revetments tend to dissipate waves and inhibit reflection better than vertical walls, thus sand removal by wave reflection is not as severe.

4.2.3 Groins

Groins are structures built to slow down longshore transport of sand by blocking its passage at a given location. They consist of fingerlike projections of hard material perpendicular to the beach (example in Figure 33 lower). They are commonly made of rubble stone, but they may consist of wood, sand bags, gabions (rocks or pebbles in wire mesh) (Figure 33 upper), or other materials. They work best where waves approach the coast obliquely. Erosion may occur downdrift of groins, necessitating the construction of a series of them (groin field). Groins have not proved to be effective solutions to beach erosion in many localities, although they have been used in abundance.

4.2.4 Offshore Breakwaters

Offshore breakwaters are short structures detached from the shore and placed normal or nearly so to the direction of the incoming waves. These structures reduce wave energy on their landward side, which causes buildup of the beach by deposition of littoral drift. These structures can be either above the high-water level or submerged. The submerged breakwater causes waves to break prematurely, thus reducing the wave energy. However, because of the beach buildup in the zone of its immediate influence, the erosion on the downdrift side of the offshore breakwaters may continue or even be accelerated. Some sand generally passes on through the system.

Offshore breakwaters have been used successfully to curtail erosion in a number of areas. A detached breakwater was constructed in 1878 at Ceara, Brazil, which extended about 430 m parallel to the coast. The longshore drift there is from east to west. The construction of the breakwater caused a tongue of sand to grow outward from the shore until it finally reached the breakwater. A 600-m-long, detached breakwater was constructed about 600 m offshore at Santa Monica, California, in 1934. Immediately thereafter, sand began to accumulate on the protected lee of the breakwater, although erosion did occur further downcoast. Breakwaters are common around the shoreline of Japan, where they are considered to be the best solution to beach erosion (discussed in detail below).

4.3 "Soft" Engineering Solutions

4.3.1 Introduction

There are many workers in the area of coastal erosion, particularly geologists, who prefer to use solutions to erosion problems that do not involve hard structures (Concerned Coastal Geologists, 1981). Two lines of reasoning are used to support this position:

1) Hard structures such as seawalls accelerate sand losses.
2) Once in place, hard structures are difficult to remove, making it virtually impossible to correct a mistake.

Some examples of alternative "soft" solutions are given below.

4.3.2 Setback Lines

The "softest" of the soft solutions is the construction of a line behind the shoreline seaward of which building is prohibited. These lines are called setback lines. They work best in areas that have not been developed as yet. The best-known example of legislation concerning the construction of setback lines on the basis of scientific considerations is a 1971 law of the State of Florida, U.S. (section 161.053, F.S.). This setback regulation is discussed by Purpura (1979) and Murday and Asherman (1981).

The criteria which are usually applied in the establishment of coastal setback lines include the following (from Murday and Asherman, 1981):

1) Erosion rates. Historical maps and charts are studied to determine rates of change, and a line is established based on the predicted life of the project (e.g., 50 years).
2) Dune protection. The line is established to protect a foredune barrier.
3) Flood hazard. A line is drawn based on flooding levels (e.g., 100-year flood).

4) Wave uprush. Several computerized prediction techniques have been developed to determine a level of uprush of severe storm waves. Construction is prohibited seaward of this level.

5) Ground contours. Elevations are chosen for construction, basically for protection from storm flooding.

6) Vegetation type. Lines are drawn based on vegetation types that have required a number of years to become established, such as a climax maritime forest or mature dune vegetation.

4.3.3 Sand-Bypassing

Jetties constructed to stabilize navigational channels usually block the flow of littoral drift. Consequently, severe erosion may develop on the downdrift side of the jetties. This is one of the more common causes of erosion problems around the world. Erosion downdrift of the jetties at the ports of Lomé, Togo, and Cotonou, Benin, on the coast of West Africa are notable examples. This problem is solved by installing mechanical sand-bypassing systems. The most commonly used methods of mechanical transfer are land-based dredging plants, floating plants, and land-based vehicles (Chestnutt, 1982; Watts, 1966).

4.3.4 Beach Nourishment

Beach renourishment with sand is the most commonly used soft solution. Kana (1983) classified these projects as those deriving sand from either external or internal sources. Many projects have been implemented on the coast of North America that utilize external sand sources. Projects at Miami Beach (Florida), Wrightsville Beach (North Carolina), and Rockaway Beach (New York) involved moving millions of cubic meters of sand. Sand for such projects may come from a variety of sources, including (1) continental shelf, (2) tidal deltas at tidal inlets, (3) trucked in from borrow sites on the mainland, and (4) dredge spoil from waterways and canals. This method of beach erosion control is discussed in detail in U.S. Army Coastal Engineering Research Center (1973). Kana (1983) emphasized the cost-effectiveness of deriving sand from local (internal) sources and moving it with land-based equipment. Sources of such sand include (1) attached shoals adjacent to tidal inlets and (2) laterally adjacent zones of accretion.

The major objection to beach renourishment schemes is that they are not permanent. Watching millions of dollars worth of sand wash away within a few years of its emplacement does not appeal to some money-conscious planners, who feel more secure with hard structures. Such projects require a careful analysis of monetary costs and benefits balanced against the aesthetic and recreational value of maintaining a sand beach in place.

4.3.5 Design with Nature

The trend of the future in beach erosion control is to attempt to mimic the natural system. Two examples of this approach include the construction of artificial crenulate bays (Silvester, 1974) and relocation of migrating tidal inlets (discussed below under case study on South Carolina coast). Silvester's (1974) approach is based on the recognition of natural spiral bay systems (crenulate bays) on shorelines with rocky headlands subject to oblique wave approach (Figure 34). On such coasts, a bay beach with a log-spiral shape develops downdrift of the protruding headland. Through a process of wave refraction, sketched in Figure 35, the bay beach develops an equilibrium form. Silvester has proposed the construction of offshore breakwaters which mimic natural headlands so that equilibrium beaches may develop on their downdrift sides. In some cases, renourished sand may be placed in the lee of the breakwaters to aid in the development of the equilibrium beach. Renourished sand would have a much longer residence time in such embayments than if it were placed on an open beach. A sketch of a shore-protection system of this type, which combines both hard and soft solutions, is given in Figure 36.

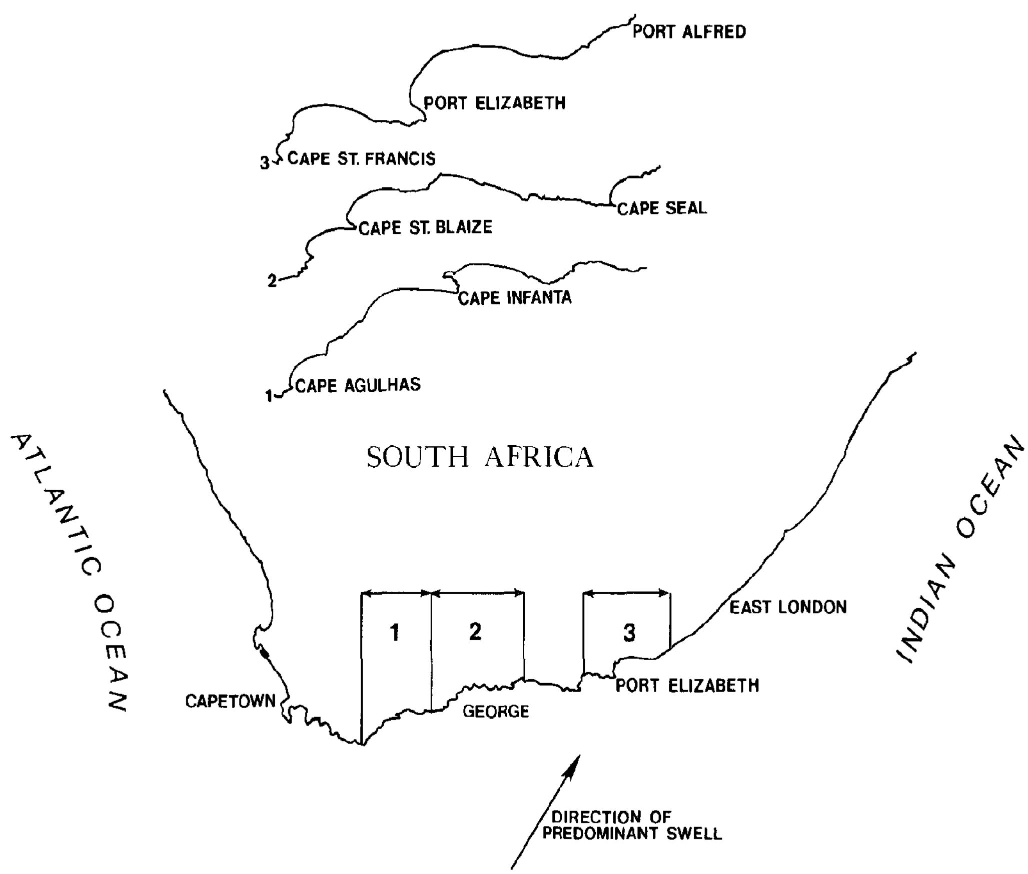

Figure 34. Examples of natural crenulate bays on the coast of South Africa (modified after Silvester, 1974, Figure 2-1).

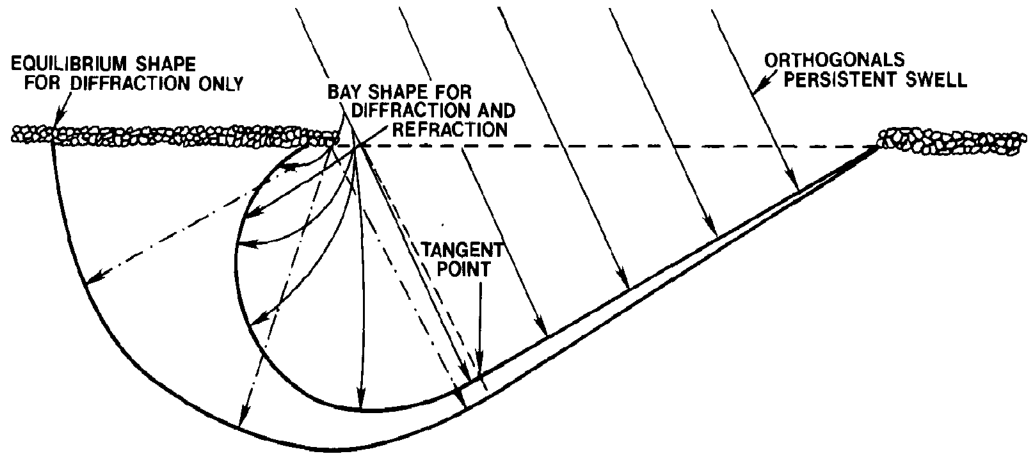

Figure 35. Schematic plan of crenulate bay showing the influence of wave refraction on the shape of the bay (from Silvester, 1974, Figure 2-2).

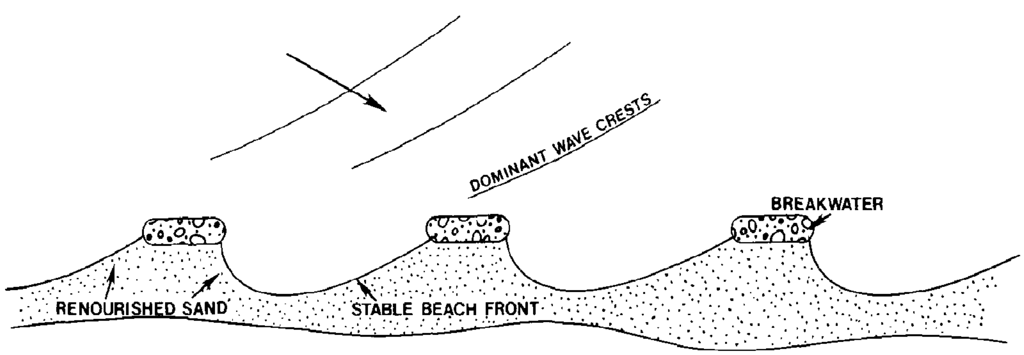

Figure 36. Sketch of beach protection scheme which involves (1) construction of offshore breakwaters and (2) emplacement of sand. The stable crenulate shape forms under oblique wave approach from the left. Based on ideas expressed by Silvester (1974).

5. GENERAL CASE STUDIES

5.1 Introduction

In order to be more specific about the problem of beach erosion around the world, a series of case studies have been chosen for discussion. First, erosion in a more regional context will be discussed, starting with a summary on erosion on the Russian shoreline and concluding with a discussion of beach erosion in Florida (U.S.). Five site-specific case studies will be presented in section 6. The intent of the case studies is to summarize lessons learned and develop guidelines for applications in developing countries.

5.2 Beach Erosion in Russia

The shoreline of Russia exceeds 100,000 km in length (counting islands; Zenkovich, 1982b) and rivals any in the world for complexity. Dramatic rates of erosion prevail in some areas, such as the eastern shore of the White Sea (5 m/yr) and the permafrost lowland of the western Kara Sea (7-8 m/yr). Only the developed shorelines of the Black Sea (including Sea of Azov) and Caspian Sea have been of much concern to engineers, however.

Zenkovich (1982a) outlined some of the methods used to curtail beach erosion in Russia. Seawalls have met with the same fate in Russia as elsewhere. Examples of failed walls which front pebble beaches are numerous (Figure 37). Breakwaters are widespread on the coast of the Black Sea. They are commonly connected to the mainland by concrete traverses to prevent scour by longshore currents. Beach renourishment projects on several bays of the Black Sea and Sea of Azov have been successful and economically justified (Alibulatov and Pogodin, 1974). On the clayey coast at Odessa, a 10-km-long groin field which has submerged breakwaters between groin heads has been constructed. Sand hauled from 30 km away was placed between the groins. According to Dodin and Ponomarenko (1972; cited by Zenkovich, 1982a), only about 5 percent of the nourished sand was lost over a 7-year period. Long-range plans that call for changing responses through time have been proposed for the coasts of the Baltic and Black Seas by Zenkovich and Kiknadge (1981). The valuable experiences gained in Russia during the past few decades, particularly from the works on the Black Sea coast, add significantly to the understanding of beach erosion problems elsewhere.

Figure 37. Erosion of seawall at Kilkhida on the southeastern Black Sea coast (sketched from photograph in Zenkovich, 1982b, Figure 11).

The principal lesson learned is that detailed assessment is required to deal adequately with beach erosion problems.

5.3 Beach Erosion in Japan

Few other countries in the world are so closely tied to their coastline as Japan, from both economical and social points of view. Japan's comparatively small land area of 380,000 km^2 is circumscribed by 33,800 km of coastline (Watanabe and Horikawa, 1983, p. 186). These coastal areas are subject to frequent attack by typhoons (high waves and storm surges) and tsunamis. Figure 38 outlines the different hazards along the Japanese coast.

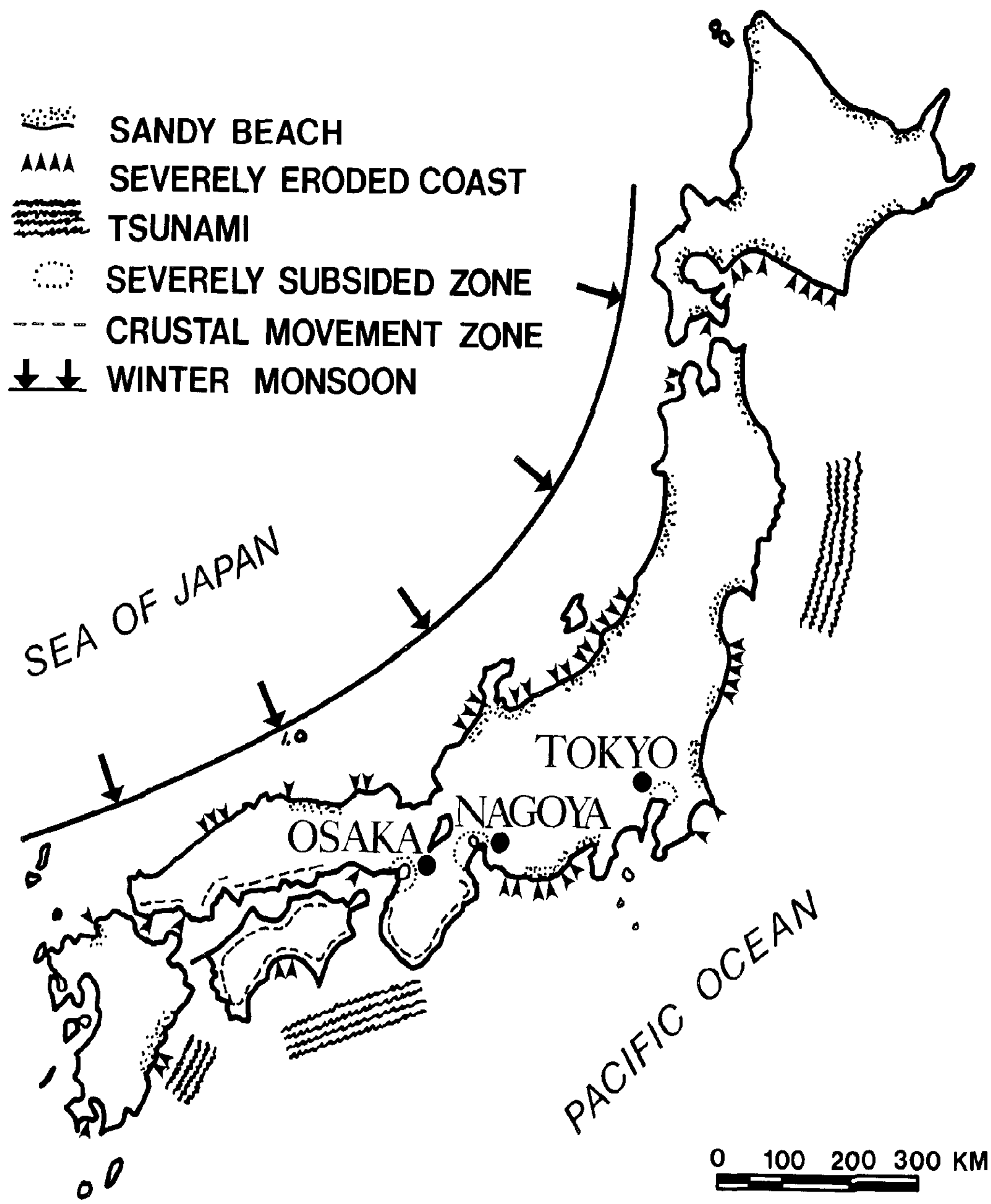

Figure 38. Outline of the different hazards to the coastline of Japan (after Watanabe and Horikawa, 1983, Figure 1).

According to Watanabe and Horikawa (1983), erosion of the coast of Japan has been a problem for only the past few decades. In fact, most of the erosion problems in Japan can be related to two forms of engineering activities by man:

1) Reduction of sediment supply to beaches by construction of dams and diversion channels and by mining of river sediment. Figures 39 and 40 clearly illustrate the relationship of dams on the Tenryu River to shoreline recession adjacent to the river mouth.
2) Interception of longshore transport by man-made structures at the coast. Beach erosion in Japan has accelerated so rapidly over the past 40 years that now one-half of its coastline (15,000 km) is protected by man-made structures.

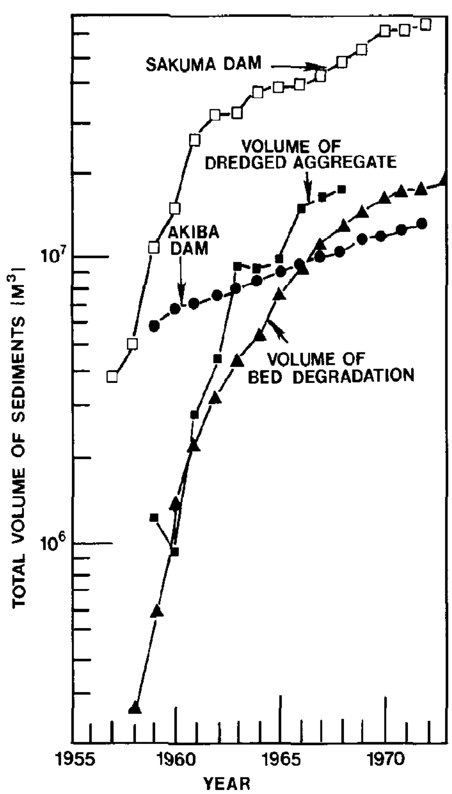

Figure 39. Sediment accumulation behind the dams built on the Tenryu River, Japan (from Watanabe and Horikawa, 1983, Figure 2).

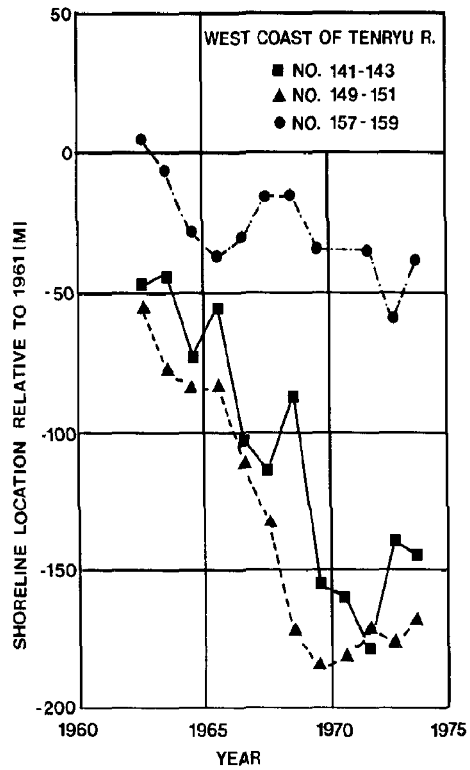

Figure 40. Shoreline recession west of the mouth of the Tenryu River, Japan (from Watanabe and Horikawa, 1983, Figure 10). This recession correlates directly with the trapping of sediments behind dams on the river (Figure 39).

A discussion of several case studies in Japan by Watanabe and Horikawa (1983) revealed the following chronology of events for any given erosional segment of the Japanese coast:

1) No problem perceived (prior to mid-1900s).
2) Interference with sediment supply by man-made structures such as dams or diversion channels.
3) Erosion recognized; seawalls, groins, and other hard structures established.
4) Structures damaged severely during typhoon or tsunami.
5) Structures continually replaced or made stronger after storms.
6) Finally, a series of detached, offshore breakwaters established.

The loss of the seawalls was usually due to scour at their toes and/or wave overtopping (Figure 41). Groins were also quite unsuccessful, as noted by Watanabe and Horikawa (1983, p. 192):

> It is rather difficult to give an example of a groin system which functioned positively without producing some adverse effect as well.

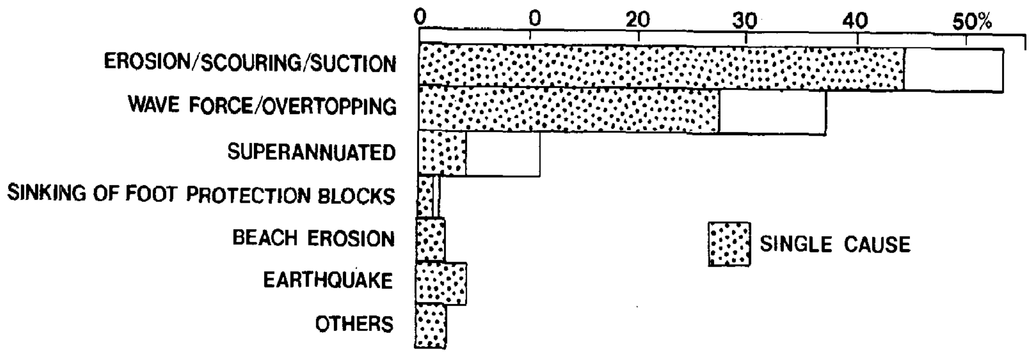

Figure 41. Causes of destruction of coastal dikes and seawalls in Japan (from Watanabe and Horikawa, 1983, Figure 14).

In the past few years, the Ministry of Construction has turned almost exclusively to coastal dikes and detached, offshore breakwaters for solutions to their erosion problems, as seen in Figure 42. An example of a detached offshore breakwater is shown in Figure 43. These structures, which were originally built strictly for shore protection, had the happy side effect of producing tombolos of sand in their lee, thus providing recreational beaches.

In their summary, Watanabe and Horikawa (1983) noted the change from hard to more soft solutions in Japan over the past few years, concluding that this change was due in part to public demand for recreational beaches. Their final words of summary, based on perhaps the world's most concentrated effort to stop beach erosion, follow (p. 193):

> We have learned that even works executed for coastal protection sometimes accelerate severe beach erosion. It should be deeply engraved in our minds that any development project must be examined from a broad view of both positive effects and negative results.

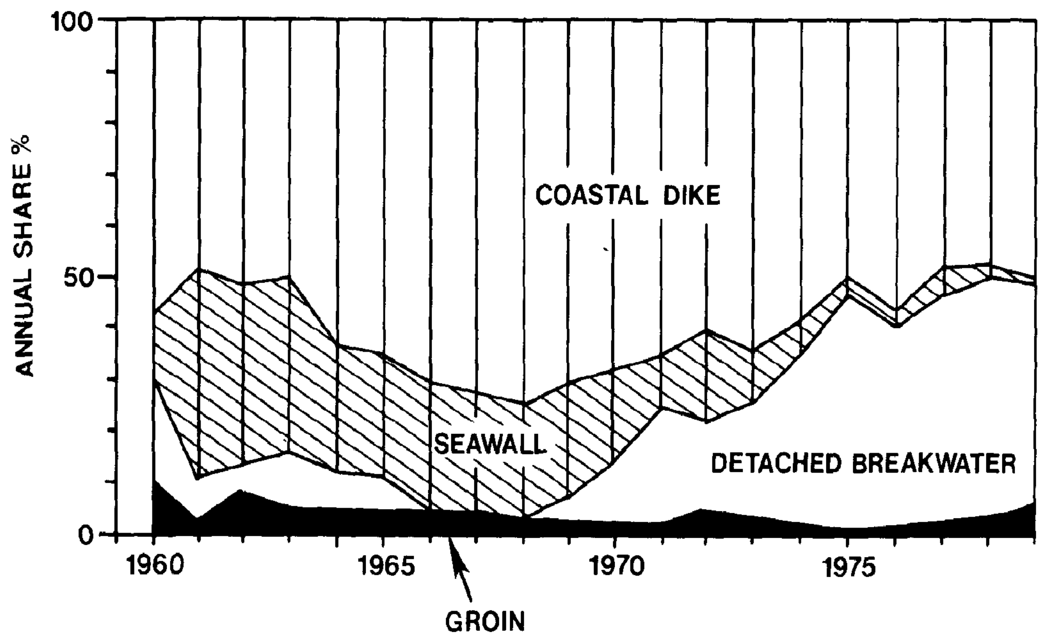

Figure 42. Types of coastal structures built by the Ministry of Construction in Japan (by fiscal year). Note the shift to detached offshore breakwaters over the past 10 years (from Watanabe and Horikawa, 1983, Figure 13).

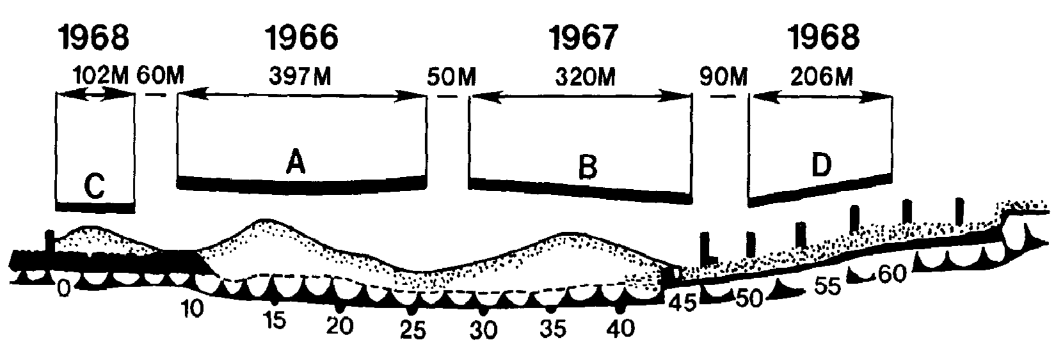

Figure 43. Detached offshore breakwaters on the Kin-eicho coast, Niigata, Japan. Note the accumulation of sand in the lee of the breakwaters (from Watanabe and Horikawa, 1983, Figure 15).

5.4 Beach Erosion in Sri Lanka

About 80 percent of the shoreline of Sri Lanka is natural sandy beaches, one of the nation's most vital resources. Crowding and unwise engineering and mining practices have induced severe erosion problems in some parts of the coast, particularly the southwestern sector.

The general setting of the country with regard to coastal processes is depicted in Figure 44. The southwest monsoon, which occurs between May and September, generates considerably larger waves (mean significant height = 5 ft) than the weaker northeast monsoon (mean significant height = 3 ft), which occurs between November and January. The most severe coastal erosion in the country occurs on the southwestern coast, which is impacted by the largest waves. Long-term erosion also occurs on the northeastern coast. Deposition prevails on the southeastern and northern shorelines, both of which are zones of accretion for the sediment transported away from the two exposed, eroding areas.

Beach erosion in Sri Lanka was related to three principal causes by Gerritson and Amarasinghe (1976): (1) natural processes, (2) man-induced changes, and (3) biological activity. The major natural causes were monsoon-generated waves (discussed above) and migration of tidal inlets. An example of a migrating tidal inlet, or river mouth, is shown in Figure 45. This inlet, located at Kalutara on the southwestern coast, had migrated fully between the 1920s and 1970s. However, southerly migration threatened a hotel that had been built on the south spit in 1973. A combination of boulder groins and rubble revetments were constructed in 1976 in an attempt to hold the inlet in place.

Man's negative activity with regard to beach erosion in Sri Lanka has occurred in the following ways:

1) Mining of sand and coral from the coastal zone.
2) Building training works and fishery harbors that impair longshore sediment transport.
3) Construction of groins and seawalls that adversely affect neighboring areas.

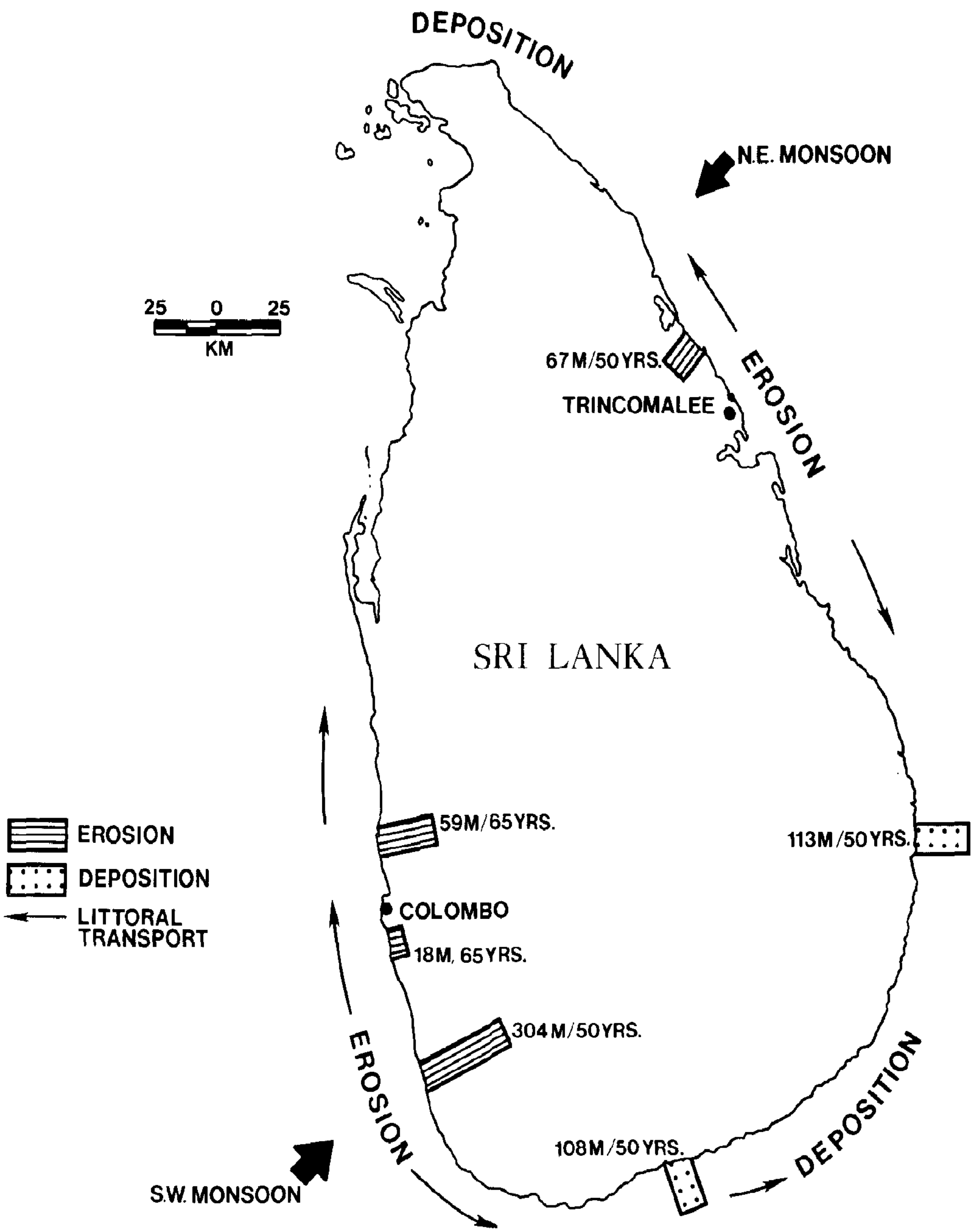

Figure 44. Coastal processes and beach erosional/depositional trends in Sri Lanka. From Figure 4 and and descriptions in Gerritson and Amarasinghe (1976).

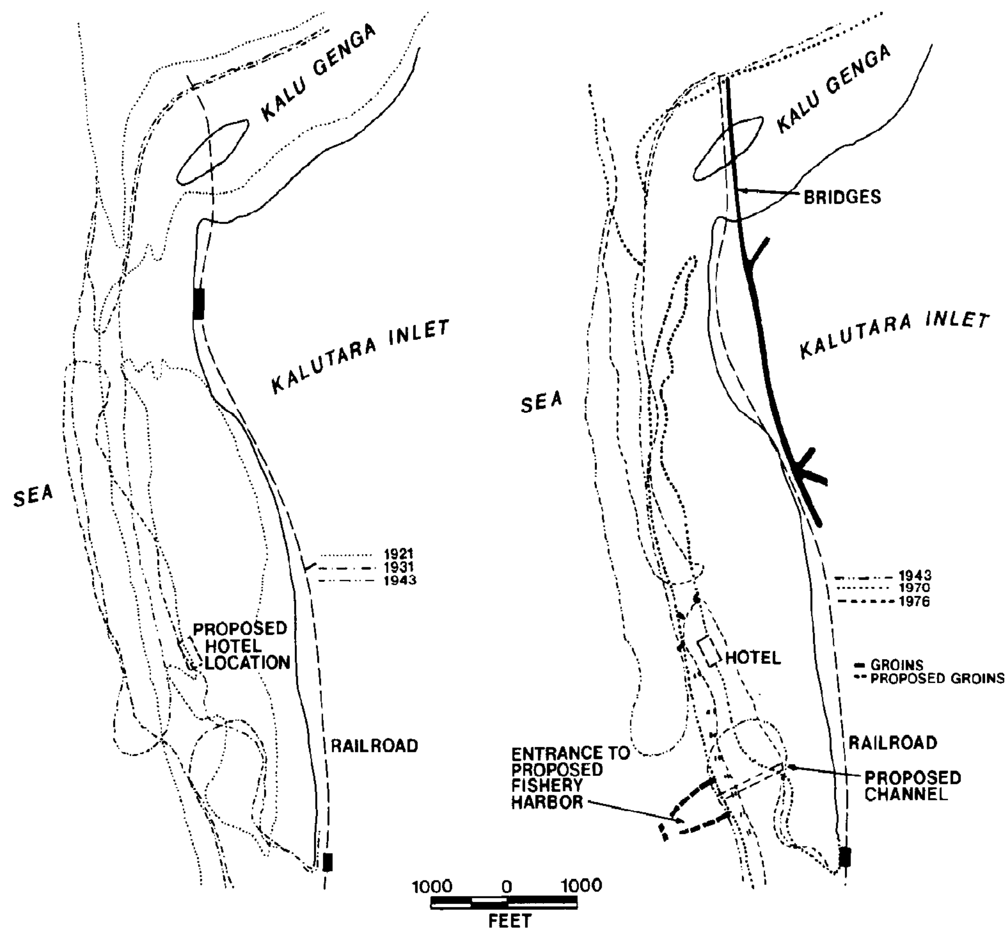

Figure 45. Migration pattern of Kalutara Inlet, Sri Lanka (from Gerritson and Amarasinghe, 1976, Figure 5).

The principal biological reason for erosion is the destruction of some of the reefs in the Trincomalee area by the coral-eating starfish Acanthastar planci.

Gerritson and Amarasinghe (1976) emphasized the need for a coastal area management plan for Sri Lanka. From the scientific standpoint, the erosion problem could be solved with adequate study, but related social problems are much more difficult to deal with. For example, hundreds of thousands of cubic meters of coral are mined from the coastal zone of Sri Lanka each year. If this practice were stopped, erosion would be abated; however, 20,000 people would no longer have a livelihood.

5.5 Beach Erosion in Florida (U.S.)

The beaches of the State of Florida are the most popular in the United States, because of the combination of abundant natural sand and warm temperatures. But, as in many other parts of the world, beach erosion is taking its toll (Figure 46). A study conducted by the U.S. Army Corps of Engineers (1971) found over 200 miles of the Florida shoreline to be in a "critical state of erosion."

Walton (1979) listed the following general causes for beach erosion in Florida:

1) Sea-level rise. As indicated in Figure 47, sea level is presently rising at the average annual rate of 3.3 mm in Florida.
2) Erosion during hurricanes. The coast is struck by a major hurricane every few years, which erodes the dunes, overwashes the barriers, and moves beach sand to offshore depths so great it cannot be returned to the beach. Dune erosion during Hurricane ELOISE (1977) is illustrated in Figure 48.
3) Modification of tidal inlets. The State of Florida has 57 tidal inlets along its shore, many of which have been deepened and/or jettied. A deepened inlet robs sand from the littoral drift system, and jettied inlets without bypass systems tend to cause erosion on their downdrift sides.

After reviewing the erosional conditions of Florida's beaches, Walton (1979, p. 10) reached a pessimistic conclusion:

In all, the picture is not a pleasing one. Erosion is with us to stay due to rising sea level and our needs for improved navigation in our coastal zone.

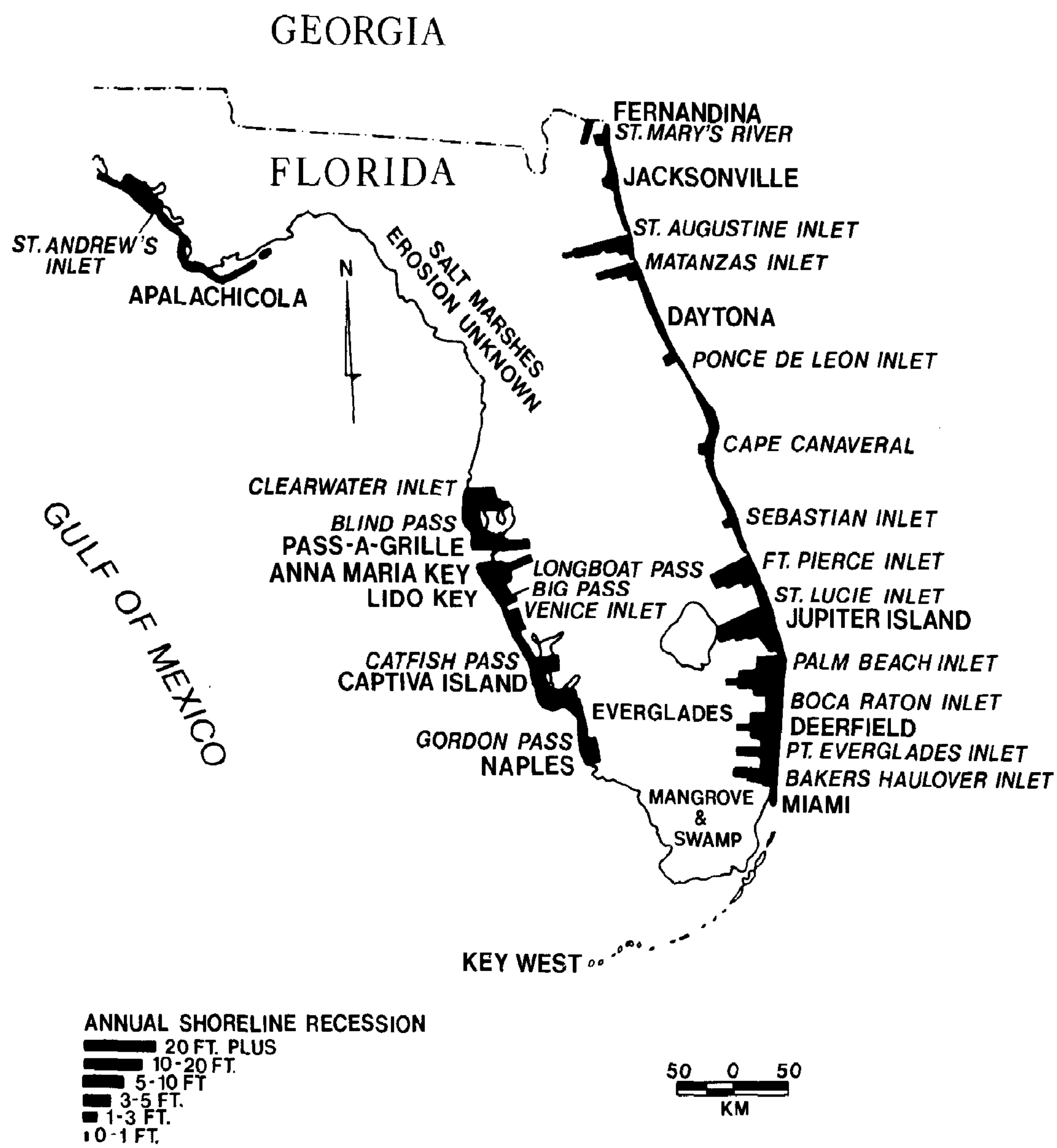

Figure 46. Erosion on the Florida shoreline during 1963 (from Walton, 1979, Figure 7).

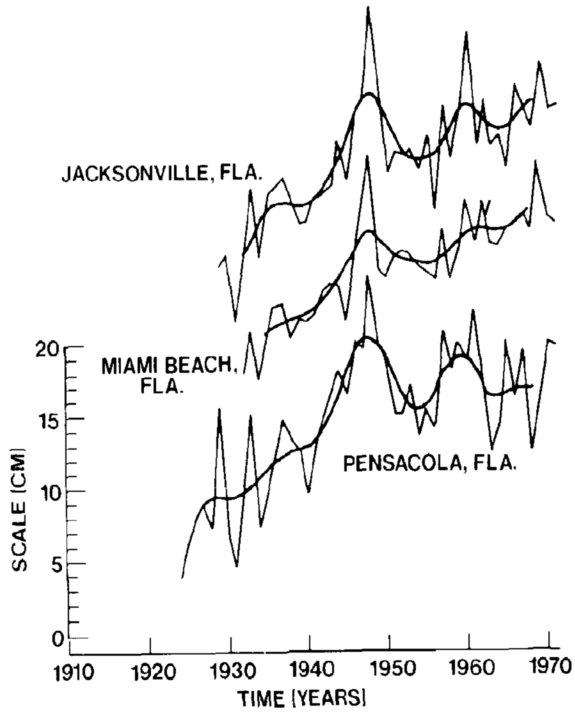

Figure 47. Relative rise of sea level in Florida between 1925 and 1970. The average of all stations is 3.3 mm/yr (after Hicks, 1973, from Walton, 1979, Figure 1).

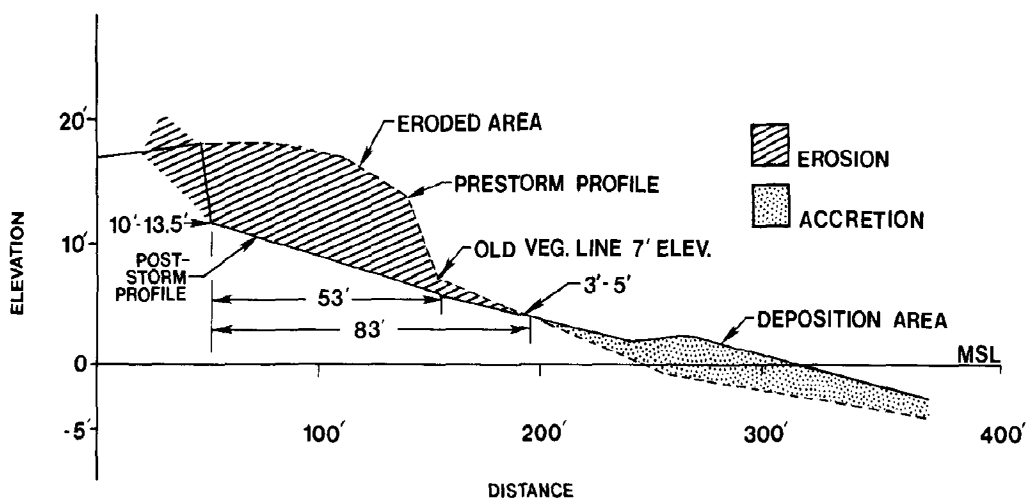

Figure 48. Results of dune erosion near Panama City, Florida, during Hurricane ELOISE (1977) (after Chiu and Purpura, 1977; from Walton, 1979, Figure 4).

6. SPECIFIC CASE STUDIES

6.1 Introduction

This section, in contrast to section 5, concentrates on specific, local areas. Section 5 presented a general picture of erosion in large areas. This section is probably the most important part of the discussion, because all lessons learned regarding beach erosion have been derived through painful trial and error at the local level.

These case studies are taken from the literature, and they represent the best judgments of the authors who have written them. A word of caution is in order, however, because given enough time, conditions may change from those described in these papers. For example, in reading Hale's (1977) discussion of beach erosion in Los Angeles County, California (U.S.), one gets the impression that beach erosion is nonexistent in the county. He implies that the county's survey methods, which were used for over 12 years to check hundreds of structure designs and to design "numerous structures," were foolproof. "We have not had one single failure," he states on page 460. Unfortunately, massive storms in the winter of 1982-1983 devastated the beaches and shore-protection structures of Los Angeles County and other areas of southern California.

6.2 Erosion in Togo and Benin

6.2.1 Introduction

Shoreline erosion in Togo and Benin, West Africa (Figure 49), is so acute that the two countries requested that the United Nations (UNEP) initiate a program to study the problem. A UNEP-sponsored workshop held in the two countries on 29 January-9 February 1979 provides a basis for this discussion. The working technical group consisted of 33 expert engineers and technicians from Togo and Benin as well as nine experts from four other countries. The writer of this document was the convener of the outside technical group.

6.2.2 Present Situation

The present state of erosion and deposition on the shoreline of the two countries is shown in Figure 50. The key elements in the problem are the

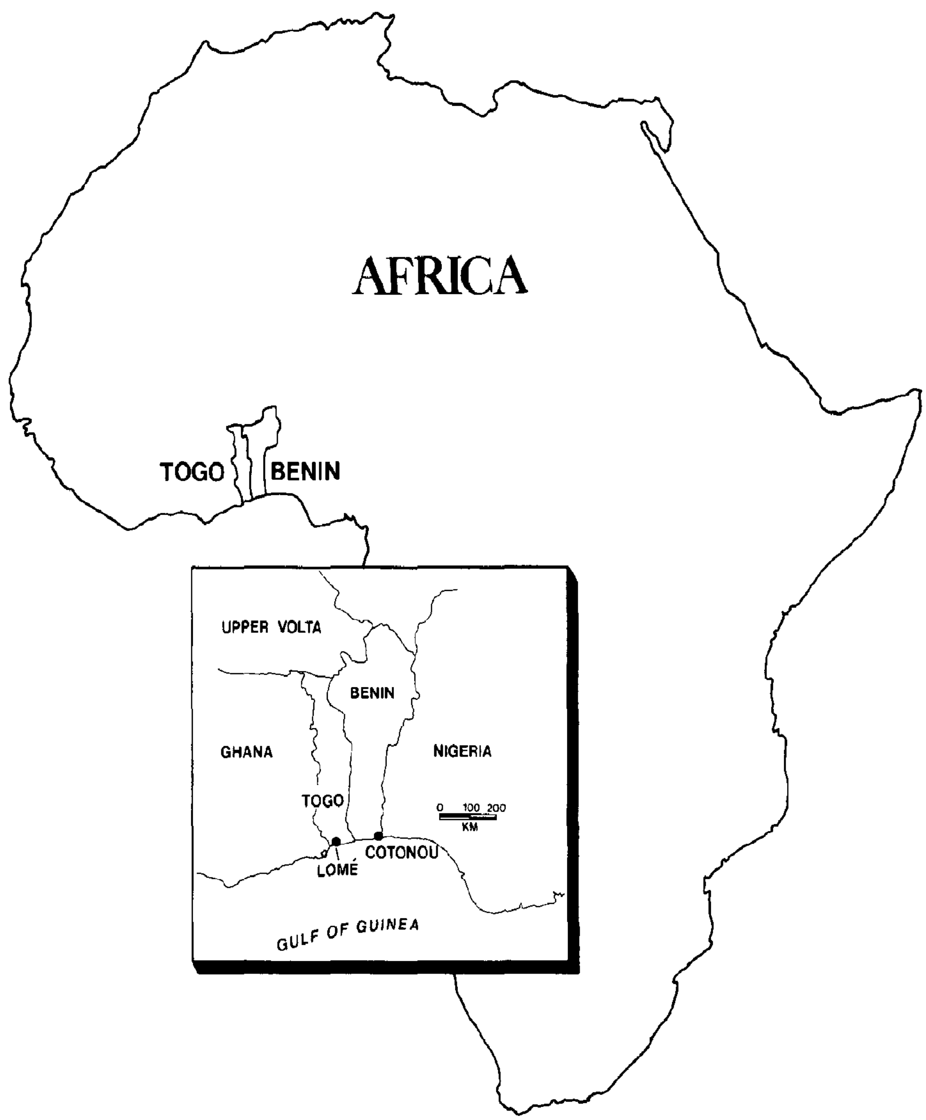

Figure 49. General location map for Togo and Benin.

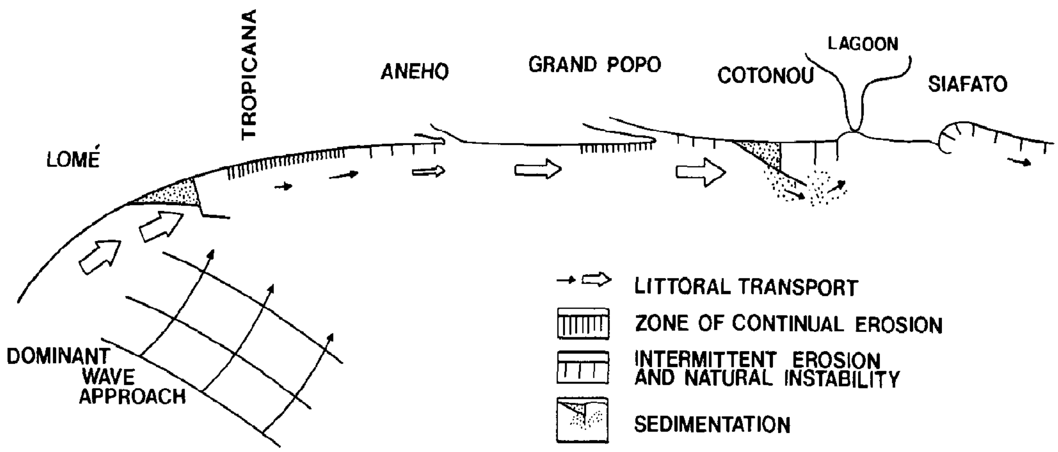

Figure 50. Present conditions on the coasts of Togo and Benin. Note the major role played by the ports in beach erosion in the two areas (from U.N. Technical Group, 1979).

construction of deep-water ports at Lomé, Togo, in 1966, and Cotonou, Benin, in 1963. The jetties of these ports interrupt the longshore transport of sand, one of the strongest in the world (greater than 1,000,000 m^3/yr; NEDECO, 1978). Transport is from west to east almost every day of the year due to the influence of waves arriving at an oblique angle to the shore from the southwest. No sand-bypass systems have been installed at either harbor entrance, so erosion has become a serious problem downdrift of both harbors.

The jetties at Lomé provide a classic case study of man's impact on beaches. The shoreline updrift (west) of the jetties is building out in excess of 50 m/yr, whereas downdrift the beaches are receding at rates up to 8 m/yr. Local outcrops of beachrock slow the erosion rate on the downdrift side. In the erosion zone, many fishing villages have been abandoned and a major tourist hotel is threatened.

East of the erosion zone, extending to Aneho (Figure 50), the coastline is subjected to periodic erosional episodes. This is due to seasonal beach evolution and perhaps local zones of higher wave energy because of offshore bathymetric variations. The inlet area near Aneho is naturally unstable due to fluctuations in inlet position and morphology.

The area of Grand Popo, Benin, is another area influenced by inlet migrations. The shoreline is evidently undergoing long-term erosion, but the data are not precise. Many dwellings and other important structures and relicts have been lost.

The erosional/depositional patterns at the jetties at Cotonou, Benin, mimic those described for Lomé, Togo. West of the port, the beach has built out 700 m since construction of the jetties (U.N. Technical Group, 1979). The area just east of the jetties is complicated because of the presence of a dam and some groins, but a huge erosional crenulate bay has formed east of the last groin. A maximum of 250 m of erosion has occurred in the middle of the bay, which is located approximately 1,000 m east of the jetties. Many villages have been moved and an industrial zone is threatened in this zone. The rest of the coast of Benin is relatively stable.

6.2.3 Other Causes of Erosion

The experts who studied the erosion in Togo and Benin (U.N. Technical Group, 1979) recognized that some of the erosion in the area could be related to causes other than construction of the two harbors. Some of these include:

1) Natural Causes
   a) Gradual rise in sea level.
   b) Periods of high wave activity, particularly between May and August. Significant wave heights are on the order of 1.3-1.4 m (NEDECO, 1978).
   c) A possible decrease in sediment supply due to a recent drying trend and subsequent reduced river discharge.
   d) Local variations in large-scale beach topography (i.e., rhythmic topography) and offshore bathymetry.
2) Man-Influenced Causes
   a) Dams on rivers. It was suggested that sediment supply might have been reduced by the construction of the Alcosombo dam on the Volta River in Ghana.
   b) Sand mining. This is a common practice in both countries. It is estimated that 200,000 m^3/yr are mined from the updrift side of the jetties in Lomé.

6.2.4 Suggested Solutions

After ten days of evaluating the problem, the group of experts, relying heavily on data supplied by NEDECO (1978), formulated several options for dealing with specific erosion problems in the two countries. Some of these recommendations are outlined on the map in Figure 51.

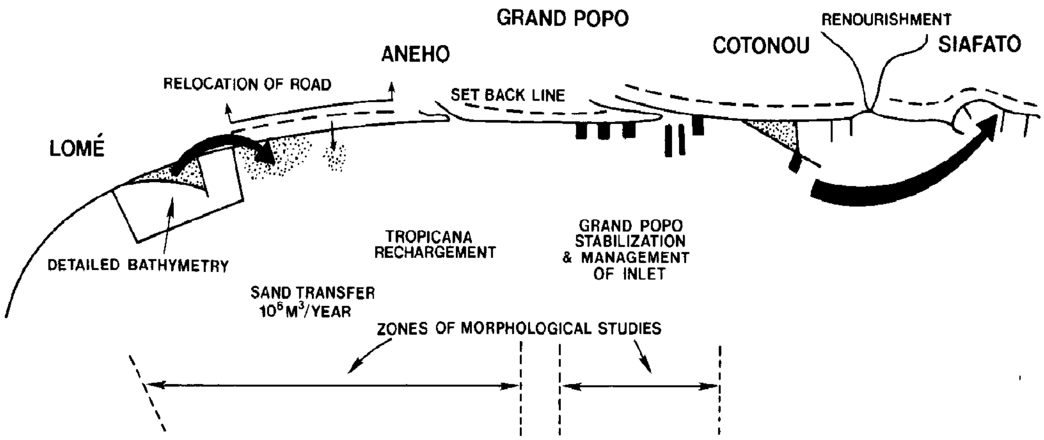

Figure 51. Some suggestions for dealing with the erosion problems on the coasts of Togo and Benin (from U.N. Technical Group, 1979).

The most obvious solution to the major problem in both areas, erosion downdrift of the jetties, would be to bypass sand at both harbors. The volume required would be on the order of one million cubic meters per year at each harbor. In view of the huge costs involved, many millions of dollars for each project, alternative solutions were sought.

The experts could not agree entirely on how to deal with the general erosion downdrift of the harbor at Lomé in the absence of a bypass system. Three alternatives were offered:

1) Establish setback line and treat isolated problems on a case-by-case basis.
2) Establish setback line and build a series of short groins to slow down erosion.
3) Pump quantities of sand (volume dictated by economics) onto the beaches where maximum erosion is occurring.

The specific problem at the tourist hotel would be solved by building a series of groins in front of the hotel. A more complete solution would involve some form of beach nourishment after construction of the groins.

A series of groins were also recommended for the protection of the town of Grand Popo, Benin. Concern was expressed about the stability of the inlet, and a detailed study of the coastal hydrodynamics of the area was suggested.

The solution to the problem of the eroded crenulate bay downdrift of the harbor at Cotonou was another area of disagreement among the experts. A laboratory model demonstrating the development of this crenulate bay is shown in Figure 29. There was considerable disagreement among the experts regarding the continued erosion of the bay, some saying it would become stable and others predicting it would continue to erode. Three alternative solutions were offered:

1) Establish a monitoring program and construct appropriate setback lines.
2) Establish setback lines and reinforce the deteriorating groin at the head of the embayment.
3) Build another groin on the eastern end of the embayment so an equilibrium planform can develop.

Several suggestions relative to scientific and educational aspects of the erosion problems in the two countries were made during the discussions. Of particular concern was the recognition that the problems go beyond the borders of the two countries and, in fact, affect the whole of the West African coast. The following recommendations resulted from this concern:

1) A study should be initiated to synthesize and summarize all consultant reports related to coastal processes in the area. The summary should pinpoint critical data gaps. Furthermore, it was recommended that future contracts awarded to consultants require enough copies of the final reports to allow distribution among the concerned countries and, further, that these reports include complete and annotated reference lists.
2) A second study, involving fieldwork, if necessary, should be initiated to fill the data gaps identified by the aforementioned study.
3) A regional sand budget study should be carried out. This would include an analysis of specific sources of the sand, synthesize existing data

(and collect new data where necessary) on longshore sand transport rates, and identify sand sinks.

These suggestions on research and education are important because as more and more case studies are examined, it becomes clear that many of the erosion problems that now exist around the world have arisen because of man's interference with the natural system. If there had been a requirement for functional sand-bypass systems to be built during the constructional phases of the ports at Togo and Benin, most of the erosion problems that now plague both countries would have been avoided. A sound preliminary study would have recognized this need, and prudent planners would have required it.

6.3 Beach Protection at Lorain, Ohio (U.S.)

6.3.1 Introduction

Much of the preceding discussion of case studies has been negative regarding beach erosion and man's role in it. A more optimistic report is possible for this case study of a beach restoration project on Lake Erie at Lorain, Ohio (U.S.).

In October 1977, the U.S. Army Corps of Engineers constructed three segmented breakwaters and placed beach fill behind them at a public park, Lakewood Park, in Lorain. This was only the second project ever carried out on the shoreline of the United States which used offshore breakwaters, although they are fairly common in other areas, notably Japan (discussed above). It has been a remarkably successful project, from both engineering and social points of view, in that the erosion problem was solved and recreational beaches were created in the process.

6.3.2 The Project

This project was constructed to serve two purposes: (1) protection of existing park facilities and the adjacent lake bluff, and (2) creation of a public recreational beach. The components of the project, which are illustrated in Figures 52 and 53, consist of the following features (Pope and Rowen, 1983, p. 757):

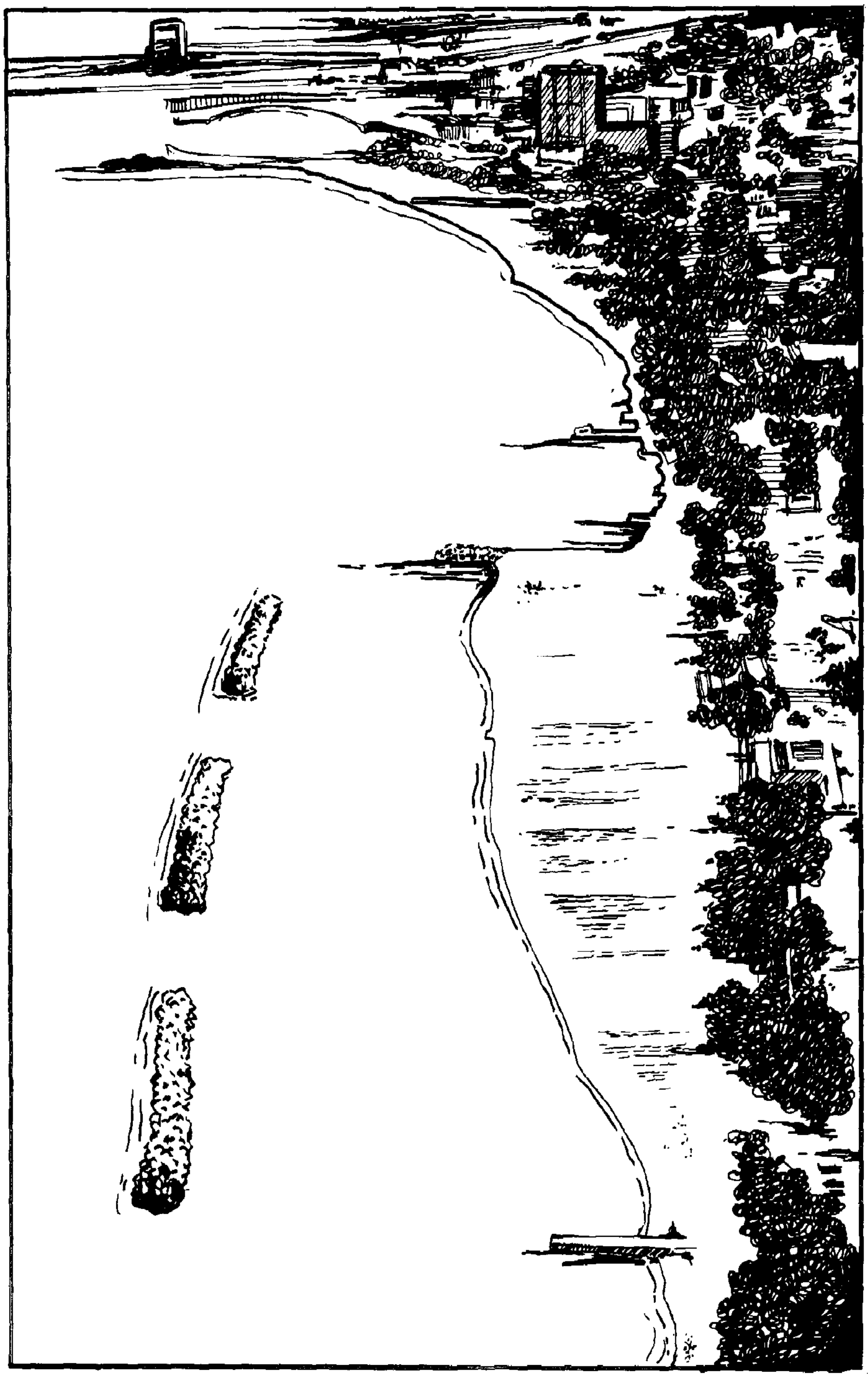

Figure 52. Sketch from oblique aerial photograph of Lakeview Park, Lorain, Ohio. View looks east (from photograph in Pope and Rowen, 1983).

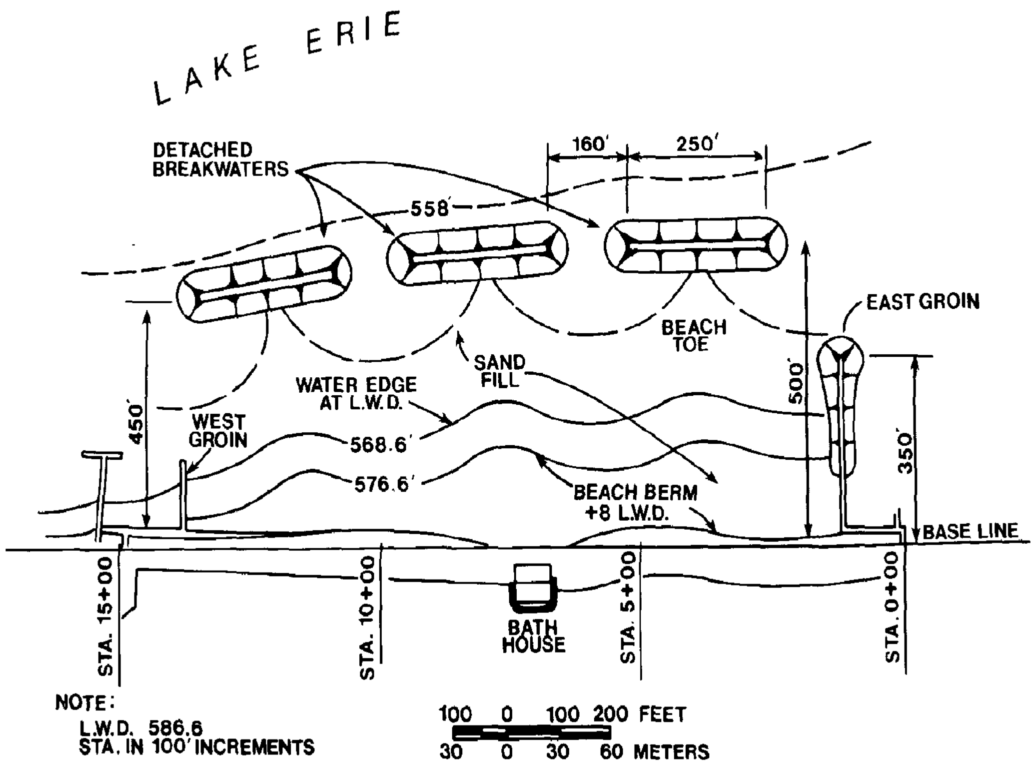

Figure 53. Outline of the principal components of the beach protection project at Lakeview Park, Lorain, Ohio (from Pope and Rowan, 1983).

1) Three 76-m rubblemound breakwaters segmented by 49-m gaps.

2) Two end groins; 46-m concrete groin on west and 107-m composite rubblemound and concrete groin on east.

3) Initial placement of 84,106 m^3 of sand with a median size of 0.5 mm between the end groins.

4) Periodic beach nourishment of 3,800 m^3/yr to replace a predicted annual loss of 5 percent of original fill.

6.3.3 Monitoring Program

This project was monitored closely for the 5-year period of 1977-1982. Sequential aerial photography showed an areal readjustment of the sand, with the beaches on the exposed, western end of the project being narrower than those on the sheltered, eastern end (see Figure 52). Bathymetric and topographic surveys carried out in the spring and fall of each year showed the following:

1) The slope of the shoreface diminished in the first six months.
2) The project has gained 2,200 m^3 of sand per year from the natural drift system.
3) The two additional beach renourishments totaling 6,900 m^3, added in 1980 and 1981, were not actually needed.

Several process-oriented studies including wave-gage measurements, near daily field measurements of wave conditions, current studies, and a model study, kept the engineers abreast of the seasonal changes of the shoreline. Detailed sediment sampling and analysis showed that native sand was being added to the project area from the east, at the rate of about 15,000 m^3/yr. Approximately 12,800 m^3 of sand passed out of the system to the east, so the zone sheltered by the breakwaters was accreting. The fact that some of the sand passed through was thought to represent an advantage of the detached breakwaters in comparison with groins or jetties.

6.3.4 Conclusion

A beach restoration project that lasts five years is unique, but one that gains sand is a revelation. Much of the success of this project is owed to the careful planning involved, as evidenced by the detailed monitoring program. Also, no shortcuts were taken nor costs spared in assuring that the project would work.

Pope and Rowen (1983, p. 767) made the following conclusion about the project:

> Lakeview Park Beach is a highly successful man-made recreational beach, not only technically, but also economically and socially . . . it has become one of the most popular and heavily used public beaches along the Ohio shoreline, providing the city of Lorain with a major recreational asset.

6.4 Erosion at the Muara Port Area, Brunei

Muara Port is the only deep-water port on the coast of Brunei, which is situated on the northern side of the island of Borneo. A natural harbor exists at Muara, but its exit to the South China Sea is too shallow and too prone to siltation to make a good navigation channel. Consequently, an approach channel was cut directly across Pelompong Spit to the open ocean in 1969 (Figure 54). The spit protrudes to the east across the natural channel (Anson Passage) as a result of a dominant wave approach from the west, particularly during the southwest monsoon. A typical swell refraction pattern for the area is shown in Figure 54. Sand transport along the spit is estimated to be 100,000 m^3/yr. The easterly growth of Pelompong Spit is reflected by the orientation of prograding beach ridges on the spit, shown in Figure 55. The growth rate was determined by Goh et al. (1983) to be 27 m/yr between 1888 and 1956 and 76 m/yr between 1956 and 1976. Six maps of the island, dating from 1888 to 1980, are given in Figure 56.

Several problems have developed since the construction of the approach channel in 1969, as might be expected for a structure built so contrary to the forces of nature. The major problems cited by Goh et al. (1983) follow:

1) Land erosion south of the east jetty.
2) Scour problem at seaward end of east jetty.
3) Seabed scour at the approach channel.
4) Potential instability of the west jetty.
5) Shoaling at the entrance to the approach channel.
6) Siltation in the inner harbor.
7) Erosion of the beach east of the channel.

Only erosion of the beach east of the navigational channel (problem 7) will be discussed here. The width of the spit east of the channel decreased from 375 m in 1969 to 80 m in 1980, as a result of the complete stoppage of the sand supply by the new navigation channel. The possibility of a breach of the spit as it continues to erode is cause for much concern, because of the following probabilities:

1) The flow velocity of the channel would drop and siltation would increase.
2) Waves would break through the spit and into the port.
3) The inner island, Pularo Maura Besar, would begin to erode.

In order to avoid these calamities, the problem was studied carefully and a design was arrived at to stabilize the truncated (eastern) end of the

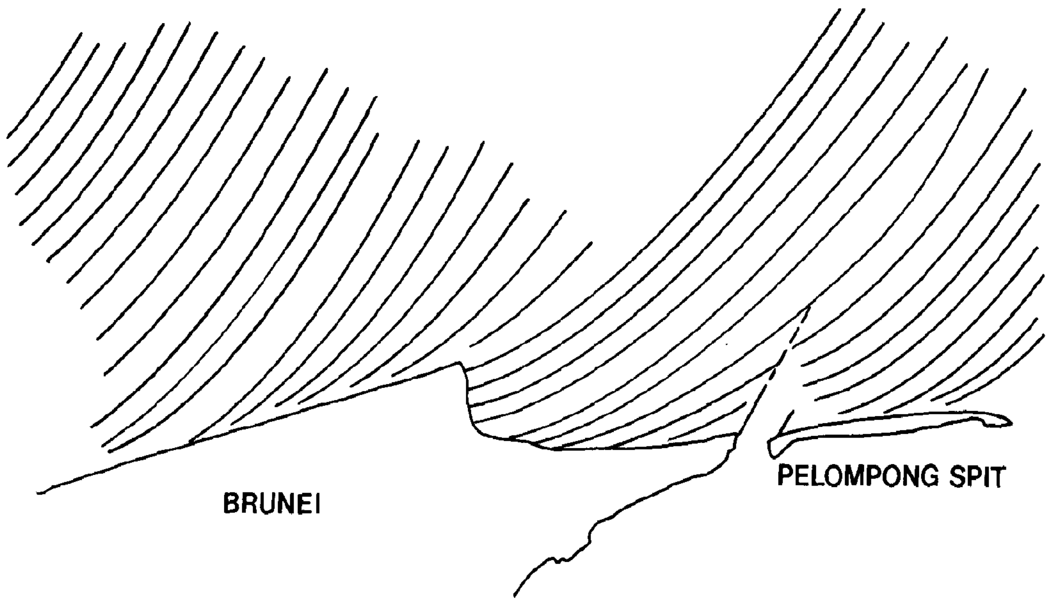

Figure 54. Swell refraction off the Pelompong Spit, Brunei. Taken from aerial photographs shot during the southwest monsoon in July 1971 (from Goh et al., 1983, Figure 4).

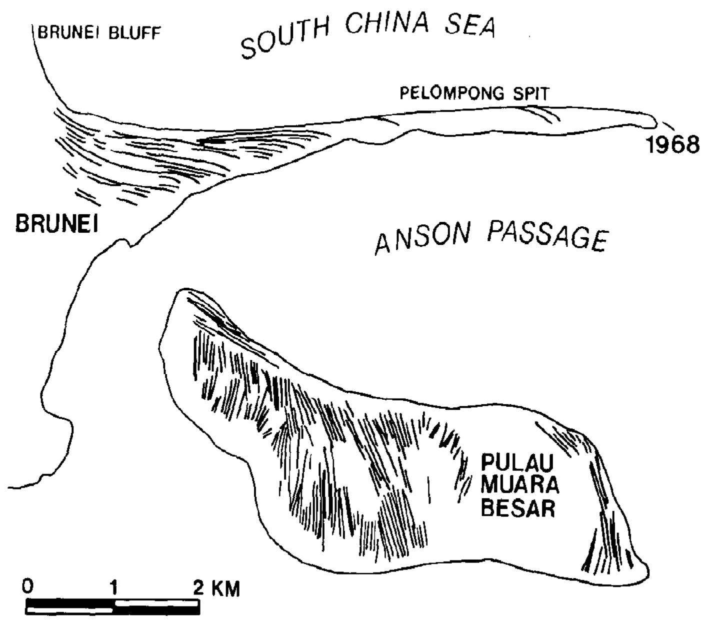

Figure 55. Prograding sand ridges on Pelompong Spit and Paula Maura Besar (after Tate, 1970; from Goh et al., 1983, Figure 5). These ridges reflect the dominant easterly longshore transport direction generated by the westerly waves depicted in Figure 54.

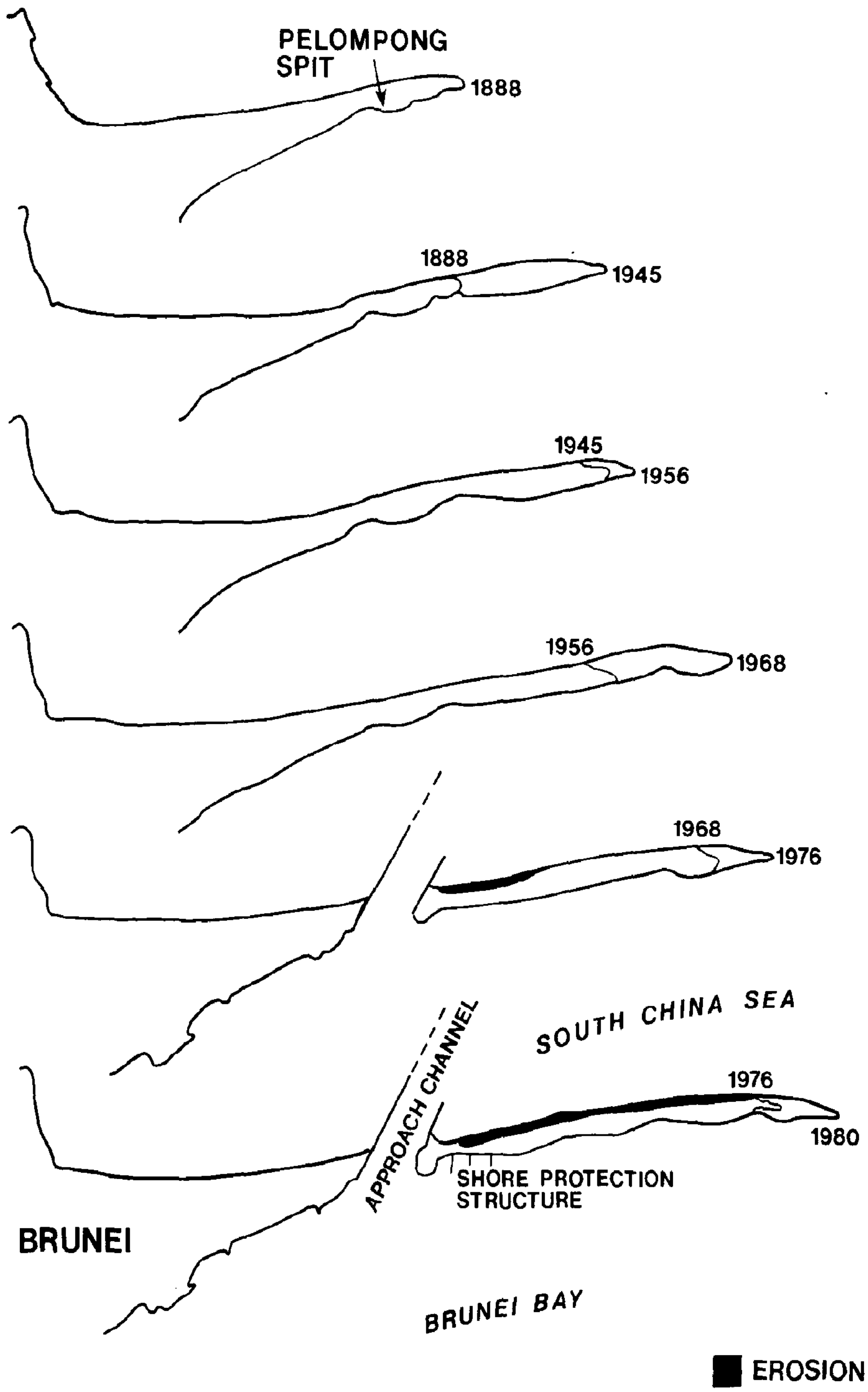

Figure 56. Growth of Pelompong Spit between 1888 and 1980 (from Goh et al., 1983, Figure 6). Note erosion of eastern limb of spit after channel was cut in 1969.

spit. The design calls for a series of 12 headland breakwaters of the type recommended by Silvester (1974). A sketch of the proposed project, which began in 1982, is given in Figure 57.

6.5 Erosion at Heron Island, Great Barrier Reef (Australia)

Heron Island is a small cay (sand island) on Heron Reef which is located in the southern portion of the Great Barrier Reef (Australia). The reef is about 9 km long and 4 km wide, and the island itself is 830 m long and 300 m wide. The island is located on the extreme leeward end of the reef where sand accumulated through time as a result of sand transport by refracted waves (Figure 58). It is a precarious feature with a maximum elevation of 4.5 m above low-water datum.

Heron Island is one of two islands that provide tourist facilities on the Great Barrier Reef. The island has a complex history of man-modifications and storm erosion. The first development was a turtle soup factory in the 1920s, which later became a tourist resort (1932). A channel was blasted through the reef in 1945, and a small boat harbor was dredged in 1966. The present developments on the island are shown in Figure 59. Heron Island is struck by tropical cyclones about once every five years, and most of them do some damage to the island. A rock wall was built in the 1950s to protect the northwestern side of the island, which had been eroded by storms. The leeward side of the island, site of the harbor and tourist facilities, has been anything but stable, as can be seen in the shoreline maps in Figure 60.

Gourlay (1983) outlined the following sequence of events which demonstrate how the behavior of the island has been influenced by man:

1) In response to erosion during several tropical cyclones, a rock wall was built to protect the tourist facilities.
2) Sand was transported by ebb currents off the reef platform and through the gap cut through the reef.
3) The sand "tail" on the cay rotated west; the wall was extended because of the increased exposure.
4) The extension of the wall into the zone of converging waves accelerated the loss of sand from the reef platform.

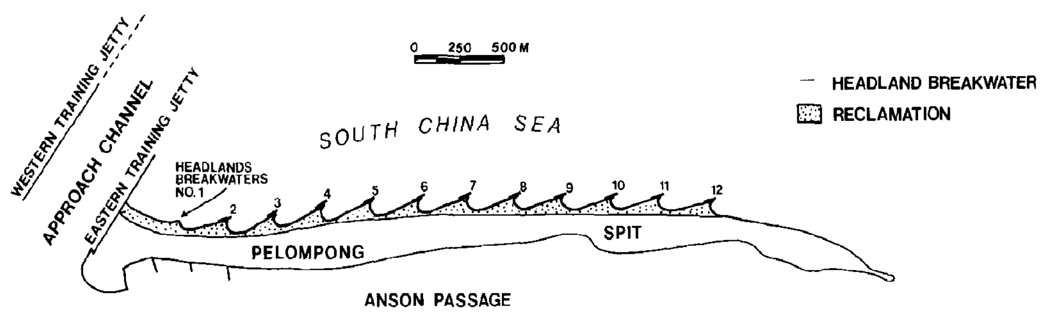

Figure 57. Design proposed to stop erosion along the truncated eastern end of Pelompong Spit (after Goh et al., 1983, Figure 15). Work began on the project in 1982.

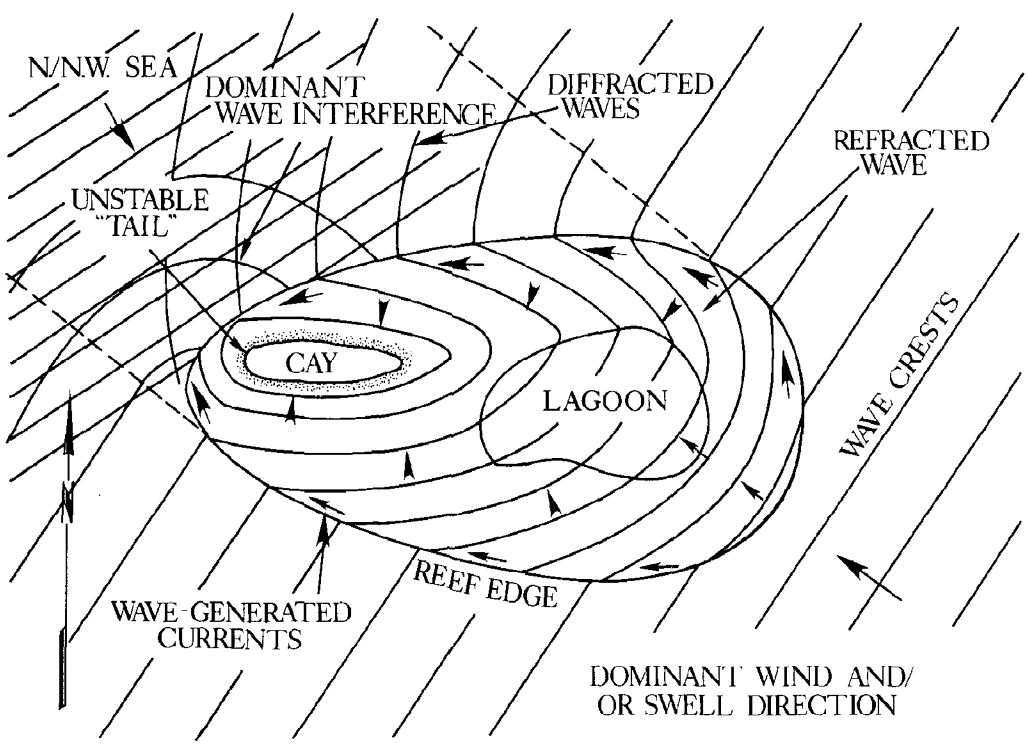

Figure 58. Model depicting the formation by wave-generated currents of a hypothetical sand cay on the sea side of a reef (from Gourlay, 1983, Figure 6). Heron Island is thought to have had a similar origin.

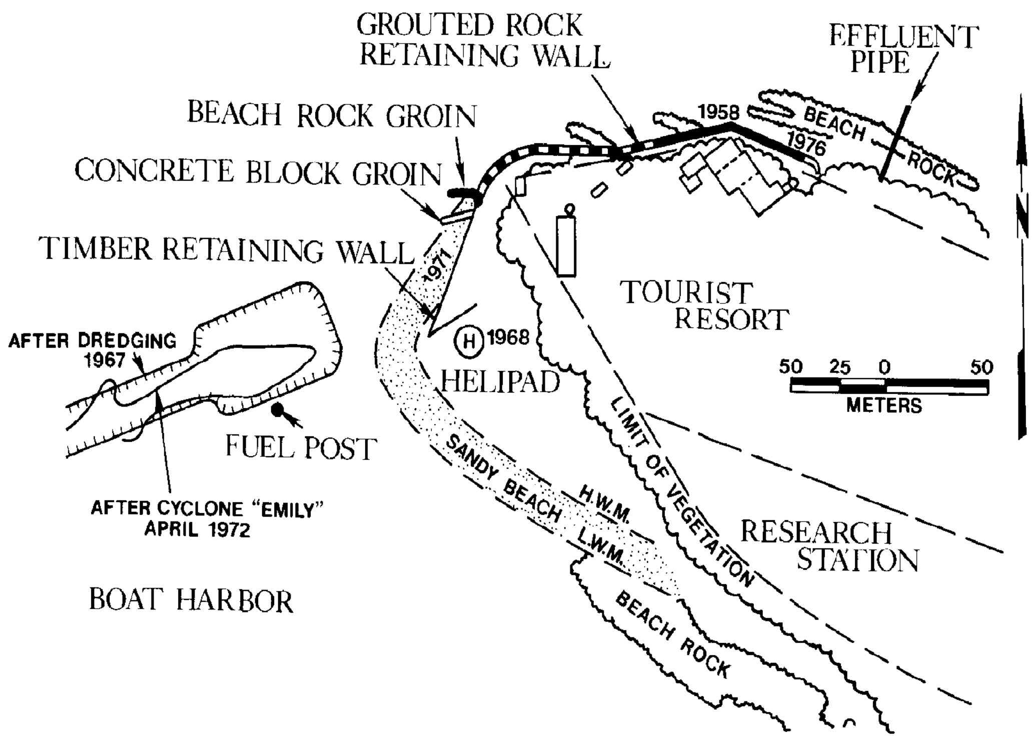

Figure 59. Modification of the western end of Heron Island (from Gourlay, 1983, Figure 4).

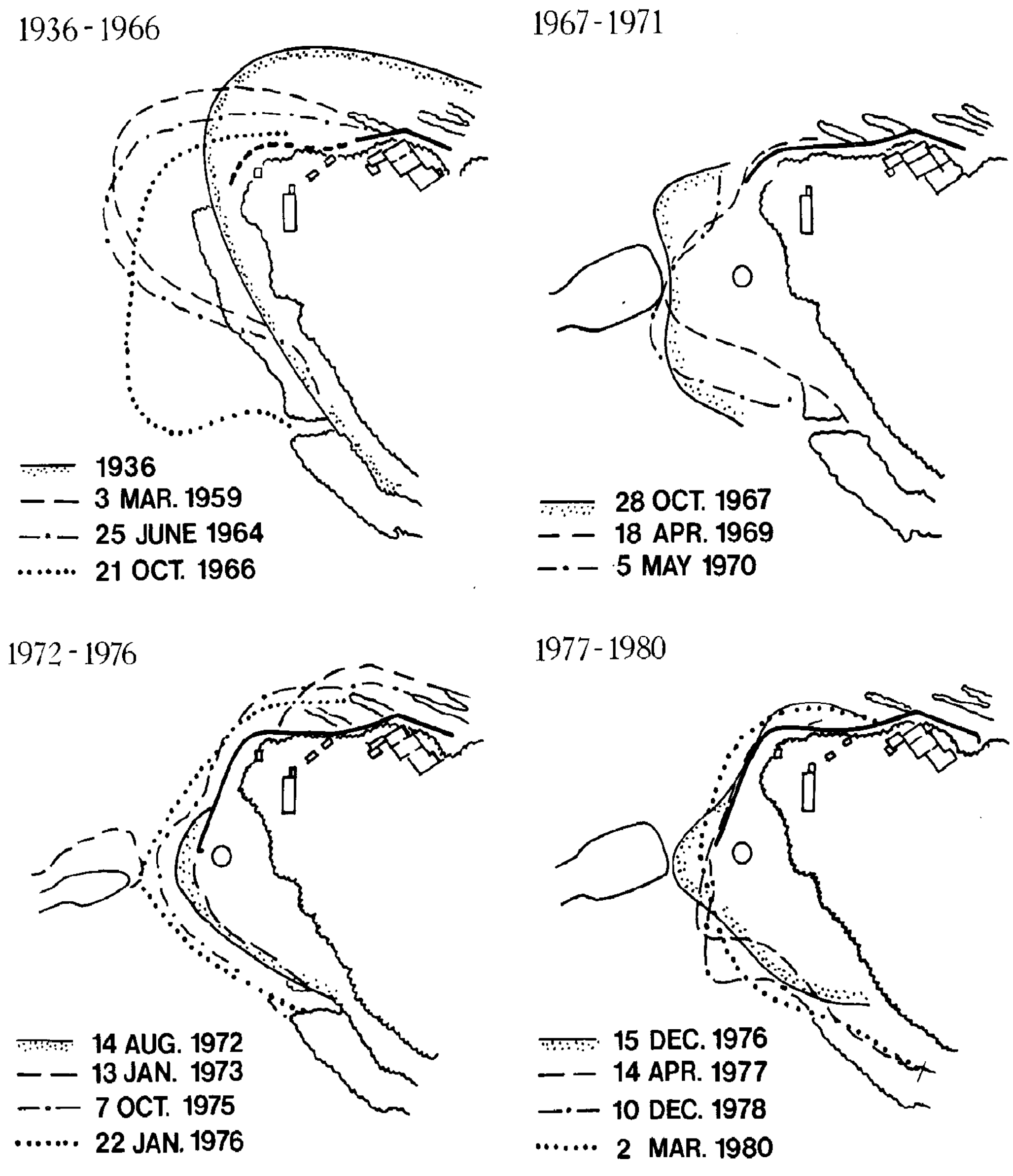

Figure 60. Shoreline changes on the western end of Heron Island between 1936 and 1980 (from Gourlay, 1983, Figure 5).

5) Wave erosion around the newly constructed helipod and destruction of retaining walls of the harbor added to the sand loss into deeper water.

6) Sand will probably not remain in front of the rock wall under present conditions, and constant repairs of the seawalls will be required.

As a result of his work on Heron Island, Gourlay (1983) made the following plea regarding development of islands on coral reefs (p. 1,481):

> In planning development on a coral cay, relatively wide buffer zones must be allowed between the shoreline and the development to accommodate both normal erosion-accretion cycles and long-term erosion. This is particularly important in the apparently sheltered lee of the cay. It should always be remembered that these islands are geologically temporary structures and could be destroyed by a severe 'direct hit' cyclone.

6.6 Beach Erosion at Seabrook Island, South Carolina (U.S.)

Seabrook Island near Charleston, South Carolina (U.S.) (Figure 61), is a typical mesotidal (tidal range = 2-4 m) barrier island consisting of vegetated beach ridges and low frontal dunes bounded by tidal inlets and a marsh/tidal creek system. It has been developed as a private vacation resort, starting in 1973. Due to its proximity to a major tidal inlet and the presence of numerous shifting offshore shoals, the ocean shoreline has tended to change rapidly in response to local variations in wave energy. This has presented significant problems to portions of the existing development. Several homes and the community center are located in erosion zones and have required seawalls or rubblemound riprap for protection, whereas some nearby beaches are presently accretional.

While coastal protection works are providing immediate relief to certain highly erosional areas of the development, they are causing long-term adverse effects, including acceleration of erosion in unprotected areas and destruction of the natural character of the island. This latter effect is of great concern since the key attraction of this and other South Carolina coastal developments is their unspoiled beaches.

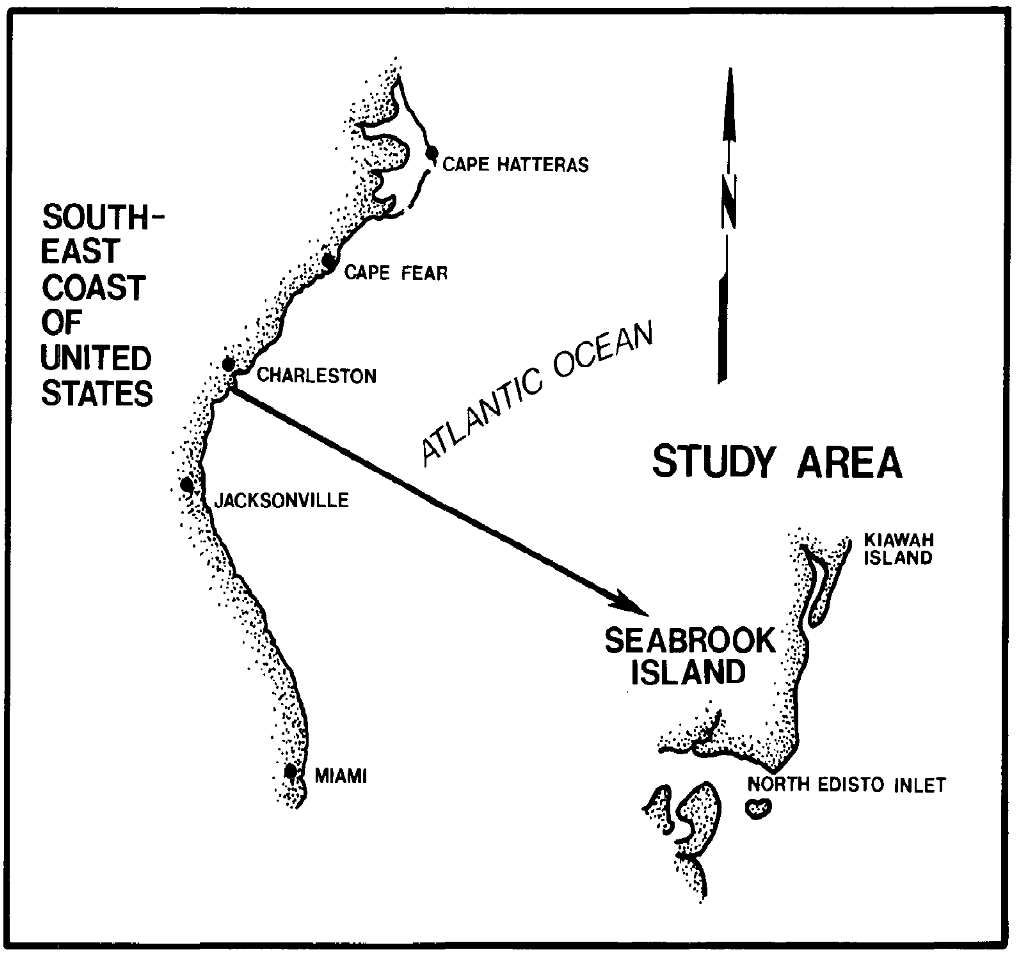

Figure 61. Location map of Seabrook Island, South Carolina (30 km south of Charleston, S.C.).

6.6.2 Modification of Coastal Processes by Artificial Structures

Coastal structures existing in 1978 at Seabrook Island included (1) sandbag groins designed to trap sediment moving alongshore, (2) vertical poured-concrete seawalls to protect a clubhouse and several houses, and (3) rubblemound riprap.

1) Sandbag Groins.

The groins at Seabrook trapped some of the sand moving alongshore and initially caused minor reorientation of the shoreline as fillet beaches developed on the updrift (northeast) side and erosion on the downdrift side. However, after the reorientation to a new "equilibrium" shoreline, the erosional trends continued despite the presence of these groins.

2) Concrete Seawalls.

The vertical seawalls at Seabrook have protected several houses and the clubhouse by retaining sand behind them. However, they have had some adverse effects including accelerated erosion along adjacent shorelines. Wave reflection from the seawalls has caused scour and sediment removal from the nearshore area.

3) Rubblemound Riprap.

These features also protected property, but like the vertical seawalls, wave reflection tended to generate scour in front of them. The riprap seawall is not solving the long-term problem of continued erosion on the island, which is the lack of enough sediment supplied from updrift.

6.6.3 Shoreline Changes

In order to learn about the more recent short-term shoreline changes on Seabrook Island, all charts and maps available were assembled and studied by Hayes et al. (1980). Particular attention was placed on the changing location of shoals and inlet channels. Five historical charts were available covering the period 1661 to 1924. A series of vertical aerial photographs covering the interval 1939 to 1973 were also examined. Historical shoreline changes of Seabrook dating back to 1853 are shown on Figure 62. Note that Seabrook was largely accretional until 1973.

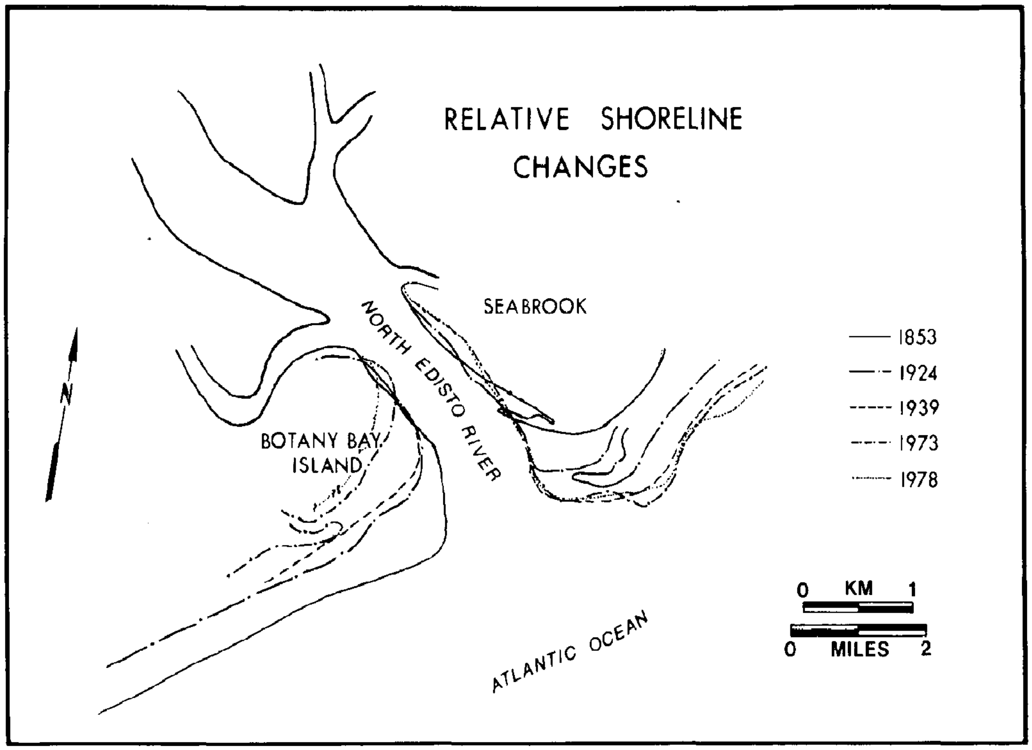

Figure 62. Relative changes of the shorelines of Seabrook and Botany Bay Islands between 1853 and 1978.

The maps, charts, and aerial photographs studied indicate that the recurved spit affiliated with Captain Sam's Inlet at the northern border of the island undergoes a cycle of change that has occurred at least four times since 1661. The cycle (Figure 63) includes:

1) Breaching of the spit at the neck (where Kiawah River crosses the island perpendicularly) during a major storm.
2) Migration of the spit southwestward at the rate of approximately 60 m per year.
3) Extension of the spit up to as much as the entire distance from the spit neck to the southwestern end of Seabrook Island.
4) Breaching of the spit by another storm.

As the spit/inlet complex migrates, the affiliated ebb-tidal delta complex migrates with it. As waves refract around the moving ebb-tidal delta, the beach downdrift of the inlet tends to build out. The migrating

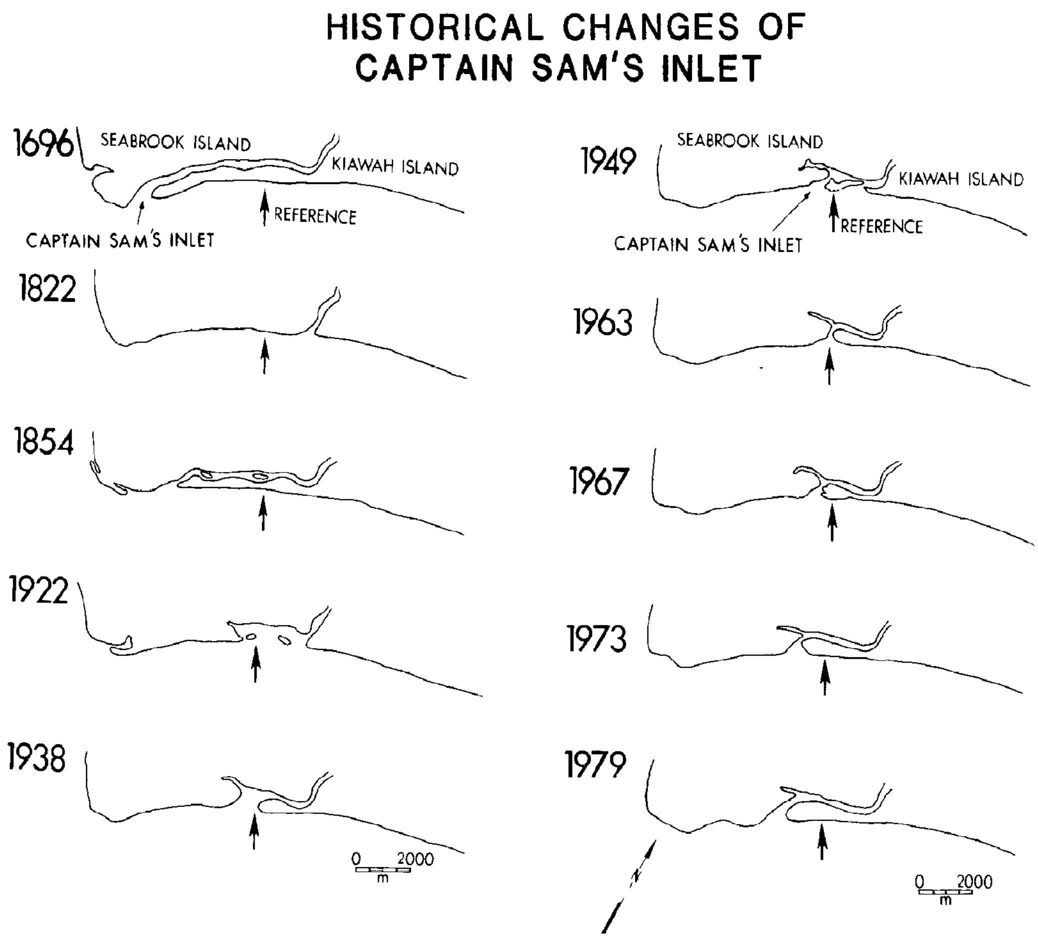

Figure 63. Historical changes of Captain Sam's Inlet, South Carolina (from Hayes et al., 1980). Note periodic migration of the inlet from northeast to southwest followed by spit breaching at an updrift location. The cycle typically runs from 40 to 80 years.

ebb-tidal delta traps large volumes of sand. When the neck of the spit is breached updrift, this sand is freed to move onto the beach to the south.

One of the most important discoveries of the historical analysis was the fact that Deveaux Bank, a huge shoal on the ebb-tidal delta to the south of Seabrook, has retreated a phenomenal amount since 1939 (over 1,000 m). From 1939 to approximately 1970, Deveaux Bank was an effective, natural, offshore breakwater that sheltered the shoreline in the vicinity of the southwestern point of the island from direct wave attack. In recent years, however, the bank is too far landward to provide this protection, a fact which has, no doubt, contributed significantly to the increased rate of erosion of the Seabrook shorefront. In recent years, the rate of erosion appears to have accelerated. Figure 64 shows the changes to Deveaux Bank up to 1978. The supratidal portion of the bank underwent rapid landward migration and erosion. The small intertidal shoal remaining in the former location is relatively ineffective in blocking wave energy at high tide.

Since the erosion area on Seabrook is located adjacent to North Edisto Inlet, one of the largest tidal inlets on the South Carolina coast, bathymetric surveys of the main channel were compared from historical records to determine if the channel had migrated north. Such channel migration would undoubtedly contribute to erosion of the adjacent shoreline. However, the surveys found no evidence to suggest channel meandering was occurring in the vicinity of the southwestern point. There was evidence, however, that the northern marginal flood channel (a secondary channel dominated by flood currents) which flanks the main channel had shifted slightly landward toward the southwestern point of Seabrook Island. This probably helped cause the observed increase in erosion.

6.6.4 Causes of Erosion

The historical evidence indicates that until 1973, Seabrook Island had undergone long-term accretion. This indication that Seabrook Island is basically a regressive barrier (seaward-building) in a geological sense, as well as the fact that tremendous volumes of sand are stored in the North Edisto ebb-tidal delta complex (roughly one-half the volume of the sand stored in the entire Kiawah/Seabrook barrier-island complex) (Hayes et al.,

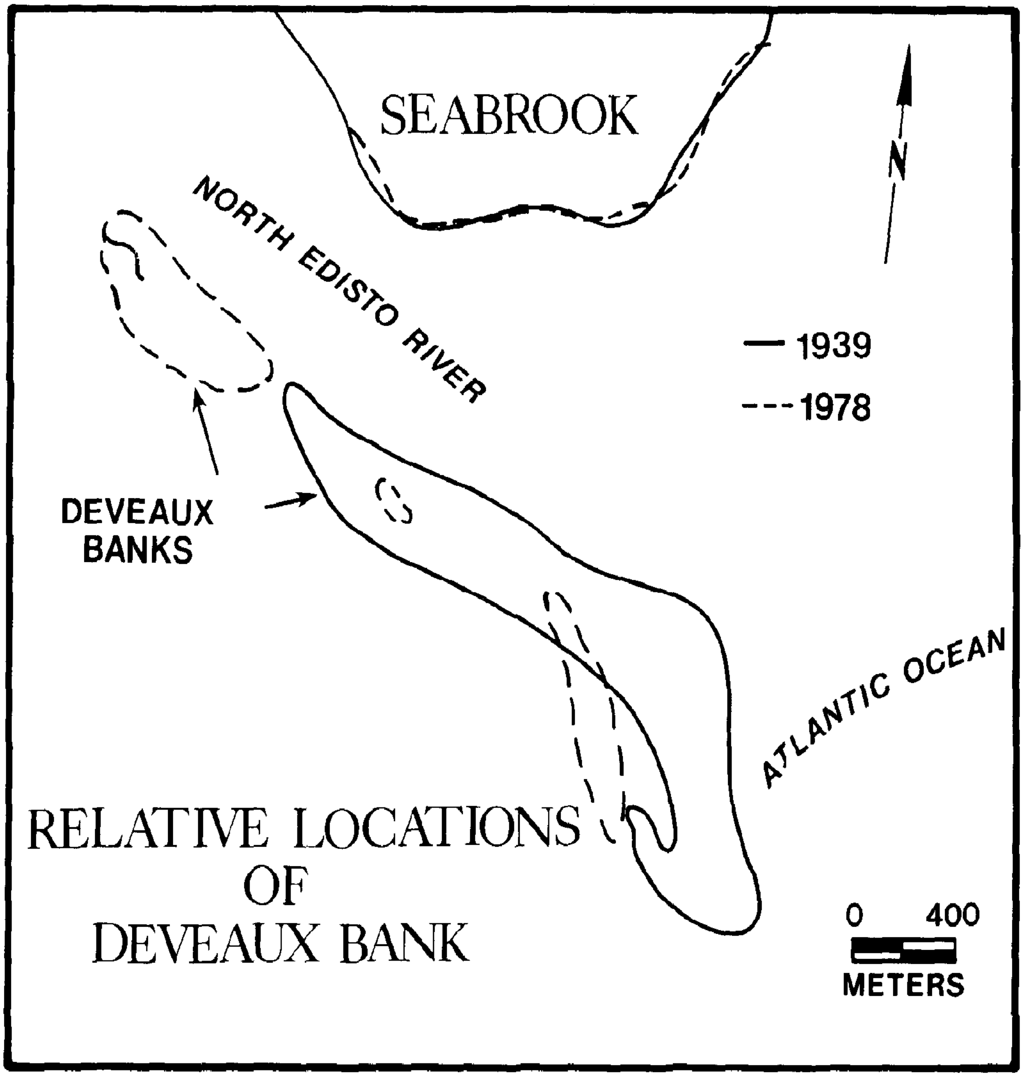

Figure 64. Comparison of aerial extent of Deveaux Bank between 1939 and 1978. The center of the bank retreated 1,500 m, and the bank decreased roughly one-fourth of its original size between 1939 and 1978. Thus, the natural breakwater effect formerly provided by the shoal was no longer available to Seabrook Island, which began to erode in 1973.

1976), suggests that localized erosion problems at Seabrook are reversible. It is primarily a matter of inducing an adequate amount of the sand available in the area to reside on the beach.

The foregoing analysis suggests the following major causes of shoreline change along Seabrook Island:

1) Southerly migration of the updrift (Captain Sam's) inlet and inlet-affiliated ebb-tidal delta which causes erosion along the inlet shoreline and accretion in the lee of the delta.
2) Encroachment of the northern marginal flood channel of the downdrift (North Edisto) inlet against the southeastern point of Seabrook Island.
3) Erosion and landward migration of an offshore supratidal bank (Deveaux) which has allowed increasing amounts of wave energy to reach the shore.

Based on the above causes of erosion, a number of soft engineering solutions were proposed by Hayes et al. (1980) to retard or eliminate local erosion problems at Seabrook Island. These included:

1) Dredging of a new inlet channel north of Captain Sam's Inlet to allow sand in the ebb delta to migrate naturally onshore at Seabrook.
2) Dredging of a new, northern, marginal flood channel further seaward on the North Edisto River ebb-tidal delta to relieve the erosive pressure at the southeastern point of Seabrook.
3) Reestablishment of a natural (or artificial) breakwater in the former position of Deveaux Bank.

One possibility for the latter would be to construct a floating, offshore breakwater. These solutions are outlined in Figure 65.

One of these recommended solutions, relocation of Captain Sam's Inlet updrift, was completed in February 1983. The design plan for the relocation is shown in Figure 66. At the time of this writing (October 1983), the new inlet is functioning as planned, and sand from the abandoned ebb-tidal delta is going ashore on Seabrook Island.

6.6.5 Conclusion

Although the solutions proposed by Hayes et al. (1980) to abate beach erosion at Seabrook Island do not have the permanence of hard engineering coastal protection works, their cost of implementation is at least an order of magnitude less than presently used structures. They also have the aesthetic advantage of preserving the character of Seabrook beaches. The apparent success of the relocation of Captain Sam's Inlet demonstrates the relevance of geologic and coastal process information not only for use in hard designs, but also as a means for determining appropriate soft design solutions for coastal protection.

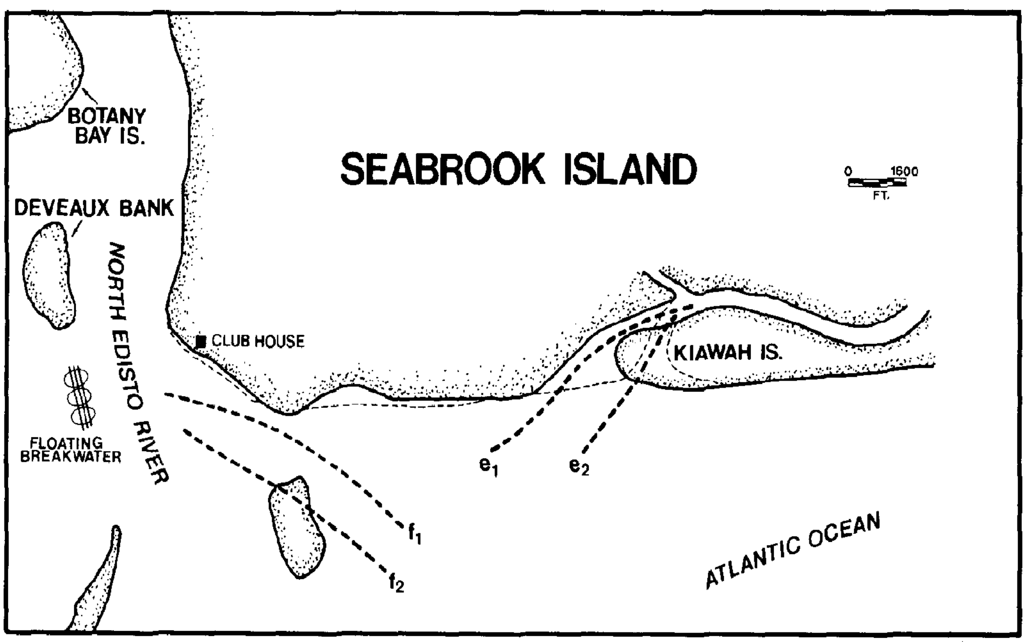

Figure 65. Proposed "soft" engineering solutions for reducing shoreline erosion along Seabrook Island, including (1) dredging new channels at e_2 and f_2, allowing existing Captain Sam's Inlet channel (e_1) and North Edisto Inlet marginal flood channel (f_2) to infill; and (2) construction of a floating breakwater (or hydraulic filling) in the former position of Deveaux Bank.

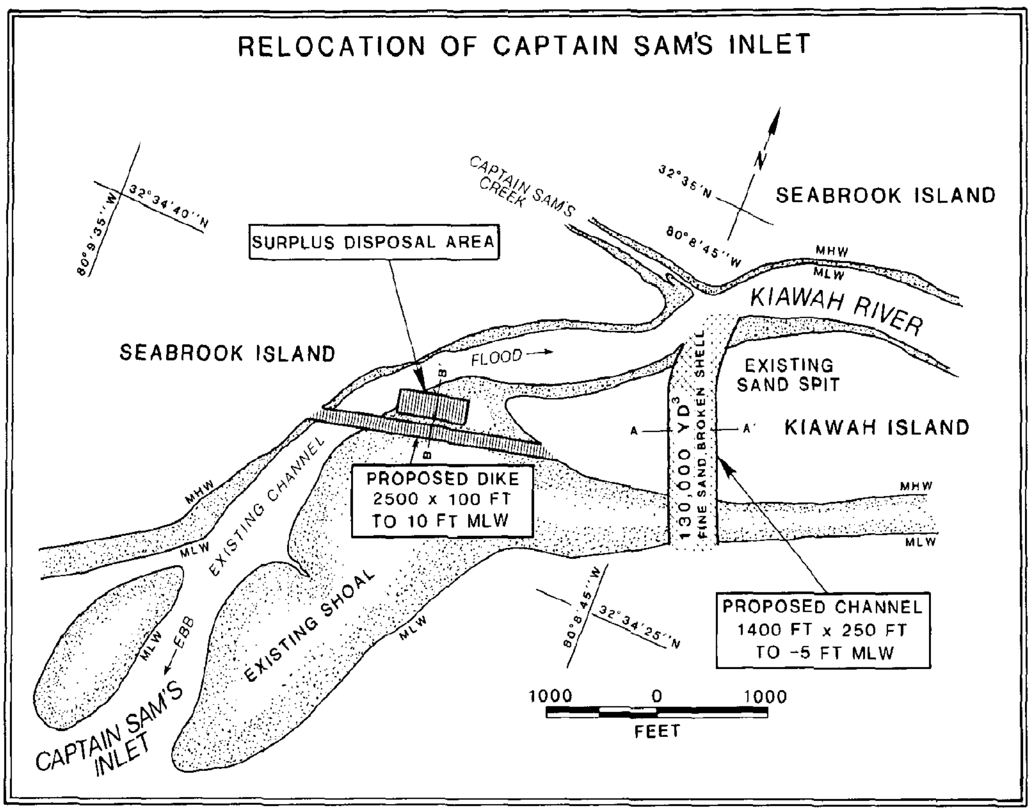

Figure 66. The plan for relocating Captain Sam's Inlet which was completed in February 1983. The project freed a large volume of sand trapped at the mouth of the existing inlet, which is now (October 1983) renourishing the eroding downdrift beach to the southwest.

7. EROSION ASSESSMENT

7.1 Introduction

Before assessing the impact of beach erosion or determining methods to combat it, baseline data must be gathered and compiled for the area in question. This process has normally been carried out at two levels: (1) a general coastal environmental assessment, which includes a wide variety of data inputs; and (2) a specific determination of shoreline erosion rates. Examples of these two approaches are discussed below.

7.2 Coastal Environmental Assessment

7.2.1 Introduction

Development of guidelines for proper management of any coastal zone requires an adequate knowledge of the nature and distribution of natural environments, land and water capability, and man's impact on the coastal zone. One of the best known efforts to tabulate such information for a specific region is a series of "Environmental Geological Atlases" that have been compiled for the coastal zone of the State of Texas (U.S.) by the Bureau of Economic Geology at the University of Texas. The principal product of this endeavor is an environmental geology map.

7.2.2 Environmental Geology Map

The techniques employed in compiling the environmental geology map (by the Texas group) is paraphrased generally as follows (from Fisher et al., 1973, pp. 2-4). Environmental geology units for the entire coastal zone were interpreted from and plotted on aerial photomosaics and corresponding U.S. Geological Survey topographic maps, both at a scale of 1:24,000. All environmental maps were printed on a regional base map of the coastal zone.

Mapping involved extensive aerial photographic interpretation, fieldwork, aerial reconnaissance, and utilization of available published data for the region. General sources and flow of data used in mapping are shown in Figure 67. Interpretation and mapping of environmental geologic units were based on a genetic grouping of the major natural and man-made features of the coastal zone. Units mapped were interpreted to be of first-order importance to the environmental character of the zone. First-order environmental units included the following:

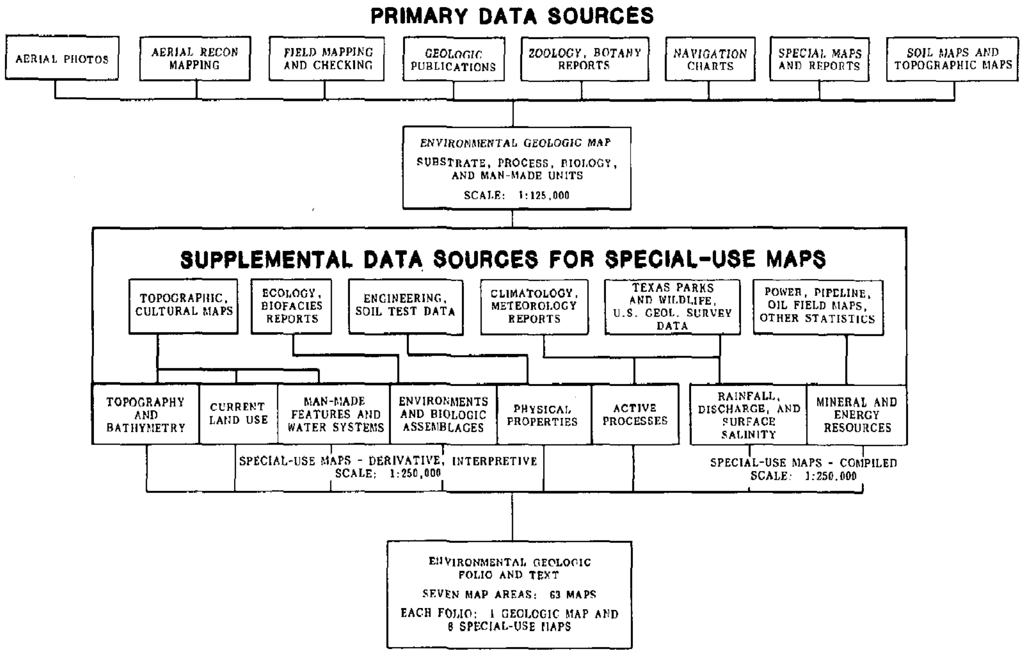

Figure 67. Sources and flow of data used in compiling the Environmental Geologic Atlas of the Texas Coastal Zone (from Fisher et al., 1973, Figure 2).

1) A wide variety of sedimentary substrates (sand, mud, shell) and associated soil units displaying distinct properties and composition.
2) Units displaying a variety of natural processes, including storm channels, tidal passes, tidal flats, fluvial channels, wind erosion, and other dynamic properties of significance in maintaining and modifying the coastal environments.
3) Biologic features such as reefs, marshes and swamps, subaqueous grassflats, and plant-stabilized sediment where biologic activity is of principal importance.
4) Man-made features such as spoil heaps, spoil wash, dredged channels, and modified land where man's activities have resulted in significant environmental modification.

Approximately 135 specific environmental geologic units were recognized and mapped in the Texas Coastal Zone. These environmental geology map units were grouped into higher order natural systems, such as fluvial/deltaic, barrier island, and bay/estuary/lagoon.

7.2.3 Other Maps Produced

Following the production of the environmental geology map, a series of "special-use environmental maps were prepared to present more specific information for a variety of potential users" (Fisher et al., 1973, pp. 5-6). The following topics were covered by the maps:

1) Physical properties (characterization of soils and land forms).
2) Environments and biological assemblages.
3) Current land use.
4) Mineral and energy resources.
5) Active processes (including a general delineation of zones of erosion and deposition).
6) Man-made features and water systems.
7) Rainfall, stream discharge, and surface salinity.
8) Topography and bathymetry.

7.2.4 Summary

The approach used by the Texas group produces a high level of understanding of the coastal zone under consideration. Unfortunately, this approach is costly and thus unattainable for many coastal management programs.

7.3 Specific Shoreline Erosion Inventories

7.3.1 Introduction

In the absence of funds to carry out an extensive survey of the type discussed in the preceding section, specific determination of beach erosion trends may be feasible. U.S. studies carried out in North Carolina (Stafford, 1971) and South Carolina (Stephen et al., 1975; Hubbard et al., 1977b) could be used as models.

7.3.2 Study Procedure

The principal data sources are all the aerial photographs of the region that have been taken. In some cases, older topographic maps and nautical charts may be used if the data are thought to be reliable.

As a first step in beginning the survey, all the overlapping aerial photographic coverage available is obtained. For best results, a spacing of 5- to 10-year intervals is required. For example, the South Carolina survey

(Stephen et al., 1975) included photographs taken in 1939/1941, 1949, 1953, 1957, 1963, and 1973.

Next, selected reference points, identifiable from year to year on the photographs, are established. Permanent structures or fixed points, such as road intersections and ends of beach ridges, are used. The distance from the reference point to the beach is measured as closely as possible. The difference, after scale corrections, between measurements from two successive photographs is the amount of erosion or deposition which occurred during the time interval under consideration. Scale corrections are calculated by using a ratio comparing the distance between two fixed reference points on photographs of known scale to the distance between the same reference points on the successive photographs. Stafford (1971) has shown that errors in measurements using aerial photographs at a reasonable scale are usually insignificant when dealing with large mean rates of change such as those which generally occur in most coastal areas.

7.3.3 Data Presentation

The results of the aerial photographic study may be presented at three levels. A general management map may be provided which delineates areas of coastline that have undergone (1) long-term erosion, (2) long-term accretion, (3) periods of both accretion and erosion (instability), and (4) stability. These terms are defined as follows:

1) Long-term erosion - Areas which have undergone relatively continuous erosion over the study interval (usually several decades).
2) Long-term accretion - Areas which have undergone relatively continuous deposition over the study interval.
3) Unstable - Areas with fluctuations greater than 50 ft over the study interval.
4) Stable - Areas with fluctuations in position of the shoreline of less than 20 m over the study period.

Use of this map allows for a rapid determination of the general character of any stretch of shoreline under study. An example of one of these maps from the South Carolina study is given in Figure 68.

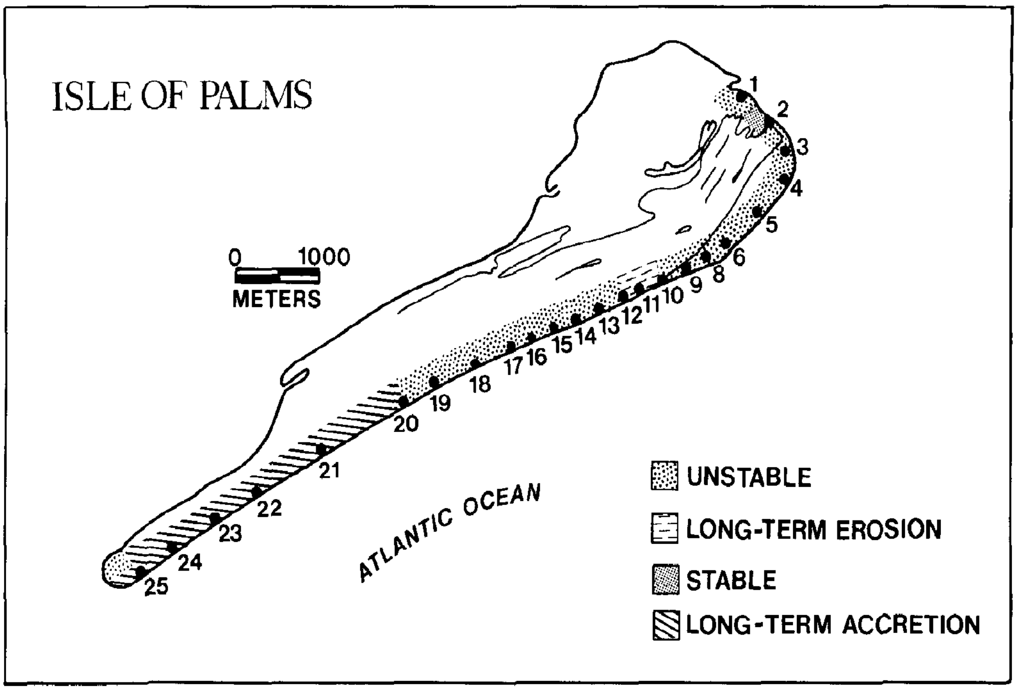

Figure 68. Example of a coastal management map based on shoreline erosion inventory. Area is Isle of Palms, South Carolina, U.S. (from Stephen et al., 1975, Figure 8).

Another type of presentation gives the cumulative trends for the migration of the shoreline at selected reference points (e.g., Figure 69). These graphs are of value to anyone interested in coastal development, because the migrational trends for very short stretches of beach (200-500 m) are clearly shown. All the interested party need do is study the graphs for the section of beach of concern, and he can immediately see if it has had an erosional, depositional, or stable history.

Finally, the incremental change between photographic years, as well as the total amount of change at each reference point, may be presented as tables.

7.3.4 Summary

The data obtained by the study of sequential aerial photographs and charts is a fundamental source of information regarding coastal zone development. An important consideration in any beach management program is the establishment of a reasonable setback line, seaward of which no construction is allowed. Critical to the determination of such a line is the knowledge of the changes that can be expected along any given section of beach through time. The individual erosion/deposition curves derived from a study of the type just outlined detail the variability that exists at given locations. Therefore, these erosion/deposition data could be used to establish zones where development should be prohibited or where remedial measures are apt to fail.

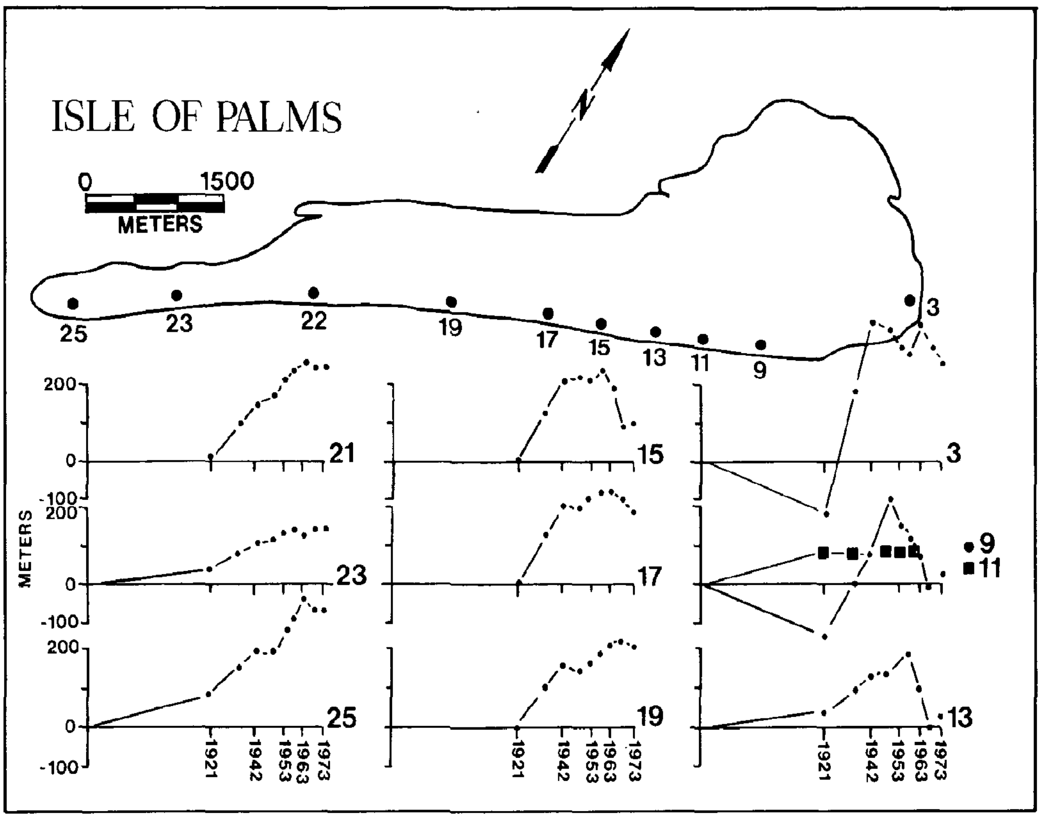

Figure 69. Erosion/deposition curves for the Isle of Palms, South Carolina, U.S. During the past 100 years, the northeastern end of the island (graphs 3-13) has been characterized by periods of erosion followed by periods of accretion. These have been caused, in part, by changes of adjacent tidal inlets. The central and southwestern shorelines (graphs 15-25) have been accretional or stable since 1872. A field of groins located along these beaches has been partially responsible for this stability (from Hayes et al., 1978).

8. LESSONS LEARNED

The goal of this report is to provide guidelines for dealing with present and potential beach erosion problems in developing countries. The best time to deal with such problems is in the planning stages for coastal developments, not after unwisely building a structure that is threatened by erosion within a few years of its construction. Much has been learned about the causes and cures of beach erosion during the past few decades. The case studies previously discussed provide many lessons learned for application elsewhere. For example, the case study in Japan demonstrated that dams on rivers cut off the sand supply. This is a problem that could not be readily solved, so ingenious engineering designs were required. Offshore breakwaters have proved to be the best solution for Japan's beach erosion problems. In other areas not so intensely developed as Japan, it is possible that relatively low-cost "soft" engineering solutions can be used, as was demonstrated at Seabrook Island, South Carolina. The writer is convinced that sound planning and management can help avoid most of the pitfalls of beach erosion in developing countries, particularly if the following basic guidelines ("golden rules") are adhered to.

9. GUIDELINES

(1) UNDERSTAND THE NATURAL BEACH SYSTEM BEFORE IT IS ALTERED. SITE-SPECIFIC STUDIES MAY BE REQUIRED AT MANY LOCALITIES TO INSURE WISE PLANNING DECISIONS.

The interface between the land and the sea is a dynamic, changing natural system. Man's interference with natural, longshore sand transport is one of the major causes of beach erosion problems. Dealing with the nearshore system requires careful study, which can be moderately costly. But, these costs are miniscule compared with the restoration costs of major losses in a beach erosion zone. Several of the case studies, the erosion in Togo and Benin for example, demonstrate that prior study and planning could have prevented most of the erosion problems that now plague those areas.

(2) DEVELOP A SETBACK LINE BEFORE CONSTRUCTION BEGINS.

This is a most important rule; however, a thorough knowledge of the historical evolution of the site is required. The case study of Seabrook Island, South Carolina, demonstrates a serious erosion problem that could have been avoided if a proper setback line had been established. Kiawah Island, South Carolina, Seabrook's neighbor to the north, has been developed without erosion problems because of the establishment of a carefully designed setback line prior to development.

(3) WHERE A MAJOR OBSTRUCTION TO LONGSHORE SAND TRANSPORT IS BUILT, SUCH AS A LARGE HARBOR, ALLOW FOR AN ADEQUATE SAND-BYPASSING SYSTEM.

Decisions to begin major developments such as harbors are usually based on weighty issues like the economic well-being of a country. Beach-erosion concerns pale when compared with such issues in the planning stages of a project. Unfortunately, a few years later, after it is too late to do anything about it, beach erosion may be so severe that it becomes the overriding economic concern. Sand-bypassing systems cost only a small fraction of the costs for a major project, so they should be integrated in the master plan for every project that will impede littoral transport. The bypass system should place as much sand on the downdrift side of the structure as arrives on the updrift side.

(4) WHERE POSSIBLE, USE SOFT SOLUTIONS, SUCH AS SAND NOURISHMENT OR DIVERSION OF CHANNELS, RATHER THAN HARD SOLUTIONS, SUCH AS REVETMENTS OR SEAWALLS, TO SOLVE BEACH EROSION PROBLEMS.

"Soft" solutions are always difficult to sell to developers and managers, who usually prefer to see a hard structure in place. The few applications of "soft" solutions carried out to date have been generally successful, so it is anticipated that these techniques will be adopted quickly by progressive engineers. Costs for such projects vary on a site-by-site basis. The rechanneling of a tidal inlet at Seabrook Island, South Carolina (previously discussed) was considerably cheaper than hard solutions.

(5) MAINTAIN A PROMINENT FOREDUNE RIDGE.

Building on top of foredunes or flattening them for construction sites are common practices in highly populated areas. Dunes should be spared so sand can always move back and forth along the beach in an unimpeded natural cycle. Removal of dunes does not allow space for the occurrence of natural erosional/depositional cycles on the beaches. The result is undercutting of the buildings on the dunes, which necessitates the construction of seawalls.

(6) IF A BEACH IS VALUABLE FOR TOURISM, RECREATION, OR WILDLIFE HABITAT, DO NOT MINE THE SAND FROM DUNE, BEACH, OR NEARSHORE BARS.

The sand supply on beaches is not limitless. In fact, the longshore transport system is so delicately balanced that removing sand from it is the surest way to guarantee beach erosion.

(7) DO NOT PANIC AFTER A STORM AND DRASTICALLY ALTER THE BEACH. WHENEVER POSSIBLE, LET THE NORMAL BEACH CYCLE RETURN THE SAND.

Resist the urge to move sand around during the first few days after a storm. Beaches recover rapidly, and the first few hours and days are the periods of greatest change.

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Case Study Three

CORAL HARVESTING AND SAND MINING MANAGEMENT PRACTICES

Random DuBois and Edward L. Towle

SUMMARY

This study addresses the coastal resource management problems associated with sand mining and coral harvesting in tropical areas. Customary sand and coral extraction techniques, large and small scale use practice, impacts on local environments, and alternative harvesting approaches to various marine minerals are reviewed. Specific examples of adverse effects on the environment from excessive, badly sited, ill-planned or un-monitored coral harvesting and beach, dune, and marine sand mining activities are presented and analyzed. These examples are based on existing documentation, and in some instances, were corroborated by site visits to areas where large scale, hydraulic dredging strategies for marine sand had been employed or land-based beach or dune sand mining were common practice.

Study findings suggest the following.

(1) The mining of beach and dune sand should be discouraged except under special circumstances, with careful advance planning and monitoring.

(2) Coral reefs, marine sand deposits, sand beaches and dunes are each a part of dynamic natural coastal systems which provide barriers to potentially damaging storm-driven waves and swells. Modifications to them resulting from poorly planned or sited sand and coral mining activity can, over time, diminish their protective capacity causing loss or damage to shoreline areas and facilities.

(3) Marine sand mining (especially by hydraulic dredging) should be confined to coastal waters sufficiently deep, open and distant from adjacent coral reefs and beaches to minimize coastal impacts.

(4) Sand and coral mining projects require antecedent impact assessments, baseline site studies and monitoring. Ideally, they should be preceded by a comprehensive sand and coral resource assessment, as part of a sand and coral management planning strategy. Post-mining site resurveys and impact assessments are recommended.

(5) The commercial harvesting of deep "precious coral" species requires specialized management strategies because of their exceptionally slow growth rates.

1. INTRODUCTION

Coastal and nearshore marine minerals of most developing countries represent both a traditional and expandable resource of economic value and strategic significance. For centuries, coastal minerals of both geological and biological origin have served as sources of building materials (rock and coral), lime (derived from coral and calcareous sands) and currency (shells and corals). More recently, as the economies of many of these countries have grown and diversified, marine minerals are being heavily exploited for uses as fuel (oil and gas), rare metals extraction (placer deposits), jewelry and tourist curios (coral and shell), and, on a much larger scale using new technologies, for construction aggregate.

Coastal areas are not only a source of valuable and useful minerals; they also represent a zone where massive amounts of sedimentary materials are often dredged or dug from one location and moved to more preferred locations as fill or discarded spoil. Harbors are often built, improved, or expanded by deepening the seaward portion, approach channels and turning basins. Excavated material is sometimes discarded but more customarily is used as fill to expand landward portions of harbors for new docks, warehousing and cargo handling facilities or waterfront renewal areas. Sea sand is occasionally dredged from "offshore" and transplanted "onshore" to restore, improve or even create a beach in a process called beach nourishment. Sometimes sand is extracted from offshore deposits and used solely as fill to create new "flat land" by covering over coastal swamplands, mangrove areas, or shallow lagoons. In these instances where "sand" is used for fill, the value of the dredged or mined material is derived largely from its mass and accessibility rather than its compositional quality.

As the uses for coastal minerals have expanded and demand continues to grow, their often unquantified, unmanaged, and unmonitored extraction has resulted in significant modifications to coastal regimes--often with considerable environmental damage and occasional economic loss. Examples of these impacts include coastal erosion, loss of habitat, declining water quality and reduced biological productivity. Due to the biological and physical processes characteristic of tropical coastal areas, these natural systems are slow in returning to pre-existing conditions or sustain irreversible impacts (see Section 4).

The principal causes of adverse environmental impacts associated with coastal mineral resource extraction include: 1) the failure to account for the relevant biological, geological and physical parameters which characterize the mining and emplacement or disposal sites; 2) failure to discern the pathways and linkages between the biotic (living) and abiotic (non-living) components associated with the activity; 3) failure to employ proper technologies; and 4) failure to develop and adopt sand and coral resource management strategies which allow for environmentally sustainable mining activities.

Though coastal and marine mining as an extractive or harvesting process implicitly involves environmental disturbance, many of its associated impacts can be reduced if not eliminated. It is the purpose of this case study to demonstrate the consequences of poorly planned or executed marine mining activities and to identify possible alternative extractive or harvesting strategies which minimize some of the negative environmental effects and which also minimize costly ex-post-facto remedial engineering interventions.

Sources of information for the case study were derived from a systematic review of the literature, reports from expert consultants, and visits to various sand mining and dredging sites in St. Lucia, the Virgin Islands, and Puerto Rico in the Caribbean and Fiji in the South Pacific. The discussion on coral harvesting per se is based on selected examples described in the literature, due to the absence of extensive hard coral block extraction activity at the beach and nearshore sand mining sites visited.

The authors acknowledge the valuable field assistance and constructive input from the following individuals: Robert Devaux and Henry Edmunds (St. Lucia); Robert vanEepoel, Thomas Nunn, James Beets, and Werner Wernicke (St. Thomas, U.S. Virgin Islands); and Dr. Uday Raj, Cruz Matos, and B. Singh (Fiji). Editorial and technical support was provided by Judith Towle (Island Resources Foundation) and Frances Roberts (World Wildlife Fund-US).

2. STATEMENT OF THE PROBLEM

Substantial portions of the nearshore marine areas and coastal zones of most developing countries are simultaneously 1) a target of expanding development initiatives and 2) a source of large volumes of mineral materials required for development activity or generated by that very development as a secondary product requiring "disposal". Unfortunately, the development process is rarely planned or scheduled to permit the "materials" needs of one scheme to be filled in a timely fashion by the mineral materials excavated in another. Locational separation of the source (or borrow site) and the emplacement (or spoil site) often exacerbates the problem. High transport costs complicate moving low unit value, high volume materials (like sand) even moderate distances.

Marine mineral material serves many different purposes and may be harvested:

- as aggregate for concrete by small and large scale users;
- for the sole purpose of later extracting small quantities of some valuable trace mineral, leaving vast amounts of waste materials called "tailings";
- because it is simply in the way and needs to be moved (e.g., harbor, canal, marina, and ship channel sediments);
- for its bulk and cheapness as "fill" (in coastal storm defense systems, causeways, roads, airports);
- for beach enhancement and storm damage repair to shorelines;
- because, in tropical areas, it is needed for its chemical and physical properties, e.g., as coral construction block, for lime production, cement manufacture, or to sell as an export (precious coral, shells, aggregate).

The most commonly harvested marine mineral is sand. In non-tropical countries, sand is an erosion product of the land areas. Rivers and streams transport sand and other sediments to the sea where they are subsequently distributed somewhat unevenly by waves and currents along the shorelines as beaches, dunes, sand spits, barrier islands, and submerged layers of sediments on coastal shelves and platforms and in estuaries and harbors. By way of contrast, in tropical countries with sea coasts and coral reefs, sand is formed in the sea biogenically. Like its terrestrially derived temperate counterpart, this carbonate sand often ends up distributed unevenly on adjacent coastal areas. Sometimes both types are intermixed in varying proportions.

Regardless of the origin of the sand or its composition, all nations have it and mine it by various methods as a mineral. It is a basic material, and developing and developed countries alike confront coastal sand supply, distribution and resource management problems for a variety of reasons:

- Sand is a vital component of various coastal processes and habitats, and is difficult to "harvest" without disrupting one or the other or both.
- Sand, although a renewable resource, is replaced only on a long-term basis or cycle due to low natural production rates.
- Sand deposits are usually in the "wrong" place when needed (i.e., often "underwater" or distant from intended use sites).
- Marine sand can be expensive to harvest or "mine"--and if large volumes are involved, the process requires specialized, elaborate and costly hydraulic dredging or excavating equipment (which is always at risk and subject to damage or loss on open coastlines under even moderate storm conditions).
- Demand cycles for marine sand and aggregate mining activity vary widely which makes advance planning difficult.
- The scale and method of extraction and the mode of transport and emplacement also vary widely, and each step poses the risk of inadvertent, undesireable environmental effects.

Unfortunately, the development planning and resource management approaches used in many developing countries are not sufficiently responsive to the complexity of local demand factors, site selection and harvesting practices. There is a need for antecedent and post-audit environmental impact assessments. The least damaging extraction and emplacement strategies need to be selected when addressing coral and sand mining requirements.

3. THE RESOURCE

3.1 Coastal Minerals

The coastal plain and adjacent nearshore submerged continental shelf constitute a zone abundant in useful mineral resources. The area serves as a sink for terrestrial alluvium and marine minerals transported onshore to beaches by wind-driven waves and tidal currents. Typical nearshore marine minerals include bauxite, phosphates, placer deposits, and aggregate (sand, gravel, shell). Beneath the sea bed of submerged coastal shelf areas may be found such economically valuable and extractable resources as petroleum and natural gas, as well as surface minerals which have been reworked downward. Dissolved minerals are present in the waters overlying the marine portion of the coastal area, of which salt (sodium chloride), the most prevalent, is commonly harvested by solar evaporation of sea water in low lying coastal areas around the world.

3.1.1 Placers

The two categories of hard minerals of greatest economic importance which occur in the coastal area are placers and aggregates. Placers are deposits of minerals and heavy-metal ores such as gold, magnetite and chromite concentrated by the mechanical sorting action of currents (Press and Siever, 1972). Due to their high specific gravity, these minerals settle rapidly near the mouths of rivers whenever stream flow energy levels fall below critical points determined by the minerals' respective specific gravity. Subsequent sorting by local waves and currents removes the lighter elements leaving behind the heavier minerals. Cronan (1980) suggested that mid-latitude and high energy tropical beaches are the most favorable environments for these deposits.

The existence of offshore or nearshore placer deposits is highly correlated with drowned river valleys and submarine terraces formed by global changes in sea level (eustatic), the submarine erosion of mineralized outcrops and occasionally nearby terrigenous sources.

3.1.2 Aggregate

Aggregate is a technical term for deposits of sand, gravel or occasionally shell. When harvested, sorted by size and washed free of clay and organic material, these materials are capable of being bound together by cementing agents for use in the construction industry. Coastal aggregate deposits, especially those of temperate zone continents and even some larger islands, are essentially the products of terrestrial erosion. They are most often associated with river beds and mouths, sand beaches and shallow offshore platforms and shelf areas.

A second major source of aggregate characteristic of many tropical coastal areas is carbonate sand derived from nearshore coral and algal communities (Figure 1).

Corals are living systems of invertebrate coelenterates which live as colonies within a self-made external supportive structure composed of calcium carbonate. A characteristic feature of one group of corals, the hermatypic corals, is the presence of symbiotic algae (zooxanthellae) which appear to serve the corals in respiration and skeletal growth (Stoddart, 1969). Many species of hermatypic or stony corals are noteworthy in that they are the principal species in forming a large and diverse but interrelated community termed a coral reef. These communities, composed of a complex assemblage of marine life, represent a reservoir of calcium carbonate, stored in the form of shells and skeletons of organisms that inhabit the reef. Due to physical and biological forces that erode and transform these organisms' skeletal remains, calcareous sand is continually being generated, and some is subsequently transported to shore by the prevailing wind-driven waves and currents.

Marine calcareous algae, often occurring both inshore of and asso- with the adjacent reef, are a second significant source of carbonate sands in tropical waters. Decay of carbonate plates and nodules connected with these algae also contributes to the sand budget of tropical coastal areas. Hubbard, et.al. (1981a) estimates that the calcareous algae and other associated members of the coral reef community (molluscs, sea urchins, etc.) may even surpass corals in production of calcareous material that becomes carbonate sea sand.

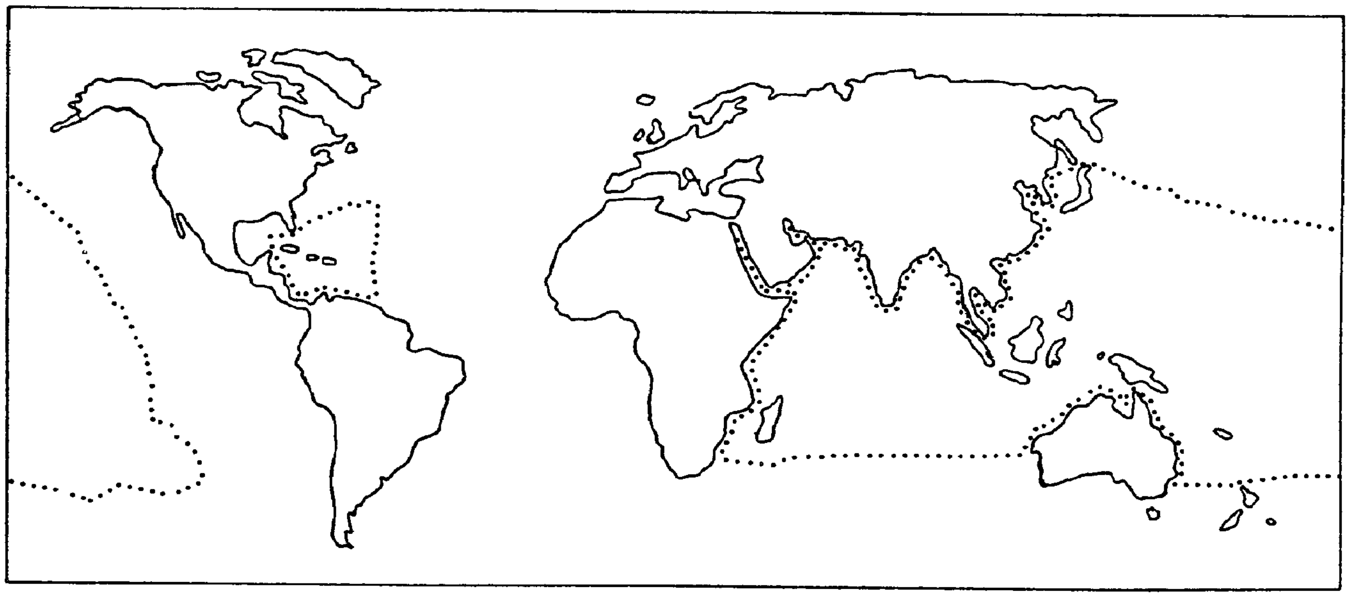

Figure 1. Geographical distribution of hermatypic corals where ten or more genera have been recorded (Source: Stoddart, 1969).

3.2 Uses

3.2.1 Placer Deposits

Industrial scale exploitation of marine placer deposits is rare among less developed countries (LDC's), due in part to limited financial and technical resources for geological surveys. Placer mining is usually of small scale and conducted through a joint venture with a second country or firm willing to invest resources in exchange for a percentage of the profits. However, increased awareness of the importance of strategic metals by the developed world, together with a desire by LDC's to diversify their economies, could result in an expansion of current activities. The ongoing United Nations program strategy to support regional Coordinating Committees for Offshore Prospecting (CCOP) is currently assisting a number of Asian and Pacific coastal and insular developing countries in the achievement of this objective.

3.2.2 Aggregate Materials

In contrast to the limited distribution of placer deposits, sand and gravel are generally plentiful and widespread. Despite this abundance, however, local scarcities do occur. Due to the low unit value and the high unit transport cost of aggregate, economics dictate that mining should occur in close proximity to the site of intended use. This is especially true when extremely large volumes of sand and gravel are extracted for fill, beach nourishment or remedial shoreline stabilization. In coastal areas, this constraint is complicated by the recent rapid growth of urban centers which has exhausted traditional nearby mining sites.

One response to this scarcity has been to exploit adjacent sandy beaches and dune systems. However, despite the short term advantages in convenience and reduced costs associated with this alternative, there are hidden long term consequences (habitat destruction, coastal erosion, and reduced natural hazard protection against storm waves).

Customary extraction patterns reflect two distinct use categories with very different scales of operation. In one category, a few--even a few hundred--persons remove sand and aggregate from a beach, dune, reef flat or lagoon system on a modest scale over a long span of time. This first approach requires one kind of resource management strategy. The second category involves massive, capital intensive, mining or dredging operations removing millions of cubic yards of material over a period of a few months from a single location on a one-time development project basis. Such a scale and intensity present a very different kind of resource management problem.

As awareness of the problems associated with beach sand extraction has grown, increasing interest has been diverted to offshore mining as a viable alternative. This technique has proven to be economically feasible in many coastal sites. Today the most active aggregate mining countries are Japan, the United States, the United Kingdom, Australia, and the Netherlands (Cruickshank and Hess, 1975). Established marine sand mining enterprises from these countries often are intermittently involved as contractors in developing country projects, using massive, sea-going dredging vessels and equipment. Such marine dredging endeavors, often harvesting large volumes of material, require different kinds of equipment, involve different kinds of impacts, and necessitate very different resource management strategies from terrestrial sand mining activities.

3.2.3 Coral Harvesting

In many developing countries coral chunks or "heads" are mined from the living reef or from the landward rubble zone behind the reef to provide a source for building "blocks" and the production of lime (Mahadevan and Nayar, 1972). Typically, coral is cut or sawn into blocks before being allowed to dry and harden by exposure to sun and air. Once blocks are set they are often covered with some form of waterproofing which also serves as decoration (Phelan, 1952).

Coral-based lime production is a centuries old traditional industry in many parts of the coastal tropics. The process only requires the application of heat (900°C.) to coral or algal limestone traditionally worked in an easily contructed basalt kiln. The calcined (burnt) limestone is then removed, slaked, graded, sacked and stored until needed.

Typical industrial and domestic uses of the lime include application in mortar and cement and as a clarifying agent, neutralizer and soil conditioner.

The use of both coral sands and coral blocks for building and construction purposes became quite common in the Caribbean and South Pacific theatres of World War II where construction of airbases and defensive fortifications required the use of locally available building materials on many of the resource-poor islands. Their use is still common today throughout most smaller offshore tropical island areas when populations are clustered along shorelines.

3.3 Methods of Extraction

Onshore sand harvesting from beaches and associated beach berms and dunes is convenient and inexpensive. As a result, it has been a traditional practice for centuries and is still common in some countries, especially in more remote coastal areas. Methods of extraction range from a hand shovel and wheel barrow or truck to various types of mechanical front-end loaders, back hoes, draglines, power shovels and bulldozers. For many people and rural villages, beaches are the only source of affordable and accessible sand (Figure 2).

Coral harvesting of dead coral blocks, taken from back-reef areas, is normally done by hand from the shallow rubble zone, "lagoon" or reef flat. Where coral heads deposited by storm waves have become "cemented" to the substrate or in cases of living corals mined directly from the reef, long handled tongs, steel pry bars, dynamite, wire rope, and power winches are the principal means of harvest. Small scale entrepreneurs use boats to transport the coral blocks ashore for processing, direct use or sale. The cumulative environmental impact of these practices, however, can be costly (see Section 5) and, in combination with a rising demand for aggregate and building material, has forced most countries to look to offshore sand resources and a dredging strategy.

In contrast to beach sand and coral mining, marine dredging represents a more technically-demanding extractive process; the required equipment is cumbersome, costly and complex where large quantities of

Figure 2. Illegal beach sand mining, St. Maarten, Netherlands Antilles.

sand are involved; the process is often at risk due to adverse weather conditions; and the impact to coastal ecosystems can be severe. Despite these constraints, dredging is a proven strategy for harvesting marine aggregate and sedimentary material for fill and construction use. Dredging is also used to create canals, harbors, ship channels, turning basins, marinas and underwater trenches for pipelines, tunnels and power cables, where the dredged material is only a by-product.

The prevailing methodology for the extraction of nearshore or offshore non-fuel minerals (especially aggregate) involves two types of dredge systems, mechanical and hydraulic. The most common mechanical types are the dipper dredge and various bucket dredges.

The dipper dredge is basically a barge-mounted power shovel (Figure 3a). It is equipped with a power-driven ladder structure and operated from a barge-type hull. A scoop-like bucket is firmly attached to the ladder and is forcibly thrust into the bottom material to be removed. Dipper dredges normally have a bucket capacity of 8 to 12 cubic yards and a working depth of up to 50 feet. There is a great variability in production rates, but 30 to 60 cycles per hour are common.

Customary use of the dipper dredge is for excavation of hard, compacted materials, rock or other solid materials after blasting. Although it can be used to remove most bottom sediments, the violent scooping action of this type of equipment may cause considerable bottom sediment disturbance and resuspension during any digging of fine-grained material. In addition, a significant loss of the finer material will occur from the open bucket during the hoisting process. Scow-type barges are required to move the dredged material to a disposal area, and production is relatively low when compared to cutterhead dredges. The dipper dredge is not recommended for use in dredging fine grain or contaminated sediments.

Bucket dredges involve a crane which may be permanently or temporarily barge mounted. If a wheeled or crawler type crane is employed, it can work from shore or from a self-built temporary causeway. A droppable bucket on the end of a wire is used to excavate bottom material. Different types of buckets can fulfill various types of dredging re-

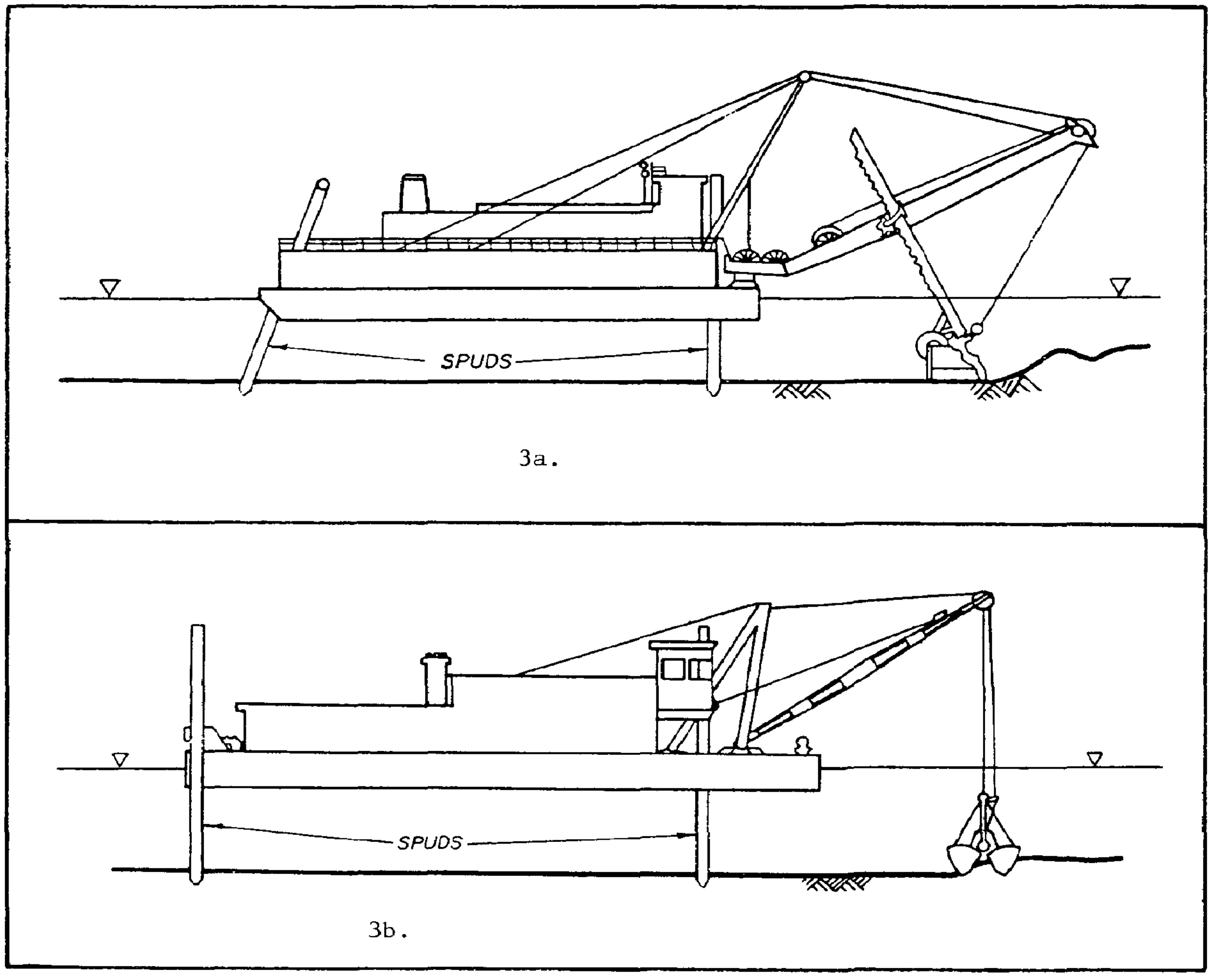

Figure 3. Dredging equipment. **3a** Dipper dredge ; 3b bucket dredge with clamshell. (Source: U.S. Army Corps of Engineers, 1983).

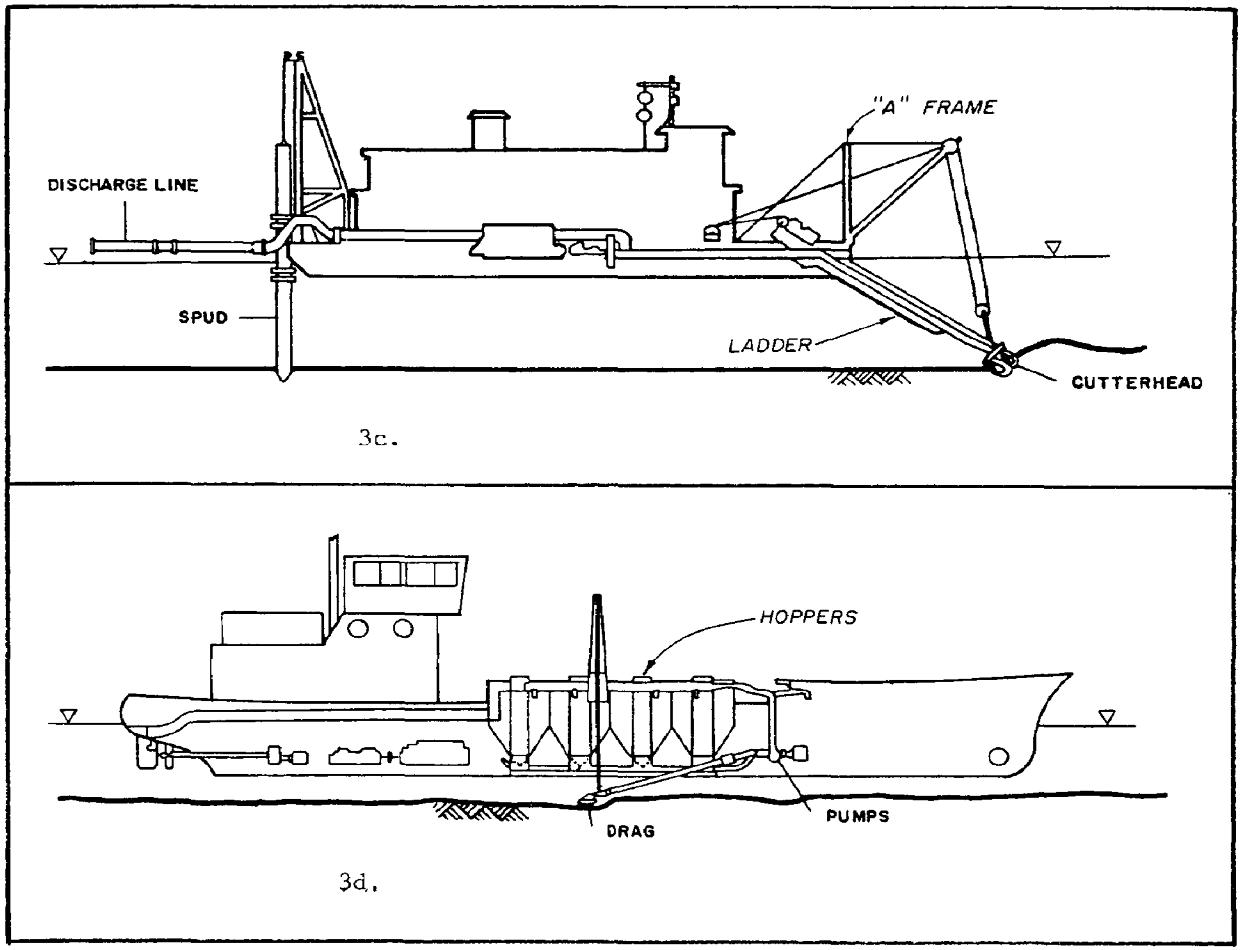

Figure 3 (Cont). 3c Hydraulic pipeline cutterhead dredge;
3d Self-propelled seagoing hopper dredge.

quirements. The most common buckets used are the clamshell and dragline types and can be quickly changed to suit operational requirements. The clamshell is worked vertically and "grabs" the sediment, while the dragline is worked horizontally and scoops up sediment (Figure 3b).

The material excavated is placed in scows or hopper barges that are towed to the disposal areas. Bucket dredges range in capacity from 1 to 12 cubic yards. Twenty to thirty cycles per hour are typical, but large variations exist in production rates because of the variability in depths and materials being excavated. The effective working depth for a bucket clamshell dredge is limited to about 100 feet and somewhat less for a dragline.

Bucket dredges may be used to excavate most types of sea bed materials except for the most cohesive, consolidated sediments and solid coral and rock. Bucket dredges usually excavate a heaped bucket of material from off the bottom, but during hoisting turbulence washes away part of the load. Once the bucket clears the water surface, additional losses may occur through rapid drainage of entrapped water and slumping of the material heaped above the rim. Even under ideal conditions, substantial losses of loose and fine sediments will usually occur. To minimize the turbidity generated by a clamshell operation, watertight buckets have been developed.

In contrast to the mechanical dredges, hydraulic sand and gravel harvesting systems are a relatively recent innovation which first became operational on a large scale in the early 1960's. The two most prominent types used in coastal waters are the cutterhead-suction and trailing suction hopper dredges. Both are capable of moving large volumes of aggregate at a rapid extraction rate.

The cutterhead-suction dredge uses a spiral shaped cutter to force its way through hard consolidated material including some coral but excluding rock (Figure 3c). Once material is broken up by the hardened teeth of the rotating cutterhead, it is sucked as a slurry (approximately 80 percent water) into the open mouth of the dredge by a suction pump. Then, it is pumped to the shore emplacement or spoil area using a semi-flexible floating pipeline or, less commonly, to an adjacent barge.

Operations of the cutterhead dredge are restricted to moderate sea conditions, especially if a floating pipeline to a shoreline dredge spoil discharge area is deployed. Such discharge pipes often range from 8" to 36" in diameter. A 24" dredge can discharge approximately 1,500 cubic yards per hour, depending on the material, pump size, pipe line distance, pipe-joint leakage factors, and elevation of the spoil area above sea level.

The trailing-suction hopper dredge is unique among the various dredge types in that it is a self-propelled, sea-going vessel, and it makes sequential shallow cuts over a large area (Figure 3d). It functions principally like a wet vacuum cleaner, by dragging a suction pipe or dragarm across the bottom which is "trailing" from the dredging vessel above. Material collected as a slurry is pumped into the ship's hoppers and periodically transported to shore. Hopper dredges are self-unloading. They can either dump the material in submarine storage pits located nearshore to be used at a later date or pump the material directly ashore. One significant advantage of the hopper dredge is that it allows operations in more exposed, heavier sea conditions due to the flexible linkage between the trailing suction pipe and the ship.

Hopper dredges are classified according to hopper capacity: large-class dredges have hopper capacities of 6,000 cubic yards or greater; medium-class hopper dredges have hopper capacities of 2,000 to 6,000 cubic yards; and small-class hopper dredges have hopper capacities of from less than 2,000 to 500 cubic yards. During dredging operations, hopper dredges travel at a ground speed of from two to three mph and can dredge in depths from about 10 to 80 feet. They are equipped with twin propellers and twin rudders to provide the required maneuverability.

The comparative advantages and disadvantages of dredge types are presented in Table 1.

Table 1. Comparison of dredge types commonly used for extraction of coastal area marine minerals.

DREDGES	WORKING DEPTH (in meters)	ADVANTAGES	CONSTRAINTS
Dipper- (single open scoop or bucket w/teeth on leading edge)	0-20	Can excavate bulky consolidated, hard materials (debris, rock, coral)	High sediment discharge Low productivity Requires calm sea conditions
Bucket (Dragline)- (single open flat scoop, not illustrated)	0-20	Low mobilization costs Barge or shore development option	High sediment discharge Low productivity Limited range Softer materials only
Bucket (Clamshell)- (double-sided closeable "bucket")	0-40	High flexibility Handles variable conditions Low mobilization costs	High sediment discharge Low productivity Not suitable for hard surfaces
Hydraulic/Cutter Head Suction	0-30	High production capacity Can work semi-consolidated materials (coral, algae sand, hard pan, clay)	Requires calm sea conditions Relatively shallow depths High mobilization costs
Hydraulic/Trailing-Hopper Suction	6-30	High production capacity Handles exposed conditions Self-propelled with hopper dumping capacity	Requires softer unconsolidated bottoms High mobilizations costs Deep draft vessel

Sources: Euroconsult, 1981; Bhatt, 1979; Clark, 1977; U.S. Corp. of Engineers, 1971, 1973, 1978, 1983.

4. ENVIRONMENTAL CONTEXT

4.1 Coastal Dynamics

In order to understand the potential impacts associated with marine mining it is helpful to summarize certain physical processes characteristic of coastal areas. A more detailed presentation can be found in the Coastal Erosion Case Study.

The coastal zone is a dynamic system where the land, air, sea and human activity meet at a common high-energy interface. The major physical forces which drive the system are wind, waves, tides and currents which in turn are generated by gravity, the rotational force of the earth and solar radiation. One element in this system, the sand and other sedimentary material, exists in a continuous state of flux between erosion, transport or deposition phases. To help understand sediment flux as it pertains to sand, the concept of a "sand budget" was devised. Bowen and Inman (1966) divided the budget into credits and debits, the net difference being evident on the shoreline as either deposition or erosion.

In temperate latitudes the primary sources of new beach sand supplies are terrestrial material requiring river or stream transport prior to coastal deposition. Supplies of beach sand attributable to terrestrial origins may be augmented from offshore sources as well. On tropical coastlines, carbonate sands derived biologically from reefs and algal flats in offshore and nearshore areas can equal or surpass terrestrial sources. Carbonate sand precipitation from salt water also represents an additional source of sand for tropical beaches (Komar, 1976). On the debit side, physical factors contributing to the erosion of a beach include abrasion, chemical breakdown, wind and wave transport (Figure 4).

In addition to these local inputs and outputs, the longshore transport of sand is significant in many cases. Herbich (1975) defined littoral (longshore) transport as the movement of sediment along the coastal area by currents created mainly by waves and tides. Such transport is primarily due to the presence of a longshore current formed by wave trains breaking at an angle to a beach. Water "piles up" on the side of the small angle formed between the wave and beach creating a current

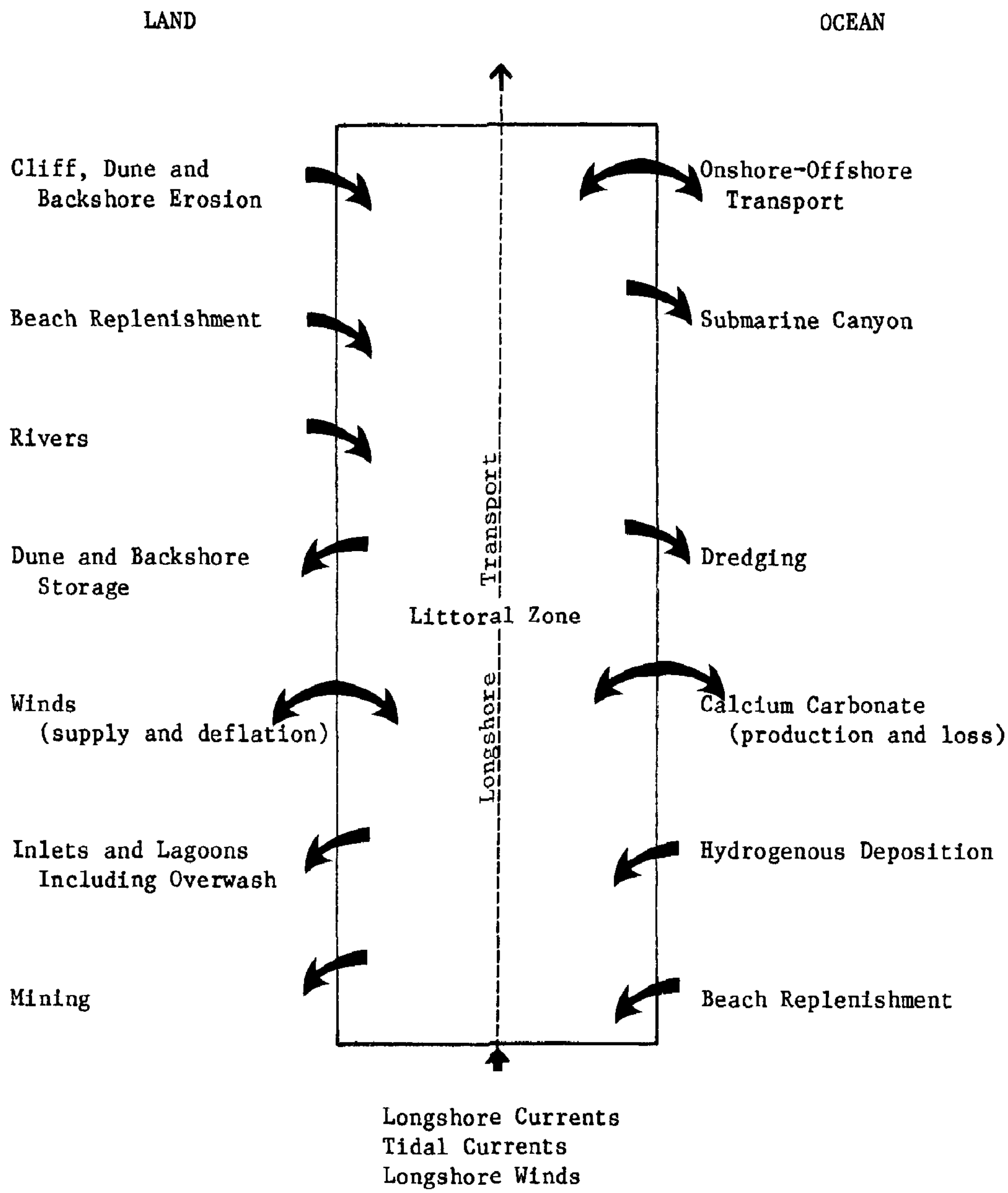

Figure 4. Sources of credits and debits to the littoral sand budget (Source: Modified after U.S. Army Corps of Engineers, 1974).

transporting water parallel to the coast in the same direction as the angle. Wind driven longshore currents when combined with wave action may have much the same effect (Komar, 1976).

The rate of sand transport is generally correlated with the angle and height of wave attack as measured from the beach. The greater the angle and height, the higher the rate. Conversely, littoral wave trains breaking more or less parallel to the beach result in little or no sediment transport and signify a relatively static situation. The volume of transported sediment depends on several factors including the velocity of flow, sediment characteristics and the slope of the bottom.

Given the importance of wind and wave forces in driving coastal processes, it is clear that seasonal variation will significantly affect beach dynamics. Whereas solitary storms passing near a coastline have been known to create or destroy entire beaches and sand cays (Stoddart, 1963), other seasonal changes are less drastic and more regimented. Beaches on northwestern United States coasts are typical of the latter, where summer shorelines characterized by sand beaches and wide back berm features contrast dramatically with the pebble and boulder beaches of the winter. This transformation is caused by the seasonal offshore transport of sand to submarine bars during the winter months due to high energy wave conditions. Under calmer conditions, sand is retransported onshore once again covering the rubble and boulder beach area before the cycle is repeated (Bascom, 1964).

While this seasonal sand transport pattern affects whole coastlines, there are localized sand transport patterns or "cells" which differ significantly in their characteristics. Inman and Chamberlain (1960) identified discrete sand transport cells along the southern California coast, each cell consisting of a beach situated between two rocky promentories. Beach sand, originating from upland areas near the first promentory, is transported "down current" where, upon reaching the second promentory, it leaves the cell as it is transported offshore.

A second type of littoral cell has been described (Inman, et.al., 1963) for a carbonate beach site on the eastern coast of Kauai, Hawaii. Offshore reefs and reef flats are periodically interrupted by shallow depressions or channels running perpendicular to the shoreline. These channels (most in-flowing, a few out-flowing) serve as traps for calcareous sands originating from the reef. Incoming swell drives sand closer to shore, serving to replenish the beach. Sand reaching the shore is subsequently moved by longshore transport to eventually be lost to the beach/reef system upon reaching a deeper inlet with a seaward flowing bottom current. Storage sinks for sand involved in the process can either be temporary (like beaches, dunes, sand bars and cays), semi-permanent features like inshore lagoons, or permanent repositories like offshore canyons.

4.2 Biological Impacts

Coral and sand mining activity involves an adverse impact on coastal or marine habitats and biological communities either directly or indirectly. Operational design, scale and duration of the activity are very significant factors as each materials handling phase--extraction, transport, and emplacement--can generate undesireable effects. Biological communites on the sea bed or lagoon/bay floor, in the water column above, or on the beach at the site of the emplacement or effluent run-off (if "hydraulic" dredging is involved) are usually affected. Organisms occurring at some distance from the mining sites may also be threatened since water-borne fine sediments associated with one or more of the extractive phases can be transported considerable distances downcurrent before finally settling out.

Additionally, the indirect biological or environmental effects associated with marine mining activities are often more complex and of greater significance than the direct impact of removing relatively small areas or volumes of material from the sea bed or beach system. These include:

- reduction of feeding and respiratory efficiencies and induced mortalities in bottom-dwelling, non-mobile organisms, such as bivalve molluscs and corals, attributed to increased sedimentation;
- reduction of primary productivity (i.e., photosynthesis)

due to reduced light transmission caused by turbidity in the water columns;

- introduction of abnormal volumes of organic material and nutrients, increasing biological oxygen demand and, in turn, reducing oxygen levels and productivity;
- re-introduction of toxic substances uncovered by mining activities in the water column, posing the risk of incorporation into the food web;
- inadvertent destruction of adjacent habitat critical to life cycles of certain organisms;
- disruption of migratory routes of motile marine organisms.

With few exceptions, a concentration of re-suspended sediments and their later deposition are the primary agents causing the biological effects cited above. Point sources of sediment vary with the existing method of extraction. For all marine dredging strategies, concentrations of re-suspended material may occur at the bottom of the water column where the cutterhead or bucket stirs it up. Mechanical dredges such as the clamshell, bucket or dipper also create a "rain" of particulates in the water column as material is brought to the surface. Hydraulic dredges also lose some sediment in pumping the material ashore when floating discharge pipe joints flex and leak due to wave action or faulty design.

Fine sediments can be lost in any barge loading process, a problem common to all dredges discharging into self-contained or along-side barges. However, hydraulic cutterhead dredges which use suction to draw up a water-sand slurry to be pumped ashore are the worst contributors as finer silt and clay sized components are often discharged at three different locations--the excavation site, along the discharge pipe, and at the spoil area ashore. This problem can be mitigated if the spoil area is "diked" and settling ponds with weirs (small dams) are employed to reduce the "fines" carried back into coastal waters by the effluent.

Any dredging operation piping into a series of large settling ponds (low energy level, long residence or settling time) is going to have less suspended sediment in the final overflow to the sea than a dredge pumping into a series of small hoppers or barges (high energy level, brief residence time). However, fine sediments discharging from a mobile hopper dredge or anchored cutterhead tend to be dispersed by current action over a large area, whereas shore based dredge spoil areas tend to concentrate discharges of fine sediments in one coastal location. For land fill purposes, the grain size of dredged material is not critical, but for construction sand or beach nourishment only a small amount of the very fine sediment can be accepted (see Section 7.1).

The degree of impact from sand mining-induced sedimentation is dependent on the sensitivity of the exposed community to stress as well as the quantity and size characteristics of sediment and rate of sedimentation. Non-motile benthic communities which filter their food are generally the most vulnerable to high rates of sedimentation. Coral reefs and marine grass beds are two tropical marine communities which are particularly sensitive to both high rates of sedimentation and abnormally high turbidity which reduces light penetration (Table 2).

In fact, sediments deposited on some coral species are likely to kill them within only a few days if the layer of material is thick enough and within weeks even if it is thin but continually replaced by recurring deposits (Johannes, 1975). Hubbard and Pocock (1972) demonstrated that coral species exhibited varying tolerances to sediment size and attributed this ability to the respective coral polyp's size and inherent filtering ability.

Other effects on corals attributed to sedimentation include reduced rates in growth (possibly due to declines in photosynthetic rates of the symbiotic zooxanthellae, Goreau and Goreau, 1959) and reduced species diversity (Brock, et.al., 1966). The quantity and size characteristics of sediment--and thus its biological impact--vary with distance from the point of suspension in the water column, which in turn is dependent on current velocity. The greater the current speed, the farther heavier sediments are carried from the source. Conversely, low velocities usually mean only finer sediments will be carried outside of the immediate area of the mining site. Particle shape can also affect distance traveled. For example, plate-like, flat or irregularly-shaped calcareous

Table 2. Documented stresses, effects and impacts from mining activities to marine grass and coral reef communities.

a. Marine Grass Communities.

STRESS	EFFECT	IMPACTS	REFERENCE
Sedimentation	Suffocation	Reduced distribution	vanEepoel (1971)
		Reduced productivity	Odum (1963)
	Reduced light transmission	Reduced density	Thayer (1975)
Resuspension of subsurface materials	Increased BOD*	Reduced density	Thayer (1975)
	Changes in Redox** potential	Reduced density	Thayer (1975)
	Reintroduction of toxics	Reduced density	Thayer (1975)

b. Coral Reef Communities.

STRESS	EFFECT	IMPACTS	REFERENCE
Sedimentation	Suffocation	Death	Brock (1966)
	Reduced light transmission	Reduced growth rate	Goreau and Goreau (1959)
		Reduced depth range	Goreau and Goreau (1959)
		Reduced species density	Brock (1966)
	Increased BOD*	Reduced species diversity	Brock (1966)
Modification of reef topography	Alter current regime	Reduced larval settling/survival rates	Hubbard (1972)
Weakening of substrate underpinnings	Toppling of corals	Death	Maragos (1982)

* Biological oxygen demand

** Reduction - oxygen

fragments derived from Halimeda (a calcareous alga) travel farther at the same velocities than round sand particles of the same weight characteristics. This may seem like a trivial factor, but it can dimensionally affect the area of corals damaged or killed by nearby dredging activity.

Additional environmental effects commonly associated with the resuspension of sediments are increased biological oxygen demand (BOD) and the re-introduction of toxic contaminents and clays into the water column. When small organic particles in various stages of decomposition buried by overburden are again exposed to an oxygen-rich, sea water environment, the rate of decay is accelerated. The result of this decaying process is a local reduction of dissolved oxygen. When significant quantities of these organics are involved (especially in coastal embayments and lagoons with poor water circulation), oxygen levels can be reduced to a point detrimental to sessile and pelagic organisms. Similarly, when buried layers of clay are uncovered by dredging, there is a risk of continuing resuspension of very fine material from the newly exposed deposit. Continued resuspension of fine sediments in the vicinity of coral reefs may prevent substrate consolidation and subsequent recolonization by many benthic organisms (especially the planktonic larvae of corals, as well as other reef invertebrates) which require hard bottom to establish themselves.

These impacts are significant in evaluating differences between available dredging technologies. Most mechanical and hydraulic dredges working from anchored positions (Figure 5a) leave a borrow pit or dredge hole (actually a depression) as a result of the extraction activity. If the pits are deep enough and occur in waters characterized by reduced circulation, they act as sinks or traps for fine particulate matter both during and after dredging. When organics are involved, these pits often become severely oxygen depleted; further, due to the trapping of fines, their bottoms are characterized by a semi-fluid anoxic sediment, with perpetually turbid water, which inhibits colonization and leaves the pits as semi-permanent features of the local sea bed. Some marine sand dredge pits, as in the U.S. Virgin Islands and St. Lucia, have not recovered after forty years (vanEepoel, et.al., 1971 and

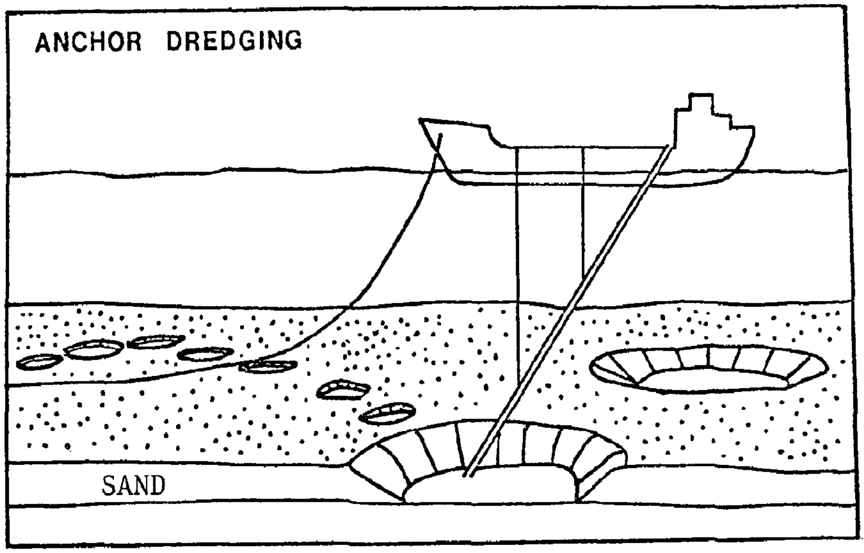

Figure 5a.

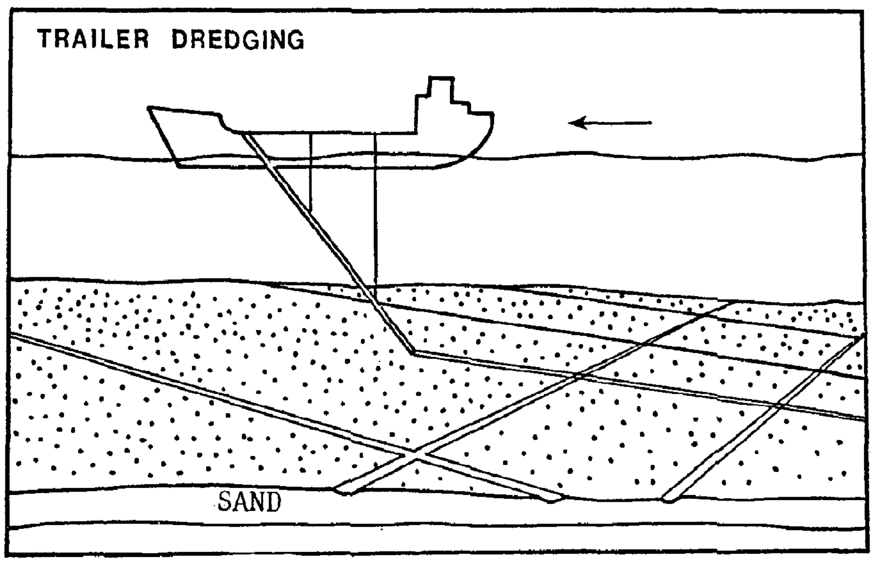

Figure 5b.

Figure 5. Two common approaches to hydraulic dredging, resulting in very different kinds of benthic impacts (Source: ICES, 1975).

Deane, et.al., 1973).

Turbidity and oxygen depletion can be ameliorated by dredging in deeper water with better circulation where currents and waves can more readily transport coarser sand, by dredging shallower borrow pits, by filling deep borrow pits with solid nontoxic waste materials to provide a hard substrate for re-colonization, or using a hopper trailer dredge which leaves long but shallow channels during the sand extraction or harvesting process (Figure 5b).

4.3 Physical Impacts

Marine mining activity, whether on the shoreline or on the adjacent submerged shelf, incurs a risk of altering physical processes (especially beach dynamics and coastal current and wind driven wave and swell patterns) which may adversely affect coastal systems. Even slight modifications in nearshore bottom contours by small scale long term or large scale short term dredging activity may induce slight changes in wave height. These changes result in significant changes in delivered energy impinging upon adjacent beaches, reefs, sea grass beds, and other shoreline areas. What often follows next is a slow erosion, slumpage or continuing "draw down" of existing beach sand, to refill the adjacent dredge hole or borrow pit that was too close to shore. Shore based sand mining that reduces beach berm and dune mass and height also poses risks of increased storm wave damage to inland areas and reduces the supply of naturally stored sand available for equilibration of the system.

4.4 Toxic Sediments

Another consideration in assessing alternative approaches, optimum mining site and mining technologies is the possibility of re-introducing previously buried toxic substances into the environment. This is especially true where mining occurs in areas adjacent to large urban centers, industrial sea ports or dump sites. Many toxic materials are non-biodegradable and as such continue to persist in the sedimentary environment. Nearshore bottom areas act as more or less benign sinks for these and other pollutants where they become smothered by subsequent sediment deposition. When these polluted bottom sediments are disturbed by mining or other similar activity, they become re-exposed and open up the risk of pollutant re-introductions into the water column at concentrations higher than when they were originally introduced. Incorporation of pollutants into local food webs is possible, creating the potential for reaching toxic levels in any of several critical organisms including man. One solution to this problem is to relocate any dredging operation to an alternative, nearby site where prior core borings have established the absence of buried layers of organic or silty sediment, toxic or otherwise.

5. EXAMPLES

The foregoing overview established the physical and biological context in which most sand and coral mining activities take place, without accounting for a "human intervention" factor in the "sand budget ledger". Such intervention can take the form of mining or dredging (a debit) or nourishment (a credit). Similarly, biological processes can also take the form of debits (die off, loss of productivity) and credits (habitat creation). Failure to account for these dynamics in the planning and management of mining activities may result in significant, inadvertent modification to coastal and nearshore environments. The indirect or deferred economic costs associated with these modifications, as demonstrated by the following case studies, can be considerable. In each case, inadequate attention to project design, environmental planning and monitoring resulted in serious damage, often with significant economic costs.

5.1 Coral Harvesting and Mining

One of the utilitarian functions of living fringing and patch-type coral reefs, *in situ* dead coral reefs, sea grass beds, beaches and coastal rubble, and sand or lagoonal-shelf deposits is to buffer adjacent tropical shorelines. These formations create a natural breakwater system, protecting coastlines from attack by high energy, storm-driven waves and swells. When this "breakwater" effect is diminished by natural or man-induced removal or degradation, incoming oceanic waves and swells, occasionally heightened by abnormally high storm tides, can pass unimpeded to break directly on the shoreline. This can accelerate normal erosional processes and raise the risk of severe damage to human life, coastal villages, roads, tourist facilities, beaches and harbors.

Given the role of coral reefs in providing storm buffering, there are sound economic reasons to draw up environmental guidelines for mining coral and coral sand resources. The following three site examples illustrate this point.

5.1.1 Bali, Indonesia

Sengkidu Beach is on the east coast of Bali, fringed by a barrier coral reef lying approximately 150 meters offshore. The reef was mined for construction block and coral material to use in the production of lime; and subsequently Praseno and Sukarno (1977), employing remote sensing techniques, identified zones of coral depletion and demonstrated cause and effect linkages between mining practices and shoreline erosion. They calculated that approximately 100 meters of beach had eroded over a relatively short period of "some decades." Beach loss at the time of the study was beginning to translate into economic losses, and adjacent plantations and lands bordering a nearby rural village were increasingly at risk (Figure 6).

5.1.2 Sri Lanka

The island of Sri Lanka (formerly Ceylon) (Figure 7) provides another example of modern coral mining practices which have resulted in significant economic costs. Coastal erosion there is not a new phenomenon but has been cited in references dating back to the pre-Christian era (Swan, 1974). Although some long-term erosion occurs on the eastern and northwestern coasts, it is most acute along Sri Lanka's southwestern coast, attributed, in part, to the coastline's continuing adjustment to the physical forces associated with the southwest monsoon (Swan, 1965).

High population densities have also created severe pressures on Sri Lanka's coastal and coral reef and sand resources. Human activities which have adversely affected coastal systems are (1) residential and recreational development; (2) salt evaporation pans (salterns); (3) mineral extraction; (4) coastal land put into cultivation; and (5) fishing (Amerasinghe, 1978).

The activity most harmful to shoreline and beach stability is the widespread mining of coral and coral sands for lime production, cement manufacture, and other purposes. Coral material is harvested from both coastal quarries and offshore using dynamite, crowbars and boats. Erosion is further accelerated by mining natural replenishment sands for use as construction aggregate, for lime production and as placers

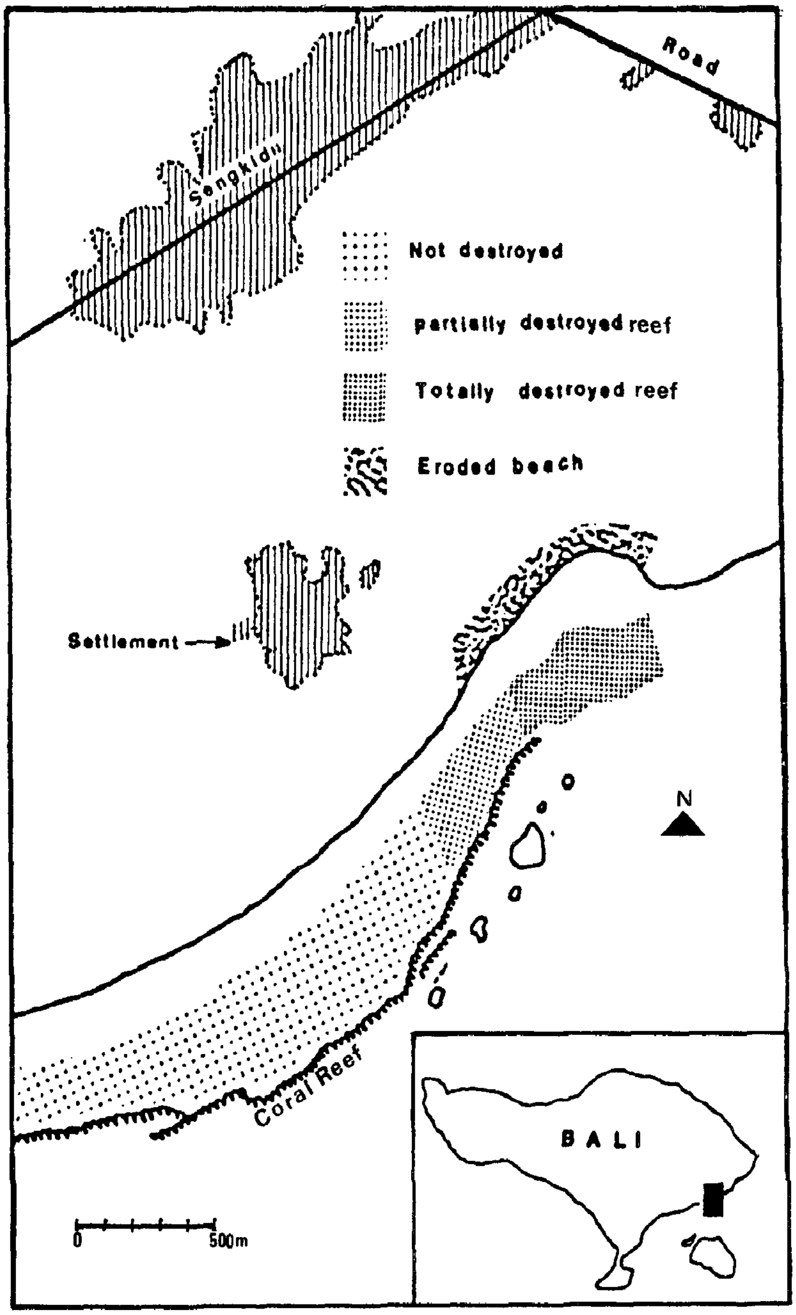

Figure 6. Coral destruction and subsequent beach erosion in Sengkidu Beach, Bali, Indonesia. (Source: Modified after Praseno and Sukarno, 1977.)

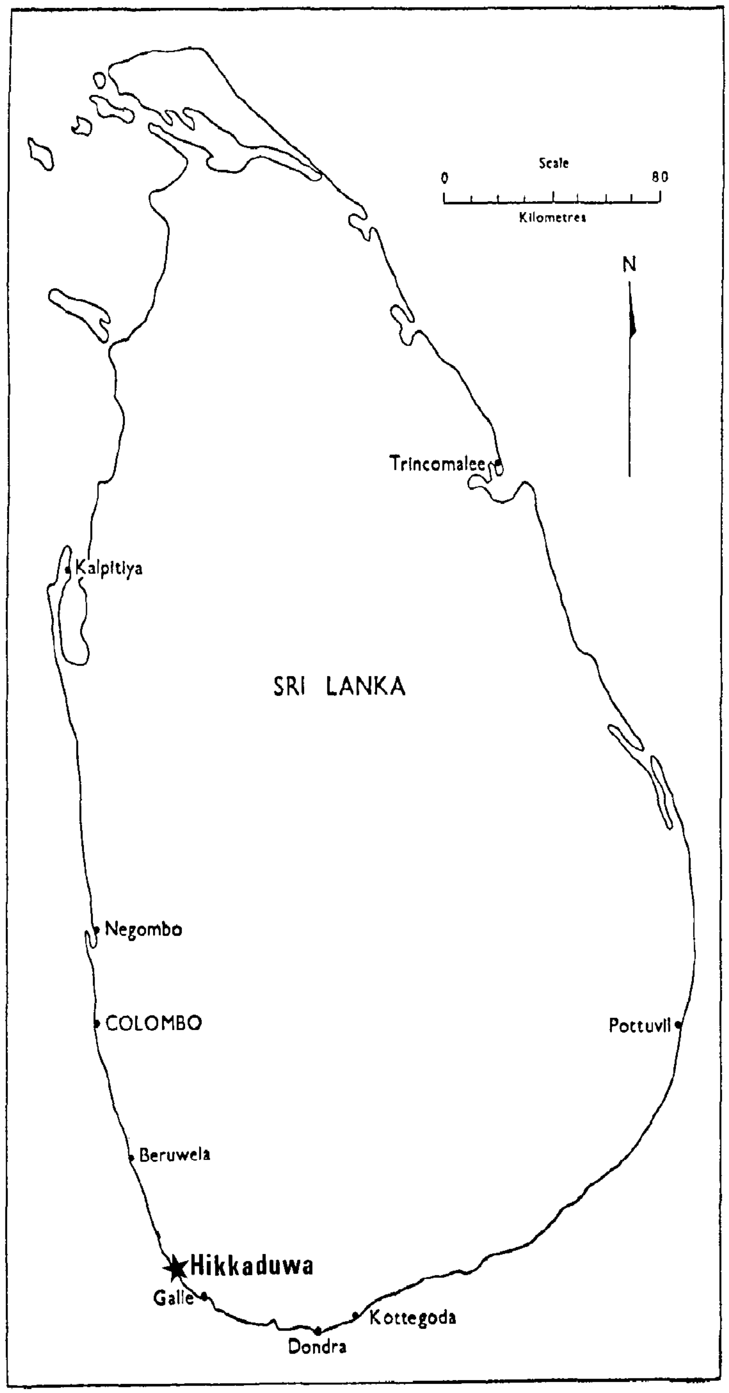

Figure 7. Sri Lanka, showing location of Hikkaduwa coastal erosion site.

(ilmenite, monazite, rutile) (Pattiaratchi, 1964).

The net effect of these practices combined with existing physical conditions has been to create zones of critical coastal erosion throughout the southwestern coastal regions of Sri Lanka.

One such zone is Hikkaduwa, some twenty miles north of Galle (Figure 7). This area is characterized by a low-lying coastline underlain and fringed by a coral reef. Swan (1974) suggested the area was somewhat erosion resistant until 1915 when a storm cut off the headland at Telwatte Point from the mainland. Despite gradual losses of beaches in the area, the existence of offshore coral reef systems played a mitigating role by moderating the seasonal forces contributing to erosional processes. However, concentrated exploitation of the offshore coral reefs have degraded the coastal defenses resulting in accelerated erosion along a six mile stretch of coastline from which an estimated 75,000 tons of coral is mined annually (Amerasinghe, 1978 and Soysa, et.al., 1982). According to Linsky (Valencia, 1981), the resulting "... loss of beach from direct wave action has been estimated at 300 meters over 50 years with a net dollar loss of over US $3 million" (Figure 8). In response to the problem, the government has constructed an expensive series of groins with little success as beach

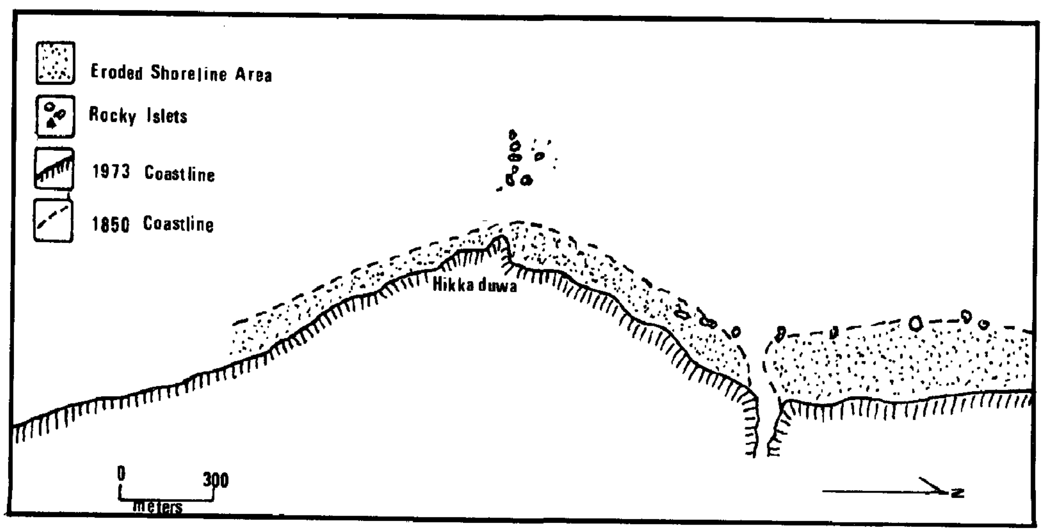

Figure 8. Erosional changes in Sri Lanka's southwest coast, adjacent to Hikkaduwa. (Source: Modified after Swan, 1974.)

areas remain exposed to the unmoderated influences of offshore wave attack (Swan, 1974).

5.1.3 Tarawa, Kiribati

The construction of expensive restorative structures to reverse erosional impacts to beach systems is not unique to Sri Lanka. These trends are also illustrated by the Tarawa Atoll site example, a reverse "L" shaped assemblage of very small islands situated in the former Gilbert Islands, now named the Republic of Kiribati (Figure 9). Situated on the equator in the central-Pacific, Kiribati has a population of 56,000, concentrated on sixteen atolls with a combined land area of only 280 square kilometers.

The Tarawa Atoll has a total land area of only 21 square kilometers, divided into rural and urban concentrations in the north and south portions respectively. The lagoon opens to the west, measures 350 square kilometers and is enclosed to the east and south by a chain of small, low-lying islands characterized by sloping beaches, limestone rock outcrops and mangroves (Bolton, 1982). Offshore, turtle grass beds and numerous coral patch reefs (living and dead) are scattered throughout the area before the coral barrier reef is met at the atoll's edge (Zann, 1982).

As in most atolls, Tarawa has a high coastline length to land ratio signifying a scarcity of land. This is particularly critical in south Tarawa where a high birth rate and in-migration from Kiribati's other populated atolls have resulted in a dramatic contrast in human densities between the north and the south (144/km^2 vs. 2,700/km^2).

Stress imposed by human activity is especially critical for the atoll's marine resources because of their significant economic utilization: fishing, dredging, breakwater and causeway construction, waste disposal, and coral and sand extraction.

Mining of coral is a traditional activity in Kiribati. Ironically one of the primary uses of coral is for the construction of barriers to protect shorelines from erosion. Howarth (1982) in a survey of South Tarawa's two major islands (Betio and Bairiki) identified eighteen

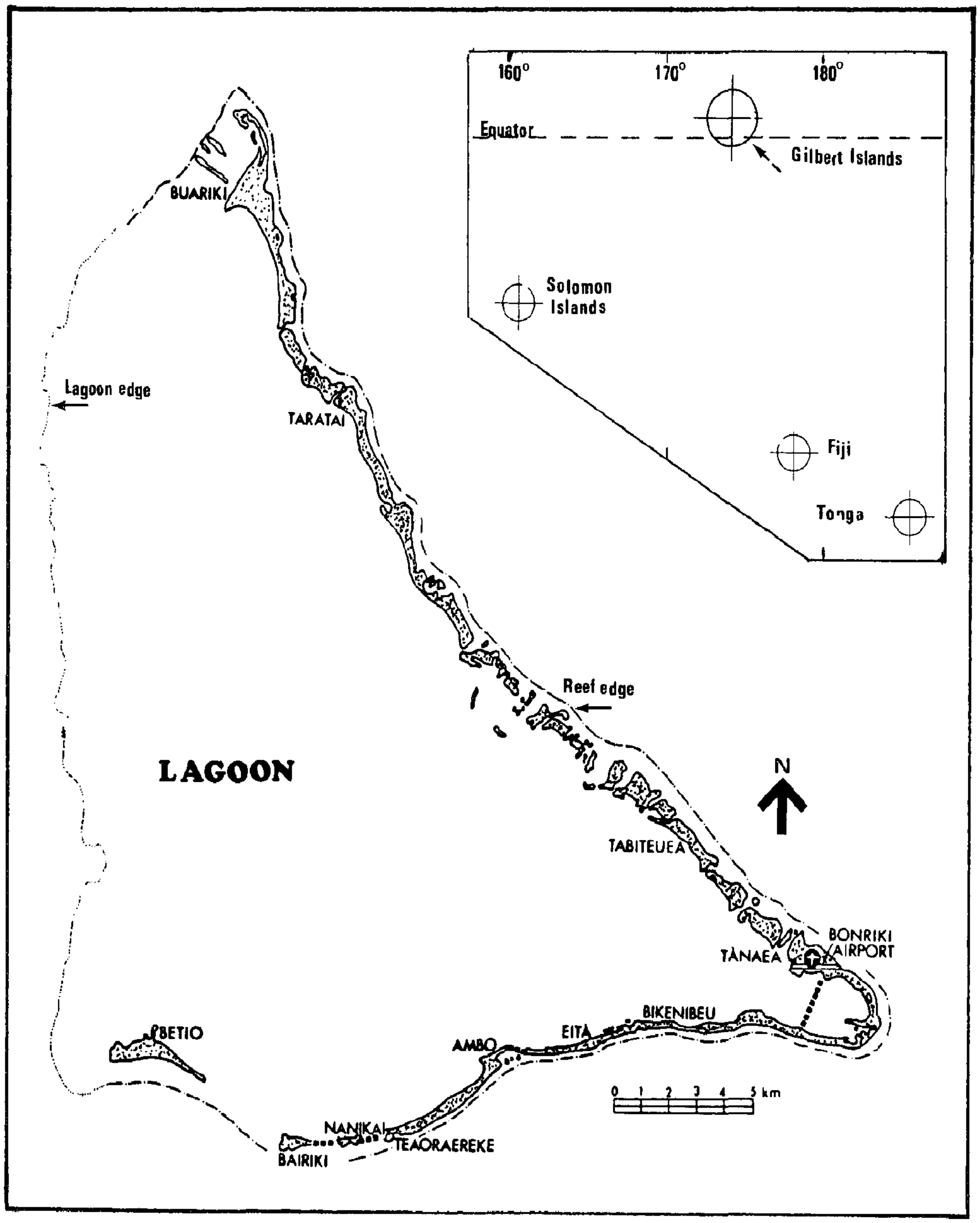

Figure 9. Tarawa Atoll, Republic of Kiribati (Gilbert Islands). (Source: Modified after Howarth, 1982.)

coastal protection zones using coral and/or concrete blocks enclosed by heavy wire mesh baskets (gabions) for shoreline protection.

Coral mining and other man-induced impacts on the coral reefs have produced major environmental problems. In a recent survey of corals in or near the islands of Betio and Bairiki, Zann (1982) found no living coral cover greater than forty percent cover of the bottom, and most sites on the lagoon side indicated ten percent or less cover. One result of the presence of a diminished living reef (partially created by the mining practices) has been increased erosion undermining coastal protective structures and creating new sites at risk. In a second irony, once coral populations were depleted, the traditional source of coastal protective structures (gabions) disappeared, and alternative sources of materials were required.

Howarth (1982) compared the number of gabions employed between September 1978 and August 1982 (Table 3a) and calculated that approximately 110 additional gabions a year were being built for coastal protection (Table 3b). Based on the price of the coral substitute, concrete blocks at 85 cents per block, the approximate cost for a four cubic meter gabion was US$213 (Table 3c). At the average annual production rate for gabions this represented an annual expenditure of US$23,430/year for preventative coastal erosion structure production (Table 3d).

Table 3a. Gabions known to be erected between September, 1978 and February, 1982, indicating the increased need for coastal protective structures. (Source: Howarth, 1982.)

Coastal Defense Zone	September/October 1978		February 1982	
	2x1x1	2x1x0.5	2x1x1	2x1x0.5
Betio	216	69	565	114
Bairiki	30	0	29	31
Total Gabions	246	69	594	145
Equivalent 2 x 1 x 1 meter gabions	281		666	

Table 3b. Average number of gabions constructed annually in South Tarawa Atoll. (Source: Howarth, 1982.)

$$\frac{\text{Total No. of Gabions in February 1982} - \text{Total No. of Gabions in October 1978}}{\text{Interim Period of Time}} = \frac{\text{Average No. of Gabions Constructed}}{\text{Year}}$$

$$\frac{606 - 281}{3.5} = 110 \text{ gabions/year}$$

Table 3c. Costs of constructing a 2m x 2m x 1m gabion with concrete block in US $. (Source: Howarth, 1982.)

	1982
Basket	83
Labor	12
Blocks @ 0.85 cents	106
Plant Hire	12
TOTAL COST PER BASKET	US$213 (approximately)

Table 3d. Annual capital expenditure on gabion construction in South Tarawa Atoll. (Source: Howarth, 1982.)

Ave. No. of Gabions	x	Cost per basket	=	Total annual capital expenditure for gabion construction
110	x	$213	=	$23,430/year

5.2 Beach Sand Mining

5.2.1 St. Lucia

In many tropical countries, coral exploitation for construction block and lime production is overshadowed by mining coastal sand for aggregate on an even larger scale. This practice is expecially prevalent in developing countries where scarce technical and financial resources prohibit the exploitation of inland sand deposits. St. Lucia, an island situated in the West Indies, is one such area where mining sand and aggregate from beaches has been a convenient and traditional practice.

Vigie Beach, located on the northwest leeward coast of St. Lucia, is a small crescent-shaped beach measuring 20-30 meters in width and extending approximately 5,000 feet between two basaltic headlands (Figure 10). No rivers enter the area, and the principal sources of sand appear to be nearby offshore calcareous algal and fringing coral reef communities supplemented by incidental erosion from the adjacent headlands (Edmunds, 1983). Waves approach from the north/northeast and vary in strength between seasons, driving an offshore-onshore sand transport cell. Longshore transport appears to be insignificant. These characteristics suggest that the beach system is relatively self-contained and dependent on sand in the system rather than on continuous replenishment from outside, upstream sources to replace losses, whether natural or man-made.

Due to the proximity to Castries, St. Lucia's capital, Vigie Beach and the narrow low lying neck of land to Vigie Point have been exposed to a variety of uses. For example, the city cemetery is located immediately behind the beach. Vigie Airport, running diagonally behind the cemetery, was built in 1943 and subsequently expanded to its present length of 5,700 feet. The only access road to the airport terminal parallels the beach (running between the cemetery and the airport runway) and also provides the access to Vigie Point. Vigie Beach has been a traditional recreational area for local residents of Castries, and since the early 1960's has served two major hotels, one at either end of the beach (Figure 10).

In addition to these activities, the beach has also served as the primary source of sand for the city and its citizens. There is little

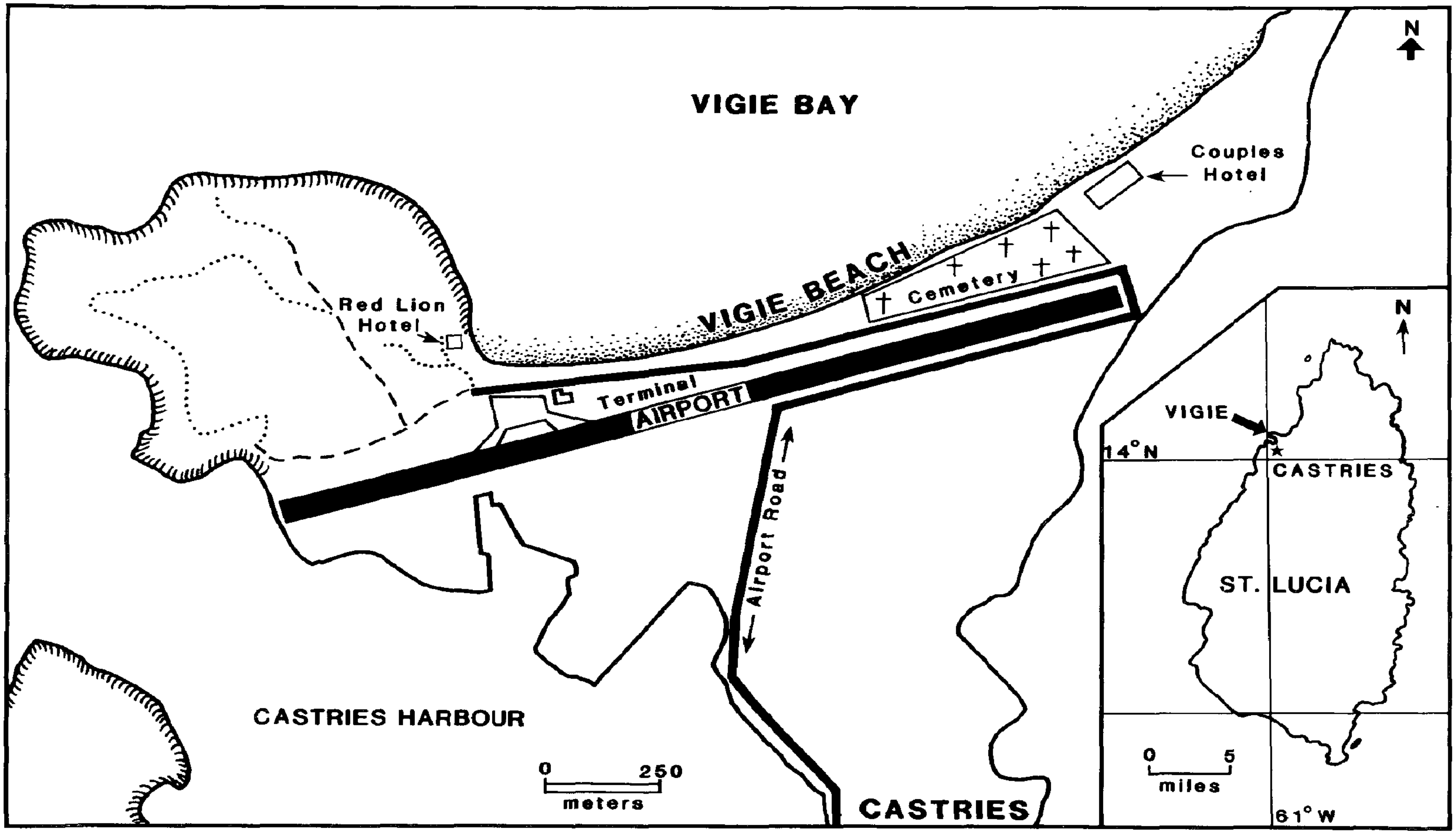

Figure 10. Location map of Vigie Beach, St. Lucia, showing interrelationship of threatened areas and facilities because of excessive beach sand mining.

data to indicate beach mining was a problem in Vigie prior to 1948. Up until that date, domestic and commercial building construction was based on lumber as a basic material, and there was little need for aggregate. However, in 1948 a catastrophic fire destroyed a large portion of Castries and in the subsequent reconstruction period concrete block and reinforced poured concrete replaced lumber as a building material. Vigie Beach became the principal source of sand for cement block manufacture and concrete. Despite early indications of beach erosion, sand mining continued unimpeded until 1963. By that year the condition of Vigie had deteriorated to the point that the government introduced a Beach Protection Ordinance which placed the mining of sand under licenses administered by the Ministry of Communications and Works. The law suffered from several weaknesses: it exempted the officers of the Crown, the Castries Town Council (one of the primary users) and the neighboring village councils; it only applied to Vigie and one other beach; and, finally, it was inadequately enforced. Sand mining continued unabated at Vigie Beach even though it was officially illegal for some users.

Exceptionally heavy swells during the winters of 1963/64 and 1964/65 exacerbated the erosion process which was further accelerated by continuing illegal sand mining. Visible narrowing and deterioration of Vigie Beach, and other St. Lucia beaches also locally mined for construction sand, led to public outcry and to the passage of the Beach Protection Act of 1967. This Act, still technically in force today, placed the administrative responsibility for all sand mining under the Director of Public Works (DPW). By doing so, the new legislation effectively broadened the scope of the 1963 Act while providing a mechanism to establish volume and time limits on beach mining activities.

Despite the passage of the 1967 legislation and its ostensibly more stringent constraints regarding sand extraction at Vigie Beach (and elsewhere), regression continued and was accelerated by the unusual winter storms of 1967/68 and by ongoing, although reduced, illegal sand extraction.

The potential economic consequences of continued beach regression began to appear critical. The estimated volume of sand mined from the

Vigie site during the period 1960-1970 had totalled 110,000 cubic yards (Table 4a). An analysis of aerial photographs between the period 1941-1970 indicated beach regression had reached 80 feet (Table 4b). A comparison of documented erosion (lost beach area) and estimated sand removal (Table 4c) suggests that beach recession was caused entirely by mining of sand for the building industry (Deane, et.al., 1973). By 1970, an estimated 10.1 million dollars of real estate alone was at risk (Table 5a). In addition to loss of land value, there were other significant issues. The city of Castries was threatened with loss of its airport access road and its principal cemetery, the city and country were threatened with a loss of tourist revenues derived from visitor use of two major Vigie Beach hotels, and the local population was faced with the loss of a traditional recreational site.

In response to these concerns and in an attempt to reduce the rate of beach and beach berm erosion threatening both the cemetery and the only access road to the airport and Vigie Point, the government elected to construct a 300 foot long strip of gabion mattresses (a system of rectangular wire mesh baskets filled with stone) on the face of the eroding beach berm near the road. This emergency measure cost approximately US$25,000--a not inconsiderable sum in 1970 for a small island government with many other public development priorities.

By 1973, the beach front of the Red Lion Hotel (at the southern end of Vigie Beach) had eroded down to a pebble and cobble beach, resulting in a reduction in tourism and lost revenues. In an attempt to restore the beach, the government used rock from a nearby quarry to build a rubble stone groin adjacent to the hotel at a cost of approximately US$5,000.

Three years later abnormally heavy sea swells from a winter storm overwashed the diminished beach and flooded the Couples Hotel. Continued flooding prompted the government to build a new set of gabion mattresses costing another US$5,000 on the eastern end of the beach. As the situation continued to deteriorate the government recognized that the "patchwork" strategy was ineffective and temporary, so another approach was needed. The new strategy was offshore sand mining for beach nourish-

Table 4a. Estimates of sand mined from Vigie Beach, St. Lucia (1960 - 1970). (Source: Deane, et.al., 1973.)

LOCATION OF SAND SOURCE	ESTIMATED VOLUME OF SAND MINED (Cubic Yards)				
	1960-62	1962-65	1966-68	1969-70	TOTAL
Vigie Beach	70,000	35,000	3,000	2,000	110,000

Table 4b. Beach loss from erosion at Vigie Beach, St. Lucia (1941 - 1970). (Source: Deane, et.al., 1973.)

BAY	STATION	COASTAL EROSION (Ft.) 1941-51	1941-66	1941-70	AVE BEACH LOSS PER YR. (1941-1970) (Ft.)
	1	16	65	80	2.66 ft.
Vigie	2	0	48	50	1.66 ft.
	3	14	54	54	1.80 ft.

Table 4c. Camparison budget of sand losses, Vigie Beach, St. Lucia. (Source: Deane, et.al., 1973.)

LOCATION	Estimate of Sand Used By Building Industry (1960-1970) (Cu. Yds.)	EROSION 1941-1970 (Cu. Yds.)
Vigie Beach	110,000	104,000

Table 5a. Current value of real estate at risk due to Vigie Beach erosion. (Source: Edmunds, 1983.)

TYPE OF REAL ESTATE	VALUE (US $)
Hotel	
Red Lion	$ 2,000,000
Couples	3,500,000
Other	
Public Road	384,615
Vigie Airport:	
Runway Costs	2,115,305
Buildings	576,923
Land	1,538,461
TOTAL	.$10,115,384

Table 5b. Estimated costs of protective/restorative activities to protect Vigie Beach and property at risk from the threat posed by coastal erosion. (Source: Edmunds, 1983.)

Activity	Location	Date	Estimated Cost (US $)
Gabion Mattress	Adjacent to Public Road	1970	$ 25,000
Stone Groin	Red Lion Hotel	1973	5,000
Gabion Mattress	Couples Hotel	1976	5,000
Beach Nourishment	Couples Hotel/Cemetery	1980	434,245

ment, selected in part because of the temporary presence of a large Jamaican-owned suction dredge working in Castries Harbor. The scope of the beach replenishment project was limited by government access to external funding which in the end amounted to US$434,000. By mid-May of 1980 the work had been completed, and a total of 289,000 cubic yards of sand was deposited on the beach in a zone extending from the Couples Hotel 1,600 feet to the southwest, building up the area adjacent to the cemetery which was most seriously threatened by erosion.

Although no data exist to determine the effects of dredging on offshore algal and coral communities, there was evidence that a considerable portion of the new beach sand put in place washed out subsequent to emplacement, a process attributed to "fines winnowing" (Edmunds, 1983).

Total investment of public funds to protect and restore Vigie Beach following long term beach sand extraction activities was estimated to be US$469,245 (Table 5b). Since sand cost US$1.87 per yard in 1980 to place on the beach, the overall restoration costs of US$469,245 represents slightly more than twice the adjusted market value of sand previously removed, legally or illegally. It was a costly lesson in beach dynamics and resource management. Unfortunately, the beach berm is still being under cut, and beach sand draw down continues although perhaps at a slower pace than previously recorded.

There is a further irony to the situation stemming from the existence of large but as yet undeveloped pumice "sand" deposits in St. Lucia, a volcanic island. Up until recently, these resources, which are relatively close to Castries, have been rejected as too costly to develop (primarily costs associated with an access road) and because greater care is required to mix cement when lighter pumice sand is used. Nevertheless, the events detailed above contributed to the establishment of a Regional Beach Erosion Control Project, which undertook the testing of pumice as an alternative source for aggregate. Upon finding that pumice blocks were structurally superior to those made with beach sand, the government began considering greater use of the resource, and an experimental project is underway using pumice as a substitute for beach sand. The extraction of beach sand at Vigie has ceased, but the future of the beach itself remains in doubt. It was a costly lesson.

5.2.2 Puerto Rico

In contrast to the leeward beach situation at Vigie in St. Lucia, many windward or more exposed insular and continental shorelines function differently. With high energy beach systems, they exhibit very different kinds of sand budgets, higher onshore-offshore sand and rubble exchange rates, and large scale sand sinks or reservoirs of material behind the beach itself.

Sand blown from exposed, generally windward beach foreshores and berms often develops into sand dune systems behind the berm crest itself. Salt-tolerant vegetation subsequently takes root and helps stabilize these sand dunes. Dunes, in turn, serve both as a secondary barrier protecting inland areas against seasonal storm waves impinging on the beach and as a reservoir of sand for the beach itself when it is attacked by storm waves, swells and tides generated by hurricanes or cyclones (Figure 11).

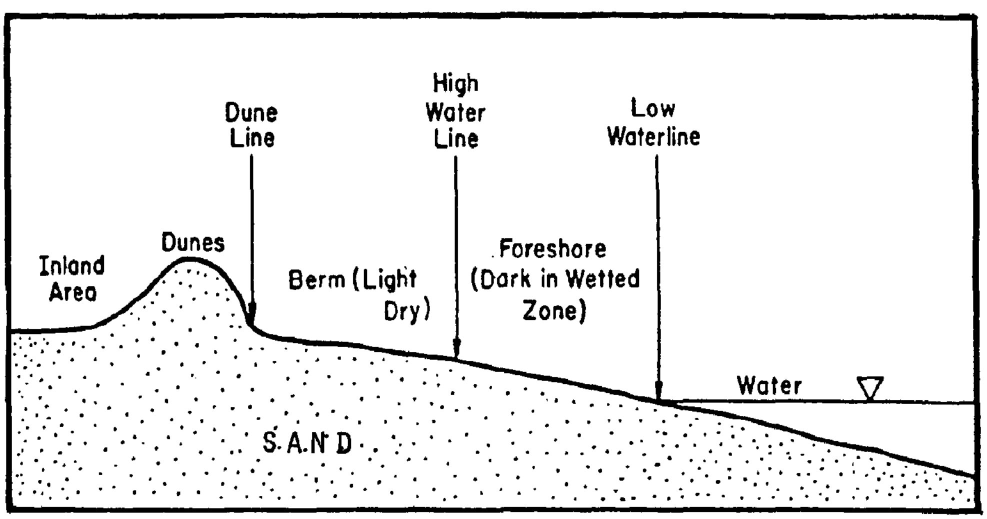

Figure 11. Idealized cross-section showing beach, dune line, and water line. (Source: Nichols and Cerco, 1983.)

Unfortunately, dune systems are also easily accessible, naturally stock-piled sources from which semi-sorted, pre-washed sand is readily obtained. Quite often, this happens without a formal government permit and with little regard for environmental consequences.

An instructive example of this exists on the north coast of Puerto Rico and has been addressed recently in an intensive policy and management study which focused on three major dune sand mining areas on the more exposed Atlantic coast of the island (Nichols and Cerco, 1983). Sites were selected by the Puerto Rico Department of Natural Resources as the most representative heavily mined areas (Figure 12).

Construction of a major international airport for the island east of its capital city of San Juan at Isla Grande in the 1950's required enormous volumes of fill. Some of the material was taken from nearby Playa de las Tres Palmetas at Carolina, east of the airport site. Within a few years, high levels of erosion were reported for the Carolina beach area. During the 1960's and early 1970's the Hatillo beach area to the west also experienced an intense large scale removal of dune sand, some by permit and some illegally. In the 1970's the Isabella beach dune areas were also harvested for large volumes of sand. Again, some mining was by permit; some was not. The justification for the dune/beach sand mining was always "development" and the long term impact remained an unknown--at least until the mid-seventies when studies by government resource managers and technical consultants (see below) suggested limits to sand extraction quantities were required to prevent further damange to Puerto Rico's sand beaches and dune systems.

The Environmental Quality Board of Puerto Rico raised the issue of excessive sand mining and long term sand resource planning as early as 1971 (PREQB, Annual Report, 1972). Preliminary guidelines for sand extraction in Puerto Rico were provided by one consultant (Hernandez-Avila) as early as 1973 based mainly on qualitative observations giving insights into sedimentary processes active in the dunes. Noticeable effects of storm waves on beach erosion and alterations of dune height and width at Playa de las Tres Palmitas, Carolina by a sand extraction episode were recorded by Cintron and Pool (1976). The problem of dune protection and

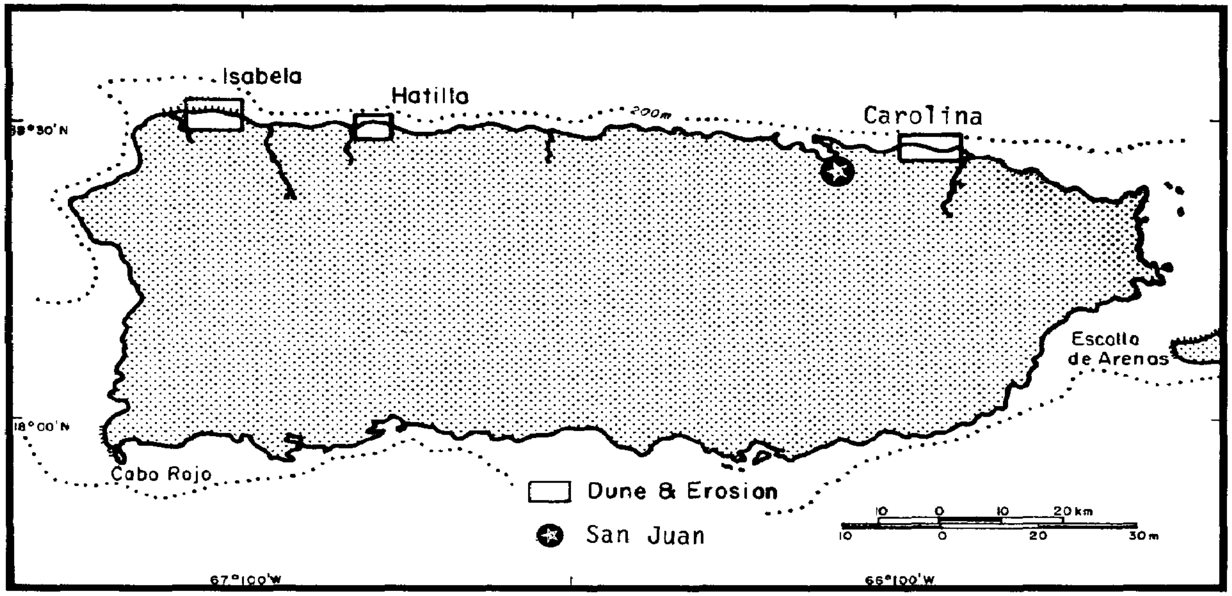

Figure 12. Location of dune erosion sites on the north coast of Puerto Rico (Source: Modified from Nichols and Cerco, 1983).

sand extraction was subsequently documented by NOAA under Puerto Rico's Coastal Zone Management Program in 1978 (NOAA, 1978). Two years later, the history and magnitude of sand extraction and estimates of Puerto Rico's total sand resources were provided by Castillo and Cruz (1980); the hazard of coastal flooding was documented in a government study (PRDNR, 1980); and three pertinent sand dune management studies from outside Puerto Rico also became available (Armon, 1980; Cullen and Bird, 1980; and Gares, et.al., 1980).

Due to increasing concern expressed by resource managers and planners over the growing evidence of impacts attributable to excessive sand extraction, the Puerto Rico Department of Natural Resources began to assemble all the available data needed to define the dimensions of the problem and to establish both a technical and policy based solution.

This took time, in part because as in most sand resource management matters the government had to address not only traditional, ongoing and new kinds of legitimate and illegal sand uses but also had to project future needs and assess those needs within the context of the associated environmental constraints. It was a difficult task.

Every prospective user of sand confronting changed controls, limits, licensing or fees wants to know why there are new "unfair" and "costly" rules which did not apply yesterday to someone else. It was necessary in Puerto Rico to build a solid government position for a new beach resource management strategy, based on sound scientific data, because of the presence of resource users accustomed to fewer restrictions. When data was collected and analyzed as part of a management planning project under the Department of Natural Resources, it produced findings which suggested there was real cause for concern. By coincidence, the outcome of the study was reinforced by exceptionally severe storm damage at the three study beach areas during the course of site assessment field work in 1982 (Nichols and Cerco, 1983).

It has been documented that over a thirty year period (1950 to 1980) sixteen million cubic meters (approximately 21 million cubic yards) of sand had been mined from Puerto Rico's north shore dunes and beach areas. Of this total, eleven million cubic meters (14.3 million cubic yards) were extracted for fill and construction use from the three key beach areas of Carolina, Hatillo and Isabella (Castillo and Cruz, 1980). The sand used, in this case, was not "free" but had a deferred cost. Nichols and Cerco (1983) summarized the situation well:

> Along the north coast, sand dunes once provided protection against storm surges, waves and flooding. They not only offered natural protection for human life and property but served as a source of sand to buffer beach erosion. Today, after several decades of massive sand extraction few natural dunes remain. By removing back-up dunes and lowering foredune crests, storm waves now [1983] overtop and breach the remaining ridge and flood lowlying areas landward. Where dunes have been completely destroyed, ocean front property, settlements and mangrove habitats are exposed to the full force of ocean storm waves....
>
> The size, height and stability of residual dunes at Isabella, Hatillo and Carolina [are now] inadequate in many places for long term protection of life and property. As a result of high northern swells, October 11-13, 1982, dune ridges collapsed, were breached at 23 points [and are] insufficient to protect the coast from wave run-up of a one in 20-year hurricane.
>
> Given the deteriorating status of the dunes in response to man-induced and natural processes, the task now is to maintain the dunes in their best achievable condition.... If the dunes are to serve both as a sand and recreational resource as well as a barrier for storm protection, they must be understood....

This case confirms that some environmental management lessons come at a price. Fortunately, some of these lessons are transferable and may reduce the risk of replication at other locations. Conclusions drawn in the Nichols and Cerco (1983) post-audit of the Puerto Rican experience are instructive for most sand dune mining activities. The problem is how to continue to mine sand from dunes while minimizing the risk of future storm damage to property and human life, thus lessening the need for costly protective structures and other remedial measures.

At the outset, the operating characteristics and natural functions of beach and dune areas must be addressed. These were identified by Nichols and Cerco:

- The dune and beach system is dynamic. Dune sand is continually exchanged between the beach or nearshore zones.
- Dunes constitute a natural reservoir of sand. When the dune face is eroded during storms, the sand released nourishes beaches and reduces erosion effects.
- Dune width and dune height provide a volume and mass of sand that reduces the landward extent of overtopping, overwash and flooding of zones behind the dunes.
- The life expectancy of protection depends on the lateral erosion rate and the dune height in relation to the heights and frequency that storm surge and runup attain.
- Over the long-term the dune/beach system can migrate landward in response to storms, erosion, rising sea level and a negative sediment budget [especially when accelerated by sand mining activity] (Nichols and Cerco, 1983).

Since the type and status of dunes vary widely, both naturally and as a result of previous sand extraction and other development activities, different management approaches may be needed. These include: (1) prohibiting all dune sand mining; (2) letting the natural process prevail, while mining some sand on a sustainable yield basis; (3) modifying the natural processes to maintain or restore the dunes for protection while mining sand on a managed by-product or secondary yield basis; (4) optimizing sand extraction and subsequently rebuilding the dunes artificially.

For most developing countries, option (1), no dune (or beach) sand mining, is unacceptable. If option (2) is chosen and natural processes are allowed to prevail, the coast must be managed in a manner that is compatible with beach and dune migration trends and historical erosion rates. The approach permits some sand extraction or development but controls it to minimize interference with natural processes and to provide a degree of protection (Nichols and Cerco, 1983).

To manage the beaches and dunes so that natural processes prevail and critical existing sand dune reservoirs are kept more or less intact, a beach/dune management zone needs to be defined (see Nichols and Cerco for the procedure). By establishing a dune management or setback zone, future sand extraction and vehicular activities, as well as development, can be directed inland away from the more active portion of the dunes. No sand mining would be allowed from the primary shoreward dune and "protection" would have precedence over "sand mining."

Should option (3) be selected to encourage the natural processes (a) to provide sand for harvesting and (b) to maintain and/or restore dunes previously damaged by a combination of sand mining and storm action, the management strategy involves:

- building up dune gaps and washover zones through fencing and planting appropriate vegetation and/or;
- building up dune gaps, washover zones and elevations of sand mining borrow pits to appropriate design heights (50 year or 100 year storm) by large scale sand nourishment from offshore using a hydraulic dredge;
- establishing a set back zone landward of surviving dunes, into which dunes can migrate and recover;
- regulating all sand mining and restricting it to carefully selected undamaged accreting and residual back dune areas behind the primary shoreward dune (which would not be mined except under special circumstances where accretion rates exceed required storm protection requirements).

Option (4), emplacing protective engineering structure in dune gaps and washovers resulting from excessive sand extraction, can only be justified where the value of existing property and facilities is very high. It is a proven high risk, short sighted approach leading to potentially disastrous and costly consequences, as illustrated by both the St. Lucia and Puerto Rico examples. Engineering structures are no substitute for natural sand dunes along open stretches of coastline.

5.3 Marine Sand Mining

5.3.1 U.S. Virgin Islands

Over the past two decades, many developing countries have stopped or reduced the practice of harvesting beach sand for construction purposes. To a degree, this is attributable to increased awareness of negative environmental impacts associated with coastal sand and coral mining activity. More significant is the simple realization that there are socially and economically valuable alternative uses for beaches, i.e., for local recreational uses and development of waterfront resorts, hotels, condominium sites and other tourist attractions. But when a government declares beach sand extraction illegal or restricts traditional harvesting practices and therefore the supply of sand, it will sooner or later be forced to identify and regulate the mining of alternative sources of aggregate.

This was the situation in the U.S. Virgin Islands in the 1960's when external factors began to stimulate economic growth in three sectors, government operations, export manufacturing and tourism. In tourism, growth rates were exponential, both in number of arrivals and in accommodations. Between 1960 and 1970, visitor arrivals increased tenfold. As the employed labor force tripled, the stock of housing doubled, real per capita income rose ten percent annually, and electric and water consumption averaged 20 percent per year growth (McElroy, 1978).

Environmental stresses from such massive social changes quickly became apparent. Open spaces were replaced by suburban sprawl, shorelines were altered by hotel, marina and industrial expansion, and prevously undisturbed ecosystems became sites of residential clusters, government facilities, commercial buildings and road networks (McEachern and Towle, 1974). Much of this activity required sand for a variety of purposes for land fill, for increasing beach width or length, for building docks, and for construction of hotels, houses and other facilities. Between 1960 and 1970 the consumption of sand tripled along with the price which went from $1.00 to $3.00 per cubic yard. In the context of a growing beach-oriented, tourism-based economy, traditional sand removal from beaches began to be publicly questioned. It was eventually legally challenged and, in 1973, prohibited by law, resulting in a sharp increase in more costly imports of sand (at $5.00 to $7.00/cubic yard) from other islands such as Puerto Rico, the British Virgin Islands, Anguilla, Barbuda, and even the distant Bahamas. Other alternatives were examined which included large scale offshore marine sand dredging to provide the needed construction sand and fill material.

Marine sand mining has a long history in the U.S. Virgin Islands. As early as 1935, over one million cubic yards of material was dredged from the bottom of Lindbergh Bay on the southwestern coast of St. Thomas. Fill was placed in a nearby, swampy area for the construction of the present airport runway, leaving a large, deep excavated turbid basin in the bay bottom. As a result of the ensuing turbidities, benthic grasses once found to a depth of 10 meters are now absent in depths exceeding 2.5 meters. Dredging effects were compounded by large quantities of fine terrigenous clays washed into the bay as a result of continuing construction on nearby hillsides (vanEepoel, et.al., 1971). The extensive sump resulting from dredging activities still, nearly 50 years later, collects fine sediments which then are available for resuspension and redistribution throughout the bay system. This periodically increases turbidity and limits the regrowth of coral and sea grasses. Adjacent Lindbergh Bay Beach, a public recreation area, remains popular with local residents (not tourists), more for its accessibility by public bus transport than its marginal water quality.

Between 1961 and 1981, over 2.2 million cubic yards of aggregate (principally sand) were extracted for local construction activity from Christiansted Harbor, St. Croix, the most southerly of the Virgin Islands (Hubbard, et.al., 1981a). Over 200,000 cubic yards of sand was harvested from each of eight other bays in the Virgin Islands (Brewers, Water, Crown, Cruz, Great Cruz, Vessup, Long, and Turners) during the 1960's and early 1970's. One area in particular, Water Bay, was the focus of repeated sand mining activities between 1960 and 1971 and was selected as the "case study" site.

5.3.2 Water Bay, St. Thomas

Situated on the northeastern shore of St. Thomas, Water Bay opens to the east facing the Leeward Passage, an inter-island channel from the Atlantic Ocean to the Caribbean Sea. It is bounded on the north by Coki Peninsula, on the west by Pineapple Beach, and on the south by the island land mass proper, ending at Footer Point. Prior to dredging, Water Bay supported marine flora and fauna characteristic of most West Indian shallow water marine communities dominated by turtle and eel grass flats interspersed with small patch reefs. The sublittoral area of the Bay was approximately twenty hectares with a relatively even bottom and gradual slope to seward (Figure 13).

Part of the Bay's southern shore is the bold slope of Mt. Pleasant, which rises steeply to a 200 foot elevation. A small indentation between Footer Point and Mt. Pleasant is known as Sugar Bay, behind which there is a lowland area which was at one time used as a public garbage dump. Until 1969 Sugar Bay had a rather nice beach; the story of its disappearance is instructive.

The seabed of Water Bay was dredged for sand on five separate occasions between 1961 and 1971 (Table 6). In 1961, as part of a resort development project at Pineapple Beach, 50,000 to 100,000 cubic yards of sand were first dredged from the shallow area near the beach to provide adequate depth for a boat dock, for beach improvement and for construction and fill use. An area continguous to the original mining site was subsequently mined in 1965 for additional construction material and fill for a swamp adjacent to the already existing hotel on Pineapple Beach. After 9,000 of a scheduled 25,000 cubic yards were extracted by a suction dredge working over a large area only six to eight feet deep, the hotel owners ordered the contractor to stop. Mounting complaints of water quality by hotel guests using the beach had reached booking agents on the U.S. mainland, who threatened to refuse to book further guests at the Pineapple Beach Resort until swimming and snorkeling conditions improved. Rather than risk the possibly irreparable loss of visitors and potential repeat customers, the hotel owners elected to absorb the added costs of hauling the required fill material.

Four years later, however, a 1967 U.S. Department of the Interior permit to dredge 600,000 cubic yards of sand from Water Bay (issued to a local concrete ready-mix company) was announced and activated by the contractor. The same hotel, perceiving that its investment was again threatened, joined forces with the environmental community to oppose the action. The owner/manager of the Pineapple Beach Resort facility re-

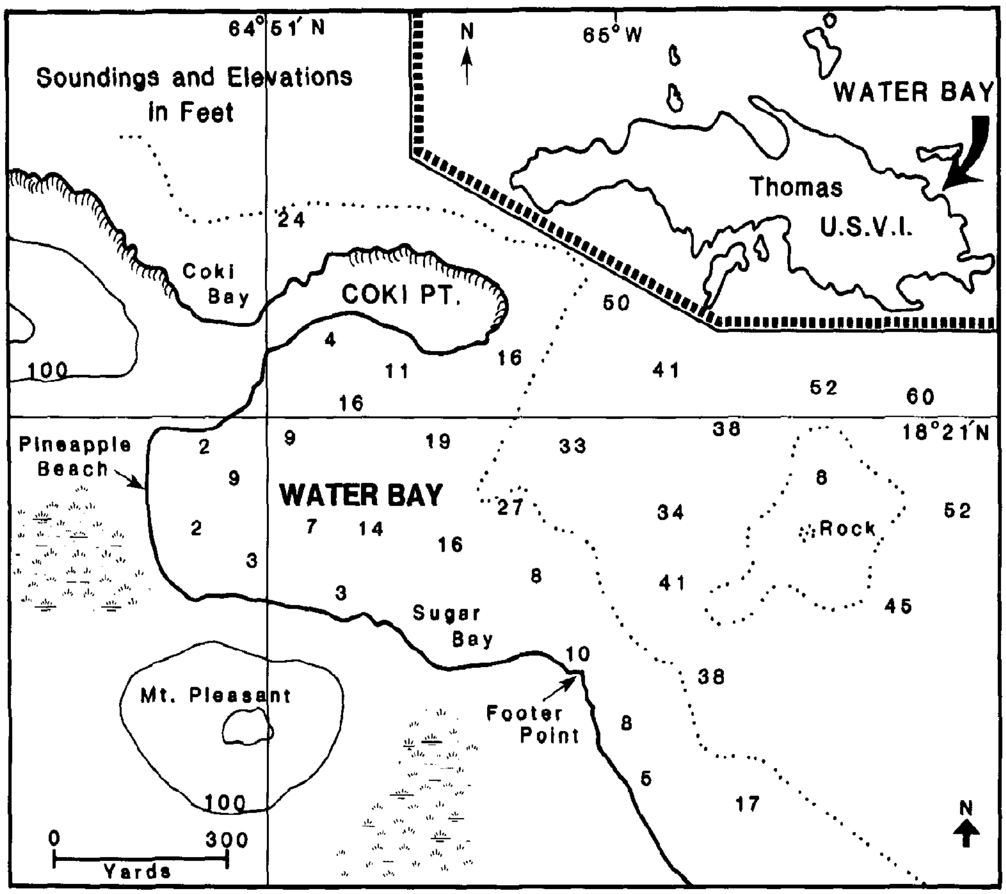

Figure 13. Water Bay, St. Thomas, U.S. Virgin Islands, showing bathymetry and shoreline swamps prior to dredge and fill operations (1960-1971). (Base map from NOAA Chart No. 938.)

Table 6 . History of marine sand mining, Water Bay, St. Thomas, U.S. Virgin Islands. (Sources: vanEepoel, 1969; Grigg and vanEepoel, 1972.)

Year	Dredging Location	Quantity (yd^3 sand)	Dredge Type	Purpose
1961 -62	Pineapple Beach (nearshore)	50,000 to 100,000 (est.)	Dragline	Construction aggregate/ beach nourishment/ dock access
1965	Pineapple Beach (nearshore)	9,000	Sand sucker	Land fill
1969	Sugar Bay (nearshore)	100,000	Hydraulic cutterhead	Fill/Aggregate
1970	Inner Bay	50,000 (±)	Hydraulic cutterhead	Aggregate - off site use
1971	Outer Bay	450,000 (±)	Hydraulic cutterhead	Aggregate - off site use

sponded to the proposed scheme as follows in a letter to the government:

> It came to my attention during the first week of January 1969 that a large dredging operation was contemplated in the vicinity of the Water Bay Area, St. Thomas, V.I.... Since we had the previous experience of a business loss on dredging only 9,000 cubic yards we [know] that dredging ... [additional sand] would cause a very sizeable operating loss we could not afford.... The greatest asset we have is our beach. By July 1969 we will have a total investment of approximately four million dollars in Pineapple Beach Club and the Condominiums. Our entire investment would be in jeopardy if the beach [is] damaged....
>
> I feel confident that this government does not want to be responsible for permitting a dredging operation to operate in an area that would cause immediate financial loss in the daily operations and possibly cause irreparable damage to one of the most popular beach resorts in the Virgin Islands.
>
> I don't feel that the Government of the Virgin Islands would want to be a party to the substantial adverse publicity that such an abusive operation would receive not only locally, but throughout the travel industry....

The author of this letter also requested that an investigation be conducted by the government to assess the potential effects of removing 600,000 cubic yards of sand from Water Bay.

The proposed scheme involved 50,000 cubic yards of sand as fill for a former garbage dump and 550,000 cubic yards of construction sand to be hauled away from the site. Despite the previously cited protests, the contractor's hydraulic cutterhead dredge was in place and commenced pumping sand from Water Bay in early April 1969. Within thirty days over 100,000 cubic yards of sand were dredged from directly in front of Sugar Bay Beach on the south coast of Water Bay and deposited ashore filling the former swampy garbage dump site. Because the dredge was urgently needed at another nearby site and to allow time for the deposited material to settle, dredging activity was stopped temporarily.

Within months from the cessation of dredging activities, Sugar Bay Beach literally disappeared and was replaced by the underlying pebble and cobble-dominated substrate. Sugar Bay Beach was originally two hundred meters long and approximately ten meters in width. Surveys conducted a few months after the 1969 dredging indicated the beach materials had slumped into the adjacent dredge pit. The pre-existing sand berm had been eroded back, forming a three foot vertical wall several feet above sea level, exposing the seagrape tree root systems (Figure 14). Slump-off resulted in high water turbidities from both the exposed remnant of the beach as well as the newly eroded deposits. Additional turbidity was caused by exposed layers of mud opened during the removal of overlying sand deposits. Serious impacts on Water Bay life forms have resulted from chronic resuspension of mud fines, clays and organic materials (vanEepoel, 1969; Grigg and vanEepoel, 1970).

Reef die-off and reduction in sea grass densities were attributed to increased rates of sedimentation resulting from the dredging operations. Grigg and vanEepoel (1970) estimated that approximately ninety percent of undredged Water Bay corals on the southeast shore and 20-25 percent of corals on the northern shore were killed by the sand extraction activity (Figure 15). Two emergency groins costing approximately $10,000 were installed by the contractor in 1969 at either end of Sugar Bay after the beach disappears. However, they failed to have any positive effect and, subsequently, also washed away.

This then was the setting which preceded a resumption of sand mining in the fall of 1970 (a continuation of the 1969 dredging activity under the same permit). By this time a number of technical reports and scientific studies had become public, documenting the impact of sand mining operations at Water Bay and elsewhere in the Virgin Islands (vanEepoel, 1969; Grigg and vanEepoel, 1970). Researchers described the 1969 mining activities at Water Bay, though of a short term nature, as a "major ecological disaster for sublittoral flora and sessile fauna" in the immediate area of dredging (vanEepoel, 1969). Therefore, as mining activities recommenced, they came under increased public and private scrutiny. Tourism and hotel industry spokesmen lobbied for a monitoring regime, arguing that further "Sugar Bay disasters" would affect the value of their properties.

Until 1969 applications for required dredging permits (then issued

Figure 14a. Sugar Bay Beach (1969), before offshore dredging in Water Bay, St. Thomas, U.S. Virgin Islands.

Figure 14b. Sugar Bay Beach (1970), after offshore dredging in Water Bay, St. Thomas, U.S. Virgin Islands.

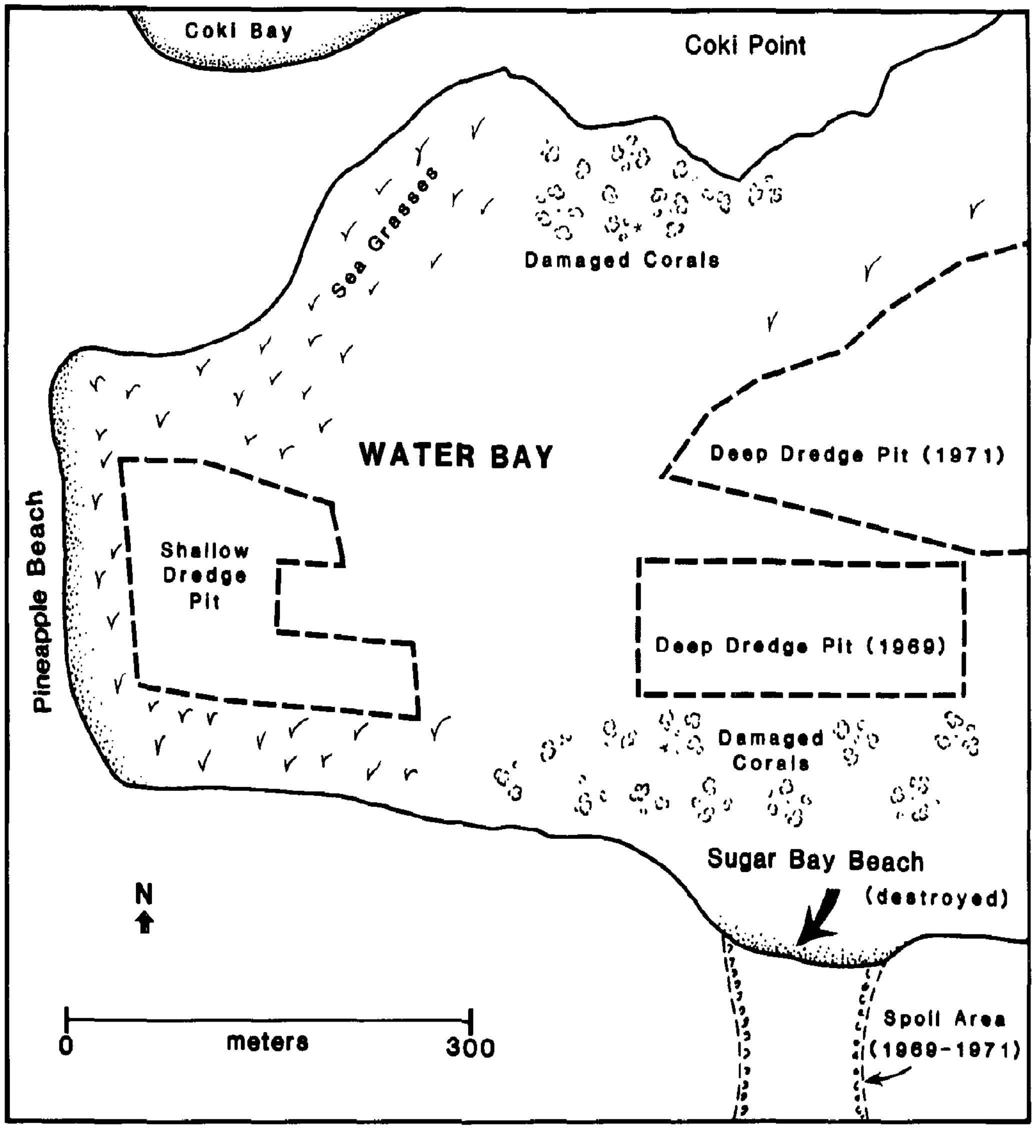

Figure 15. Water Bay, St. Thomas, U.S. Virgin Islands, showing dredge sites and adversely impacted areas including Sugar Bay Beach.

by the U.S. Department of the Interior) were seldom scrutinized. When approved, they were subject to little monitoring or enforcement and were issued as open licenses for extended periods. However, as a pre-condition to recommencing mining activities at Water Bay in 1970, the follow requirements were imposed by the local Virgin Islands government:

- Dredging had to be transferred to deeper areas at the entrance to Water Bay;
- Prior to dredging, core borings in the remaining seabed mining areas were to be taken to determine quality and depth of bottom and to assure that no disturbance of clay and organic "fines" would occur;
- A sediment discharge settling basin on the inshore disposal site, equipped with proper weirs to extend residence time, was to be maintained;
- Dredging in waters less than 35 feet in depth was prohibited;
- A surveillance program was to be established to ensure the adequate protection of the environment.

However, despite these required modifications and systematic attempts by local scientists to monitor the renewed dredging activity, conditions at Water Bay worsened during final stages (1970-71) of the now accelerated effort by the contractor to dredge the remainder of the total 600,000 yards approved under the original 1967 permit. Matters finally came to a head when the Governor of the Virgin Islands requested that the U.S. Department of the Interior withdraw the dredging permit. Cancellation was ordered on November 3, 1971, long after damage was done.

The positive legacy of the Water Bay experience was the establishment of a new territorial policy regarding beaches and dredging and a monitoring program to prevent future similar occurances. The negative legacy is the number of dredge pits which still exist in Water Bay with unconsolidated bottoms acting as chronic sources of turbidity and preventing recolonization near the mining site (Grigg and vanEepoel, 1972; Insular Environments, 1975; Island Resources Foundation resurvey of site area, 1983). Sugar Bay's former sandy beach continues to be a narrow strand of rubble and shows no signs of natural recovery nearly fifteen years later.

6. ALTERNATIVE MANAGEMENT APPROACHES

6.1 Coral Mining

6.1.1 Stony (Hard) Corals

Most "hard" or stony corals (scleractinians) have rather slow growth rates, ranging from one-tenth of a centimeter to ten centimeters per year in length (Stoddart, 1969). For this reason, they are often seen by more conservative scientists and managers as non-renewable marine resources since natural production rates are frequently exceeded by even very low levels of harvesting. When hard corals are exploited commercially, and, therefore, in effect treated as renewable resources, their slow growth rates suggest the need for careful resource management plans to control their harvesting for lime manufacture or, in the case of smaller, more delicate corals, as tourist curios and in the ornamental export trade (Wells, 1981).

Unfortunately, no comprehensive management strategies or regulations are known to exist for small stony corals, although some countries have export restrictions (Wells, 1981). The state of Hawaii, where extensive coral harvesting occurs, currently manages corals by establishment of a restricted zone (within 1,000 feet of shore and under 30 feet in depth) where the harvesting of coral and sand is prohibited; collecting for research purposes is excepted.

Grigg (1976) proposed the following minimum requirements: commercial "fishing" licenses; collection of catch/effort data; establishment of minimum size limits significantly above the determined age of reproductive maturity; estabishment of a monitoring program focused on heavily harvested reef areas; and a public information program to educate users on the importance of coral conservation. He also recommended the prohibition of all forms of random dredging for corals due to catch inefficiency (losses) and destructive impacts on the slower growing, deeper corals and their hard bottom habitats.

The need for sound management strategies for coral harvesting cannot be overemphasized due to the resource's slow rate of natural replenishment. Excessive exploitation implies a long recovery period and, translated into economic terms, a prolonged period of reduced harvests.

Because of these considerations, the U.S. Western Pacific Regional Fisheries Management Council (based in Hawaii) proposed that prior to the commercial harvesting of any virgin stocks in the region, a resource assessment should be completed to include total area of the bed, density estimates, and species present (U.S. Dept. of Commerce, 1979).

6.1.2 Precious Corals

Certain types of rare, slow growing corals are referred to as "precious corals" because of their special color, shape, hardness, texture, ornamental value and widespread commercial use by the handcrafts and jewelry industry (Poh, 1971; Wells, 1981). Wholesale prices for raw (dockside) precious coral can range from $50 to $500 per kilo, depending on the species, size, quality and color of the specimen (Eade, 1980). Ninety-five percent of the world's harvest of this resource comes from the Pacific. The most commonly harvested precious coral species are of the genera Corallium (white, pink, red, gold, and bamboo coral) and Antipathes (black and wire). They are only found in isolated colonies on hard substrates in water depths of between 30 and 500 meters.

Precious coral mining dates back to 100 A.D. in the Mediterranean region. In the Pacific the earliest recorded activity dates to the early nineteenth century in Japan but fell into temporary decline and was only recently revived by the Taiwanese in the mid-1950's. Today the sector is dominated by Japan, Taiwan, the Philippines and Hawaii (Grigg, 1970, 1976; Wells, 1981).

Harvesting techniques are of two types: non-selective use of a tangle net dredge (like an enormous industrial floor mop) which is dragged on deep coral beds to break off and ensnare specimens, or the use of one or more costly, more selective techniques (SCUBA, camera-assisted grabs, and minisubmarines with power driven cutting devices).

The non-selective, tangle net dredge approach has the obvious advantage of comparatively low capital and operational costs (boat, net, winch, and crew), continuous operation, and simplicity. The principal disadvantages of the technique are: damage to the substrate, low catch efficiency and removal of immature under-valued specimens. Conversely, selective direct harvesting for deep-water species incurs high capital costs, has depth limitations and is technologically more complex. These factors, however, are offset by the fact that environmental degradation is minimized and a high catch efficiency assured.

Precious corals grow even more slowly than most hard corals (Noome and Kristensen, 1976). Since harvesting activity is expanding and prices continue to rise, the need for proper management of this rather exotic but valuable resource is obvious. The traditional approach to the management of precious coral resources has been by rotation of harvesting effort from bed to bed as dictated by the economics of a slow-growing species. This strategy, first documented in the Mediterranean in the nineteenth century, was self-imposed and based on traditional nine year cycles. Within the past two decades, more "scientific" approaches to coral management have evolved. Growth rates for black coral and the deeper-water species of Corallium were estimated to be six and one cm./year, respectively, and have been used to determine a maximum harvesting pressure which the coral population could sustain for an indefinite period of time, or maximum sustainable yield (MSY). In the case of black coral (which is more accessible), this was determined to require limiting annual harvesting to an area measuring two to four percent of the total bed (U.S. Dept. of Commerce, 1979).

The MSY determined for black coral has been adapted by the Western Pacific Regional Fishery Management Council (WPRFMC) to other slow-growing coral species, at least until data become available to support a more species-specific management approach. To implement the MSY through subsequent regulations the WPRFMC employed the concept of three discrete management units: established beds (determined by a history of exploitation); conditional beds (those beds whose location and area are approximately known and optimum yield determined by analogy with established beds); and exploratory beds (all remaining areas).

Based on these management units, regulations were formulated and proposed in a draft management plan for precious coral. These encouraged use of more selective approaches to harvesting and establishment of weight quotas and size limits for pink and black coral species.

In addition to these operational regulations, permits were required and refuge areas established for purposes of providing research control areas and reproductive reserves.

6.2 Beach Sand Mining

Information available on successful management strategies for mining beach sands is marginal. Campbell (1978) recommended that where physical or economic constraints require harvesting sand from beaches, a rigorous monitoring program be initiated prior to and during mining. The program would include an official responsible for regulating the removal of sand and confine all extractive activities to designated, pre-selected sites situated between high and low tides and rotated over time from beach to beach to allow for the rejuvenation of the mined area. Sites should also be confined to accreting beaches, and limited harvesting would be allowed only after a sand resources survey had been completed, calculating the sand budget and the effects of any sand mining "debit" factors. For detailed beach dune sand mining management requirements, the reader is referred to Nichols and Cerco's report on Puerto Rico (1983).

6.3 Marine Sand Mining

One alternative to mining beach sand and nearshore deposits is to identify suitable reserves for mining farther offshore. Areas where sand extraction causes minimal impact to the adjacent environment are channels and submarine canyons on the edge of some continental or insular shelf areas. These features act as sinks for the sand and are the terminal points for the sand transport cells (described in Section 4.1). Channels which have continued to receive sand over geological time have built up huge reservoirs of sand capable of sustaining most aggregate demand for extended periods. Nevertheless, care should be taken to avoid mining in proximity to the zone of active transport into the area for fear of accelerating up-drift erosion.

6.4 New Technologies

One result of increased concern over environmental degradation associated with marine mining activities has been a focus on the development of new technologies designed to ameliorate undesired impacts. One such technology, the Submarine Sand Recovery System (SSRS), was developed and tested in Hawaii. The novel feature of the SSRS is the use of a suction probe which burrows beneath surface layers to extract sand, thereby reducing sediment loads. Designed to be used in thick sand deposits, the basic system consists of a small barge or boat, a vacuum pump, a flexible hose connecting the pump and suction head and a submerged plastic pipeline to facilitate direct pumping of sand to shore (Casciano, 1976). Sand is pumped shoreward as a slurry into a settling basin.

The SSRS was tested off the coast of Hawaii in fifty to sixty feet of water at a distance of 300 feet from shore inside a fringing coral reef. It is instructive to compare two post-operations environmental assessments, one completed four months after mining activity ceased (Maragos, 1977) and a second approximately five years later (Maragos, 1982). Interestingly, some of the significant near-term impacts (destruction of benthic molluscs, localized damage to corals, sea urchins trapped in sand pits) appeared to have no long-term consequences. The sand craters which were originally six meters deep and filled with "fines" had all but disappeared as adjacent sands migrated to fill the conical pit. However, this sand migration caused the undermining of an adjacent coral reef. As a result, a ribbon of coral collapsed along the reef edge, measuring 1-3 meters wide for a distance extending 200 plus meters along the reef-sand deposit interface.

Maragos (1977) recommends that a buffer zone 100 meters in width be established between any proposed mining activity and adjacent coral reefs and should be proportionally widened if the mining exceeds 10,000 cubic yards or creates a crater deeper than seven meters. The Water Bay experience reported in Section 5.3 suggests that Maragos' recommendations are appropriate, except that sand mining near a beach area should take place outside the ten meter depth contour with a buffer zone of at least 200 meters from the nearest beach.

7. ATTEMPTS AT RESTORATION

7.1 Beach Nourishment

Beach nourishment has become an increasingly popular strategy to mitigate erosion impacts on beaches, increase recreational space, and compensate for other causes of beach loss. Nourishment involves placing sand on an eroding beach, taken generally from offshore areas using any one of several extractive technologies. This is a potentially attractive strategy, but there are complications. First, the source of the original erosion must be identified and arrested and the beach stabilized or else the new sand will erode with the old. Secondly, a degree of short term biological disruption is to be expected at both sites of extraction and deposition. Finally, the emplacement of new beach sand may create longer term turbidity and sedimentation problems from fines washing out as sediment stabilization takes place over time.

Matching textural and size characteristics between existing beach and mined sand will reduce the rate of erosion. Analytical techniques are now available to identify this information. New fill must be able to withstand both storm surge as well as the moderate wave action typical of the beach if the threat of erosion is to be reduced.

Walton, et. al. (1977) described a beach nourishment project on Carolina Beach, North Carolina. There 2.5 million cubic yards of fill were placed on an eroding beach, of which 1.2 million cubic yards (or forty-six percent) were lost in two years due to erosion. New fill was deposited and a groin built, but both measures proved ineffective as total losses surpassed fifty percent. Loss of the beach was attributed to the mining of the fines and their subsequent displacement seaward by wave action and the cessation of upbeach littoral drift from the creation of the Carolina Beach Inlet (a man-made cut completed in 1952).

Where erosion persists after new fill is deposited on the beach, vegetation techniques are occasionally employed for purposes of stabilization. Best results have occurred in areas where some vegetation already exists or has existed in the past (Davis, 1975).

Where significant littoral movement occurs without natural replenishment, construction of groins may be necessary to contain fill. This technique was successfully employed in Key West where fill placed on a rocky shore to create a 3,000 foot beach in 1960 was protected by four previosly installed rock groins. Erosion over a six year period was estimated to be only thirty-seven percent, attributed primarily to wind transport (Walton, et. al., 1977).

However, a word of caution about groins is appropriate. In the cases of Water Bay (St. Thomas, U.S. Virgin Islands), Vigie Beach (St. Lucia)--see Sections 5.2 and 5.3--and on numerous other occasions, hastily installed or badly sited groins have failed to accomplish their purpose (beach sand accretion or stabilization) and either further damaged the site or were themselves damaged or destroyed. The decision to use groins depends on the particular physical characteristics of the proposed replenishment or stabilization site. Groin construction which fails to account for local beach sand transport patterns and seasonal variations can result in major adverse modifications to adjacent beach areas. The construction of these structures should be recognized as a complex task requiring a sound environmental and engineering plan.

7.2 Dredge Pit Stabilization

There is little information relative to the success of restoration attempts of dredge pits. One technique which has been attempted is the construction and emplacement of artificial reefs at the bottom of the borrow pits. Artificial reefs were first defined as man-made or natural objects placed in selected areas of the marine environment to provide or improve rough bottom habitat for purposes of increased productivity (Parker, et. al., 1974). Since 1974 artificial reefs have been used to accomplish commercial and recreational fisheries enhancement and solid waste disposal. In the only known use of these structures to fill dredge pits, Penn (1983) utilized an assortment of materials (rubber tires, concrete, car bodies) in Laucala Bay, Fiji to fill old dredge sites and to facilitate the development of a benthic community. Based on preliminary findings, he noted that car bodies were particularly conducive to settlement due to their rough metallic edges. There is no evidence that this attempt effectively stabilized the dredge pit.

Important considerations in the use of this technique are the existence of toxic substances in the materials (gas, oil, lead, copper); the location and site stability (bottom type, current and wave action); and the availability of suitable materials.

As an alternative to the use of artificial substrate to stabilize bottom, there have been numerous attempts at transplanting both sea grasses and corals to disturbed areas, including old sand and coral mine sites.

Sea grasses have demonstrated a capacity to bind bottom sediments with their root systems, reduce wave erosion through the protective covering afforded by their blades, and increase rates of sedimentation by current retardation attributed to their leaf structure (Thayer, et.al., 1975). Because of these characteristics, marine grasses have been the object of numerous replanting efforts. Of the approximately 125 attempts at sea grass restoration, the majority have occurred in the Gulf of Mexico and Caribbean regions. Despite these attempts in a history that dates back to 1945, problems continue to exist. Penn (1983), in an attempt to restore dredge pits in Fiji with sea grasses, cited high death rates attributed to herbivorous fish and turtles and the cost as the major constraints. Lewis, et.al., (1981), in a comprehensive experiment testing various combinations of grass species and techniques, achieved only mixed success in his attempts to restore a ten hectare borrow pit created in the Florida Keys over thirty years ago. However, even in the most successful combinations of sea grasses and transplanting techniques, costs ranged from $27,000 to $86,000 per hectare, suggesting --if only in economic terms--the importance of impact assessment and sound mining practices designed to preserve habitat rather than requiring its later, more costly restoration.

7.3 Coral Restoration

Even less is known about re-introduction of corals in previously disturbed areas. Maragos (1974) attempted to transplant two common species of corals in Hawaii to a degraded bay hoping to provide a site of settlement for coral larvae and to restore the bay's fauna. Based on the experiment, he concluded coral transference may be an effective procedure for preserving and creating coral reefs, provided the original sources causing die-off were removed and allowance was made for the current and wave energy tolerances of coral species. In a related experiment, Maragos estimated that coral recovery may entail a 30-50 year time frame. Factors known to influence the period required for recovery are: extent of initial damage, condition of substrate availability of coral larvae, the role of grazers, competition from other species, and food availability (Pearson, 1981).

8. LESSONS LEARNED

8.1 Coral Mining

- Coral communities serve as one of the principal sources of sand for beaches and nearshore areas in tropical waters. Biological and physical weathering of these highly productive communities provide a major source of sand to nearby coasts, often surpassing the inputs from terrigeous sources.
- Coral reefs act as barriers for coastal beaches, communities and facilities, protecting them from the natural hazard of damaging storm-driven, high-energy ocean swell and waves. Removing or modifying some coral reefs can initiate or accelerate abnormal coastal erosion processes, resulting in economic loss and expensive restorative measures. Site examples from Indonesia, Sri Lanka and the Republic of Kiribati demonstrate the indirect economic costs associated with coral mining in terms of loss of shoreline land, declining coastal land values, and the increased need for costly remedial engineering work in affected coastal areas.
- Living corals are slow-growing colonial organisms which cannot sustain localized commercial exploition without their rapid depletion. There was no evidence in the three site examples described (based on the literature) that the exploited reefs have demonstrated any signs of recovery. For environmental planning purposes, these organisms should be treated as non-renewable resources. No effective exploitive management strategy has yet been developed, nor are restorative techniques sufficiently well known to permit significant commercial harvesting. Even non-commercial artisanal harvests of coral should be monitored closely, as extraction rates, although low, may still exceed natural re-generation.

8.2 Beach Sand Mining

- Adverse effects of excessive beach mining may be deferred for years before they become evident due to seasonal and other ephemeral factors affecting beach dynamics. In both the St. Lucia and Puerto Rico examples, large scale changes in beach dynamics were delayed several years. In the case of St. Lucia, a major tropical storm was contributory in accelerating the effects of chronic sand mining on Vigie Beach. In Puerto Rico, widespread erosion on Carolina Beach was not reported until several years after initiation of mining activities.

- Many small scale beach sand cells with few outside sources of sand renewal cannot support intensive extraction pressures. St. Lucia's Vigie Beach appears to be an excellent example of this beach type. Natural inputs could not compensate for extraction pressures, and sand had to be replaced finally through costly beach nourishment.
- Beach dunes play a critical role in shore protection; their removal or degradation could signify large scale economic loss associated with storm surges, waves and flooding. The three beaches described in Puerto Rico demonstrate that reduced size, height and stability of dunes resulting from mining activities increased natural hazard risk.
- Preservative and restorative responses to beach degradation are costly, often offer only temporary relief, and may themselves have adverse environmental impacts at both site of extraction and deposition. In St. Lucia the "ineffectiveness" of a patchwork strategy at Vigie Beach, involving experiments with gabion mattresses, rock groins and eventually beach nourishment, was demonstrated.
- Long term economic losses resulting from beach sand exploitation must be analyzed against shorter term economic gain--the balance may justify the development of alternative sources of aggregate. If the total costs associated with the mining of Vigie Beach could have been predicted, coupled with the long term aggregate needs of Castries, the development of nearby terrestrial pumice sand resources, as an alternative to beach sand, might have been selected when this option was first considered more than a decade ago.

8.3 Marine Sand Mining

- High turbidity and increased sedimentation associated with marine sand mining can result in severe degradation of benthic communities (marine grass beds and coral reefs), especially those requiring consistently good light penetration and non-turbid water. Surveys conducted in Water Bay (St. Thomas, U.S. Virgin Islands) after sand mining documented significant coral kill (ranging from 20 to 90 percent) directly related to proximity to the dredge sites.

- Mining too close to shore can affect coastal nearshore processes, resulting in major changes such as the loss of an adjacent beach, alteration of berm and coastal vegetation die-off. The Water Bay site history documents the loss of Sugar Bay Beach by its slumping into the adjacent dredge pit. Other changes included reduction in height of the back berm and die-off of exposed coastal vegetation.
- Failure to define the characteristics of the target materials for mining through pre-dredge boring at the site can result in the exposure of highly erodible substrates beneath sand deposits which may later act as chronic sources of turbidity. Exposed layers of mud directly underlying sand deposits mined in Water Bay created a source of chronic water turbidity. The continuing suspension of mudfines, clays and organic materials may have played a significant role in the observed coral die-off and prevention of recolonization of both the dredge pits and adjacent impacted areas.
- Sand mining often conflicts with other coastal uses and, if beaches and water quality are degraded, may result in economic losses. Water Bay provides an excellent example of resource use conflict which first became apparent during an initial hotel-sponsored dredging operation. That activity ultimately conflicted with the desire of resident and prospective hotel visitors to have access to undisturbed water quality at the beachfront, and when subsequent dredging activities were proposed for an adjacent area, opposition arose from the hoteliers who recognized the economic consequences (i.e., reduced occupancy) of indiscriminate or badly sited dredging operations and argued publically for environmental controls.
- Mining in shallow protected waters can leave bottom "borrow" pits as semi-permanent features which act as traps for fine sediments and become chronic sources of resuspended material. Some of the

traps identified in the Water Bay case study, originally dredged in the 1960's, still show little evidence of filling or of recolonization.

- Although restorative techniques exist, in general, they are expensive, technically demanding, and only partially serve their objectives. In the final analysis, careful planning and management of mining activities is far preferable to restoring degraded sites.

9. GUIDELINES

(1) Commercial mining of living coral reefs should be restricted and in most cases prohibited. Corals are slow growing organisms. Since effective management strategies have yet to be discovered, living reefs do not appear to be able to sustain extractive pressures. Their importance as productive marine systems, artisanal and commercial fishing sites, recreational attractions, and natural breakwaters seems to far outweigh the value derived from their direct exploitation for construction material or other consumptive uses. Zoning allowable uses for coral reef system "exploitation" is a desirable strategy, demarcating protected areas and sites and sectors for artisanal harvesting, fishing, diving and mining activities. Permits are useful but require performance and practice monitoring. An alternative to harvesting the living reef for meeting these local needs is the rubble lagoonal area and algal reef flats behind the reef crest. Caution is, however, required as this zone also serves as a wave energy absorption barrier, and excessive dead or live coral harvesting can have seriously damaging effects on adjacent shorelines. Mining of the rubble area and reef flats should be discouraged in areas adjacent to eroding shorelines and more vulnerable beaches.

(2) Precious corals, which grow much slower and deeper than most reef corals, require special management approaches as they come under pressure from commercial harvesting activity. Commercial tangle net dredging for precious corals damages both the substrate and immature specimens and should be gradually phased out in favor of more selective harvesting methods which should be encouraged. Extraction activity should not exploit more than four percent of known bed area per annum. Weight quotas and size limits should be applied and a permitting systems established for commercial uses.

(3) The mining of beach sands should generally be discouraged. When the scarcity of accessible alternative sand resources dictates the need for beach and dune mining, extraction should proceed slowly and be carefully monitored and regulated, employing such management

tools as periodic beach profiling and rotation of sites, licensing of commercial users, and quantity quotas as needed, based on site-specific sand budgets. Preferred sites include accreting (growing) beaches, multiple dune systems, or other stable reservoir areas known to be the terminus of sand circulation cells or sinks. When sand mining is terminated, beach berm and dune sites (especially on windward shorelines) should be replanted with appropriate stabilizing vegetation to prevent further sand loss due to wind erosion.

(4) The mining or dredging of offshore sea bed sand and aggregate is the preferred alternative to beach and dune mining, providing adequate site selection strategies, antecedent impact assessments, and controls are employed to prevent or minimize potential adverse effects on coral reefs and coastal areas. Waters should be sufficiently deep and open to currents in order to speed the dispersion of suspended sediments and leveling of dredge sites upon completion of operations through natural movement of bottom sediments. Preferred marine sand deposits are stable reserves at the ends of the submarine sand circulation pattern, such as near the heads of submarine canyons where sands are known to be drifting deeper and are no longer a part of the local circulating sand budget. Windward facing bays and beaches are more unstable than leeward systems, and wind and wave approach angles can be important factors in chosing a sand mining site.

(5) Mining activities for sand and aggregate should be preceded by a country-wide, systematic resource inventory to provide a rational strategy for selecting appropriate sites and extraction technologies and to link the mining project with local supply and demand options. The inventory should include:

- identification of existing, high quality sand "reservoirs";
- identification and classification of marine sediments scheduled for removal by dredging as waste material or spoil;
- characterization of the deposits (depth, sediment sizes and proportions, extent of coverage);

- characterization of the local environment of each site to include identification of the existing sources and sinks of the particular sediment deposit (sand, aggregate, silt), relevant processes linking the two (current regime and transport units), marine communities potentially affected by mining activities, potential for reintroduction of toxic substances, and storage options;
- economic and environmental assessment of exploiting alternatives to coastal/marine sources (pumice, quarry fines, river sand).

(6) Marine sand mining sites, except those in major harbors and ship channels, should be located as far as possible from living coral reefs and sandy beaches. A minimum buffer zone of 100 meters between the dredge borrow pit edge and the nearest coral reef is recommended (more if the mining exceeds 10,000 cubic yards or the pit is deeper than seven meters). Any nearshore marine mining adjacent to a beach should take place outside the ten meter depth contour and have a minimum 200 meter buffer zone separating the dredging site and the beach's edge at low tide. Special monitoring of the current borne plume of fine sediments generated by any marine dredging is important if there are sensitive marine habitats (e.g., coral reefs) in the area. The plume shape and axis can change dramatically due to ephemeral wind, wave, and current factors and can necessitate prompt reduction in plume densities and dimensions by reduced extraction rates or even temporary shut-down.

(7) Marine mining site selection, especially for sand and aggregate, should be based on a thorough analysis of the available environmental information and relevant socio-economic data necessary for assessing alternative locational, dimensional and technological options. In the absence of an antecedent, comprehensive sand resource inventory (Guideline 5) there is a need to elicit coastal current data from local fishermen, divers and others who traditionally use the area, also encouraging their participation in future "monitoring" strategies regarding impacts. Final site selection should consider issues such as biological productivity,

alternative present and future uses, and shoreline spoil disposal and emplacement problems.

(8) Once site selection has been completed, a more comprehensive baseline study and project management plan for the specific location is desirable in order to establish detailed operational guidelines for the contractor. An understanding of the precise physical, biological and biochemical characteristics of a site and environmental quality tolerances of specific biotic communities (which may have been subjected to prior stress) are required if monitoring activities with clearly identified standards are to be effective.

(9) A monitoring program should be developed adhering to pre-determined environmental quality standards. Monitoring parameters should include: environmental factors most likely to be affected by mining activities and tolerance ranges of potentially affected biotic communities to environmental disruptions. Once the parameters are identified, standards should be set using the baseline and other pre-existing information. Standards, if exceeded during operations, would warrant a modification or temporary cessation of activities. An assessment of available extraction and control options should be completed to determine the most appropriate system for site conditions. Whenever possible, full scale mining operations for large projects should be preceded by a pilot mining phase in order to test impact assessment, monitoring procedures, and control strategies.

(10) Follow-up (post-audit) environmental assessments should be completed after any temporary or final cessation of mining operations. Follow-up assessments are required to confirm volumes harvested and to guage the degree of impact on and recovery of the site and adjacent habitats after cessation of activities. They also represent a means to fill a critical data gap in the understanding of specific types of mining activities carried out in local waters, essential to the development of improved, practical standards and more cost efficient strategies for future dredging or mining operations appropriate to the area.

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Case Study Four

COASTAL FISHERIES MANAGEMENT
LESSONS LEARNED FROM THE CARIBBEAN

Random DuBois

SUMMARY

This study demonstrates the need for more comprehensive approaches to the management of coastal fish stocks. Caribbean fisheries for spiny lobster and conch, two highly-valued species occurring throughout the region and known to be under intense exploitive pressure, were selected for analysis. The approach taken documents (1) the history of the two fisheries leading up to present exploitation patterns, both locally and regionally; (2) the importance of conch and lobster resources to local economies; (3) the socio-economic effects resulting from their apparent over-exploitation; and (4) the major constraints on their effective management. Information was derived from existing literature, a questionnaire distributed to fishery officers throughout the region, and selected interviews and site visits to the U.S. Virgin Islands, Turks and Caicos, Antigua, and Belize which confirm the intense harvesting of both conch and lobster stocks, with possible over-exploitation evident in some cases. The structure and effectiveness of existing fisheries management programs are compared and analyzed.

Study findings suggest that:

(1) Long term sustainable utilization of coastal fish stocks requires comprehensive fishery management programs with well defined, practical objectives and financial, human, and technical resources appropriate to the task.

(2) Data collection and enforcement aspects of management program implementation can be enhanced through educational outreach activities and by restricting the number of production and/or processing centers in order to facilitate the monitoring of regulatory compliance.

(3) Continuing re-evaluation of objectives and criteria for fisheries management programs is essential and requires the systematic collection and interpretation of catch and effort data necessary for monitoring the status of fish stocks and harvesting practices.

(4) Management programs must be sufficiently flexible to accommodate external impacts of a local, national and regional character which threaten fish stocks, their habitat and the fishery itself.

1. INTRODUCTION

The subject for the present case study is the management of the harvest of <u>nearshore</u> marine commercial fisheries. Coastal fishing may well represent the single most important extractive use of the oceans. Levy (1976) estimated that over 90 percent of the world's fish catch is derived from the continental shelf and from coastal upwelling areas. In terms of employment in the LDC's alone, there are an estimated 12 million fulltime fishermen and perhaps twice that amount fishing on a part-time basis (Sfier-Younis, 1980).

The economic significance of marine fisheries varies widely among developing areas, however. While Valencia (1978) has reported an average of 2.7 percent of GNP for South China Sea countries; it is less than 1 percent in the U.S. Virgin Islands, about 2 percent in Antigua and Belize, 6 percent in in St. Lucia, 8 percent in Grenada and 15 percent in Turks and Caicos, where it is a very important source of export generated revenue (see Section 4). In some developing countries, especially islands, traditional village-based subsistance fishing activities or "artisanal fisheries", are extremely important to the local, non-market economy and nutritionally and socially significant. Artisanal fisheries are, however, often placed at risk by attempts at expanded commercial market oriented exploitation of fisheries resources. Therefore, the successful development and management of fishery resources requires an integrated approach which extends beyond the immediate coastal waters to encompass both the coastal zone proper and the adjacent ocean. This approach must attempt to reconcile such potentially competitive factors as the biological and ecological demands of a fish population, the socioeconomic demands for the stock's exploitation, and other human activities (for example, sand mining) which impose environmental demands on the habitat and may endanger the stock's current status. Reconciliation of these three types of demands can be facilitated through the establishment of a comprehensive management framework which documents and monitors the status of fish stocks and guides extractive uses and relevant coastal resource development activities with the goal of optimal utilization of the species. It is not an easy task, but an analysis of successes and failures of previous approaches to the management of fish stocks provides lessons and guidelines to serve as a basis for the design of future management strategies.

The wider Caribbean region was chosen as the area most suitable for the case study. This was based partially on the author's familiarity with the region and the presumed availability of a relatively large data base needed to support the study.

Once the region was selected, the choice of fish stocks was relatively easy. Basically the species had to occur within proximity of the shore, be well described in the scientific literature, and have been both the subject of documentable intense exploitative pressures and management efforts. Based on these criteria the two species selected were the spiny lobster (*Panulirus argus*) and the queen conch (*Strombus gigas*).

The initial approach involved a literature review from which to develop the proper context for the study and a mailed survey questionnaire circulated to the region's fishery officers soliciting their views on relevant fishery management issues and potential solutions. Sites were then selected primarily for their illustrative value for the purposes of the case study. These were: Antigua and Belize -- both independent countries, Turks and Caicos Islands -- a British Crown Colony, and the Virgin Islands -- a U.S. territory (Figure 1).

Some unanticipated difficulties were encountered. First, the desired documentation of trends in stock status proved to be elusive due to data scarcity, specifically the absence of significantly long time series of catch per unit effort (CPUE) and length/weight data. As a result, the study is based largely on total catch figures, extracted from export figures elicited by or derived from the interviews and survey questionnaire, as indicators of stock well-being. A second problem concerned the lack of supporting documentation for such related management issues as the effects of habitat degradation on fish stocks. Finally, the depth and quality of the data varied significantly between sites. In cases where major data gaps occurred, the author attempted to integrate examples drawn from the literature into the case study.

The author wishes to acknowledge the many individuals who contri-

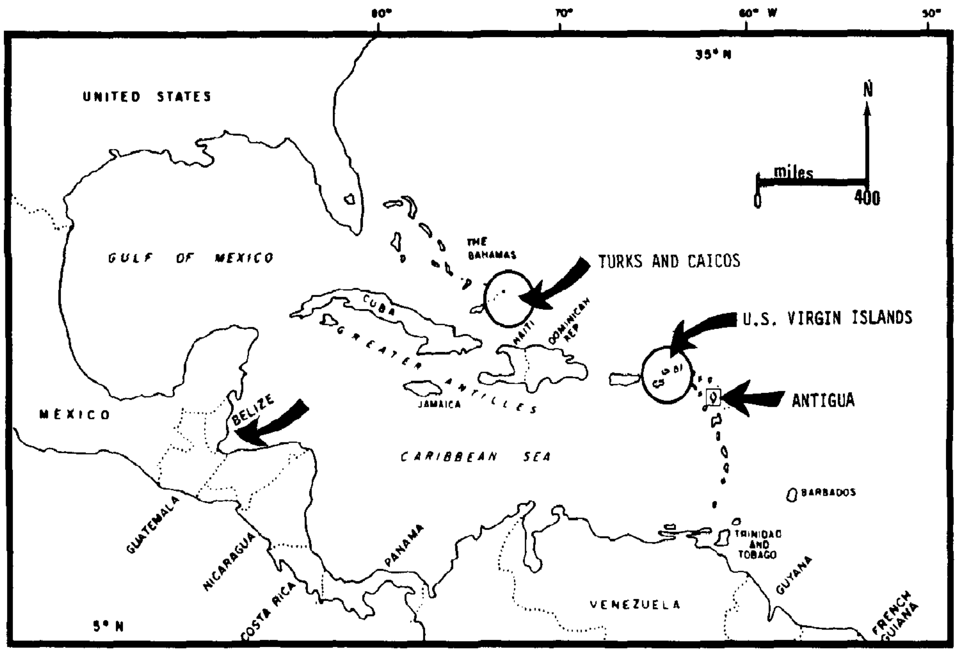


Figure 1. Location map of fisheries case study sites: Belize, Turks and Caicos, U.S. Virgin Islands, and Antigua.

buted to this endeavor. Those persons who provided special assistance were: Mr. Winston Miller and Ms. Janet Gibson (Belize Fisheries Management Unit); Mr. Christie Hall (Turks and Caicos Fisheries Office); Dr. Scott Siddall (State University of New York at Stony Brook); Dr. Arthur Dammann (of St. John, U.S. Virgin Islands, and formerly chief scientist to the Caribbean Fisheries Management Council); Dr. Jerome McElroy (St. Mary's College of Notre Dame and formerly senior economist with the Virgin Islands Department of Commerce); Dr. Melvin Goodwin (Environmental Research Projects, Inc., Rhode Island); and Ms. Judith Towle (Island Resources Foundation, St. Thomas, U.S. Virgin Islands).

2. BASIC PRINCIPLES

2.1 Management Objectives

A management program must have clear objectives. These objectives, based on biological, social and economic considerations, are principally focused on regulating yields of particular species. The variations in desirable yield may be significant depending on the choice of objective and the respective weight given the underlying variables. For our purposes there are three objectives commonly considered desirable in fisheries management: maximum sustainable yield (MSY); maximum economic yield (MEY); and optimum yield (OY).

Gulland (1977) has defined MSY as the greatest yield volume that a stock can produce year after year. It can be most easily conceptualized in terms of a total product curve used in traditional economic analysis (Figure 2). In this example of a high-value species, fish yield increases with increasing effort until point E, or MSY, is reached. Beyond this point over-fishing occurs when added effort results in declining total product or yield. This is indicated by the negative marginal product curve (added output resulting from each added unit of effort).

If the desired management objective is to maximize the economic returns, defined as the greatest value of catch minus costs of capture, or MEY, total product yield would be reduced to the point of maximization of the marginal product curve (E_1).

In addition to MSY and MEY, a third objective, optimum yield (OY), has found increasingly common use in the U.S. Optimum yield attempts to incorporate both social and cultural considerations with their biological and economic counterparts characteristic of the previous models so as to obtain an "optimal" yield of the resource. Optimum yield is generally set below or equal to MSY and is consequently considered sustainable (OSY).

2.2 Management Tools

Once agreement on a management objective has been reached, its subsequent achievement depends on the efficacy of tools applied toward its implementation. The most common tools employed are (Armstrong and Ryner, 1978):

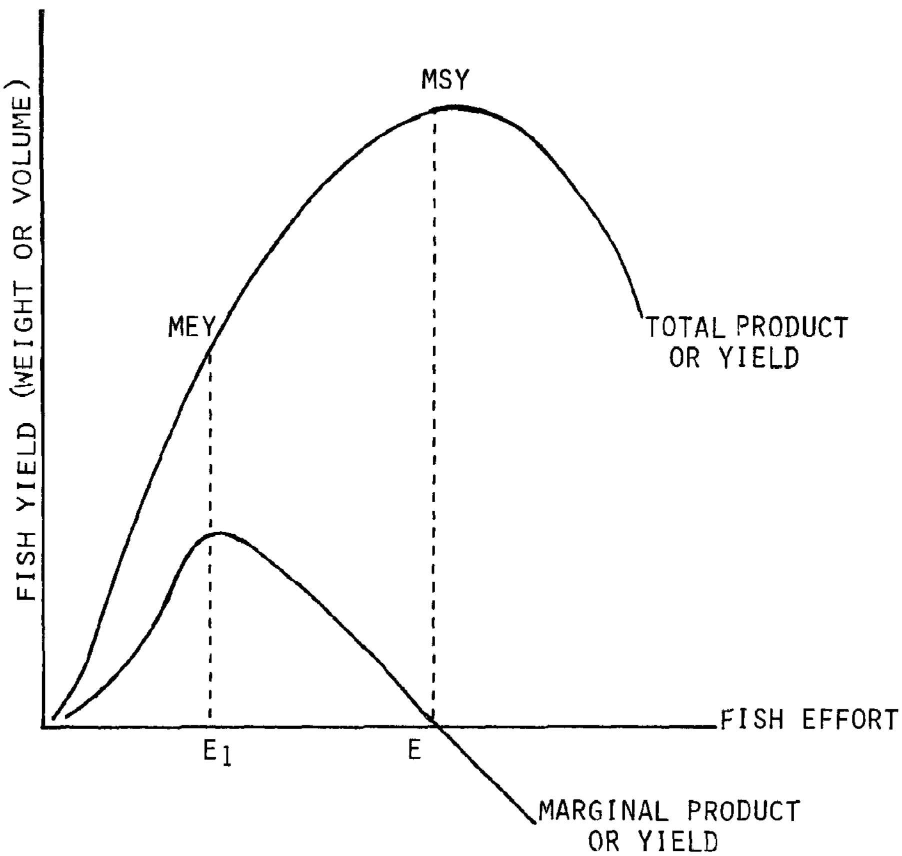


Figure 2. Total product curve for a hypothetical high-value fish stock. (Source: adapted from Knight, 1977.)

(1) Limited access. Limitation of the fishery to a defined number of production units (boats, fishermen, gear type and number).

(2) Closed areas. Prohibition of fishing in spawning or other areas often considered critical to one or more stages of a species' lifecycle.

(3) Closed season. Closure of a fishery during specified periods of the year, usually correlated with peak breeding and/or spawning periods.

(4) Selective harvest. Restrictions on harvesting individuals of a population in critical life cycle stages (moulting, carrying eggs).

(5) Size and/or weight restrictions. Measures to protect premature or maintain sustainable levels of harvest.

(6) Gear restrictions. Limitations on gear types to reduce efficiency of harvest.

(7) Quotas. Enforcing individual and/or total catch ceilings.

2.3 Management Constraints

The degree of effectiveness of these management tools is based on several assumptions.

First, both the monitoring of effectiveness and the measurement of achievement of management objective presumes on-going data collection. At a minimum, data should include catch and effort statistics for each species managed. Total annual catch compilation does not make allowance for yearly variations in effort, precluding calculation of effort-yield curves.

This leads to the second assumption, that reported data are reliable estimates of actual fishing activity. For example, one report estimates that less than 10 percent of traditional artisanal fish catch is reported in the Caribbean region (Reintjes, 1979). Failure to account for this added exploitive pressure on fish stocks can render most management efforts ineffective.

Third, many of these tools require specific data characterizing a fish stock's population dynamics. In most developed countries this presents few problems where there are long time-series data sets for coastal species inhabiting tropical waters.

Fourth, it must be recognized that these tools are tailored specifically for the biological management of the fish stock. They assume that other factors which might affect the "well-being" of target species are absent. No account is made for such real world externalities as pollution, illegal foreign fishing, or loss of distant parental stocks serving to replenish local populations. While these considerations may be ignored by the theoretician, they must be incorporated into the manager's program if it is to be a success.

The degree to which these tools prove effective will vary in direct proportion to the extent they are applied and accepted by the users. This may be the most complex element in the management process. Enforcement and acceptance of rules of conduct (in our case, fishery regulations) involve a host of variables which include resource user perceptions, education, economic need, and governmental enforcement capabilities.

Finally, while limited money and manpower may be important constraints, the real key to effective fisheries management programs lies in their design, appropriateness, and implementation.

3. HISTORY

3.1 The Region

The Caribbean basin covers an area of approximately 2.4 million km^2. Within the region there are 31 political entities which include independent and associated states, territories, and colonies, commonwealths and departments. States bordering the wider Caribbean range in type and size from small islands measuring 98 km^2 (Montserrat) to continental nations as large as 9.7 million km^2 (United States).

The region's political and physical variety is matched by a similar diversity in its economic, cultural and linguistic characteristics. Few areas of the world can demonstrate a disparity in economic well-being as extreme as that which exists between the United States and Haiti. In traveling through the region, one may overhear conversations in French, Patois, English, Dutch, and Spanish between descendents from West African slaves, English pirates, Spanish conquistadores, French colonists, and East and West Indians. This pronounced cultural and ethnic diversity concentrated in a relatively small area has stimulated development of resource utilization patterns which have potential applications to larger and more complex economic systems.

3.2 The Waters

Apart from the large continental shelf areas and localized zones of upwelling, the Caribbean region's tropical waters are characterized by low productivity in comparison to temperate waters. This is largely attributed to the presence of a permanent thermocline inhibiting nutrient exchange between water layers and the absence of large land bodies and shelf areas which serve as sources of nutrients and nutrient traps respectively (Sverdrup et al., 1966). Despite these existing conditions, small insular shelf areas may be highly productive supporting such ecologically diverse communities as coral reefs and marine sea grass beds. These areas also provide sources of habitat for a diverse assemblage of fish species many of which represent a means of employment and income to the region's many fishermen. Two species in recent years have grown in market value to become the region's most economically important fisheries exports and are the subjects of this case study.

3.3 The Resources

The two species chosen for this case study are the Caribbean spiny lobster (*Panulirus argus*) and the queen conch (*Strombus gigas*) (Figures 3 and 4). The continued high demand for these two species in both regional and extraregional markets has resulted in widespread over-fishing of stocks and, in a few instances, the development of successful management programs.

3.3.1 Caribbean spiny lobster

The spiny lobster industry began to develop at the end of World War II. Up until that period demand in the United States was low and satisfied by production from Florida. In the Caribbean, lobster was mostly caught in West Indian fish pots as incidental "by-catch" and often used as bait for fish. As America's taste for shellfish widened and demand began to increase, an export market developed (Table 1). Today, lobster imports from the Caribbean represent a sizeable component of total lobster imports into the United States, ranging between 12 and 26 thousand metric tons in the period 1960-1980 (Figure 5).

During the same period, however, an interregional trade pattern was also developing for lobster. Demand in the more affluent islands, fueled by foreign government assistance and rapidly growing tourist industries (Puerto Rico, U.S. Virgin Islands, French and Dutch West Indies), quickly exceeded local supply, resulting in new alternative markets for spiny lobster. It has been the rapid development of these new markets, both in the U.S. and Caribbean, coupled with rapidly increasing value of lobster (Figure 6), that has provided the economic incentives resulting in the region's presently heavily exploited stocks.

3.3.2 Queen conch

Conch, in contrast to lobster, has been a traditional source of protein throughout the Caribbean. Its use for food has been most common in the coralline island systems characterized by large shelf areas and limited

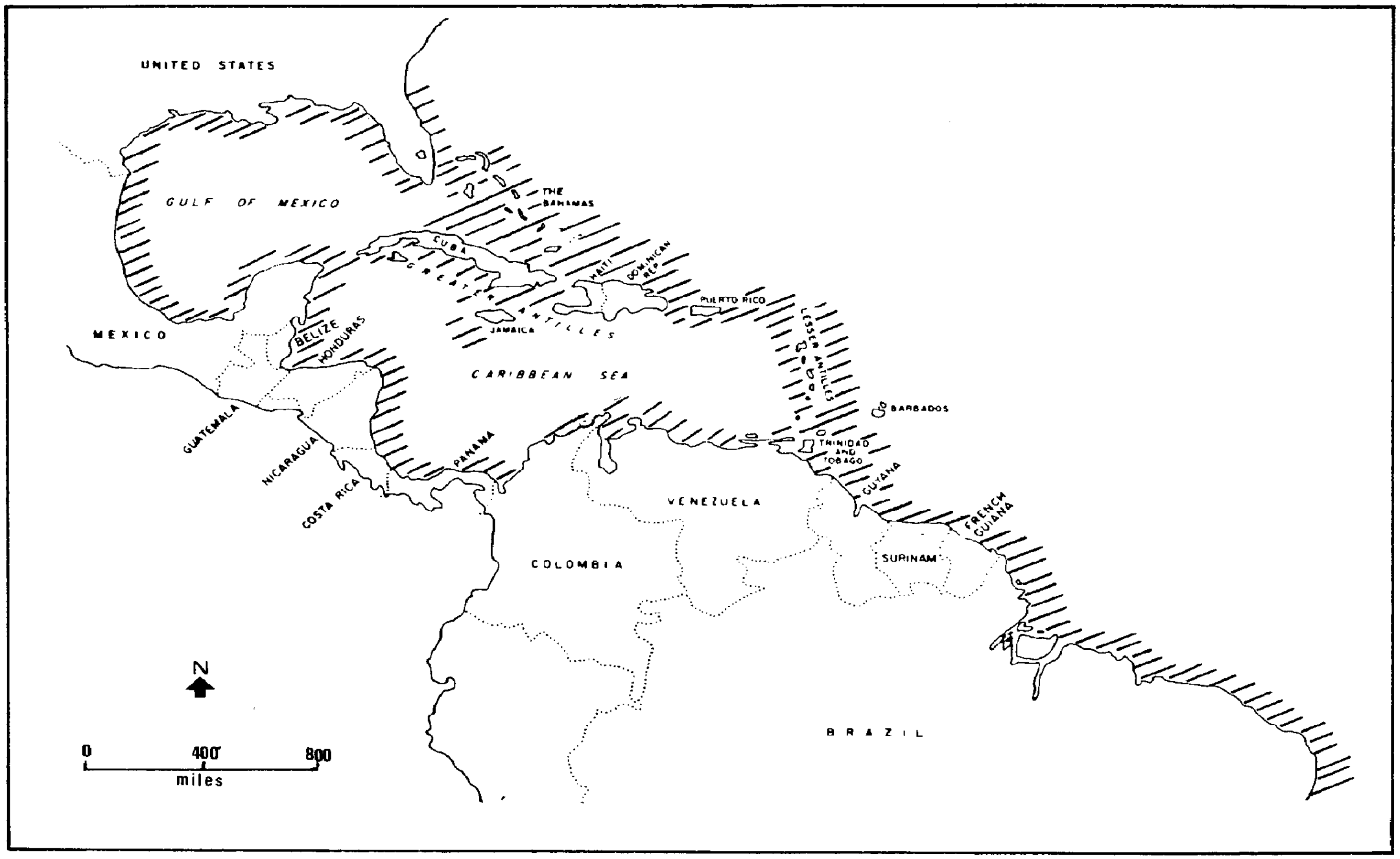


Figure 3. The area of distribution for Caribbean spiny lobster. (Source: Fischer, 1978.)

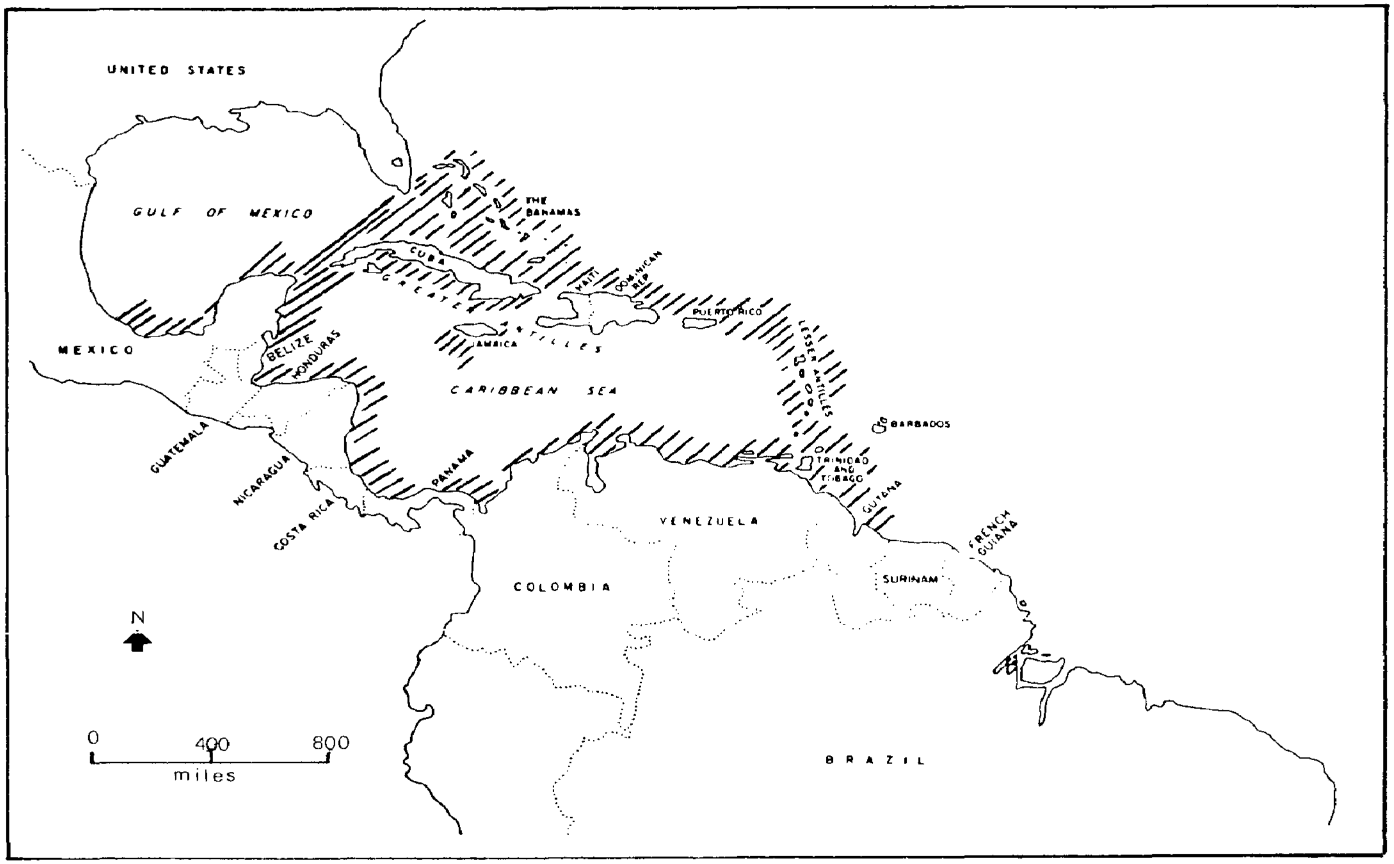


Figure 4. The area of distribution for queen conch. (Source: Fischer, 1978.)

Table 1. U.S. imports of spiny lobster by country, 1960-1980 in metric tons (converted to live weight).[a]

Country	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970
Bahamas	2,050	2,300	1,830	1,086	1,150	1,350	760	750	1,010	960	1,090
Belize	550	390	400	466	400	470	480	310	600	610	370
Bermuda	0	3	0	0	0	0	0	0	1	0	1
Brazil	3,240	4,910	6,390	5,400	3,930	3,660	3,370	2,810	4,780	8,030	8,130
Cayman Is.	c	c	c	c	c	c	c	c	c	c	c
Colombia	0	10	0	0	10	40	40	10	70	40	100
Costa Rica	560	980	150	512	220	500	100	160	150	300	400
Cuba	3,900	1,960	130	0	0	0	0	0	0	0	0
Dom. Rep.	0	5	2	2	30	40	70	40	120	90	50
Fr. Guiana	0	0	0	0	0	0	0	0	80	0	80
Fr. W. Indies	0	0	10	0	0	1	0	0	0	40	40
Guatemala	0	10	20	14	40	60	20	10	10	5	10
Guyana	0	4	0	0	0	0	4	0	0	120	0
Haiti	80	100	100	115	170	330	290	330	410	430	300
Honduras	20	60	250	57	180	120	110	160	130	200	1,500
Jamaica	100	90	110	102	110	160	200	150	330	320	420
LWI[b]	40	4	10	2	1	0	50	40	20	10	10
Mexico	1,500	2,010	1,960	1,470	2,350	2,210	3,060	2,130	2,680	2,770	2,640
N. Antilles	0	5	70	56	0	0	0	0	0	0	0
Nicaragua	20	120	420	724	360	660	430	520	440	480	470
Panama	10	220	80	137	1	170	80	10	50	100	320
Surinam	0	20	0	0	0	0	0	0	0	10	30
Trin./Tobago	0	0	1	0	0	20	10	10	0	10	20
Turks/Caicos	c	c	c	c	c	c	c	c	c	c	c
Venezuela	0	0	30	30	3	70	20	20	90	180	110
Total	12,070	13,201	11,963	10,173	8,955	9,861	9,064	7,460	10,921	14,705	16,091

Table 1. Continued.

Country	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980
Bahamas	1,420	1,940	1,680	1,255	1,204	1,827	1,324	745	1,290	1,763
Belize	540	510	410	415	262	281	338	283	456	446
Bermuda	0	0	0	0	0	0	0	77	0	0
Brazil	7,030	8,300	8,070	8,424	7,138	7,069	7,200	9,050	8,306	7,328
Cayman Is.	c	c	c	c	c	175	21	58	0	58
Colombia	110	320	70	163	315	122	90	49	35	0
Costa Rica	80	100	50	223	229	577	285	342	203	10
Cuba	0	0	0	0	0	0	0	0	0	0
Dom. Rep.	80	70	100	11	70	90	137	175	261	37
Fr. Guiana	0	0	0	0	0	0	0	0	0	0
F. W. Indies	70	0	0	0	0	0	0	0	0	0
Guatemala	20	20	40	10	0	0	0	0	0	69
Guyana	0	0	0	0	0	0	0	55	0	0
Haiti	300	340	210	235	253	334	193	398	355	315
Honduras	800	400	360	999	2,097	2,504	2,241	2,373	3,497	2,581
Jamaica	780	770	420	336	439	68	0	0	0	0
LWI[b]	50	100	90	59	82	144	548	253	84	27
Mexico	3,170	2,810	2,910	2,935	3,113	1,144	2,920	2,151	2,477	6,527
N. Antilles	4	0	0	0	0	0	0	0	0	0
Nicaragua	360	540	760	1,336	2,456	2,973	1,137	3,759	3,255	4,916
Panama	50	150	40	57	78	341	400	158	204	1,859
Surinam	0	0	0	0	0	0	0	0	0	0
Trin./Tobago	80	20	20	0	50	68	0	0	0	0
Turks/Caicos	c	c	c	c	0	233	423	389	477	806
Venezuela	70	20	80	12	0	0	0	0	0	0
Total	15,014	16,400	15,310	16,470	17,846	17,900	17,267	20,315	20,900	25,878

Source: Bureau of the Census, U.S. Department of Commerce. U.S. Imports for Consumption and General Imports; Streeter and Weidner, 1976.

[a]Conversion factors used: tails to live weight: 1:3; canned to live weight: 1:4.63; unspecified to live weight: 1:3.

[b]Leeward and Windward Islands.

[c]Not available.

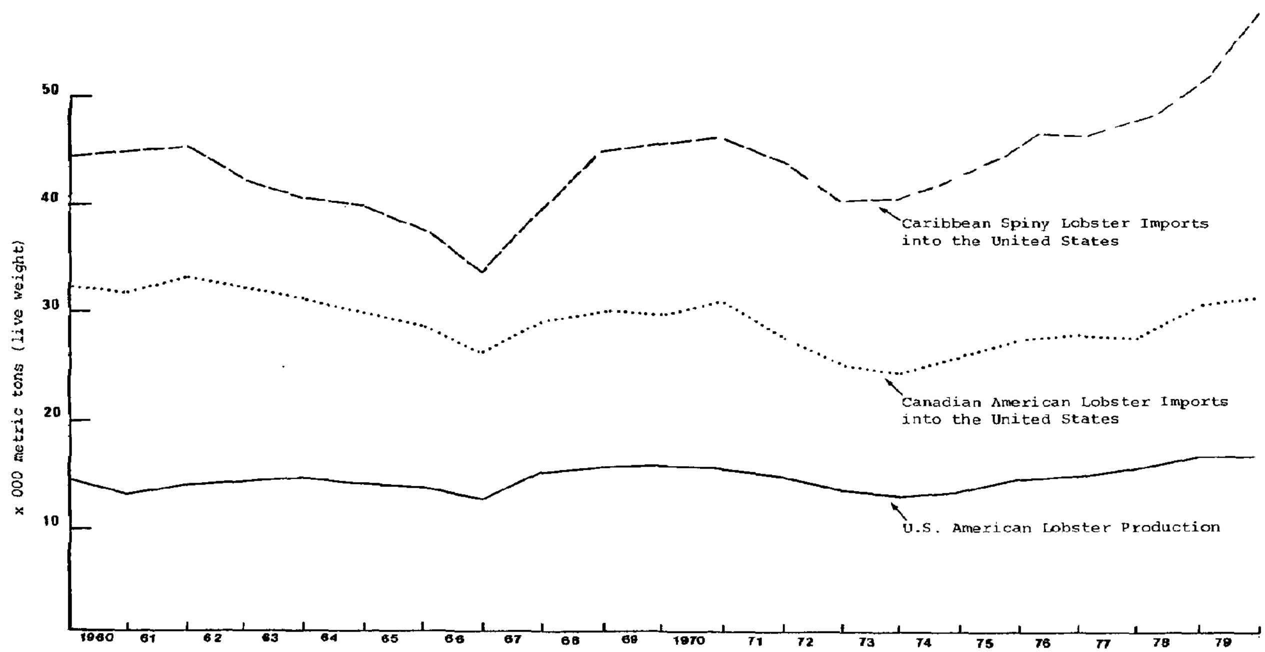


Figure 5. Cumulative totals and relative values of U.S. production and U.S. imports of Canadian American and Caribbean spiny lobster, in metric tons. (Source: U.S. Dept. of Commerce, 1981; Streeter and Weidner, 1976.)

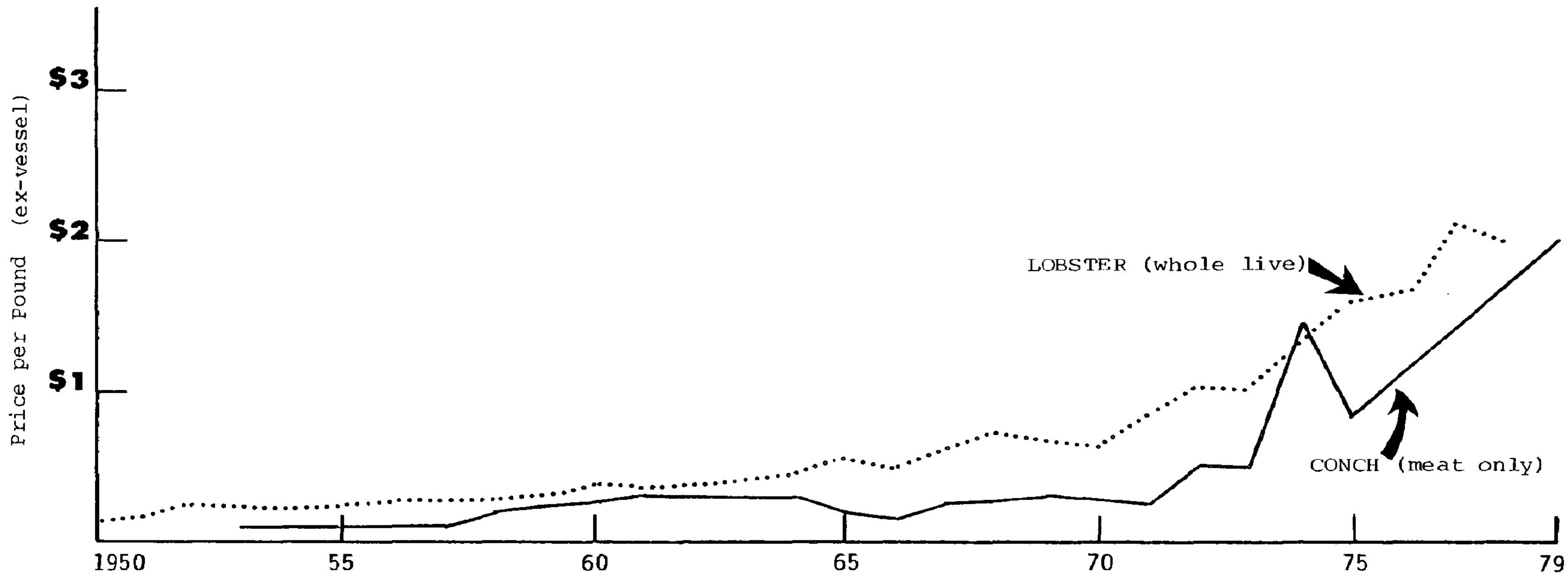


Figure 6. Price per pound of conch and lobster in Florida (1950-1979). (Source: Stevely and Warner, 1978; Labisky et al., 1980.)

sources of protein (Bahamas, Turks and Caicos, the Grenadines). Conch, unlike lobster, has also been a traditional intraregional trade commodity, often being exported in exchange for fruits and vegetables from neighboring islands. Demand for conch in the U.S. market began to climb in the early 1970's (Table 2). This has been attributed to three factors: increased restrictions on harvesting Florida's rapidly depleting stocks, a growing tourist industry in south Florida desiring to consume local seafood, and increasing Latin and West Indian populations in the state (most notably Cubans) with a tradition for eating the product (Stevely and Warner, 1978). As demand has increased in the United States and elsewhere in the region, so has the value of the product (Figure 6). The result is non-sustainable exploitation in many areas of the Caribbean similar to that for the lobster.

3.4 Regional Exploitation Patterns

Due to the region's long and varied history of political affiliations with several developed continental countries, many of the islands receive external subsidies and benefits from metropolitan capital and markets which fuel their development. Such examples include the U.S. Virgin Islands, the U.S. Commonwealth of Puerto Rico, the French Departments of Guadeloupe and Martinique, and the various islands which comprise the Netherlands Antilles. In still other cases, such as Barbados, a long and productive colonial legacy has provided the island with both expertise and economic links that continued after political ties with the United Kingdom were no longer deemed desirable or necessary.

As these islands became more developed, increased pressures were brought to bear on resident fish stocks. The sources of these pressures included the increased affluence of the local population, a growing cosmopolitan resident community, increased tourism and the development of alternative export markets for selected fish species. To meet demand, local catches, where they continued to exist, were supplemented by imports of conch and lobster from neighboring, less economically developed islands or occasionally from large mainland exporting markets. Barbados is one example of an increasingly cosmopolitan community where tourism

Table 2. Conch imported into the U.S. through Miami during the period 1970-1982 in metric tons.

Place of Origin	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982
Belize	145.7	265.0	382.9	245.1	376.7	330.5	222.5	159.9	135.8	147.8	87.7	173.6	69.1
Colombia	0	0	39.8	107.7	122.5	50.3	13.5	11.2	62.3	2.5	0	0	23.3
Dominican Republic	0	0	0.5	24.4	10.1	0	2.1	0	0	6.4	0	79.5	33.9
Haiti	0	0	2.2	4.1	0	0.2	0.2	14.9	58.3	82.8	80.1	160.1	38.0
Honduras	58.0	32.4	88.2	83.4	5.7	36.3	57.7	3.7	21.4	0	7.5	7.2	18.4
Jamaica	0	0	1.5	4.1	28.5	40.7	0.8	0	0	0	0	0	0
Mexico	0.2	0	8.6	2.2	0	11.7	3.2	1.8	1.5	0	4.5	0	0
Turks and Caicos	2.0	2.3	0	0	0	65.9	150.9	221.7	262.8	141.5	256.8	256.3	179.8
West Indies	0	0	1.2	22.1	3.9	7.2	2.2	0	0	0	0	.2	
Other[a]	8.4	0.8	2.7	1.8	2.0	7.8	14.8	2.3	13.2	2.2	5.2	32.7	13.9
Total	214.3	300.5	527.6	494.9	549.4	550.6	467.9	415.5	555.3	383.2	436.9	704.6	376.4

Source: National Marine Fisheries Service, Fisheries Development Analysis Branch, New Orleans, Lousiana. Taken from Brownell and Stevely, 1981.

Note: Approximately 27,000-30,000 kg of queen conch are imported to the United States each year directly through New York.

[a]Bahamas, Cayman Islands, Costa Rica, Guatemala, Nicaragua, Panama and Venezuela.

growth created a growing demand for imports which nearby Eastern Caribbean islands could not supply in the face of rising local demand (Table 3). In several islands, native stocks became so depleted that local consumption had to be met largely by imports. This was the situation in the U.S. Virgin Islands (see Section 4.1) and in St. Maarten (Netherlands Antilles) following the development of tourism in the 1960's (van Buurt, personal communication).

Table 3. Barbados imports of conch and lobster from the Eastern Caribbean for the period 1971-1981 (lb x 000).[1]

	1971	72	73	74	75	76	77	78	79	80	81
St. Lucia	2.1	.1	0	0	0	1.0	0	0	0	0	0
Grenada	0	0	0	14.6	1.8	0	0	2.0	0	0	0
St. Vincent	0	0	0	2.9	1.4	15.4	7.0	3.2	.9	0	1.4
Antigua	0	0	0	0	.8	0	0	0	0	0	0
St. Kitts/ Nevis	0	0	0	0	0	0	0	.5	1.9	0	0
TOTAL	2.1	.1	0	17.5	4.0	16.4	7.0	5.7	2.8	0	1.4

Source: Barbados Govt. Statistical Services, 1981.
[1]Data are summed for fresh, chilled, and frozen categories.

The regional trade patterns which have evolved for conch and lobster over the past 30-year period are depicted in Figure 7. These patterns identify both the region's present exporters and those areas where stock depletion and/or situations where demand has exceeded supply have forced countries to become importers of these shellfish. More importantly, when interpreted together with the previously cited literature, these patterns support a growing concern that over-fishing of conch and lobster may be rapidly shifting from being a local problem to one of regional proportions.

3.5 Management Responses

At the local level the response to over-fishing and depletion of fish

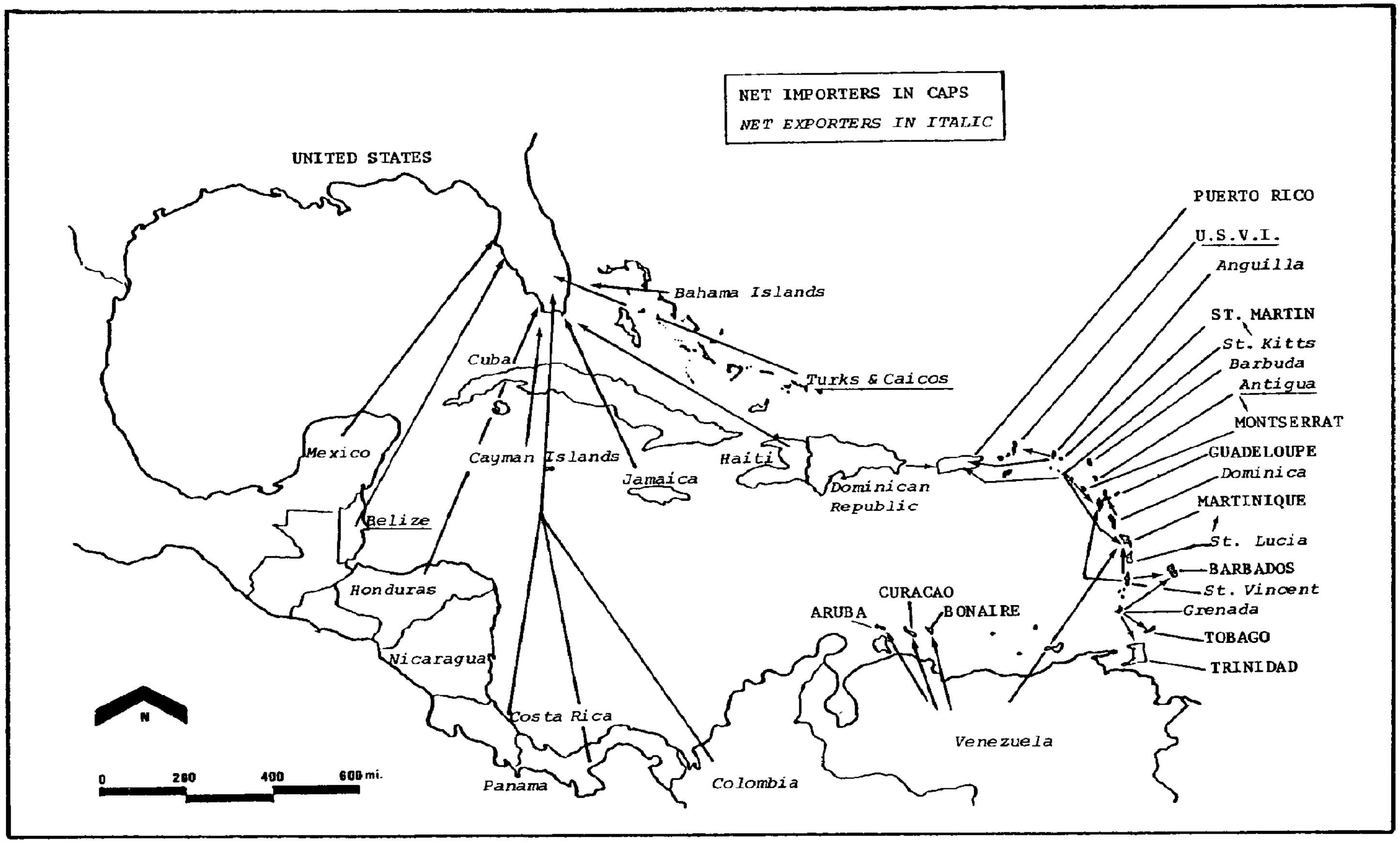


Figure 7. Trade patterns for conch and/or spiny lobster between countries in the wider Caribbean for the period 1981 to 1983 (**with case study sites underlined**). (Source: Brownell and Stevely, 1981; Island Resources Foundation, 1983.)

stocks has been the development and implementation of management regulations. Results from the survey questionnaire initiated for this study (and other sources) indicate lobster regulations are both geographically more widespread and more restrictive than those for conch (Table 4). The development of lobster regulations also appears to have preceded their conch counterparts by at least a decade (the Bahamas is the only known country to have established a conch management program prior to 1970). In both cases regulations were implemented subsequent to the development of the fisheries and in many countries only after stocks began to demonstrate indications of over-fishing.

Despite the presence of regulations the management of conch and lobster stocks, with few notable exceptions, has proven to be largely ineffective. This would indicate that regulation alone is insufficient to guarantee a stock's adequate management, supporting a principal theme of the case study. To be sure, regulations are considered a vital component of management especially when tailored to an individual species' population characteristics. But the regulatory component must be placed in a larger management framework which includes education, dissemination and enforcement elements. Finally, and perhaps most importantly for the purposes of this Casebook, design of a management program must take place within the larger context of the overall coastal and marine environment in which stocks are to be controlled.

Table 4. Existing regulations for conch and lobster in the Caribbean region.

	LOBSTER								CONCH							
	minimum size	minimum weight	closed season	closed area	berried females	gear restrictions	closed fishery	catch allocation	minimum size	minimum weight	closed season	closed area	gear restrictions	closed fishery	catch allocation	export restrict.
Anguilla	-	-	x	-	x	-	-	-	-	-	-	-	-	-	-	-
Antigua/Barbuda	x	x	x	-	x	-	-	-	-	-	-	-	-	-	-	-
Bahamas	x	x	x	-	x	x	-	-	-	-	-	-	-	-	-	-
Barbados	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Belize	x	x	x	-	x	x	-	x	x	x	x	-	x	-	-	-
Bermuda	x	x	x	-	x	-	-	-	-	-	-	-	-	-	-	-
Brazil	x	-	x	x	x	x	x	-	NA							
Cayman Islands	x	-	x	-	-	x	-	x	-	-	-	-	-	-	-	-
Colombia	x	x	-	-	-	-	-	-	-	-	-	x	-	-	-	-
Cuba	x	-	x	-	x	x	-	-	NA							
Dominica	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dominican Rep.	x	-	x	-	-	-	-	-	NA							
Grenada	x	-	x	-	x	-	-	-	-	-	-	-	-	-	-	-
Guatemala	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Guadeloupe	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Haiti	-	x	-	-	-	-	-	-	-	-	x	-	-	-	-	-
Honduras	x	-	-	-	x	-	-	-	-	-	-	-	-	-	-	-
Jamaica	x	-	-	-	x	-	-	-	-	-	-	-	-	-	-	-
Martinique	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mexico	x	-	x	-	x	-	-	-	NA							
Montserrat	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
N. Antilles	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Nevis/St. Kitts	x	x	x	-	x	-	-	-	-	-	-	-	-	-	-	-
Nicaragua	x	x	-	x	x	-	-		NA							
Panama	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Puerto Rico	x	-	-	-	x	-	-	-	-	-	-	-	-	-	-	-
St. Lucia	x	x	x	-	x	-	-	-	-	-	-	-	-	-	-	-
St. Vincent	x	x	x	-	x	-	-	-	-	-	-	-	-	-	-	-
Trinidad/Tobago	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Turks/Caicos	x	x	x	-	x	x	-	-	x	-	-	-	x	-	-	-
US(Florida)	x	-	x	x	x	x	-	-	-	-	-	-	-	-	x	-
Venezuela	x	-	x	x	x	x	-	-	-	-	x	-	-	x	-	-
Virgin Islands(UK)	x	-	-	-	x	x	-	-	-	-	-	-	-	-	-	-
Virgin Islands(US)	x	-	-	x	x	x	-	-	-	-	-	-	-	-	-	-

Sources: Adams, 1971; GCFI, 1980; IRF, 1980; IRF, 1983; Villegas et al., 1982.

NA: Not available.

4. SITE EXAMPLES

For a closer examination of events leading up to the adoption of a management program and its subsequent effectiveness four sites were visited and are briefly described below.

4.1 U.S. Virgin Islands

Within the region, perhaps the U.S. Virgin Islands represents the most dramatic example of depletion of stocks due to excessive demand associated with growth and tourism development. As late as the early 1950's, the economy of the U.S. Virgin Islands was based on agriculture dominated by the production of sugar and its by-products, molasses and rum. The population was relatively stable at 25,000, actually dropping from 30,000 at the turn of the century. Fisheries, as in many other areas of the Caribbean, were exploited only for subsistence purposes. Fiedler and Jarvis (1932) in one of the earliest known written account of the islands' fisheries did not report conch and lobster as part of the landings.

Upon passage of the "Organic Act" by the U.S. Congress in 1954 (legislation which provided investment tax incentives for business), major changes in the islands' tax structure and expanding levels of federal assistance stimulated economic growth principally in the government, export manufacturing, and tourism sectors. In the latter, growth rates measured in terms of tourist arrivals and accommodations were exponential. In the 10 years between 1960 and 1970 alone, visitor arrivals increased tenfold, the employed labor force tripled, stock housing doubled, real per capita income rose 10 percent annually and electric and water consumption rates increased, on the average, 20 percent per year (McElroy, 1978).

The changing character of this burgeoning population and rising affluence also generated a rapid convergence of resident Virgin Islands consumption patterns with U.S. mainland standards (McElroy and Caines, 1980). These new tastes in combination with income-elastic tourist patterns have visibly effected the local fisheries. For example, as late as 1960 enough lobsters were caught in Virgin Islands waters to create a surplus for export to Puerto Rico (Caribo, 1961). However, by 1967 the

U.S. Virgin Islands had become a net importer of lobster and has remained so to this day (Table 5). Imports of lobster over this period have reached as high as 75 percent of total consumption, measured in both weight and value. Moreover, this situation appears to be more than just a simple case of demand exceeding supply. Recent trends in the fishery, including an increase in lobster pot thefts, a tripling in market value, and a decline in average size indicated that the species may be overfished (Dammann et al., 1976). This initial conclusion appears to be further substantiated by interviews conducted in the course of the present case study indicating that depletion of lobster stocks in nearshore areas has caused many fishermen to travel increasing distance from shore at additional cost and personal risk (Figures 8 and 9).

While CPUE data is being collected in the U.S. Virgin Islands, up until 1980 it had been reported solely on a voluntary basis. Comparisons of fishermen's reports with two years of port sampling indicated that less than 50 percent of all lobster are reported. This data gap prevents a more objective approach for determining the present status of stocks.

While few data exist concerning the status of conch populations, the results of interviews indicate that commercial quantities no longer exist in the Virgin Islands following a trend similar to that described for the lobster (Figures 10 and 11).

The Virgin Island resident fishing community is small, composed of an estimated 420 full- and part-time fishermen (Olsen, 1982). The impact of the apparent decline of these two fisheries on the community's economic well-being is difficult to ascertain due to the absence of accurate historical data. Per capita income for fishermen in 1981 was $6,681 of which less than 20 percent was represented by conch and lobster and the balance by fish (Olsen, 1982). The disproportionately small share representing such high-value species suggests a loss of income that is significant.

Distribution of catch in the Virgin Islands has always been diffuse and characterized by fishermen selling directly to the consumer and retailer or occasionally to the intermediary. An effort to bring more structure to the system through the establishment of cooperatives on

Table 5. Domestic landings and imports of lobster in the U.S. Virgin Islands (in U.S. dollars).

	Domestic Landings		Imports		Total Consumption		Total Consumption	
	lb (x 000)	$ (x 000)	lb (x 000)	$ (x 000)	lb (x 000)	$ (x 000)	lb (%)	$ (%)
1967	85.9	73	260.1	209	346	282	75	74
1970	NA	NA	34.6	24.8	NA	NA	NA	NA
1971	NA	NA	52.5	40.2	NA	NA	NA	NA
1972	NA	NA	68.0	53.5	NA	NA	NA	NA
1973	NA	NA	55.7	NA	NA	NA	NA	NA
1974	NA	NA	NA	NA	NA	NA	NA	NA
1975	49.6[a]	99[a]	55.7	NA	105.3	NA	53	NA
1976	86.5[a]	173[a]	55.8	58	142.3	231	39	25
1977	129.8[a]	260[a]	77.5	60	207.3	320	37	19
1978	157.1[a]	393[a]	42.2	69.4	199.3	462.4	21	15
1979	162.7[a]	NA	NA	NA	NA	NA	NA	NA
1980	109.1[a]	NA	81.9	165.8	191	NA	43	NA
1981	97.7[a]	415[a]	NA	NA	NA	NA	NA	NA

Sources: U.S. Dept. of Commerce, 1980; Olsen, 1982.

NA: Not available.
[a] Signifies estimates based on voluntary reported landings.

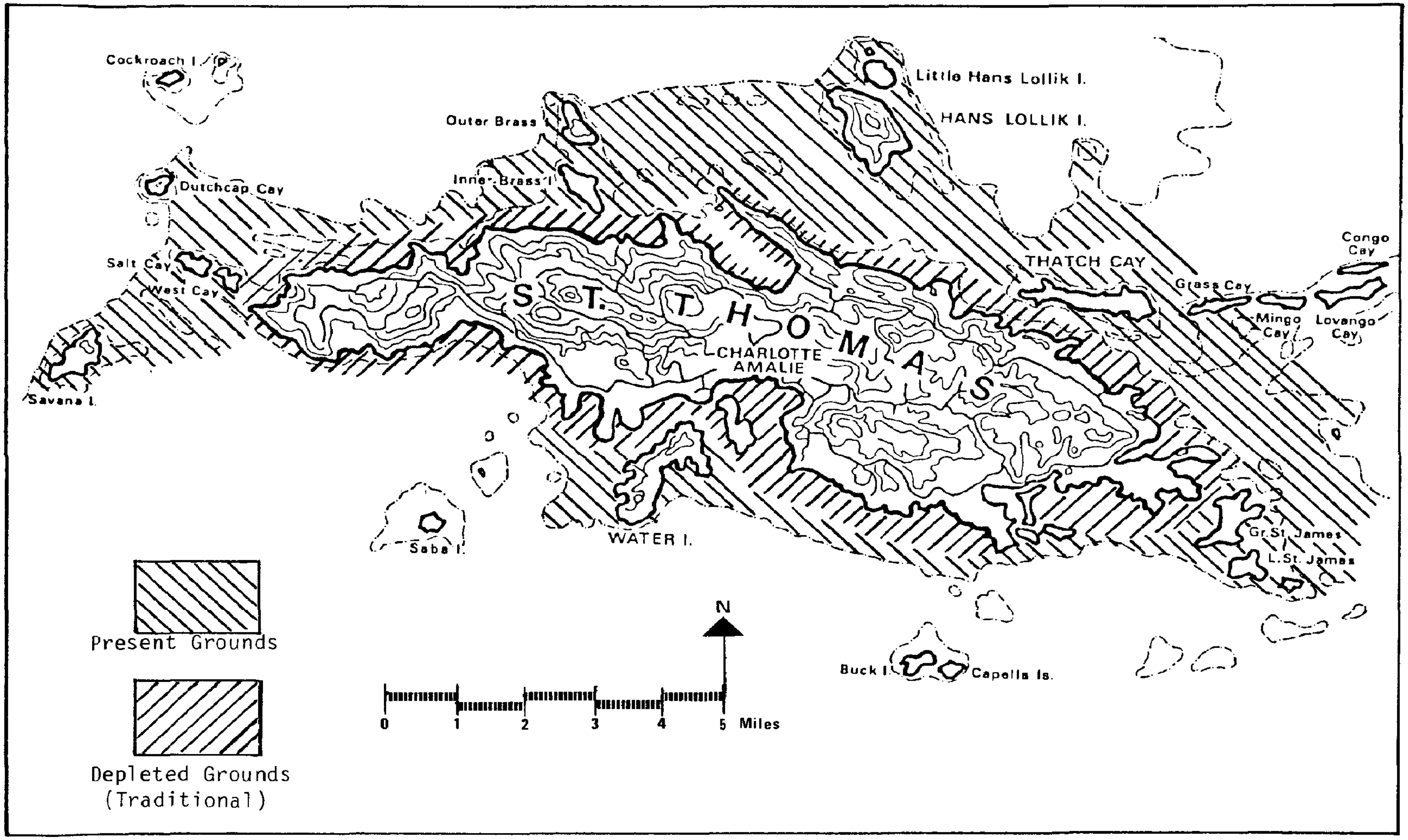


Figure 8. Traditional and present lobster fishing grounds of St. Thomas, U.S. Virgin Islands. (Source: LaPlace, personal communication, 1983.)

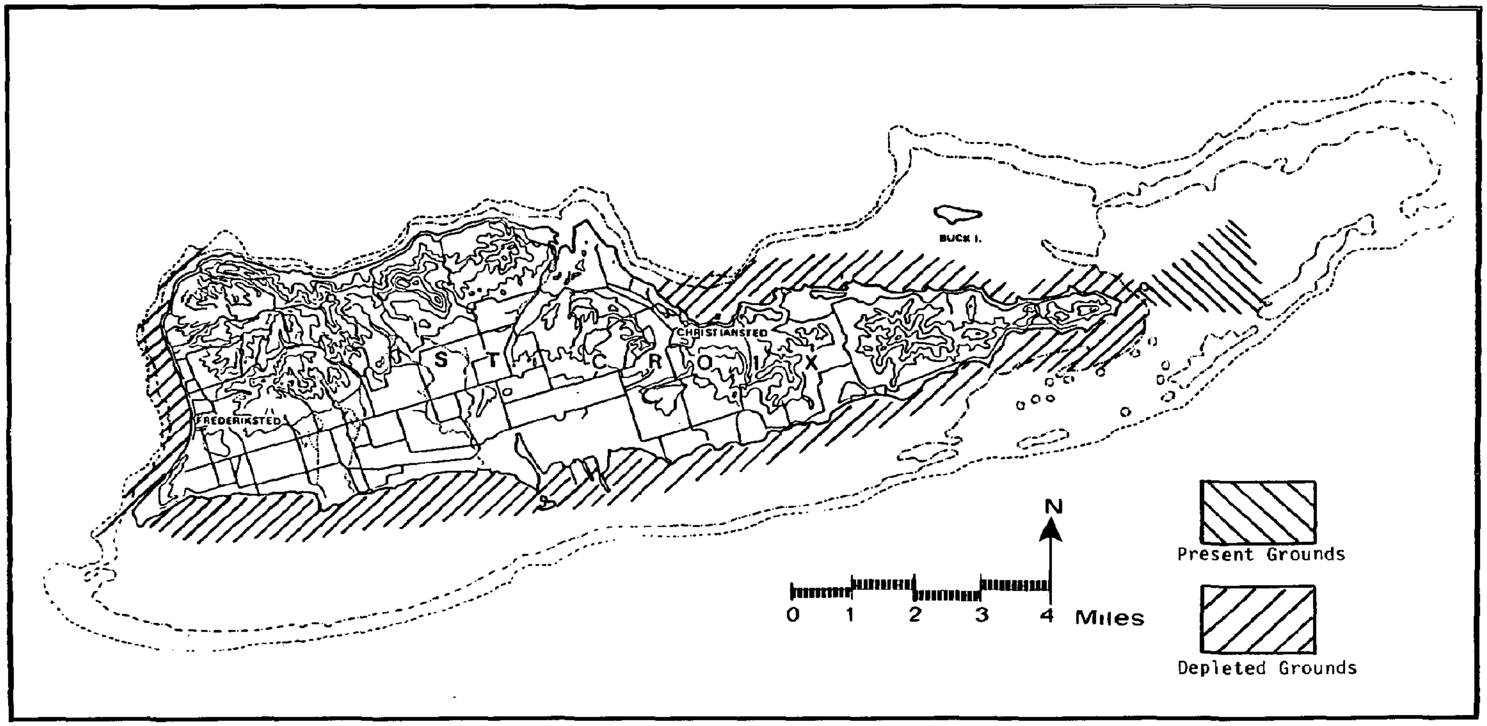


Figure 9. Traditional (depleted) and present lobster fishing grounds of St. Croix, U.S. Virgin Islands. (Source: Information furnished by Skov, personal communication, 1983.)

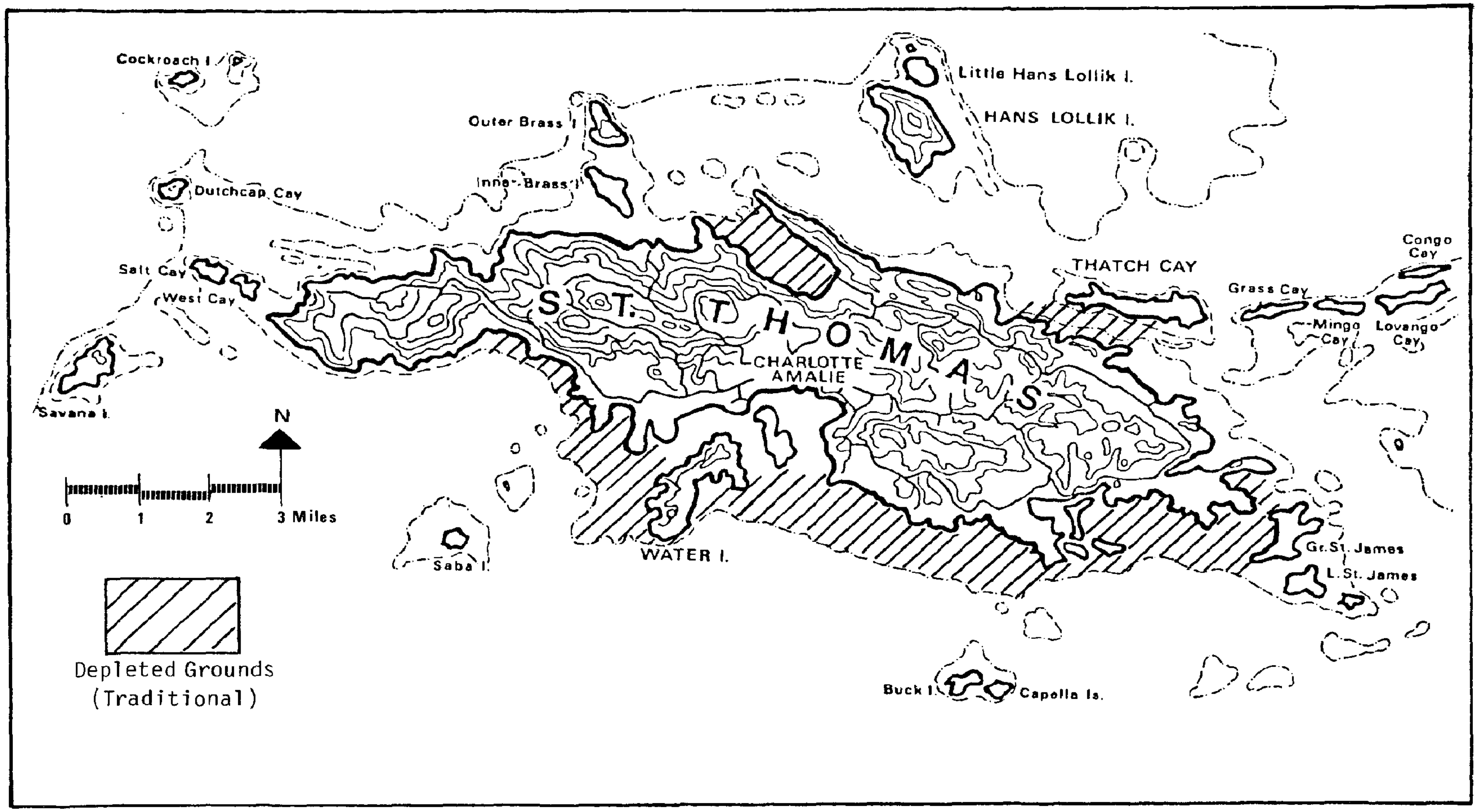


Figure 10. Traditional conch fishing grounds of St. Thomas, U.S. Virgin Islands. N.B.: No present grounds exist. (Source: LaPlace, personal communication, 1983.)

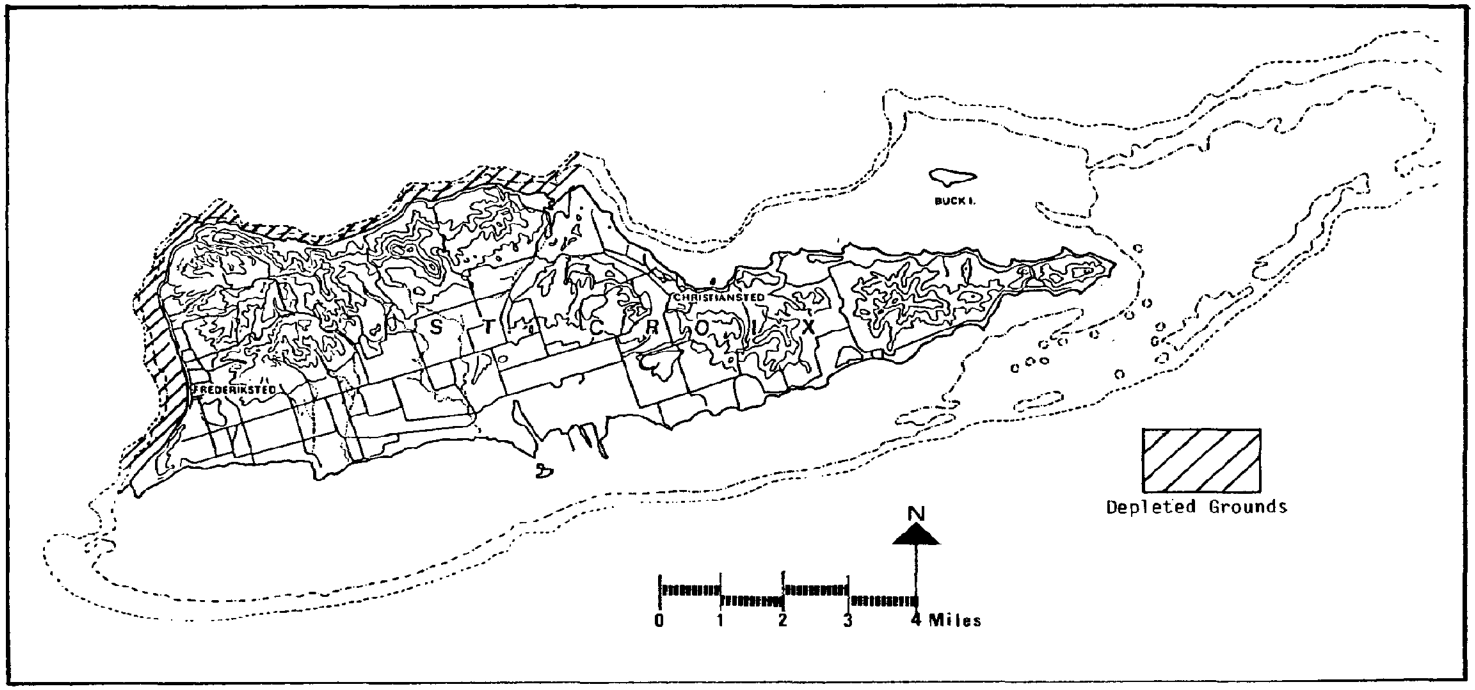


Figure 11. Traditional (depleted) conch fishing grounds of St. Croix, U.S. Virgin Islands. N.B.: No present grounds exist. (Source: Information furnished by Skov, personal communication, 1983.)

both St. Thomas and St. Croix ended in failure. This pattern of distribution has important implications for management and regulatory enforcement of the fisheries which will be discussed in more detail in Section 5.

In sum, with the example of the U.S. Virgin Islands, we have examined a developing area characterized by over-fishing and an increased demand for lobster and conch. To explore how the circumstances of the Virgin Islands relate to those of other parts of the region, we chose to examine the neighboring island of Antigua.

4.2 Antigua

Antigua, together with its dependency, Barbuda, is fortunate to possess an extensive shallow water shelf area (2,500 km^2) which is rich in demersal fish resources. Available trade statistics indicate that Antigua was exporting as much as 200 thousand pounds of lobster as early as 1957-1958, before reaching a peak of 275 thousand pounds in 1978 (Figure 12). However, since that period, a decline in landings and subsequent exports began which has continued into 1982. Estimated landings have declined from 334 thousand pounds in 1978 to 95 thousand pounds in 1982 for an average of a 23.5 per cent negative annual change over that same period (Joseph, personal communication).

Although catch per unit effort (CPUE) data are rare in Antigua, for the four-year period between 1970 and 1974 CPUE declined from 1.5 pound to 1 pound per trap, indicating the possible over-exploitation of the fishery (Peacock, 1976). Further evidence for this condition exists in records for total landings and the results from discussions with the Antiguan fisheries officer and local fishermen. One factor substantiated in these discussions was the necessity for fishermen to leave traditional fishing grounds as they became depleted for more distant areas elsewhere (Figure 13), a pattern reminiscent of the one described for the U.S. Virgin Islands.

There are an estimated 800 (full- and part-time) fishermen in Antigua of whom approximately 640 depend, at least in part, on income derived

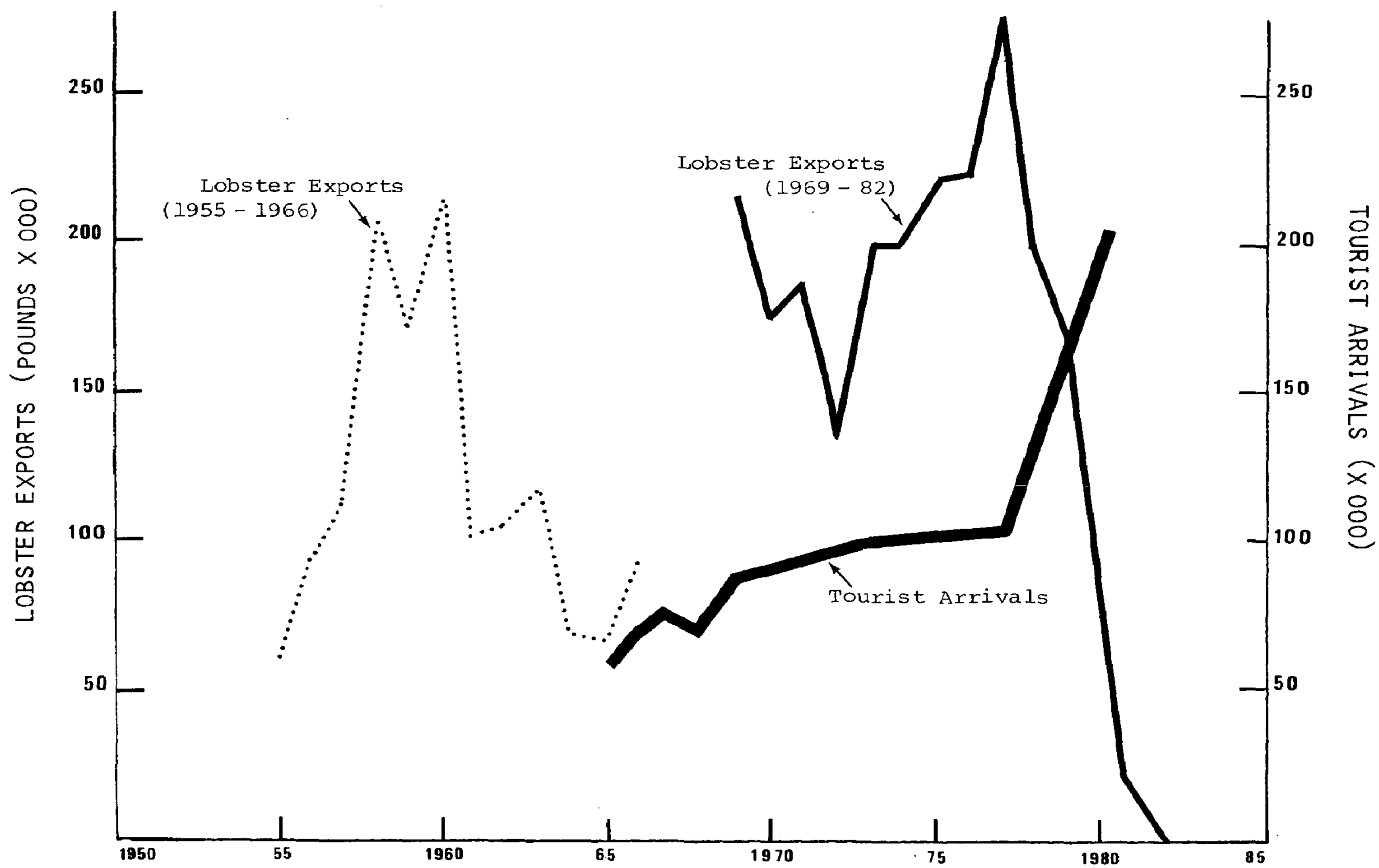


Figure 12. Lobster exports and tourist arrivals for Antigua. (*Source:* Information provided by Ministry of Agriculture, Lands and Fisheries.)

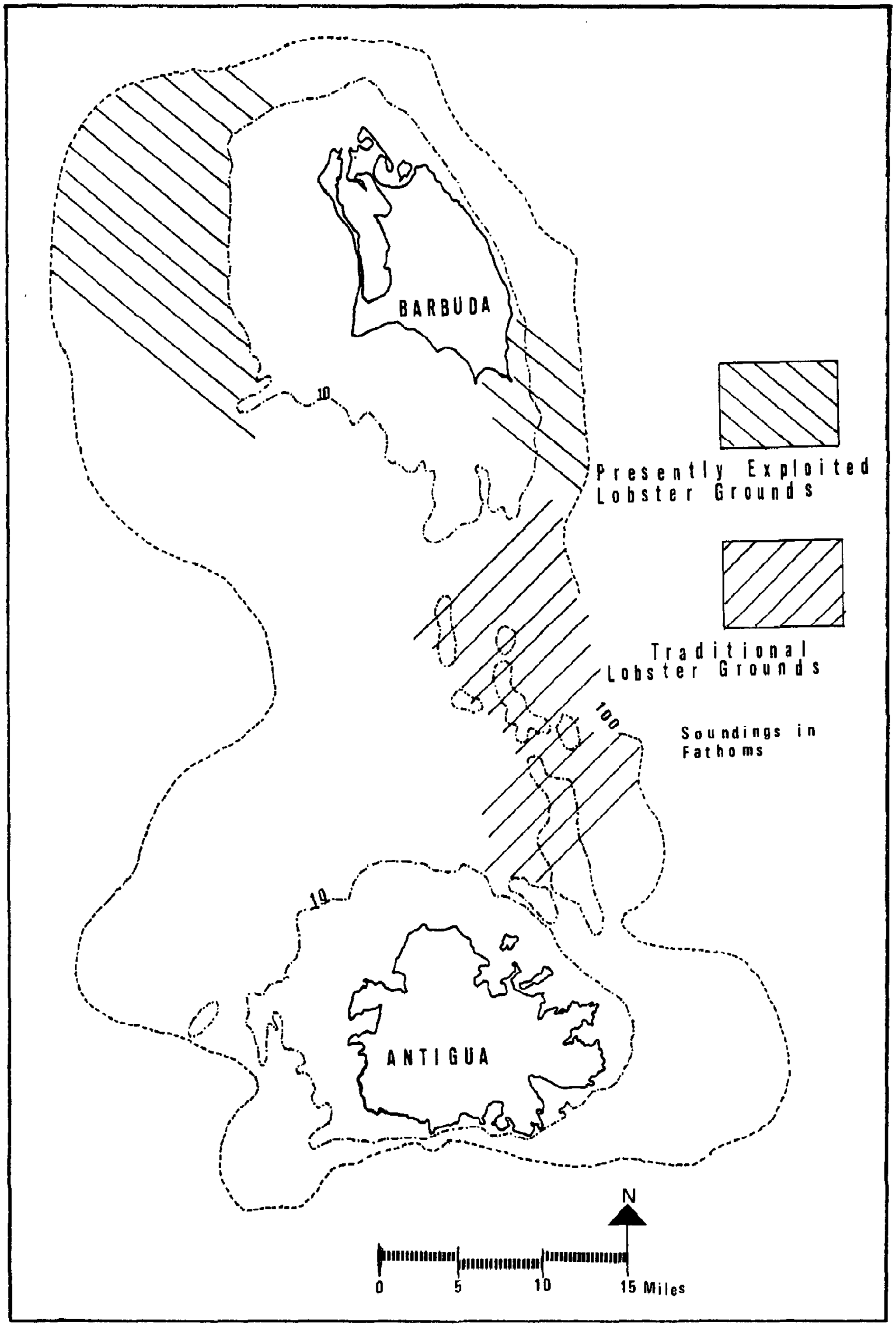


Figure 13. Traditional and present lobster fishing grounds of Antigua. (Source: Martin, personal communication, 1983.)

from conch and lobster. While there are no data available to assess the economic impact of a collapsed fishery on a per capita basis, gross loss of income to the community must be considered significant.

As a final note, as lobster catches have dropped and tourism has continued to grow, lobster is increasingly being diverted from export markets to local outlets (Figure 12). Despite this diversion, there continues to be a scarcity of the resource during the tourist season which has resulted in the species being dropped from the menus of several hotels and restaurants (Joseph, personal communication). If the U.S. Virgin Islands is a model with potential application to Antigua, the conversion of Antigua to a net importer of lobster is a real possibility. Unlike the Virgin Islands, which in an earlier period had alternative source areas to turn to, Antigua may not have the option as the region's stocks become increasingly scarce.

Unfortunately, Antigua seems to be representative of many of the small developing countries which are rapidly exploiting their natural resources as a means to obtain scarce foreign exchange. However, there are two countries which have been able to implement efficient and relatively successful management programs for their conch and lobster resources. These are Belize and the Turks and Caicos Islands.

4.3 Belize

The Belize fishery sector, dominated by the lobster and conch fisheries, has become one of the country's most important industries. As recently as the early 1950's fishery exports consisted of only small quantities of lobster destined for the United States. Now fishery exports are more significant, exceeding US$6,000,000 in 1982 (Figure 14).

The lobster fishery began in 1921 with the introduction of the first lobster pot from Nova Scotia (Craig, 1966). Despite the success of the pot equipment, failures in the packaging plants led to the fishery's demise in 1935. The industry was revived with the introduction to the region of refrigerated cargo boats owned and operated by the U.S. import companies (Smith et al., 1948). Since that period the industry has grown (Figure 15) to become the country's most important export fishery.

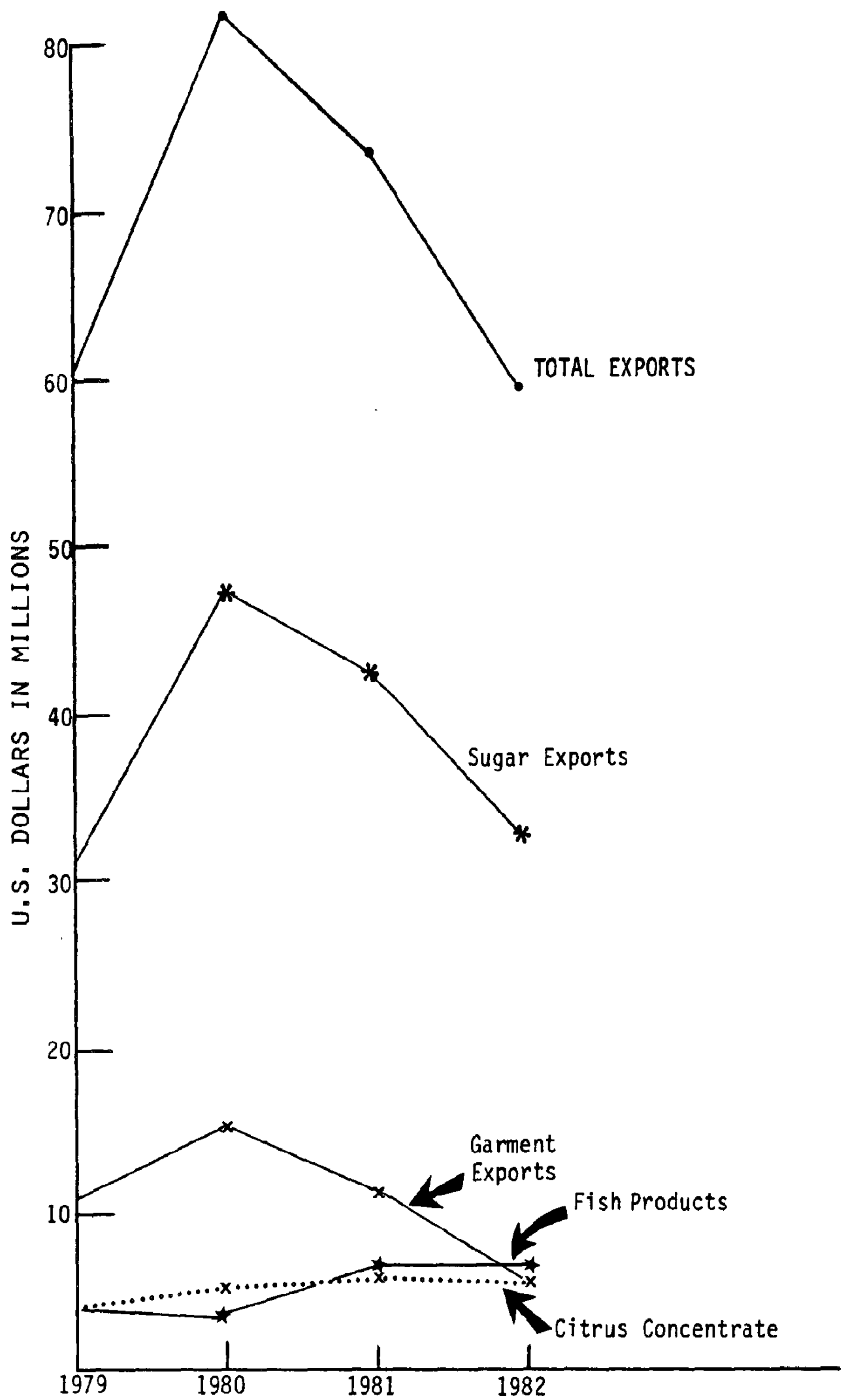


Figure 14. Value of Belize's major domestic exports in U.S. dollars. Data for 1982 are estimated. (Source: Belize Govt. Statistical Office, 1982.)

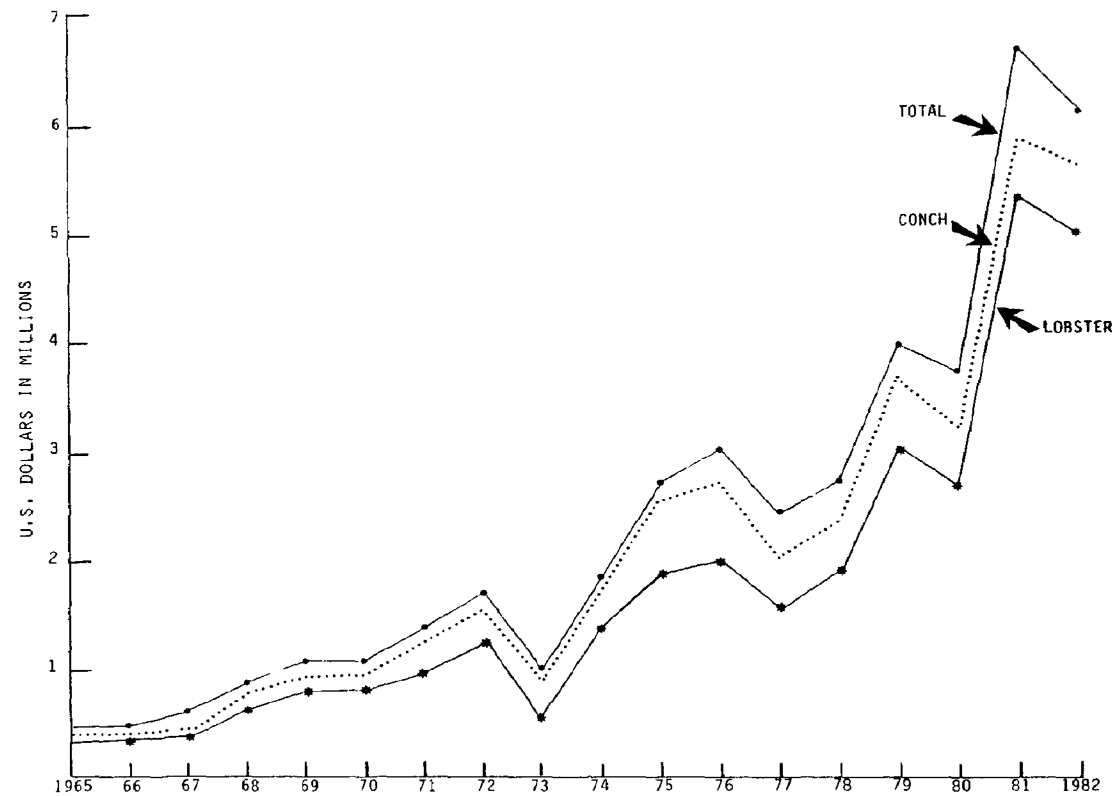


Figure 15. Cumulative totals and relative values of fishery exports in Belize, 1965-1982. (Source: Blakesley (1977) and information provided by the Fisheries Management Unit, Ministry of Health, Housing and Cooperatives, Belize.)

In contrast to lobster, conch was a relatively unimportant fishery until the early 1960's. With increased demand in the U.S. market, however, exports grew from 100,000 pounds in 1965 to a peak of 1.25 million pounds in 1972 (Figure 16) and are currently the country's second most important source of "fish"-derived export revenue (Figure 15).

As the fisheries grew in Belize the economic necessity to provide finished products and negotiate competitively in external markets became readily apparent. In response the government encouraged the development of cooperatives whose function would be to "provide procedures and means for the efficient production, distribution, processing and sale of marine products through the united efforts and funds of its individual members" (Gibson, 1978). In fact, according to McElroy (1965), it was the establishment of the first indigenous lobster processing cooperative in the early 1960's that shifted the control of market from a U.S. buyer/processor monopsony to the local producers resulting in a dramatic rise in wholesale prices paid to fishermen that, in turn, was largely responsible for the rapid increases in lobster effort and catch after 1965. Based on a total of 800 full-time fishermen, gross per capita income was estimated to be $4,130 in 1982.

Presently there are five cooperatives operating in Belize which represent over 700 fishermen and 450 boats. The cooperatives are the only legal means for exporting fish from Belize. They possess processing and packaging facilities, negotiate export markets annually, provide loans to their members and import equipment as needed.

The annual financial cycle of a cooperative consists of negotiating price and quantity contracts with foreign importers prior to the start of the fishing season. Once the season is under way, the cooperative's members receive initial payments for each landing they make. A second payment is made at the close of the fishing season based on the respective members' total landings and the external market price and quantities sold by the cooperative. A third payment is made at the end of the budget year, based on net profit of the cooperative, and distributed to its membership as determined by each member's respective number of shares. The breakdown of costs and revenues of one cooperative, illustrating the

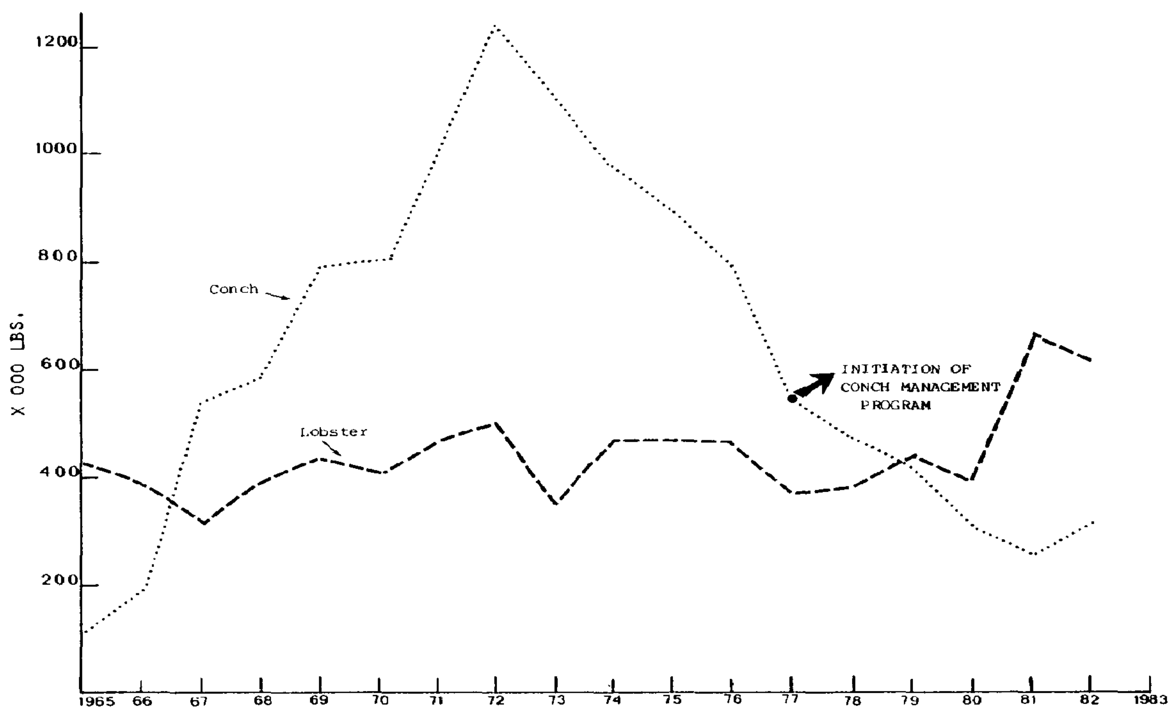


Figure 16. Conch and lobster exports from Belize. (Source: Information provided by the Fisheries Management Unit, Ministry of Health, Housing and Cooperatives, Belize.)

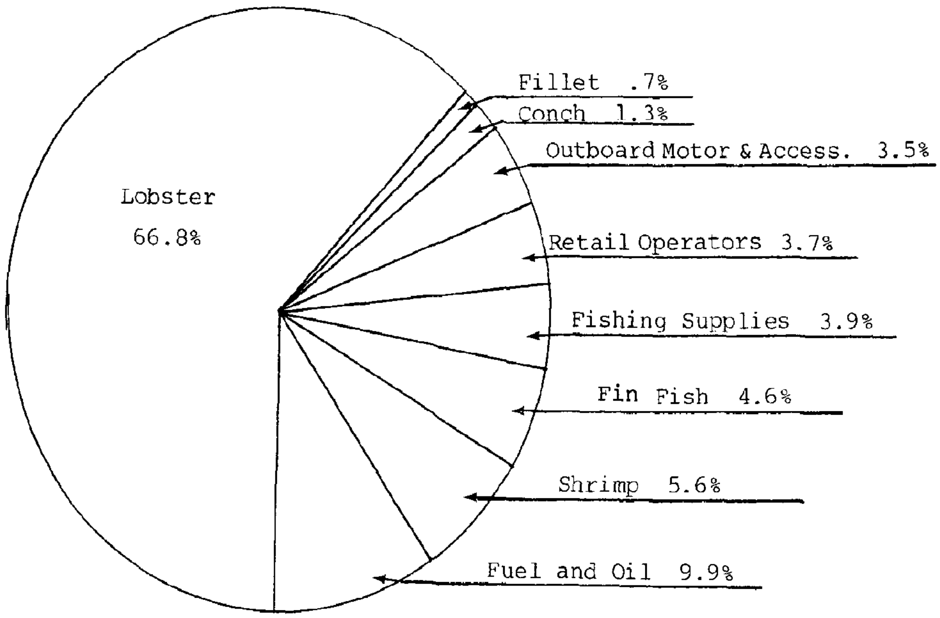
importance of lobster as a revenue earned, is displayed in Figure 17.

Catch per unit effort data collected for the lobster fishery over the previous five-year period indicated that present catch levels are at or near MSY. While the data period was too short to confirm this trend, the use of alternative analytical techniques (yield per recruit) with growth parameters derived from Florida lobster populations supported this preliminary conclusion (Gibson, 1981). These indicators, together with the fluctuation of total catch figures in a range between 250 and 600 thousand pounds over the last 16 years (Figure 16), led the chief fisheries officer to conclude that lobsters were currently being harvested at MSY (Miller, 1981). In contrast, conch reached an export peak of 1.25 million pounds in 1972 and then fell into a rapid and steady decline, continuing until 1981 before the trend was reversed and the first increase in catch was recorded (Figure 16).

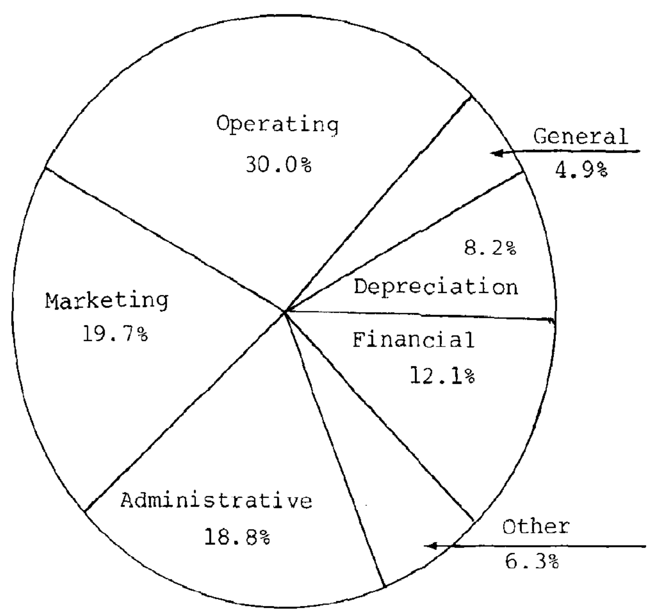
While lobster preceded conch as an export commodity in Belize, the history of fishery development in the Turks and Caicos Islands was just the reverse.

4.4 Turks and Caicos Islands

The Turks and Caicos Islands group, situated at the very southermost end of the Bahamian chain, is typical of flat coralline islands found in many parts of the Caribbean (Caymans, Antigua), characterized by a sparse vegetative cover and few natural resources. Turks and Caicos is fortunate however, to possess an extensive shallow submarine bank fringed by reefs providing suitable habitat for conch and lobster. The island group is unique in its long export record for conch extending back to the early 1900's (Figure 18). Doran (1958) described the early years of the trade as a traditional export fishery to Haiti. The resource was fished by men working from dinghies operating from 30- to 40-foot sailing sloops. Using only a water glass and gig, conch were "hooked" to a depth of 20-25 feet from the surface. The animal was "cleaned" and dried on the sloop. The product was taken to Cap Haitian, Haiti, where in exchange for conch, the sloop brought back stores of fruit and vegetables to islands poor in such produce, and then repeated the cycle.



THE INCOME DOLLAR SOURCE



THE EXPENSE DOLLAR BREAKDOWN

Figure 17. Percentage income and expenses of Caribena Cooperative for the operating year 1981-1982. (Source: Caribena, 1982.)

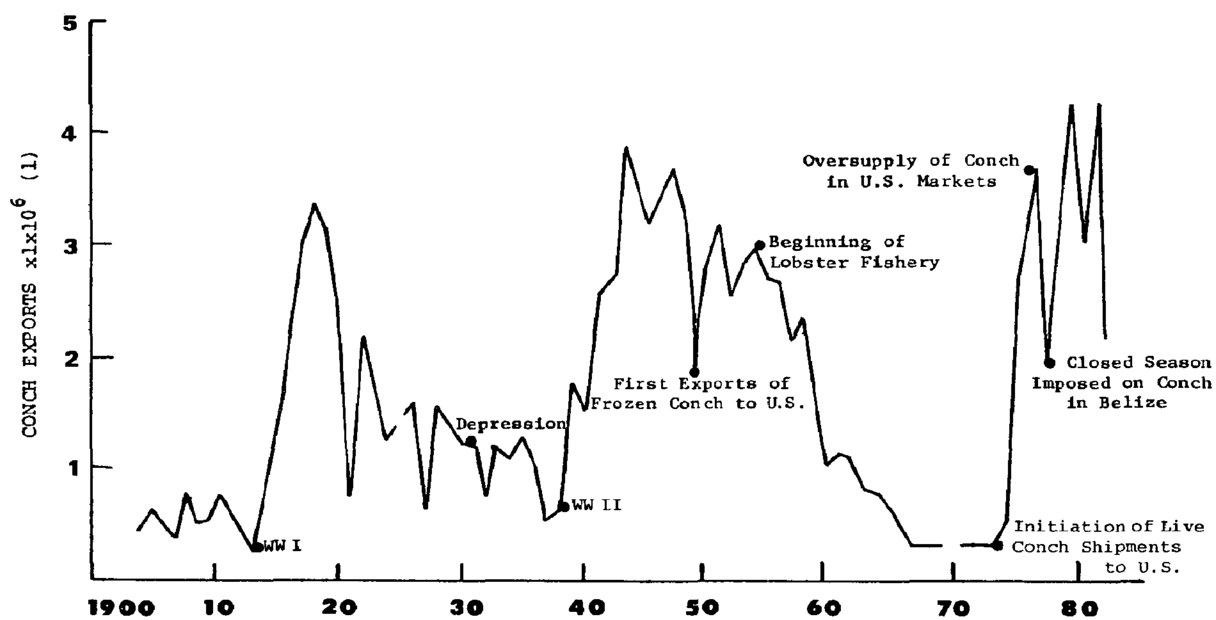


Figure 18. Conch exports from the Turks and Caicos Islands (1904-1982). Includes both dried and frozen meats. (Source: Nardi, 1982; adapted from Doran, 1958.)

Doran estimated an average of 1.7 million conch were exported annually over the years until the late 1950's with a maximum of 3.9 million reached in 1944. Doran attributed the increases in conch exports at the initiation of World War I and II to the diversion of cargo ships away from the region which had been importing alternative sources of protein that competed with conch. The decline in exports between the two World Wars was attributed to the worldwide economic depression and decreased purchasing power. The increase in production from the late 1940's to the mid-1950's was attributed to the development of a frozen conch export market to the United States. Since that period a diverse range of factors, both local and external, have been identified as influencing the status of the fishery, including the development of the more lucrative lobster fishery (Hesse and Hesse, 1977), passage of legislation in Florida affecting conch harvesting in 1965 and again in 1971 (Stevely and Warner, 1978), development of a growing market which began in the United States in the late 1960's (Brownell and Stevely, 1981), and reduction of supply from competing exporting countries in the late 1970's (Brownell and Stevely, 1981). Despite fluctuations in exports of conch, the islands came to dominate the market during the period 1970-1978 (Figure 19) and accounted for $717,000 in export revenues in 1981.

The lobster fishery first developed in the late 1950's and has grown to a level averaging 620 thousand pounds per year for the period 1974-1979, surpassing the conch fishery as the primary source of foreign revenue (Kucharski, 1980). Together these two fisheries constitute 95 percent of all fish export revenues generated, representing an estimated $2.2 million in 1981.

The industry consists of five commercial processing facilities, four of which are located on South Caicos. While policies vary among plants fishermen generally can work either as "independents" selling their daily catch directly to the company or on contract in exchange for use of the plant's boats and supplies. The industry dominates the island's private sector, employing an estimated 300 fishermen and providing additional employment opportunities to as many as 2,000 individuals working in related support and service sectors (Hamaludin, 1982). Estimated per capita in-

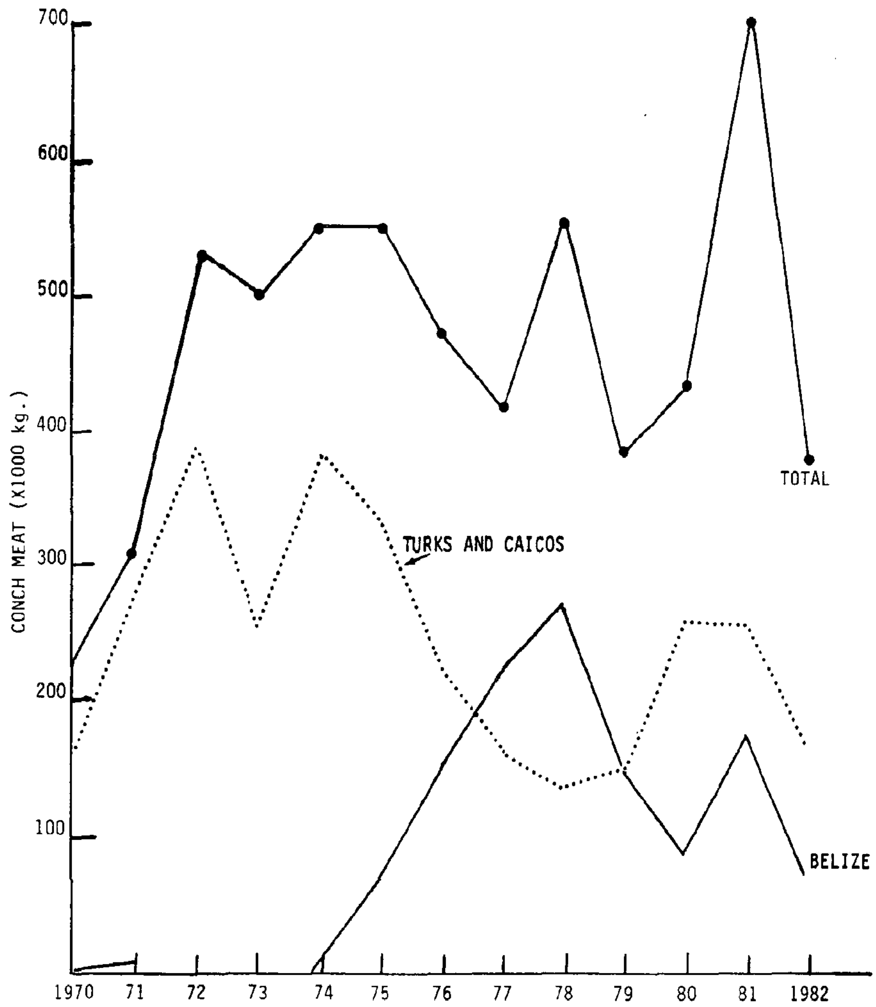


Figure 19. Conch meat imported through Miami, 1970-1982. (Source: Brownell and Stevely, 1981; and information from the National Marine Fisheries Service, Fisheries Development Analysis Branch, New Orleans, Louisiana.)

come to fishermen from conch and lobster was $5,246.

As in our previous site examples, accurate determination of the status of Turks and Caicos lobster and conch stocks is constrained by a poor data base. However, based on the results from interviews with the islands' chief fishery officer (Hall, personal communication), a plant owner (Gasgill, personal communication), and a review of the literature (Hesse and Hesse, 1977; Nardi, 1982), there appears to be a consensus that conch stocks are diminishing, although there is lack of consensus whether this is strictly a localized condition or occurs over the entire shelf area. Nardi (1982) provides data showing conch exports from 1975 to 1981 averaging a relatively constant one million pounds per year, but it is difficult to ascertain if these levels are sustainable yields or represent the exploitation of the population's capital base. Fears of the latter have resulted in new regulations which will be described below.

There appears to be a higher degree of certainty with regard to the lobster population as CPUE data exist back to 1974. Based on an assessment of these data and landings dating back to 1959, Kucharski (1980) states all available evidence indicates the fishery is at or near its MSY.

5. COMPARING MANAGEMENT APPROACHES

In the previous examples, the developing conch and lobster fisheries in four different Caribbean areas have been outlined, their economic significance described, and some of the issues associated with apparent over-exploitation identified. At this point, it would be productive to examine and compare the individual management regimes which have been put in place since the commercial development of the fisheries in each of the four study areas and then attempt to determine what factors played a role in successful management. However, having stated our objective, it would be prudent to avoid too rigorous a comparative analysis. This is due, in part, to the paucity of data by which to judge the "true" status of local fish stocks. Further, natural fluctuations in fish populations, as well as other factors beyond the scope of the present study, affect stocks and serve to complicate the evaluation of at least the short term effectiveness of a particular management approach. Finally, each of the four areas have a different development history and resist strict comparative analyses. Despite these caveats, drawing comparisons can still prove instructive and are therefore presented. In the discussion of management regulations, which follows, we make occasional reference to the management tools previously identified in Section 2.2 above, but for brevity's sake they are identified by number only in the discussion of the first study area.

5.1 Belize

As the example with possibly the most successful existing management program, Belize is a logical place to begin.

Regulation of lobster first began in 1963. In those regulations, which have been periodically updated, an annual total allocation was set to be divided among the cooperatives on the basis of number of members and past landings. This allocation (currently set at 600,000 pounds) had the effect of limiting overall catch which, in the case of Belize, is determined by a best estimate of MSY (tool no. 7). Other regulations presently include: a 6-ounce minimum tail weight or 3 1/4-inch minimum carapace length (tool no. 5); a four-month closed season extending from

15 March to 16 July (tool no. 3); prohibition of the capture of egg-bearing and soft-shelled moulting lobster (tool no. 4); and prohibition of use of SCUBA (tool no. 6).

Unlike lobster, conch remained unregulated until 1977 when the continuous decline in landings forced the formulation of management regulations. These are: a minimum seven-inch shell length and three-ounce (market clean) meat weight (tool no. 5), a three-month closed season extending from 1 July to 30 September (tool no. 3), and prohibition of SCUBA use (tool no. 6). Whereas the lack of CPUE data makes it difficult to judge the effectiveness of these new regulations, the reversal of a downward trend in 1981 with the first annual increase in conch levels may in fact be partially attributable to their implementation. Siddall (1983) estimates queen conch reach average market size in 2 1/2 years. Based on this evidence and the assumption the regulations have been effectively enforced, the time period between regulation implementation and first observed increases in catch would have allowed for three year classes to enter the size range suitable for harvest.

The key to the effective enforcement of these regulations appears to lie with the cooperatives. Besides functioning as the principal means to process, package and export conch and lobster they also function as a vehicle for managing the country's fisheries. By requiring all fish exports to be channeled through the five cooperatives, the government has limited the production centers required to focus enforcement activities. Through periodic enforcement checks, adequate penalties for violating fishing laws, and a growing awareness by management of the need for a regulated fishery to preserve cooperative investments, Belize's fishery sector has become relatively efficient.

The current personnel support available to manage the Belize fishery consists of 12 staff members comprising the Fisheries Management Unit (FMU) with an operating budget of US$86,535. The fishery more than pays for its management and development through a five percent ad valorem duty which generated $310,000 for the government in 1982 or 70 percent more than was expended for government-related fishery affairs that year (Table 6).

Table 6. Management costs, export values, and revenues for Belize's conch and lobster fishery in U.S. dollars.

FISHERIES MANAGEMENT COSTS AND REVENUES

FISHERIES MANAGEMENT STAFF:

Fisheries Administrator	1	Technicians	2
Fisheries Officers	2	Clerical	2
Asst. Fisheries Officer	1	Boat Crew	1
Inspectors	1	Watchmen	2

TOTAL STAFF: 12

FISHERIES MANAGEMENT BUDGET AND REVENUES (1983-1984):

$$\frac{\text{Fisheries Budget}}{\text{Est'd Annual Govt. Revenue from Fisheries}} = \frac{\$86,535}{\$310,000} = 28\%$$

EXPORT VALUES AND REVENUES

EXPORT VALUE (1982):

Lobster	610,110 lb	@ $8.25/lb (approx.)	=	$ 5,033,407
Conch	314,350 lb	@ $2.12/lb (approx.)	=	667,993
Other		@ $0.89/lb (approx.)	=	457,164
				$ 6,158,564

$$\frac{\text{Fisheries Budget}}{\text{Gross Export Value of Fishery}} = \frac{\$86,535}{\$6,158,564} = 1.4\%$$

(Conch and lobster total fish production, as percentage of total = 93%.)

ESTIMATED VALUE TO FISHERMEN:

Lobster	610,110 lb	@ $4.55/lb	=	$ 2,776,000
Conch	314,350 lb	@ $1.68/lb	=	528,108
				$ 3,304,108

$$\frac{\text{Gross per capita income attributed to conch and lobster}}{\text{Direct employment}} = \frac{\$3,304,108}{800} = \$4,130.00 \text{ per employee}$$

Sources: Caribena, 1982; information from the Ministry of Health, Housing and Cooperatives, Belize.

It is important to note the role educational activities have played in assisting the FMU to manage a fishery valued at more than $6 million. Through both local and foreign assistance, a wide variety of programs have been funded which have been directed towards increasing the community's awareness on a variety of fishery-related issues including conservation. These have included short-term training programs overseas, local workshops, and public information dissemination activities.

The wide public exposure and involvement in many such educational efforts can be partly attributed to the development of a relatively large and sophisticated institutional infrastructure concerned with fisheries development and management. These include the Belize Fishermen Cooperative Association and the Fishery Advisory Board. The Association is a thirteen-member body elected from the cooperative membership which serves to oversee cooperative activities and represent their interests to government (Gibson, 1978). The Advisory Board is composed of members from government and the fishery and business communities with responsibilities to advise the government on matters which could affect the industry.

Despite what appears to be a relatively effective national management program of an economically significant fishery, problems still remain. Chief among these are issues of an extra-national character. Due to lack of enforcement capabilities and disputed territorial waters, illegal fishing of high-value species occurs most notably in the south in disputed waters with Guatemala and Honduras. More complicated are illegal transactions involving Belizians selling lobster and conch to foreigners, by-passing the cooperative system. Black markets such as these provide outlets for catches beyond the maximum national quota as well as for illegal lobster (shorts, out of season, egg-bearing). From a management perspective this represents a "leak" of a national resource outside of the existing management regime, the magnitude of which cannot be determined or controlled within the present management and enforcement structure. These extra-national issues are not unique to Belize and will surface again in the present study.

5.2 Turks and Caicos

In comparing the Belize experience with that of the Turks and Caicos Islands, one discovers more similarities than differences. Management regulations for lobster consist of a 3 1/4-inch carapace length and/or 5-ounce tail weight and a closed season from August 4 to March 31. Conch regulations consist of a minimum meat size of 4 inches and/or minimum shell diameter of 7 inches. Scuba is also prohibited in the commercial fisheries.

However, due to the perceived over-fishing of conch stocks, the Fisheries Department is now reviewing all regulations. At present, that agency is considering the implementation of a closed season and annual maximum quota for conch as well as a proposal to require that all landings pass through a central landing site to facilitate enforcement efforts.

The fisheries department staff is relatively small (7) in contrast to the economic significance of the fishery it has been charged to manage. The department's present budget is US$56,000, or less than 60 percent of the government revenue generated by the fisheries but proportionately more than the ratio calculated for Belize (Table 7).

As in Belize, in these islands enforcement responsibilities are appreciably facilitated by centralization of the five processing plants in the islands (four are located on South Caicos).

Conservation education activities directed toward the community are minimal. Rather, there appears to be a reliance by the fishery officers on the plant owner's long-term self-interest to govern harvesting practices and facilitate the enforcement officers' duties. The validity of this assumption is open to question, at least in the case of Turks and Caicos. If maximization of profit is the sole objective of the company, one might be able to justify in economic terms a short-term harvesting strategy characterized by low capital investment, high rates of extraction and possibly absentee or foreign ownership. In this light, a plant with little capital investment might accept the trade-off of losing the long-term sustainable exploitation of a species for the short-term maximization of profits. Enlightened self-interest cultivated by education

Table 7. Management costs, export values, and revenues for the conch and lobster fishery of Turks and Caicos in U.S. dollars. (Source: Hall, 1982.)

FISHERIES MANAGEMENT COSTS AND REVENUES

FISHERIES MANAGEMENT STAFF:

Fisheries Officer	1	Clerical	1
Inspectors	4	Boat Crew	1

TOTAL STAFF: 7

FISHERIES OPERATING BUDGET (1982): $56,000

ESTIMATED ANNUAL GOVERNMENT REVENUE GENERATED FROM FISHERIES:

Commercial Fishing Licenses	300 @ $20		$ 6,000
Boat Registration Fees	150 @ $50 (mean)		7,500
Fishery Plant Registration Fees	5 @ $5,000		25,000
Excise Taxes:			
Lobster - 237,396 lb	@ 17cents/lb	(approx.)	40,115
Conch - 358,702 lb	5cents/lb	(approx.)	17,935
			$96,550

$$\frac{\text{Fisheries Budget}}{\text{Govt. Revenue Generated from Fisheries}} = \frac{\$56,000}{96,550} = 58\%$$

EXPORT VALUES AND REVENUES

EXPORT VALUE (1980-1981):

Lobster			
Tails	142,810 lb	@ $8.00/lb	$1,142,480
Whole cooked	73,640 lb	@ $3.00/lb	220,920
Cooked meat	20,946 lb	@ $2.00/lb	41,892
Conch	717,404 lb	@ $1.00/lb	717,404
Scale Fish	46,054 lb	@ $2.50/lb	115,135
			$2,237,831

ESTIMATED VALUE TO FISHERMAN:

Lobster (est'd.)	564,908 lb	@ $2.00/lb	$1,129,816
Conch	888,318 lb	@ .50/lb	444,159
			$1,573,975

$$\frac{\text{Gross per capita income attributed to conch and lobster}}{\text{Direct employment}} = \frac{\$1,573,975}{300} = \$5,246 \text{ per employee}$$

Source: Hall, 1982.

may succeed in Belize because the motives of the fishermen and owner are the same but fail in other areas where economic and conservation objectives differ. These differences must be taken into account by the individuals responsible for management.

Also as in Belize, the most serious problem facing these islands' industry, as perceived by the fishing community, is foreign poaching by fishermen from the Dominican Republic and Honduras. Lack of enforcement capabilities appear to be the principal constraint to preventing illegal fishing.

Whereas the two preceding site examples were of relatively "structured" fisheries in that the control of production was held by only a few entities (cooperatives in Belize, centralized processing plants in Turks and Caicos), the Virgin Islands and Antigua are characterized by unstructured distribution networks. This, it is suggested, places an added burden on achievement of the effective application of management regulations.

5.3 U.S. Virgin Islands

Management of spiny lobster in the U.S. Virgin Islands was first provided for in Territorial Act 3330 in 1972. The principal regulations affecting lobster called for a minimum tail length of 5 1/2 inches, certain gear restrictions, and the voluntary submission of catch data. Prior to this date, lobster regulations were limited to a prohibition against the taking of gravid females and certain general fishery ordinances (e.g., prohibition against the use of poisons). Enforcement was confined to periodic spot checks of the islands' principal landing centers (Fiedler and Jarvis, 1932).

However in 1980, in response to the federally mandated requirement to develop fishery management plans, the Caribbean Fishery Management Council drafted a plan for lobster management. In this plan OY was defined as equivalent to MSY. The lobster population was treated as a unit sharing a common shelf of Puerto Rico and the U.S. Virgin Islands and thus subject to the same regulations. The specific regulations proposed were protection for gravid females and all animals with a carapace length (CL) of less than 3 1/2 inches and the submission of catch/effort data.

To date no management regulations have been developed for conch.

The agency responsible for the management of marine fisheries in the Virgin Islands is the Division of Fisheries and Wildlife. Within this agency 10 of the 17 staff members are assigned to fisheries duties. In contrast to the other examples, responsibility for enforcement lies in the Bureau for Environment and Enforcement, an agency outside of the Division but sharing its parent agency (the Department of Conservation and Cultural Affairs).

A relatively large budget and the ability to defray enforcement expenses through a sharing of resources with other government agencies gives the Fisheries Division a greater capability to monitor regulatory compliance than exists in the other three case study areas. The use of government patrol boats gives the Division a sea-going capability virtually non-existent in the other site examples. In addition, a large fisheries staff assures a higher frequency of spot checks at landing sites and retail outlets, while master fishermen are employed to work with local fishermen and to verify the accuracy of their CPUE data. All these activities come at a cost, for the Division's operating budget is more than four times the size of the next highest budget among the four sites (Belize), amounting to $360,000 for the 1983-1984 fiscal year excluding the aforementioned enforcement expenses.

5.4 Antigua

Antigua lobster regulations provide for a closed season extending from December 15 to May 1. There also are prohibitions on the taking of lobster smaller than of 3 1/2 inches carapace length or 10 inches total length and of gravid females. These regulations, implemented in 1978, represent a significant increase in the degree of management constraint. Formerly, legal restrictions only applied to exported animals, including a minimum size of 4 inches total length and a prohibition against the export of gravid females (Peacock, 1974).

There are no restrictions on the harvesting of conch.

The export industry is largely in the hands of individuals who serve as "middle men" between the fishermen and importers. The primary role of these individuals is to identify and negotiate agreements with importers from the external market, purchase and prepare conch and lobster from local fishermen, and, finally, arrange for shipment to fulfill their contractual commitments. Exporters are licensed biannually by government.

The Antiguan Fisheries Department is small, consisting of one fisheries officer and a small secretarial support staff. The government's primary responsibility has been to provide ice for the country's fishermen. Enforcement activities are confined to periodic spot checks at principal landing sites and hotels and restaurants.

In recognition of the "inefficiencies" in the present marketing system, several fishermen have joined together to form a burgeoning fisheries association with the intent of eventually developing into a cooperative.

5.5 Analysis

In light of these comparisons, we offer several observations. First, a principal constraint shared by all fisheries management units was lack of an adequate data base to determine the status of stocks with any degree of certainty. Secondly, in each unit the stated management objective for lobster was MSY. Common management tools shared by all were size and selective harvest (Table 4). However, in terms of number of tools employed to achieve the stated objective, Turks and Caicos and Belize appear to have more restrictive management programs and a well-defined harvest, processing and distribution system which facilitates monitoring activities, unlike the diffuse structure in the Virgin Islands and Antigua. Finally, of the four examples discussed, only Belize and Turks and Caicos currently have conch management programs.

At the risk of over-simplification, Antigua appears to be following the development path previously taken by the U.S. Virgin Islands. Continuing growth of Antigua's tourism sector is creating shortages of local conch and lobster, causing cutbacks in the export market. Whether this trend will continue, resulting in the island's eventual conversion to a dependency on conch and lobster imports, remains to be seen.

On the assumption that we can accept the available evidence indicating continuing levels of exploitation of lobster stocks at or near MSY in Belize and Turks and Caicos, and thus a measure of apparent success of their respective management programs, we can make a few tentative conclusions as follows. Management effectiveness of coastal fish stocks, which is related to the degree of restrictiveness and appropriateness of the tools applied, cannot be guaranteed by the presence of regulations alone, and appears to be closely linked to monitoring a few well-defined production centers rather than monitoring dispersed harvest and distribution networks. Savings in staff and budget derived from concentrated facilities is not applicable to Antigua, with its sole fishery officer. This finding indicates that a certain "critical mass" of management staff is needed to carry out minimal management functions. Finally, Belize was the only country which had an extensive outreach and educational program associated with the fisheries management program, a critical element, in the author's opinion, in determining the program's success.

6. OVERCOMING MANAGEMENT CONSTRAINTS

In light of the four site examples and brief comparative analysis, we need to identify measures to overcome constraints which block the development of effective fishery management strategies in tropical developing coastal countries.

6.1 National Constraints

6.1.1 Data Base

One constraint is the absence of an adequate data base upon which to develop a management program. The traditional response to meeting this need has been to by-pass the data collecting phase and adopt regulations for the same or similar stocks which have been developed elsewhere. In the case of the spiny lobster, much of the early work on life cycles and population dynamics was done in Florida. Since the initiation of management programs based on this work, first by the State of Florida, then by the Southeast and Caribbean Fisheries Management Councils, many Caribbean countries have adopted similar regulations.

In another more recent approach, Munro (1983) describes a technique in which the status of fish stocks can be determined solely by the routine collection of length-frequency data. The significance of this technique is the facilitation and simplification of data collection procedures which would prove particularly relevant to understaffed fishery units. At present at least one such data collection program is under way in Nevis and St. Kitts (Goodwin, personal communication) and is being expanded to include several other Eastern Caribbean Islands.

6.1.2 Enforcement

Once a management data program has been developed, whether designed internally or adopted from other similar programs, the emphasis shifts to implementation. Here one meets a second major constraint, the need for adequate resources, both human and financial, to enforce the newly proposed management regulations.

In Belize, the government's partial response to this need has been to actively solicit the cooperation of the fishermen in support of the achievement of the stated fishery management objectives. Cooperation is facilitated through several participatory programs which, in part, demonstrate that management and conservation of the country's fisheries is to everyone's own best interest. A similar approach is presently being pursued by Environmental Research Projects in Nevis and St. Kitts (Goodwin, personal communication). Both these approaches are in contrast to the more adversarial relationships which exist between harvesters and managers in many developed countries. While differences in effectiveness of regulation implementation may exist between these approaches, for our purposes the principal advantage of the former is the reduced enforcement costs implied by the active cooperation of the fishermen in the management program.

Enforcement costs can be further reduced when landing sites or production centers (cooperatives, processing plants, etc.) are few and concentrated. In both the examples of Belize and the Turks and Caicos Islands, the few sites in need of policing signified reduced manpower demands and more efficient application of available resources to assure regulatory compliance.

In countries where effective enforcement procedures already exist for fin fish stocks but are absent for conch and lobster (or other high-value resources) due to their relative scarcity (such as in shelf-poor Barbados), the management of local production can often still be justified on a cost-effective basis. Continued local production of high-value species can reduce dependency on expensive imports as luxury items for the tourist market or domestic consumption. Where the capabilities already exist to monitor the catch of fish stocks, only a modest additional effort is required to enforce regulations for conch and lobster species (assuming landing sites or processing and marketing facilities are shared with the regulated fisheries). Where these facilities do not exist or in the absence of any organized fishery, benefits accruing from effective enforcement of management regulations for small conch and lobster stock sizes may not offset the associated costs.

6.1.3 Depleted Areas

Up to this point, we have been discussing solutions to management constraints where existing stock levels still justify traditional approaches. In severely depleted areas where management of the remaining stocks is largely an academic exercise "reseeding" is becoming increasingly popular as a management tool for conch. This approach takes advantage of established successful mariculture techniques presently capable of raising conch from eggs to juveniles. Egg supply still remains dependent on collection from the wild, though research is continuing on hormone-induced spawning of captive females (Siddall, 1983).

While present economic and technical constraints may prevent raising juvenile conch to market size (Orr, 1983) the development of low-technology methods and equipment at the University of Miami's Rosenstiel School of Marine and Atmospheric Science (RSMAS) may make restocking strategies a viable venture.

In 1981, the Netherlands Antilles, with the assistance of RSMAS, initiated the Carco project in Bonaire. The project consisted of setting up a small laboratory, collecting conch egg masses, and hatching and rearing conch to the juvenile stage. The first batch was released in 1983, and the initial findings indicate survival rates are much higher than expected (van Buurt, personal communication). Other hatchery activities are currently under way at the University of Puerto Rico and Foundation for PRIDE in the Turks and Caicos Islands.

Advances in culturing spiny lobster have been slow. Its long and complicated larval phase has so far prevented artificial rearing efforts to complete its life cycle. Despite these problems initial experiments conducted by Environmental Research Projects in Grenada, employing settlement plates to collect recently metamorphosed lobster juveniles for pen rearing have proved promising.

These restocking tools would be unnecessary in an ideal world where effective natural stock management is commonplace. But in a real world characterized by rapidly diminishing conch and lobster populations, we are fortunate restocking strategies do exist and their continued development should be encouraged.

6.1.4 Habitat Modification

FAO has estimated that between 50 and 70 percent of the world's commercial fish catch comes from species which utilize coastal and estuarine areas (FAO, 1980). Uses vary among species and include one or more of the following: critical habitat for spawning or nursery grounds, feeding sites and protection. Coastal areas also provide the major source of nutrients to adjacent waters on which the food web is built and fish populations are dependent.

Coastal alterations without adequate planning can significantly affect these relationships often at the expense of many of the dependent coastal species. In the example of the Virgin Islands, due to the absence of baseline information, we will never know to what extent intensive coastal development during the 1960's and the subsequent loss of highly productive communities affected offshore conch and lobster populations.

In recognition of the growing problem of coastal degradation, Odum (1982) identified three basic approaches to incorporate coastal land use considerations into fishery management strategies. The first, and simplest, is to protect the fish populations during the stage of their life history when they use critical habitat. The second approach is to protect specific types of habitat such as in the designation of protective marine and estuarine reserves. Finally, the third, and most difficult, is to protect all habitat types which affect the coastal regime.

Recent legislation in Belize represents an example of an approach which falls between Odum's second and third options. In response to increasing deterioration of the coastal area due to pollution, tourism and urbanization (Miller, 1981) and the threat it posed to the country's fisheries, the government approved new regulations which gave the ministry responsible for fishery affairs the power to declare marine reserves to include adjacent lands. Reserve designation provides a protective status for the area and prohibits the destruction or disruption of its environmental quality. Attempts are under way to strengthen the existing regulations providing for power of review for any proposed coastal land use activity and to assess potential impact on the nation's fisheries.

The common thread shared by these approaches is the importance of acknowledging the linkages between the coastal area and its marine fisheries and the need to account for these relationships in both the management of fisheries per se as well as in the development of a comprehensive coastal area management strategy.

6.2 Regional Constraints

Despite evidence of the potential success of many of these innovative solutions to traditional management constraints, they remain national approaches which are most effectively initiated at that level. In addition to these national approaches, several issues argue for a broader management approach than one based solely on physical or national boundaries. For our purposes, we will call these transboundary issues.

6.2.1 Foreign Fishing

One transboundary issue, foreign fishing, represented a major obstacle to effective management of stocks in both the Turks and Caicos Islands and Belize examples. This activity in effect circumvents national management efforts, making them less effective. Such illegal fishing not only places additional pressure on fish stocks but creates a potentially more serious problem among local fishermen. The typical reaction by locals to the realization that foreigners are flagrantly violating management regulations for fish stocks is to adopt the same behavior. This, in turn, makes a difficult situation worse and can eventually lead to the defeat of the proposed management program objectives.

One potential solution may exist in the example of the reciprocal fishery agreement signed between the United States and the United Kingdom which has permitted existing and historical patterns of fishing to continue between the waters of the U.S. and British Virgin Islands. A similar approach is being followed by Antigua and Guadeloupe to establish the right of mutal access for fishermen to their respective territorial waters. These agreements in turn provide the basis for the formulation of a common management program applicable to the signatory countries' respective fish stocks.

6.2.2 Biological Linkages

Transboundary issues can also be of a biological nature. Experiments by Ingle et al. (1963), indicating the occurrence of abnormally high densities of lobster larvae in Florida waters, suggested larvae could have been transported by ocean currents from distant spawning areas located to the south of the Yucatan Channel. Other researchers have suggested that lobster larvae are of local origin which have become trapped in gyres contributing to susbsequent increased population counts (Johnson, 1974). While these explanations have yet to be satisfactorily resolved, the existence of possible relationships between two populations could have profound management implications. An example of a recent attempt to treat fishstocks separated by a political boundary as a single population unit is the lobster management plan developed by the Caribbean Fisheries Management Council. This plan recommended that uniform regulations and a common MSY be adopted by the governments of the U.S. Virgin Islands and Puerto Rico.

6.2.3 Economic Linkages

These political and biological transboundary examples share an economic counterpart. If a major producer country introduces a new technology, or older technologies previously prohibited due to their effectiveness in harvesting a resource to depletion, the short term effect is to lower international market prices. This, in turn, puts pressure on producers in other countries to adopt the same methodology to stay competitive. In the case of conch, many experts feel that a partial explanation for the success of the Belize and the Turks and Caicos management programs has been the prohibition of SCUBA which protects deeper water inhabitants which act as brood stocks to shallow water populations (Dammann, personal communication). However, recently increased levels of imports of conch into the Miami market taken by SCUBA in Colombia (estimated to be 103 thousand kg from the period January to October, 1983, NMFW, New Orleans) have placed pressure on at least one Turks and Caicos producer to ask the government to reconsider conch management regulations in the islands (Gasgill, personal communication). While the expanded use of this technology would eventually result in the depletion of the resource causing both a shortage in Miami and higher prices, many producers prefer not to wait. Thus, economic pressure dictated by one country can have a deleterious effect on stocks regionally.

6.3 Regional Planning

International transboundary issues must be taken into account in planning for the management of living marine resources and require some form of regional strategy to supplement and coordinate existing national approaches. This is not a new concept, and there is evidence that some, albeit slow, progress is occurring toward achievement of that objective. In regard to fishery management, the Western Central Atlantic Fisheries Commission (WECAFC) in 1980 endorsed standardization of size limits on spiny lobsters within its area of jurisdiction. This recommendation was seconded in an informal joint workshop in Costa Rica involving fishery professionals from 23 countries in the west central Atlantic region (Villegas, et al., 1982). In the area of enforcement, transboundary issues are also being addressed. Three countries in the region (Barbados, St. Lucia and St. Vincent) are negotiating the development of a regional patrol boat capability to enforce newly declared exclusive economic zones on a shared cost basis. The United Nations Environmental Program's (UNEP's) Wider Caribbean Regional Seas Action Plan identified investigative studies of the role of coastal ecosystems priority issue (UNEP, 1980). It is only through the continuation and support of these kinds of efforts leading toward a regional management approach of living marine resources that the long-term sustainable utilization of the common resource will ever be fully assured.

7. LESSONS LEARNED

(1) Economic Significance

- Coastal fisheries are important to many tropical developing countries. Conch and lobster fisheries represent major sources of employment and income to many coastal peoples of the Caribbean. The two fisheries, in combination, provide Turks and Caicos' primary source of foreign exchange and account for significant portions of GNP in Belize and Antigua. Among the four areas studied as examples, an estimated 2,000 fishermen depend heavily on the income derived from these two fisheries resources, earning an average income ranging from US$4,000 to $7,000.

(2) Market Considerations

- Harvest pressure on coastal fisheries is extremely sensitive to market demand. In most cases cited in the study, no commercial market existed for conch or lobster prior to 1950. Lobster was considered a nuisance fouling fish pots, and conch was harvested only for local consumption, Turks and Caicos' Haitian market being the exception. Rapid increases in demand attributed to increased consumer sophistication and the development of alternative markets led to increases in exploitative pressures on lobster. Similarly, in response to declines in Floridian conch populations and increased demands from the United States' Latin and West Indian populations augmented by tourism, market prices rose, providing the incentive for conch exportation to the United States.

(3) Over-fishing Risks

- Rapid increases in fishing pressure in the absence of management constraints can result in over-fishing and eventual stock depletion. In all sites described in the study, with the possible exception of Belize's and Turks and Caicos' lobster fisheries, increased pressure to export conch and lobster resulted in apparent rapid population declines. This pattern appears to accurately depict a larger regional phenomenon, based on the results from a survey questionnaire.

- Depletion of fish stocks may result in significant local social and economic costs. The U.S. Virgin Islands represents a good example of decreases in local stocks, coupled with increased demand, resulting in a reversal of the territory's traditional role, i.e., from lobster exporter to importer of both lobster and conch. There are indications that Antigua is following the same pattern. Other "costs" include the increased distances fishermen must travel to exploit new grounds, lost income from reduced catch, and secondary costs such as reductions in supplies of traditional protein sources in Haiti and Turks and Caicos as the regional market for conch developed.

(4) Management Requirements

- The existence of fishery regulations alone do not assure a stock's successful management. In all site examples, with the possible exception of Belize, the apparent declines in lobster populations took place despite existing regulations. This implies that effective management requires a more comprehensive approach which includes, in addition to appropriate regulations, educational outreach programs to solicit active cooperation from the fishermen and community at large, adequate enforcement and data collection activities.
- Increased management efforts characterized by more stringent harvest regulations were developed only after over-fishing of conch and lobster become evident. Despite widespread indications of local stock depletion, present lobster regulations were implemented only recently in the U.S. Virgin Islands (1980), Belize (1963 and amended periodically since then), Antigua (1978), and Turks and Caicos (1973). Presently, conch remains unregulated in the U.S. Virgin Islands and Antigua. These results appear to be generally indicative of the situation in the wider Caribbean region based on information collected from the questionnaires.
- Successful management programs can be both efficient and economical. In terms of cost, both Belize and Turks and Caicos represent examples of areas where ad valorem taxes based on exports of conch and

lobster bring in income which far exceeds the costs of management. In addition, management effectiveness can be increased at reduced costs by encouraging active cooperation from the fishermen through outreach programs (Belize), and concentrating the number of landing sites and/or production facilites required to monitor for compliance.

- The absence of adequate data collection programs is a major constraint on the management of fish stocks. The case study adequately demonstrates the difficulties encountered in determining the status of fish stocks in the absence of sufficiently long time-series data collection. Gross catch statistics do not account for effort invested and thus are inappropriate to judge the effects of fishing pressure on stocks and the effectiveness of the management program. Methodologies have been developed which simplify data collection procedures and provide staff-short fishery units with the means to make rudimentary assessment of fish stocks.
- The increased incidence of fishery issues which are of an international (transboundary) nature argue for new integrative approaches to fishery management. These issues demonstrate the need for a more holistic approach to fishery management. On a national basis this may include the adoption of review measures for coastal development activities which threaten critical coastal habitats or species shared with adjacent states or territories. Regionally, the development of bilateral or multilateral management programs may be required.

8. GUIDELINES

(1) Management objectives should be defined prior to the development of a fisheries management program. Management objectives will differ depending on whether the stated goal is maximization of catch, net revenue or a larger set of socioeconomic benefits. In most cases, levels of yield will change between goals. It is the desired yield level which will serve as a target of the fishery program and govern the selection of the appropriate management tools.

(2) A comprehensive fisheries management program requires the systematic collection and analysis of data. The status of fish stocks and in turn the effectiveness of the management program cannot be determined without minimally collecting catch per unit effort (or length frequency) data over a sufficiently long period to identify trends in fish populations.

(3) To increase the effectiveness and chances of success of a management program, the active cooperation of producers and harvesters should be pursued. Sustainable yield management objectives are ultimately in the best interest of the producers as well as the consumers. An active effort to involve the users of the resource (the fishermen) in management program design is essential. This participatory approach should extend to the designing of management regulations. Mechanisms should be established to provide means for ongoing dialogue and education in both directions. Where possible, fishery management should be approached as a cooperative venture rather than an adversarial one especially in countries where artisanal (subsistence) fisheries survive side-by-side with commerical fisheries.

(4) Facilities for commercial fishery landing and product processing should be concentrated to facilitate monitoring for regulatory compliance. Dispersed landing and distribution sites create excessive demands on enforcement staff. In countries where financial constraints dictate that government management and enforcement programs be highly efficient, marketing or processing "control points" can ease monitoring and enforcement procedures.

(5) Research activities should be integrated in a comprehensive management program. Most existing fish population models have been developed in temperate latitudes and have little relevancy for tropical fish populations, suggesting the need for new models more appropriate to tropical systems. Research is also needed on the linkages between tropical coastal habitat modifications and fisheries activities.

(6) In addition to monitoring and governing fish harvest activities, any framework for fisheries management needs to monitor other coastal resource harvesting and development activities which may adversely affect fish stocks. Increased losses of coastal fish production attributable to habitat degradation, from pollution or other environmental modifications, signify the need for a management mechanism which will evaluate the possible impact of proposed development on coastal fish stocks and provide means for mitigation. Options for such a mechanism include incorporating an environmental impact assessment requirement for coastal-related projects, empowering the existing fisheries management unit with a review function or the creation of a multiagency body to resolve conflicts over coastal resource use.

(7) Where coastal fisheries are significantly affected by forces of a regional nature, bilateral or multilateral organizations or agreements may be required to remedy the problem. The apparent increasing incidence of issues of transboundary nature which affect coastal fish stocks demonstrate the inadequacies of national or local management approaches. New management approaches and mechanisms must be developed to address and resolve transboundary issues.

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APPENDIX 1

Summary, Sources and Methods of Data Acquisition

One phase of the data collection process consisted of mailing one survey questionnaire to each Caribbean country fishery officer (or equivalent where the position did not formally exist). The objectives of the survey were to obtain an additional perspective on the important issues related to conch and lobster management as well as to collect further information for the completion of the case study.

A master mailing list was compiled from a list previously developed by the author for an earlier survey, personal knowledge of particular individuals in the field and through information provided by the National Marine Fisheries Service.

Of the 34 countries (colonies, commonwealths etc.) identified within the geographic distribution of conch and lobster, surveys were mailed to 27 officers. The remaining seven countries, due either to recently completed or pending trips, were deleted from the list as the questionnaires were considered redundant to scheduled personal interviews in each of the countries.

The format (Attachment 1) consisted of six parts requesting general information and various data concerning the harvesting, marketing, imporation, management and discernable trends in the status of both conch and lobster.

Of the 27 questionnaires mailed, 13 were filled out or responded to by letter for a 48 percent rate of return (Table 1). Together with the 9 countries visited, information was collected from 22 of the 34 countries equivalent to 65 percent of the total. Data from the remaining 12 countries were obtained through review of the literature, use of the results from previous surveys (IRF, 1980), and contact with other investigators in the field. In general, while the latter approach sufficed in collecting basic information relating to the two species, more detailed and/or current data concerning their status were scarce.

Three tables have been constructed summarizing the information ob-

Attachment 1

ISLAND RESOURCES FOUNDATION

May 27, 1983

Coastal environments in many developing countries are undergoing significant alterations as a result of development activities. One approach to understanding these changes is to document examples of current coastal resource management practices in these countries in order to anticipate future uses of the coastal zone as well as needed technical assistance programs by bilateral/multilateral agencies.

As a part of a larger documentation/case study effort initiated by U.S. AID and the U.S. National Park Service, the ISLAND RESOURCES FOUNDATION is presently examining the effectiveness of sustainable-yield management strategies in the development of coastal fisheries in the Caribbean region. Our specific objectives are *to document the development of the conch and spiny lobster fisheries in selected Caribbean countries, identify effective local management practices where they exist, determine why certain approaches have been effective and evaluate their potential application to other areas in the region.*

To assist us in the early stages of this effort, we have developed a questionnaire (enclosed) which focuses on information about resource utilization patterns as these have developed over time on a country specific basis. While we recognize how time consuming questionnaires can be, we also observe that well-documented case studies will provide a basis for more effective management of the Caribbean's renewable resources. To help build a solid information base, we are asking for your input to this task.

We should also emphasize that our documentation effort is not simply another "shelf study" but will ultimately influence the technical assistance efforts of international aid agencies supporting fisheries development programs in the Caribbean region. We hope you will be able to help us in this effort by returning the enclosed questionnaire at your earliest convenience. A return envelope is also provided. Thank you for your cooperation.

Sincerely,

Edward L. Towle, Ph.D.	Random DuBois
PRESIDENT	MARINE RESOURCES SPECIALIST

/ss
Enclosures (2)

RED HOOK CENTER BOX 33 • ST. THOMAS, U.S. VIRGIN ISLANDS 00802 • (809) 775-3225

Attachment 1

ISLAND RESOURCES FOUNDATION

CARIBBEAN REGION CONCH AND LOBSTER CATCH AND MANAGEMENT QUESTIONNAIRE

PART I - GENERAL INFORMATION.

COUNTRY (OR TERRITORY) ______________________________

CURRENT FISHERIES OFFICER ______________________________

ASST./DEPUTY FISH. OFFICER ______________________________

BEST MAILING ADDRESS ______________________________

____

QUESTIONNAIRE COMPLETED BY ____________________ DATE ________

Reimbursement for the airmail postage for returning questionnaire is requested. yes ______ no ______

We would like to receive a questionnaire summary and the IRF "Bulletin". yes ______ no ______

INSTRUCTIONS FOR FOLLOWING PAGES OF THIS QUESTIONNAIRE:

When citing quantitities of landings of conch and lobster, please specify if these are live animals OR lobster tails or conch meat (without shell).

When citing value, please specify currency/unit (for example: EC dollars/lb. or US dollars/kilo, or any equivalent). Indicate BOTH currency and weight or volume unit used. Convert to US dollars if convenient. If not convenient, please cite official currency exchange rate for the currency used.

Feel free to elaborate or cite special seasonal or locational variations or exceptions (using the back of each questionnaire page for any extended remarks).

Whenever possible, enclose with the returned questionnaire any available and relevant recent fisheries statistical data, reports, or summaries. We shall reimburse you for postage and return any documents provided if requested to do so.

THANK YOU.

RED HOOK CENTER BOX 33 • ST. THOMAS, U.S. VIRGIN ISLANDS 00802 • (809) 775-3225

Attachment 1

USE BACK SIDE FOR ADDITIONAL COMMENTS. PLEASE INDICATE QUESTIONNAIRE ITEM NUMBER WHEN SO DOING.

PART II - HARVESTING THE RESOURCE.

1. HOW MANY FISHERMEN DEPEND ON FISHING (CONCH, LOBSTER AND FINFISH) AS A LIVELIHOOD?

   FULL TIME ________ PART TIME ________

2. HOW MANY FISHING BOATS ARE CURRENTLY REGISTERD? ________

3. HOW MANY FISHING VESSELS ARE MOTORIZED? ________

4. HOW MANY FISHERMEN DEPEND, AT LEAST IN PART, ON FISHING CONCH/LOBSTER? ________

   BOAT OWNERS ________ CREW ________ OTHER ________

5. WHAT WERE THE ESTIMATED QUANTITITES LANDED FOR EACH RESOURCE FOR THE MOST RECENT YEAR FOR WHICH DATA EXISTS?

   CONCH ________ (year ________)

   LOBSTER ________ (year ________)

6. WHAT HAVE BEEN THE RECENT TRENDS (CHANGES) IN LANDINGS OF CONCH? LOBSTER?

   CONCH ________ (year prior to no. 5 above)
   LOBSTER ________ (year prior to no. 5 above)
   CONCH ________ (five years ago)
   LOBSTER ________ (five years ago)

   If figures are not available, please indicate whether there was an increase or a decrease.

7. HAS THE TRADITIONAL METHOD UTILIZED FOR HARVESTING THE RESOURCE CHANGED, AND HOW?

   CONCH(traditional) ________ ; (present) ________

   LOBSTER (traditional) ________ ; (present) ________

8. WHAT ARE THE RANGES OF DEPTH AND PRIMARY GEOGRAPHICAL LOCATION(s) CURRENTLY FISHED FOR:

   CONCH - DEPTH ________; LOCALITY (ies) ________

   LOBSTER - DEPTH ________; LOCALITY (ies) ________

PART III - MARKETING THE RESOURCE.

9. WHAT QUANTITY OF LANDINGS PER YEAR IS:
   a) SOLD DIRECT TO THE CONSUMER? CONCH ________ LOBSTER ________
   b) SOLD TO LOCAL TOURIST FACILITIES? CONCH ________ LOBSTER ________
   c) EXPORTED? CONCH ________ LOBSTER ________

10. WHAT IS (ARE) THE PREDOMINANT EXTERNAL DESTINATION(s) FOR EXPORTS?

    CONCH ________ LOBSTER ________

11. IN WHAT FORM IS THE RESOURCE EXPORTED (FRESH, FROZEN, CANNED, ETC.)?

    CONCH ________ LOBSTER ________

12. WHAT IS THE MOST RECENT PRICE OF THE RESOURCE AT DOCKSIDE (WITHIN THE PAST 12 MONTHS)?

    CONCH: HIGH ________ LOW ________ LOBSTER: HIGH ________ LOW ________

13. WHAT IS THE MOST RECENT PRICE OF THE RESOURCE SOLD FOR EXPORT?

    CONCH: HIGH ________ LOW ________ LOBSTER: HIGH ________ LOW ________

14. WHEN DID SIGNIFICANT (OVER 20% OF THE CATCH) EXPORT OF THE RESOURCE FIRST BEGIN?

    CONCH: ________ LOBSTER: ________

Table 1. Sources of Data for the Case Study.

	Recipient of Questionnaire	Returned Questionnaire	Site Visit	Literature Review/Other
Anguilla			X	X
Antigua/Barbuda	X	X	X	X
Bahamas	X	X		X
Barbados	X	X	X	X
Belize			X	
Bermuda	X	X		X
Brazil[1)]	X			X
Cayman Islands	X	X		
Colombia	X	X		X
Cuba[1)]	X			X
Dominica	X	X		X
Dominican Republic	X		X	X
Grenada	X			X
Guatemala	X	X		
Guadeloupe	X			X
Haiti	X		X	X
Honduras	X	X		
Jamaica	X	X		X
Martinique	X			X
Mexico[1)]	X			X
Montserrat	X	X		X
N. Antilles	X	X		X
Nicaragua	X			X
Panama	X		X	
Puerto Rico				X
St. Kitts/Nevis	X	X		
St. Lucia	X		X	
St. Vincent	X			X
Trinidad/Tobago	X			X
Turks/Caicos			X	
U.S. (Florida)				X
Venezuela	X			X
Virgin Islands (U.K.)			X	X
Virgin Islands (U.S.)			X	

[1)]Data on lobster only.

information was not provided, responses were vague, or the literature failed to address the issue, it was noted by the designation N.A. (not available).

Table 2 describes the currently perceived status of the respective fish stocks by fishery officers. "Stable" can be interpreted as equal to or near MSY. "Good" signifies under-utilized stocks, and "unknown" in most cases was attributable to lack of information on which to base a judgement.

Table 3 lists only those categories identified by the fishery officers in their responses. Illegal fishing pertains to both national and foreign fishing activities.

Similarly, Table 4 lists only those constraints identified by the respondees in the questionnaires. One response, poverty, was incorporated under the socio-economic constraint category.

Table 2. Estimated present status of the conch and lobster resource in Caribbean nations.

	Depleted/ Overfished Conch (C)	Depleted/ Overfished Lobster (L)	Stable C	Stable L	Good C	Good L	Unknown C	Unknown L	Source
Anguilla	X	X							S.V.
Ant./Barb.		X					X		1983 Q
Bahamas					X	X			1983 Q
Barbados		X							1983 Q
Belize	X			X					S.V.
Bermuda	X	X							1983 Q
Brazil									N.A.
Cayman Is.	X	X							1983 Q
Colombia							X	X	1983 Q
Cuba									N.A.
Dominica	X	X							1983 Q
Dom. Rep.							X	X	S.V.
Grenada						X			1980 Q
Guatemala							X	X	1983 Q
Guadeloupe									N.A.
Haiti							X	X	S.V.
Honduras	X	X							1983 Q
Jamaica						X	X		1983 Q
Martinique									N.A.
Mexico									N.A.
Montserrat	X	X							1983 Q
N. Antilles	X	X							1983 Q
Nicaragua									N.A.
Panama							X	X	S.V.
Puerto Rico	X			X					L.R.
St. Kitts/N.		X					X		1983 Q
St. Lucia				X					1980 Q
St. Vincent	X								L.R.
Trin./Tob.					X				1980 Q
Turks/Caicos				X			X		S.V.
U.S. (Fla.)			X	X					L.R.
Venezuela		X							1980 Q
V.I. (U.K.)							X	X	S.V.
V.I. (U.S.)	X	X							S.V.

Source Key:

S.V. = Site Visit
1980 Q = Island Resources Foundation Fisheries Questionnaire, 1980
1983 Q = Island Resources Foundation Fisheries Questionnaire, 1983
N.A. = Not Available
L.R. = Literature Review

Table 3. Major causes of depletion of the lobster and conch resource in Caribbean nations.

	Lobster			Conch			
	Over-fishing	Illegal fishing	Habitat Destruction	Over-fishing	Illegal fishing	Habitat Destruction	Source
Anguilla							
Ant./Barb.	X						1983 Q
Bahamas					X		1983 Q
Barbados	X						1983 Q
Belize		X		X			S.V.
Bermuda	X		X	X		X	1983 Q
Brazil							N.A.
Cayman Is.	X			X			1983 Q
Colombia							N.A.
Cuba							N.A.
Dominica	X			X			1983 Q
Dom. Rep.					X		S.V.
Grenada	X						L.R.
Guatemala							N.A.
Guadeloupe							N.A.
Haiti	X			X			S.V.
Honduras	X	X		X	X		1983 Q
Jamaica	X						1983 Q
Martinique							N.A.
Mexico							N.A.
Montserrat	X			X			1983 Q
N. Antilles	X						1983 Q
Nicaragua							N.A.
Panama	X						S.V.
Puerto Rico	X			X			L.R.
St. Kitts/N.	X						1983 Q
St. Lucia	X		X	X		X	S.V.
St. Vincent							N.A.
Trin./Tob.							N.A.
Turks/Caicos	X			X			S.V.
U.S. (Fla.)		X					L.R.
Venezuela							N.A.
V. I. (U.K.)	X			X			S.V.
V. I. (U.S.)	X			X			S.V.

Source Key: S.V. = Site Visit
1980 Q = IRF Fisheries Questionnaire, 1980
1983 Q = IRF Fisheries Questionnaire, 1983
N.A. = Not Available

Table 4. Principal constraints to effective management of the conch and lobster resource in Caribbean nations.

	Socio-economic	Lack of Cooperation from Fishermen	Increased Education Needs	Lack of Enforcement	Data Needs	Technical Needs	Source
Anguilla				X	X		S.V.
Ant./Barb.						X	1983 Q
Bahamas				X			1983 Q
Barbados	X		X				1983 Q
Belize				X			S.V.
Bermuda				X			1983 Q
Brazil							N.A.
Cayman Is.					X		1983 Q
Colombia							N.A.
Cuba							N.A.
Dominica					X		1983 Q
Dom. Rep.				X	X		S.V.
Grenada							N.A.
Guatemala							N.A.
Guadeloupe							N.A.
Haiti							N.A.
Honduras	X						1983 Q
Jamaica		X		X	X		1983 Q
Martinique							N.A.
Mexico							N.A.
Montserrat			X				1983 Q
N. Antilles							N.A.
Nicaragua							N.A.
Panama							N.A.
Puerto Rico				X	X		L.R.
St. Kitts/N.					X		1983 Q
St. Lucia					X		S.V.
St. Vincent							N.A.
Trin./Tob.					X		L.R.
Turks/Caicos				X			S.V.
U.S. (Fla.)							N.A.
Venezuela							N.A.
V.I. (U.K.)				X	X		S.V.
V.I. (U.S.)				X	X		S.V.

Source Key: S.V. = Site Visit N.A. = Not Available
L.R. = Literature Review
Q 1983 = IRF Fisheries Questionnaire, 1983

Case Study Five

COASTAL FISHERIES, AGRICULTURE AND MANAGEMENT IN INDONESIA: CASE STUDIES FOR THE FUTURE

R. Eugene Turner

SUMMARY

Two case histories in Indonesian coastal management are described as revealed through field visits, interviews, literature review and author's experience. One case study involves an agricultural development plan for a Java estuary. It was rejected in favor of maintaining the existing estuarine-dependent coastal fisheries. The second study reviews a single purpose and massive agricultural land reclamation in the sparsely populated coastal swamps of South Kalimantan. Lessons and guidelines developed include recommendations for 1) integrated and flexible long-term ecosystem management involving local, regional, and state resource agencies, 2) comparative field studies of existing programs to determine trends in agricultural yields, cumulative impacts, and social structure and function, and, 3) conservation of ecosystem functions, particularly those of mangroves, which support sustainable economies.

1. INTRODUCTION

This paper presents two case studies on the coastal management of Indonesia. The Indonesian setting is briefly outlined and then the two case studies are described individually in terms of geography, management issues, and present situation. Broadly stated 'lessons learned' from these case studies follows next. This paper concludes with specific guidelines applicable to individual management situations in Indonesia and elsewhere.

Indonesia is a logical choice for study because Indonesia's coastal zone is Indonesia. The 2 million square kilometers of 13,677 islands are about two-fifths the area under her jurisdiction. Five of the world's ten largest islands are in Indonesia. Her population is the fifth largest in the world and exceeds the combined total of all other southeast Asian nations. In the year 2000 it is projected to reach 220 to 240 million people. Approximately 61% of the population live in districts bordering the 62,000 km coastline. Java, with only 7% of the land area, has 62% of the population living at 620 persons per square kilometer. Consequences of the present 2.34% annual population growth rate (Figure 1) are that people are either migrating to less populated islands or trying to produce more in already crowded living space near the sea. Tensions and conflicts inevitably develop and the long-term resource stability is tenuous.

The government has attempted to address the pressures of a growing population in three ways: population planning, increased resource exploitation, and opening up new areas for agriculture and transmigration in the

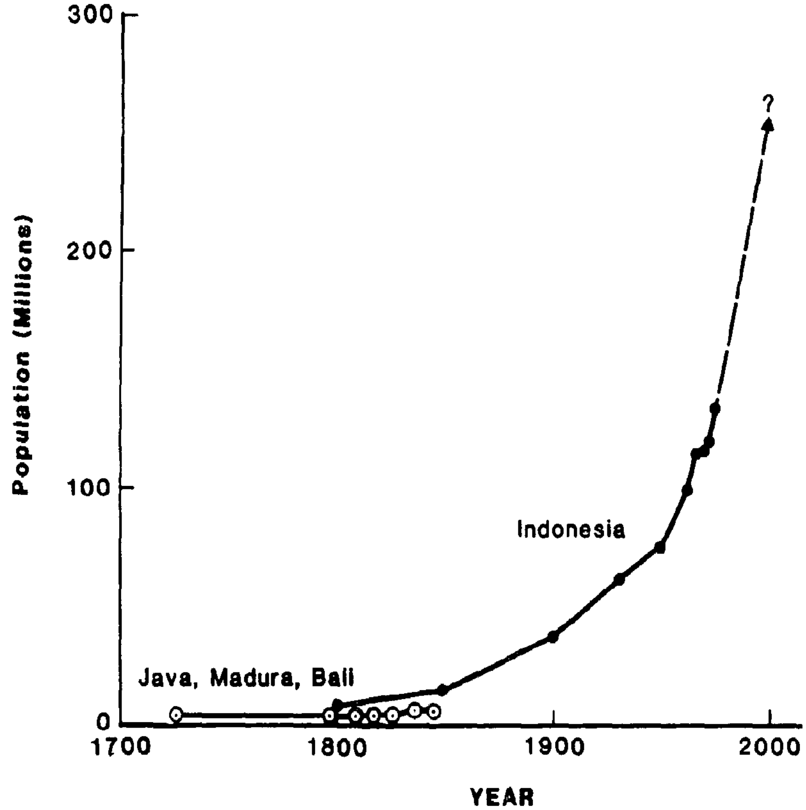

Figure 1. Population growth in Indonesia over the last two hundred years (from various official government estimates).

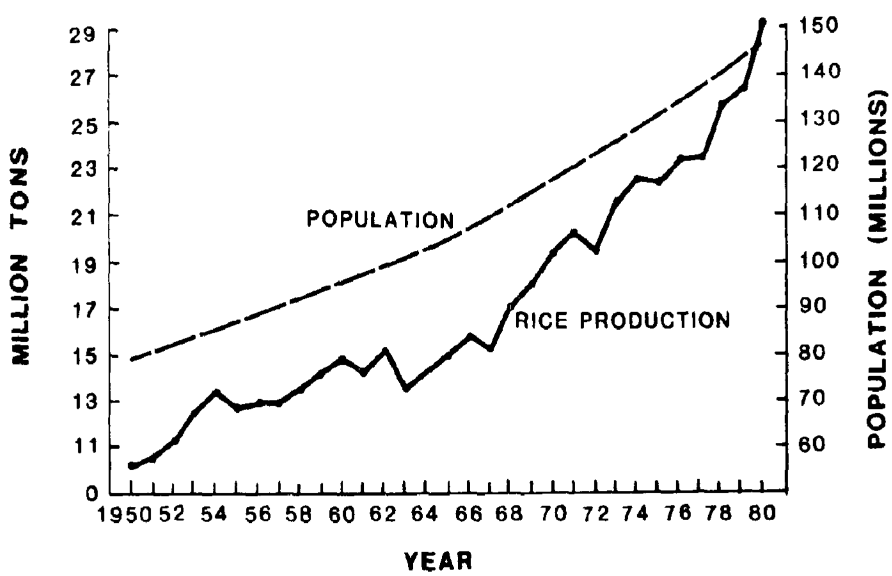

Figure 2. Rice production from 1950 to 1980 (from Oldeman and Frère, 1982).

coastal zone. Population planning does not appear to be successful, at present. However, total rice production has tripled from 1950 to 1980 and per capita production increased from 130 kg to 200 kg over the same period (Figure 2). The increase in rice production in the 1950s was almost entirely due to an increase in land under cultivation. Since then the production per unit area has increased from 2,050 kg per ha to 3,000 kg per ha of rough rice. Most of the increase has been from wetland rather than upland rice.

In spite of these remarkable increases, Indonesia has been annually importing roughly 2 million metric tons (mt) of the world's 8 million mt of rice exports (Afiff et al., 1980) and the gap between national production and demand is widening. In years of poor yields, such as 1977, up to one-third of the world's exportable supplies have been purchased to maintain price stability. Thus, decreasing imports and increasing foreign exchange earnings are important for maintaining both food supplies and financial stability. In 1981-1982 oil exports were 82% of the total export earnings. In 1983 oil earnings tumbled by 30% (Arndt, 1983). The natural resource base is thus under increasing pressure to make up the difference.

Vast expanses of sparsely populated coastal land outside of Java, Bali, and Madura may seem to be the hoped-for relief from overpopulation and to be a stimulus for economic development. A national goal has been to move large numbers of the rural poor and often landless people into the estimated 40 million hectares of potentially productive agricultural coastal swamplands (Andriesse, 1974). Three purposes have dominated official transmigration planning from as early as 1902 to the present day (Tjokroamidkjojo, 1977; Hardjono, 1977; Charras, 1982): 1) reducing population in densely settled areas, 2) expanding manpower to areas of short supply, and 3) extending control of the central government to the lesser developed outer islands. The intensity of transmigration has varied from an annual average of 1,013 people from 1905 to 1931, to between 6,900 and 24,000 people from 1932 to 1969, to an average of 36,480 from 1970 to 1974 (Jones, 1979). Most, but not all, of the interprovincial movement is between what is known as the 'inner' islands of Java, Bali, and Madura and to the other 'outer' islands (Figure 3; Hugo, 1979a, b, c). The majority move from Java to Sumatra.

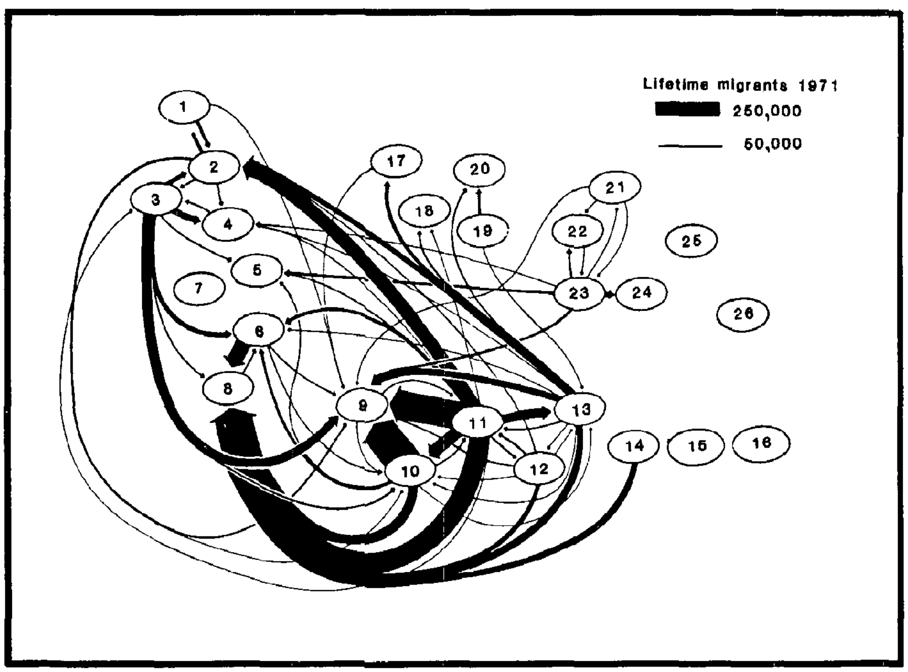

Figure 3. Migration between provinces as of 1971 (from Hugo, 1979a). The provinces are shown in the top panel, the net lifetime movement in 1971 in the bottom panel.

Both government sponsored and spontaneous migration occur. Government sponsorship may include transportation, temporary housing, food for 12 to 18 months, tools, education and health facilities, and seeds. Acreage allotments are presently about 2 ha per family. The spontaneous migrant, a distinctly different type of migrant, arranges for his own personal transportation and settlement although rations and tools are occasionally supplied.

Although transmigration policies are changing (Suratman and Guinness, 1977; Hjardjono, 1977), projects still suffer from mismanagement, agricultural difficulties, and social conflict (e.g., Jakarta Post, 1983). Optimistic predictions of the numbers planned to be moved have routinely not been achieved. But people have moved. However, total migration is small compared to population growth. Jones (1979) points out that while some 990,000 people were moved from 1932-1974, Java's population grew by 39 million.

Rice cultivation was, and still is, the primary concern of new settlements. The newly settled land is usually not on the neutral volcanic soils found on Java. Significant differences in climatic regimes and soil exist between islands as one would expect (e.g., Fyfe et al., 1981; Oldeman and Frére, 1982). In 1978, for example, the average national yields of rough rice were 3,170 kg per ha. They were 2,175 kg per ha in Kalimantan, but 3,755 kg per ha on Java (Oldeman and Frére, 1982).

In contrast, supplies of animal protein, particularly marine fisheries, appear to be reaching a maximum for present technology (Figure 4). In 1955 the average production from fresh water and brackish water fish ponds was 379 kg per ha and 224 kg per ha, respectively (Soekarno, 1959). In 1980 production was 1,724 kg per ha and 519 kg per ha, respectively (from Annual Reports of the Indonesia Directorate General of Fisheries). From 1960 to 1980 the total yield from inland fisheries increased an average 1.3% annually, compared to 11% for marine fisheries (now approximating a steady-state situation).

Indonesia is struggling to find socially acceptable solutions to the natural resource problems before reaching the limits of climate, soil fertility, social cohesion, energy resources, and technology. Her resources to do so may seem large but they are limited too. Indonesia has only one sixty-fourth of the total per capita government expenditures of the United

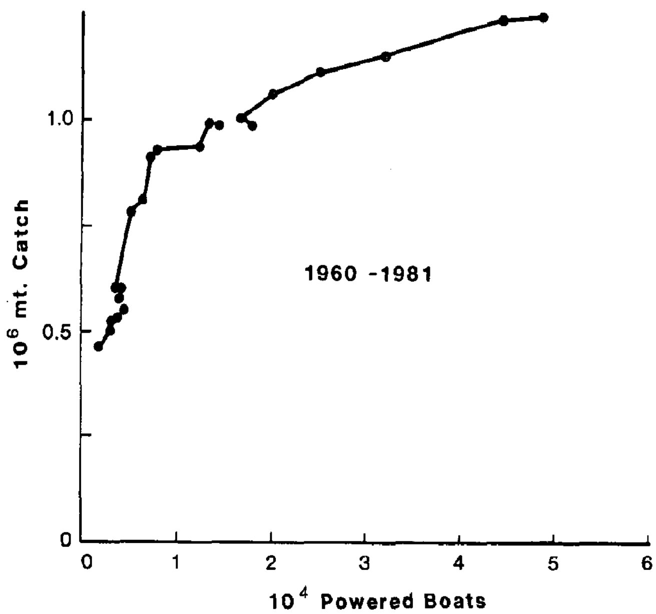

Figure 4. Marine fisheries production and the number of motored vessels in the fleet, from 1960 to present (from Annual Reports, Directorate General of Fisheries of Indonesia).

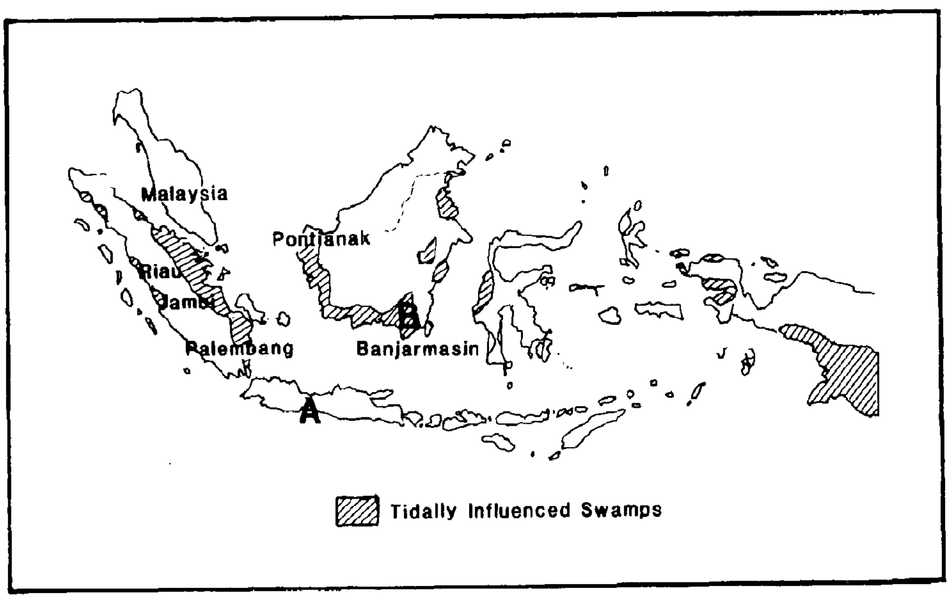

Figure 5. The location of the tidally influenced swamps and two study sites in Indonesia. 'A' is Segara Anakan. 'B' is the Pulau Petak delta.

States (in 1978), but a similar population size and a larger territorial jurisdiction. Already there are constructive discussions and serious differences within the government about the merits of using coastal mangroves primarily as a forestry, offshore fisheries, pond culture, or agricultural zone. Traditional land use practices are changing with the expansion of the central government via roads, canals, and movement of official transmigrants into sparsely inhabited lands. There is a sense of urgency to quickly meet these challenges before opportunities and solutions disappear. In the face of such expansion and rapid change one may rightfully ask "is a man with an empty belly able to think in terms of safeguarding his own environment against disaster?" (Andriesse, 1979).

The purpose of this study is to present two apparently contrasting examples of coastal management in Indonesia to illustrate some lessons framed in a local context. The two areas are a brackish estuary near Cilacap on Java and a coastal swamp near Banjarmasin, Kalimantan (Figure 5). The Javanese estuary is on the most densely populated island in Indonesia and perhaps in the world. In contrast, Kalimantan is 28% of Indonesia's land area, but it has only 10% of the country's population and is growing at a mild 1.4% annual growth rate. The Javanese example is the result of foregoing an agricultural development project in favor of maintaining an existing coastal fisheries. The Kalimantan project is primarily designed to open up new lands for farming settlements in an area of traditional farmers. In both cases coastal management has not reached equilibrium but is dynamically developing. A complimentary third case study is described for coastal swamps in Sumatra by Hanson and Koesoebiono (1979).

These case studies involve six activities commonly found in the coastal management programs of other countries: 1) fishing and shrimping, 2) aquaculture, 3) agricultural reclamation, 4) forestry, 5) conservation of protected areas, and 6) research and training. Powerful interest groups often conflict over these land uses with a concomitant and seemingly unnecessary loss of time and energy. The intent here is thus to help resolve unnecessary conflicts and to reduce tensions in the coastal zone. Indonesian society developed many historically valid approaches in this area and is thus a good natural laboratory for the study of past and present management and the trial use of new options.

I thank J. Clark, R. Allen, C. Neil, S. McCreary, M. Wells and two unidentified reviewers for constructive comments, Ms. D. Baker, draftsperson and Ms. B. Grayson, typist. Mr. and Mrs. Kaswadji were delightful hosts in Indonesia. Drs. Burbridge, Collier, Salm, Soegiarto, and Watson helped significantly to illuminate issues and gather literature.

2. SEGARA ANAKAN

2.1 Introduction and Area Description

This case study concerns a tropical estuary, Segara Anakan, which was proposed to be converted into irrigated rice fields. First, the pre-project geography and management is described. Second, the proposed development is discussed as revealed by internal working papers, project summaries, and external reviews prepared by Indonesian and international consultants. Finally, the decision to stop development as planned and the events occurring since then are reviewed 1) to illuminate what the important management issues are now, and 2) to lay the foundation for the sections on 'lessons learned' and 'guidelines'.

The Segara Anakan estuary is located near the town of Cilacap on the south coast of Java (Figure 6). It is subject to tidal action from the Indian Ocean through two channels. The major channel is at the southwest corner near where the Citanduy River enters the estuary. An eastern waterway connects the estuary to the Donan River and the port of Cilacap through a shallow tidal divide. The Cibeureum River enters from the north and the Nusawuluh weir diverts water and sediments into the estuary. The other main tributary rivers are the Kayumati, Cikijang, and Jagadenda. The central lagoon and tidal channels of approximately 8,000 ha are surrounded by intertidal swamp, consisting mostly of mangroves (Rhizophora sp. and Avicennia sp.), nipa palm (Nypa fruticans), and shrubs, which encompasses 24,000 ha. This area represents 50% of the remaining mangrove area in Java (Sukardjo and Akhmad, 1982) and is the only major mangrove zone in the south Java coast.

Small subsistence-level fishing villages with a total population of 30,000 people are within the estuary and there are about 3,500 ha of rice fields in the former swamps (Figure 7). Another 3,000 ha are periodically cleared for marginal rice swamp fields, fishing poles, boat materials, or firewood. Though brackish water fishculture has been practiced on Java

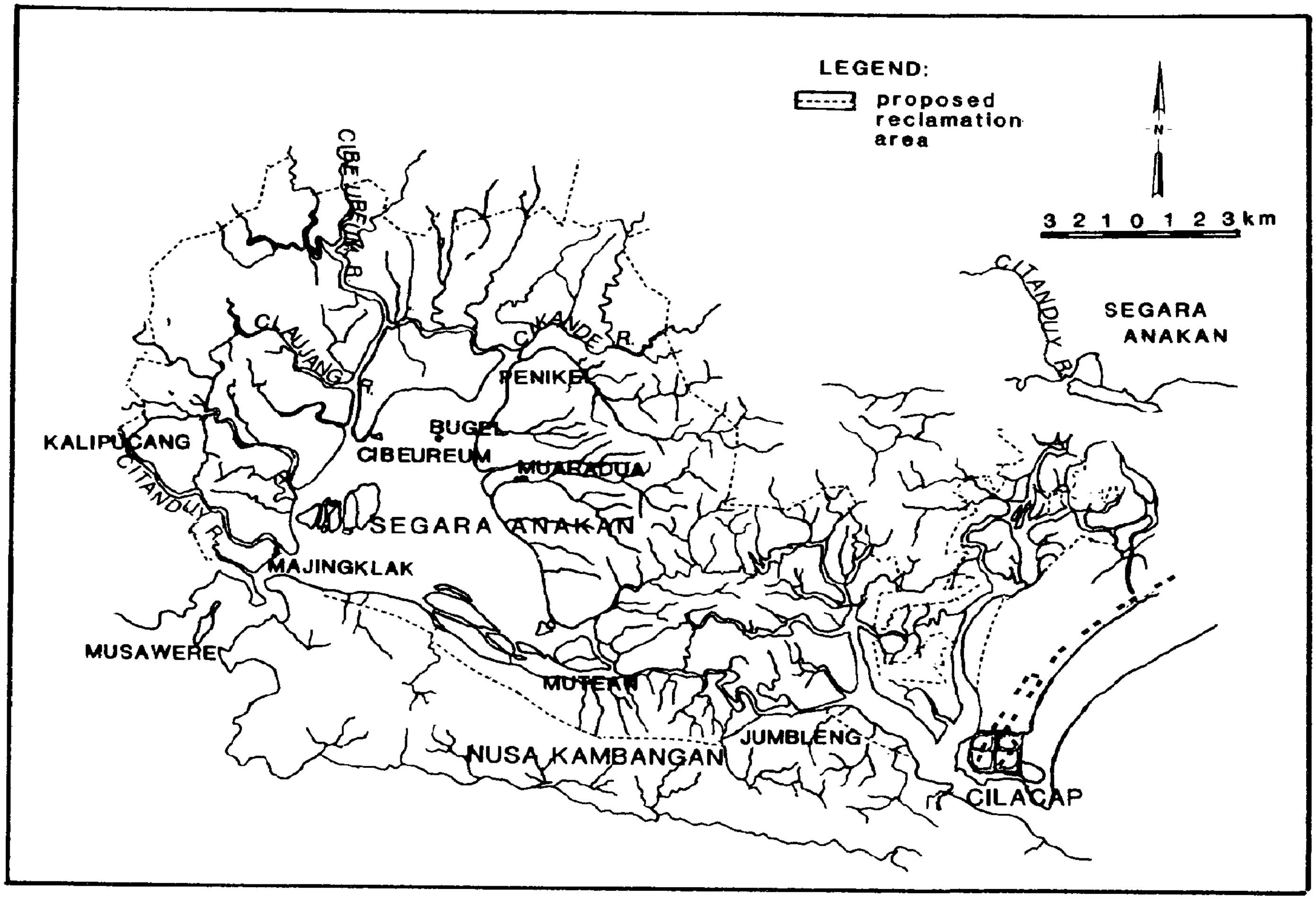

Figure 6. The Segara Anakan estuary.

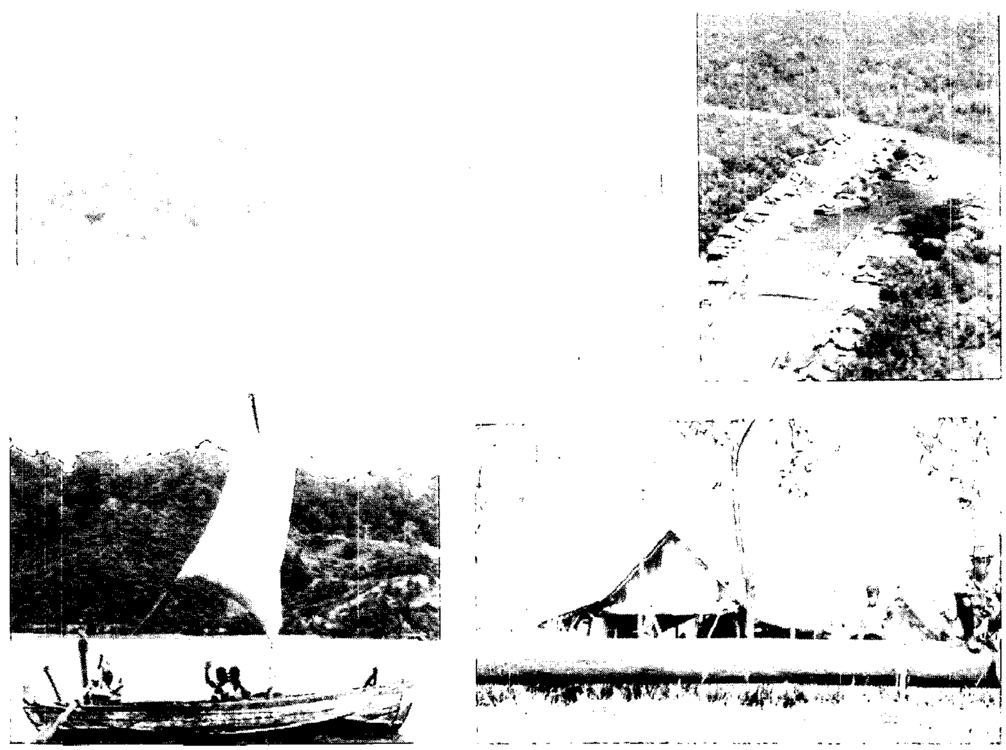

Figure 7. Scenes from the Segara Anakan estuary. Top left: the south-western channel leading from the mouth of the Citanduy River to the Indian Ocean past the island Nusa Kambanggan. Top right: a village in the middle of the estuary which once was on the waterfront, but is now behind mangroves following siltation. Bottom left: a village sailboat used for fishing and transportation. Bottom right: villagers resting on a recently completed log canoe built from a tree poached off of Nusa Kambanggan. Photographs by the author.

since at least the 13th century, or earlier (Soekarno, 1959; Sukardjo and Akmad, 1982), there is little present in Segara Anakan. A motorcraft transports people and light cargo within the estuary and to Cilacap and the Citanduy River village of Kalipucang. A 30-km-long island, Nusa Kambangan, separates the estuary from the sea on the southern estuarine margin. A prison and wildlife refuge are on that island. The 12,000-ha island is composed of tilted beds of reef limestone and limestone, and volcanic breccias which may reach 100 m high at the beach. It was densely forested in 1974, but is now heavily cut over.

Cilacap is the only major ocean port on the south coast of Java. Plans were underway in 1975 to modernize the port and harbor facilities. In 1984 the Cilacap oil refinery will represent 30% of the installed refinery capacity for Indonesia (Arndt, 1983). The city population is about 90,000 people, or 5,000 persons per square kilometer. The employed labor force is probably 35,000-40,000 persons. Excellent quality shrimp and fish are caught by artisanal fishermen in Cilacap (Figure 8). The fishing industry of Cilacap has been increasing since 1971-1973 when the first large trawling vessels began to enter the fleet in significant numbers (Figure 9). The Citanduy River fisheries' landings from 1968 to 1973 averaged 36,000 kg.

2.2 Development

2.2.1 Pre-project Management

The Segara Anakan is under the jurisdiction of the Department of Forestry. In Dutch colonial times the intertidal forests were considered public lands and therefore not open to private ownership. Attempts to regulate mangrove forests in Java were made in 1933 when the Ministry of Public Health prohibited the cutting of mangroves within 3 km of a village in order to control the mosquito population. The Ministry of Agriculture later tried to introduce silvicultural methods to the Cilacap mangrove forest. Under Regulation No. 13062/465/BIR-1/7/1938 the forest was divided into three areas of production. They included a zone of a minimum seed tree density and minimum diameter cutting size amid a zone of clear-cutting, an area of coastal and riverine protected reserve, and a zone of unproductive forest (Burbridge and Koesoebiono, 1982). Sagala (1956) re-examined the Cilacap mangrove forest and his recommendations formed the basis of mangrove management practices for Indonesia until 1978. The

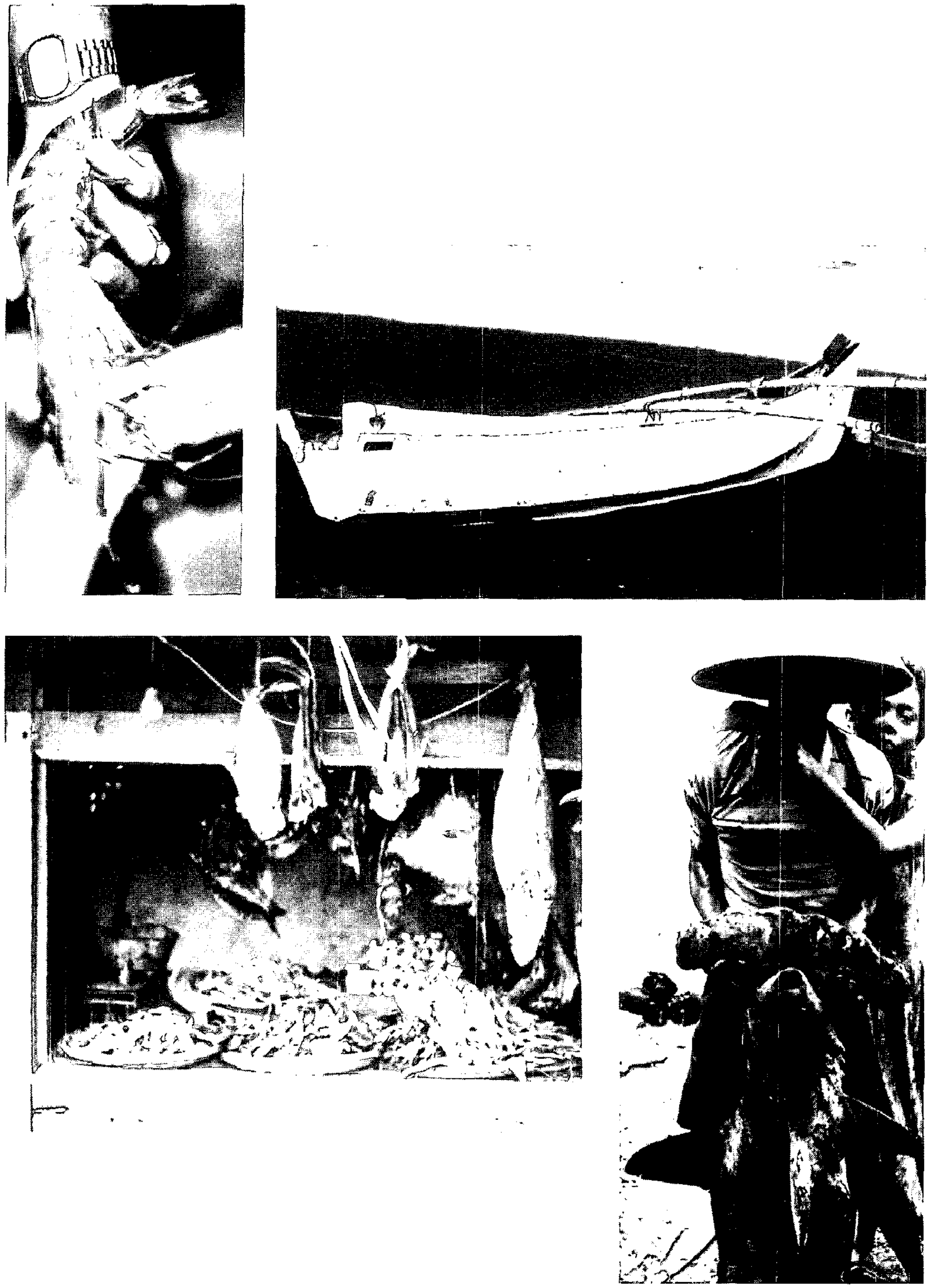

Figure 8. Fishing people, equipment and yield from the Cilacap-based fisheries. Top left: specimens sold in the daily government auction. Top right: these boats travel 5 km offshore with gill nets, hook and line, and small monofilament trawls. A small motor is often used to supplement sails. Bottom left: fresh and dried fish in a local store are by-products of the shrimp fisheries. Bottom right: part of the daily catch. Photographs by the author.

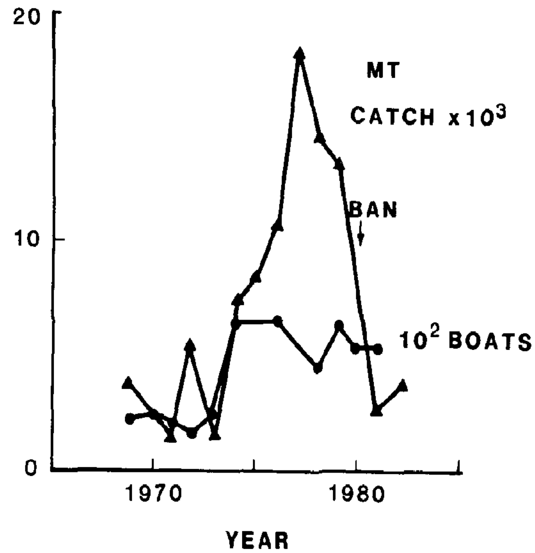

Figure 9. The officially recorded catch of fish and shrimp at Cilacap (from the local fisheries officer in Cilacap). The catch rose in the early 1970s as trawlers, mostly from Sumatra and Jakarta, entered the fleet. In 1980 a total ban on shrimp trawling went into effect.

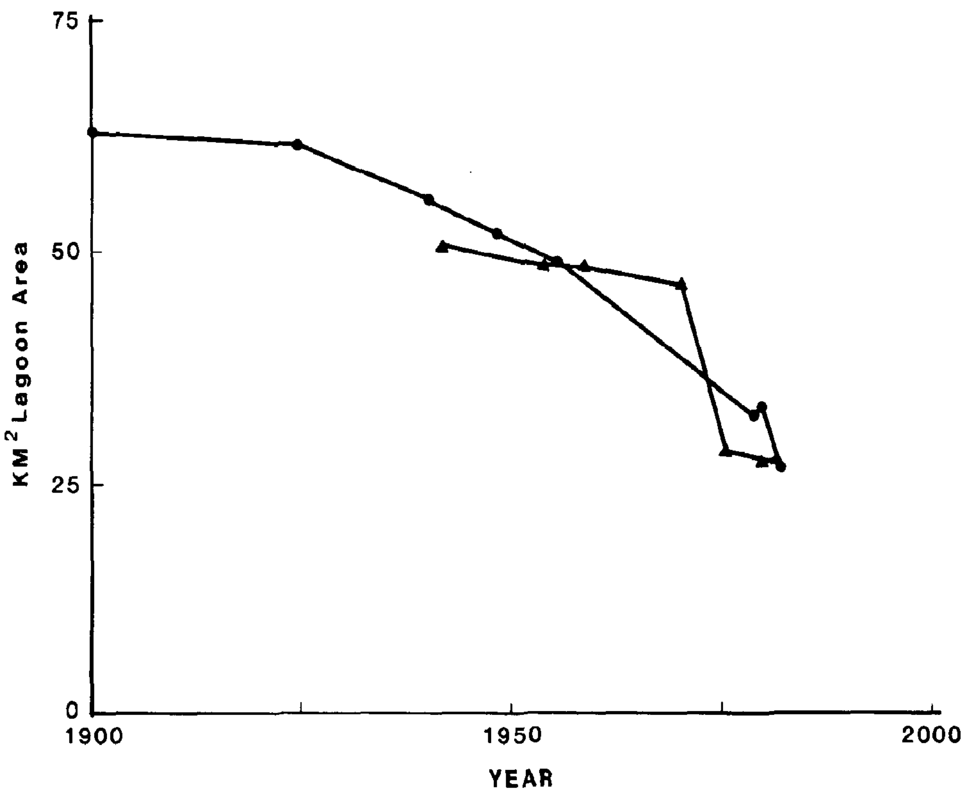

Figure 10. The estimates of lagoon area for different periods as recorded from two different sources. Data points shown as circles are estimates from Hadisumarno (1964, 1979). The data points shown as triangles are from Ludwig (1983b).

modified practices adopted in 1972 promoted the following (adapted from Burbridge and Koesoebiono, 1982):

1) No logging within 50 m of the coast or within 10 m of a river.
2) Logging is permitted only in 50-m strips at a right angle to the coastline, with a 20-m strip between to be left uncut for regeneration and seed trees.
3) Only trees greater than 7 cm diameter could be cut in the production strips.
4) Supplemental planting of seedling must be carried out if natural regeneration is not adequate.
5) Logs are to be removed by rafting or artificial channels.
6) A 20-year rotation cycle should be observed.

Additional regulations that apply to large lumber concession owners include the requirement for an inventory by the concessionaire, cutting limits determined by the Department of Forestry, and restrictions on the area as determined from estimates of seed tree density.

Complications often arise between owners of the local fish ponds, or tambaks, and the Directorate General of Forestry when tambak construction encroaches into the public forest lands, such as mangroves. A modified tambak forest system of mangrove plantings surrounded by 4- to 5-m ditches (used to transport logs and to grow fish) was introduced to overcome conflicts. There has been modest success with a 10-ha plot in Cilacap as of 1977 (Burbridge and Koesoebiono, 1982). The difficulties with this system include unclear property ownership, which makes it difficult for prospective operators to secure bank loans, snakes and birds that find refuge in the trees where operators work, and the problem that operators are trying to maximize production of the milkfish *Chanos chanos*, which eats algae, not mangrove detritus.

In 1976 the Directorate General of Fisheries instructed all provincial governors to set aside a 400-m-wide 'greenbelt' around the estuarine water edge. This vegetated zone, or greenbelt, was thought to act as a buffer zone and to provide for most of the estuarine functions which mangroves significantly influence. These instructions conflicted with the Department General of Forestry and a mutual agreement has not yet been reached. This leaves the tambak fishermen in a tenuous position when applying for funds, permission, and technical assistance.

2.2.2 Project Development

Increasing food supplies, mostly through expansion of rice fields, was, and still is, the primary consideration of proposals to manage Segara Anakan. Farmlands surrounding the estuary are only marginally successful because of acid sulphate soil conditions, salinity intrusions, and poor drainage. Salt water intrusions during the dry season affect groundwater supplies, surface water quality, and crop irrigation. Inhabitant per capita dollar earnings, health standards, and integration into society are thought to be inadequate compared to others on Java. There is obvious evidence that the lagoon is filling in. By 1974 there was a sense of urgency to do something to compensate for the presumed declining fisheries, diminishing opportunities to stabilize water resource supplies and quality, and to increase opportunities for development. Related issues include the threat of increased pollution from an expanding Cilacap Harbor, malaria, and the general welfare of the population.

The proposal to meet these concerns evolved from the staff managing the upstream watershed conservation and development project on the Citanduy River (Engineering Consultants, Inc., 1974a, b; 1975a, b, c). Its purpose was to convert the lagoon into a freshwater lake and to control water surface at mean sea level by constructing cut-off dikes and tide gates at its outlet to the sea. Levees would isolate the present lagoon from its eastern tidal connection. After two years of lake freshening, the surrounding tidal lands, once deforested, would be reclaimed by leaching the soils. Low-income families from Java would then settle the area over ten years. The Citanduy River would be diverted directly into the Indian Ocean. The newly constructed lake was to serve as a freshwater supply for Cilacap, for irrigation, and as a large fish reservoir. Expected ancillary project benefits included increased recreational opportunities and reduced demands for construction of the nearby proposed Jeruklegi Reservoir.

Total project cost was estimated to be $26 million (U.S.; in 1973). Estimated annual maintenance costs after ten years were $763,000 (U.S.) compared to annual benefits of $3.9 million. Recognized development problems included the sensitivity of these soils to shrinkage following excessive drainage, soil toxicity (mostly due to sulfides arising from subsurface marine clays), retraining of migrants, relocation of the existing population, and fish stocking in the new lake. The environmental impact statement was probably the first prepared for any development project in Indonesia.

These proposals, once articulated, were evaluated by local, regional, national and international management agencies. Experts were consulted for specific areas of concern. After ten years the project has not been authorized, and unanticipated developments have changed the situation from what existed in 1973. Three characteristics of Segara Anakan became important obstacles to project development: 1) sedimentation rates in the estuary, 2) the importance of the local fisheries, and 3) the resistance from the local inhabitants.

2.2.3 Sedimentation

Sedimentation within the estuary is important because of its influence on fisheries, vegetation, soil properties, water quality, potential for reclamation and continuing productivity. Explicit arguments used in favor of quickly beginning the project were that reclamation would be more difficult and less successful as the estuary filled in, that fisheries would decline, and that future uses of the proposed freshwater lake would become less obvious. Further, if the lagoon were perceived to be lost in 10 years, then why should an agency wait for the inevitable rather than assist the process? Estimates of sedimentation rates made in the original project surveys, and subsequently, placed the lagoon life at 5 to 150 years with closure occurring within 10 to 20 years. Accurate predictions are essential, therefore. There are two ways to obtain them: with a sediment budget, and empirically, by following the historical trends.

Sediments enter the Segara Anakan from three major sources, the Segara Anakan catchment area, the Citanduy River and its tributaries, and shoreline sediments transported by littoral drift and tides. The Citanduy River is leveed for a major portion of its lower length and does not lose much sediments from overbank flooding. Its catchment basin is presumed to be a minor source of sediments since less than 15% is agricultural land. The estimates of sediments brought into the Segara Anakan with and without an upstream sediment diversion, the Nusawuluh Diversion, are in Table 1.

Documentation for lagoon filling began in 1900 (Hadisumarno, 1964; 1979). Figure 10 summarizes two estimates of lagoon area. When the Nusawuluh diversion was completed in 1977, the sediments moving into the

Table 1. Sedimentation estimates (dry weight) for the Segara Anakan with and without the Nusawuluh Diversion (from Engineering Consultants, Inc., 1975a; p. ii-2, and calculations based on Figure 10).

Source	With Diversion	No Diversion
from the Segara Anakan Catchment	0.55 MCM	0.55 MCM
from the Citanduy River	1.30 MCM	0
annual total	1.85 MCM	0.55 MCM
assumed trap efficiency	75%	75%
total annual sedimentation	1.4 MCM	0.4 MCM

Table 2. Fish and shrimp production in Segara Anakan, 1972 (from Turner, 1975).

Item	Total Weight (kg)	Value ($ U.S.)
fish	115,000	18,600
shrimp	378,000	75,600
Total	493,000	75,600

Table 3. The projected annual impacts on fisheries based on average employment on Java and official landings statistics for the Segara Anakan development project of 1975 (from Turner, 1975).

	Conservative Estimate of Changes to Occur		
	1000 $ U.S.	Mt	Fishermen employed
inshore	+108	+311	+2,600
offshore	-5,760	-10,350	-5,000
net	-5,650	-10,040	-2,400

NOTE: A more moderate estimate of changes to occur was $9.76 million dollars annually (based on higher shrimp yields, greater export earnings from shrimp, and including impacts on the local subsistence economy).

lagoon increased by an estimated 236% (Table 1). If the sediment supply has been increasing since 1900, as one might expect following watershed deforestation and cultivation, then the sedimentation trapping efficiency of the lagoon is decreasing.

The historical filling in of the bay is about 0.6 square kilometers annually. The average depth of the lagoon is presently 1.2 m, so the average recent annual historical sedimentation rate approaches 0.72 million cubic meters, wet weight, or 0.50 MCM dry weight. This is close to the estimate in Table 1 before the Nusawuluh diversion went into operation. There is still no conclusive evidence that the sedimentation rate went up after the diversion. Infilling seems to be proceeding at similar rates as before the diversion. Further, the Gulunggung volcano erupted in 1982 leaving an equivalent ash contribution many times the annual stream-derived sediment which normally enters Segara Anakan. The best analysis seems to be that at historical rates the lagoon would be closed by the year 2025, <u>if</u> it were to close at all. However, tidal channels are already showing signs of deepening, and with rising sea level (Gornitz et al., 1982) and declining trapping efficiencies, it is more likely that there will always be a smaller and stable residual lagoon.

2.2.4 Fisheries

The principal economic and subsistence activity among the population in Segara Anakan is fishing. Fish capture within the lagoon is accomplished using stationary V-shaped traps located in shallow areas and oriented to capture on the ebb tide. Their orientation in southeast Segara Anakan delineates the tidal divide between the lagoon and Cilacap harbor. Throw nets, hook-and-line, and crab traps are also used. Stationary nets are placed parallel to mangrove banks to collect shrimp leaving on ebb tides. Weir traps and gill nets are sometimes situated at the ends of small drainage channels.

The catch consists mostly of crabs, small mysid and penaeid shrimp, and mullet (Table 2). The movement of the shrimp and fish between the nursery ground in Segara Anakan and the sea is continuous but peaks during the wet season. As the organisms mature or are forced out by increasing amounts of freshwater, they are caught in the 200-300 V-shaped weirs. The villagers have learned from experience which phases of the moon are best for each species. These fish are either eaten, sold to the fish cooperative in the village, or transported to the regional auction.

The Directorate General of Fisheries estimated from partial market surveys that the daily catch from these traps is between 1 and 5 kg each. The villagers from Mutean said in interviews that their catch was 3-5 kg and 10-15 kg per man during the dry and wet seasons, respectively, and that they eat about 1 kg daily per family. Based on the number of traps and limited interview data, the actual annual catch is 400-660 kg compared to the average for Java of 458 kg per man in 1973. In 1972 the catch was estimated to be 493 metric tons worth $24 (U.S.) per fisherman.

The production per water surface area within the estuary lagoon was estimated to be about 163 to 86 kg/ha, depending on whether the lagoon or lagoon + tidal sloughs were included, respectively. This compared to a small fish pond production rate in Java of 1,200 kg/ha.

Fisheries potential in the lagoon was originally predicted to decrease as sedimentation decreased the open water area.

> A very important consideration that vitally affects the future of fishing in this area is the fact that the shoaling of the waters due to an accelerating rate of sediment deposit within the lagoon is reducing the already poor annual fish production. If conditions are left unchanged, the remaining period for productive fishery is projected to be about 20 years. If the project were to be built, the fishery production could be maintained indefinitely. (Engineering Consultants, Inc., 1975a, p. II-19).

There was no evident decline in the catch statistics for landings from 1962-1972, however. Instead, there was a fluctuation related to river-flow patterns of the Citanduy River. Data accumulated since 1975 also support that conclusion.

The Directorate General of Fisheries, aware of the potential loss of a large estuary near a major fishing zone, began survey work on the plankton and shrimp larvae in the area (Naamin, 1972; Naamin and Sudradjat, 1973; Martosubroto and Sudradjat, 1973). A joint Indonesian-UNDP study of the Cilacap fisheries was initiated simultaneously and led to the documentation of the growth and decline of the fishing fleet (Naamin and Zalinge, 1974; Zalinge and Naamin, 1977). At the same time the United Nations (FAO) was concerned with the relationships between mangroves and fisheries. Coincidental with the project proposal, the author of an FAO report on shrimp and mangroves (McNae, 1974) consulted with the Directorate General of Fisheries and encouraged their participation in discussions. The original planning document was circulated by the Ministry of Public Works to various ministries, knowledgeable environmentalists in universities, and to BAPPENAS, the lead planning agency. The subsequent critism led to new studies by Indonesian scientists and the request to the contractor to examine certain issues more closely.

A separate evaluation of the lagoon fisheries was eventually commissioned (Turner, 1975) which examined the couplings between the intertidal mangrove community and the fisheries in the lagoon and offshore. It is unclear if such a relationship is primarily due to habitat or food resources but it occurs worldwide (Turner, 1977). Where there are mangroves, there are penaeid shrimp; if there are no mangroves, marshes or seagrasses, there are virtually no commercial quantities of penaeid shrimp. The fish present in and near Segara Anakan have a similar dependence on the mangrove. As a result, the shrimp and fish harvest following project development was predicted to decrease in proportion to the loss of mangrove area, and the employment and export earnings from shrimp fishing were also predicted to decline significantly (Table 3). Additional concerns included the retraining of fishermen into farmers, pesticides from the new agricultural areas affecting the remaining fisheries, and aquatic weeds originating from upland watersheds taking over the open water surface area. The logic of extrapolating from small fish ponds to large reservoirs was also questioned. Closing off the Segara Anakan was conservatively estimated to result in an annual net loss of 5.5 million dollars (U.S.), 10,000 mt of fish and shrimp, and 2,400 jobs (Table 3). A more moderate estimate was an annual loss of $9.76 million.

Such large considerations equalled 33% of the total construction cost, two times the projected annual project benefits, and ten times the projected maintenance costs. Additionally, valuable export earnings from foreign-sold shrimp would be lost.

2.2.5 Villagers' Perceptions

The villages apparently existed in 1835 after being established as "watch posts" to supervise trade routes between Cilacap and Kalipucang. At one point villagers were enticed by the government to move to Patimuan, but after selling the land given to them, they moved back to Segara Anakan. Recent efforts by transmigration officials to move people out of the estuary to government transmigration sites have been unsuccessful. In one year 90% of the people moved came back. The next year less than ten left.

As the lagoon has filled in, the area of mangroves has expanded seaward. Villages have either moved seaward or have become sequestered inland along the tidal creeks and channels (Figure 7). No village has been closed off to the estuary, and none have been abandoned.

Since 1979 the Segara Anakan villagers successfully initiated an effort to ban Cilacap fishermen from entering the bay to fish. There have also been conflicts between the fishermen aboard offshore trawlers and the fishermen from Segara Anakan and Cilacap who fish outside the estuary from small boats. The trawlers were to remain outside the normal fishing range of the smaller vessels. They often did not and communal strife, including combat, resulted. Collier et al. (1977) have described this elsewhere in Java. Finally, a 1980 Presidential Decree banned trawlers from Java, Bali, and Sumatra. In 1983 it included all islands except certain joint ventures in the Arafura Sea. The results have pleased the local fishermen, but resulted in a drastic decline in fisheries' yields (Figure 9).

2.3. Decisions

The 1975 consultant's report, together with three other independently written ones, provided a strong argument for the Directorate General of Fisheries when presenting their case for an unchanged situation to the Central Bureau of Planning, BAPPENAS. BAPPENAS "did not expect these implications for the shrimp industry at all, and decided to make further studies, before reaching a final decision" (correspondence from one of the participants). By then the precarious national financial situation, highlighted by overspending by the government-run oil company, had become serious.

Subsequently, another review was prepared on the impact of the reclamation on coastal fish stocks. Marr (1976) concluded that to modify some portion of the estuary was better than to take no action. He proposed to reclaim the western half and to leave the rest unaltered. Marr estimated that the estuary would fill in within 5-15 years (as of 1976) with a subsequent loss of shrimp nursery grounds and mangroves. National and expatriate fisheries experts by then had completed more studies of the developing fishing industry and contributed to the continuing critique of the proposals. The availability of Marr's new report offered another opportunity for criticism and additional means for communication between the Directorate General of Fisheries, then firmly opposed to the project, and BAPPENAS. Permission for the project was ultimately denied.

2.4. Subsequent Events and Analysis

During the last ten years a number of Indonesian institutions have investigated and monitored various aspects of the estuary. These have ranged from individual projects, to team research funded by external agencies, to its use as a natural laboratory (Table 4). Two international symposia on mangroves have been held since and Segara Anakan has been discussed in each (Srivastava, et al., 1979; Kostermans and Sastroutomo, 1982). Several conferences have been held, including one at Cilacap, with all materials organization the responsibility of nationals.

The present development plans involve another analysis of the estuary with the following possibilities for fisheries: to conserve part of the estuary as a nursery area and/or to convert it into aquaculture ponds to replace fishing (Ecology Team Report, 1983). The authors note that manpower is limited, the problem large, the time short, and that the joint cooperation with a socio-economic approach is needed. One drawback to the analysis is that the final decision is presently to be based on an economic analysis derived from marketplace dynamics applied to a subsistence economy. The stated objective is to assist the Directorate General of Rivers and Directorate General of Water Resource Development in "formulating an optimal management plan for utilizing the Segara Anakan resources with maxium benefit to the country considering its values for agricultural production (especially paddy) on land filled in by silt, for fisheries including aquaculture, and for preservation as a precious natural resource." Three alternative plans are envisioned: 1) the 'do nothing' plan, which assumes the eventual filling of the lagoon; 2) utilizing engineering measures to encourage the lagoon to fill in under the explicit assumption that the "eventual loss of the lagoon ecological integrity is inevitable," and 3) using engineering measures to perpetuate part of the lagoon which would be large enough to preserve its "ecological integrity." (Ludwig, 1983a, memo to participants). The lagoon is once again a central part of the ecological integrity of the swamp; engineering, agriculture, and

Table 4. Selected Institutional investigations of Segara Anakan since 1973.

Year Initiated	Institution	Purpose
1973	Marine Fisheries Institute, Jakarta	shrimp studies (continuing)
1977	Workshop, sponsored by National Institute of Oceanology (LON)	education
1978	Gadjah Mada University	physical, biological monitoring
1979	Lemigas	baseline study
1980	LON	plankton
1980	Asian Development Bank, Biotrop, DPMA, LON, and others	optimal planning document

tradeoffs are envisioned; and foreign experts are once again central to moving a development project forward.

This most recent study has again referred to measurements of the lagoon filling with the assumption that, at present rates, it would be complete in 5-7 years, which is clearly not the historical example. Some objectives of this latest study are to identify and measure the resources in order to "better manage" the resources, to "estimate the minimum size of the resource necessary to support the offshore marine fisheries and to delineate the area to be maintained as the residual core lagoon;" and "to evaluate the potential for brackish water aquaculture, to delineate the lagoon areas which should be allocated to aquaculture, and to prepare preliminary designs for the proposed aquaculture." (Ludwig, 1983a). Internal documents of the project management state that "unless corrective measures are taken the lagoon environment appears to be doomed." The study area is confined to the estuary, and does not now appear to give much attention to the Cilacap-based fisheries. It does seek to incorporate traditional tambak culture into a local area of low tambak density. Although the project involves many local institutions, the development agencies and foreign experts are taking the lead in project planning and guidance. Another consideration is that the Ministry of Public Works has mapped a land reclamation scheme north of Segara Anakan. Some Indonesian observers have postulated that this is designed to meet the legal requirements for a reservoir to be built upstream on a tributary entering Segara Anakan. In Indonesia agricultural land lost to reservoir construction must be compensated for by land reclamation elsewhere. The conjecture is that reservoir construction cannot and will not proceed without land reclamation within Segara Anakan. Those dependent on Segara Anakan may thus be hostages to another project's success outside the hydrologic unit.

The initial assumptions about the 1973 proposals were tested through the invitation for examination by outside experts, national distribution of the proposals, and subsequent discussions within the national managing agencies. In Table 5 are two sets of considerations which were crucial in the decision not to pursue the project. First, the initial project focused best on the narrow range of issues common to agricultural projects, such as price supports, irrigation requirements, fertilizers, yields, and drainage. The project as conceived was less successful in

Table 5. Assumptions about the Segara Anakan leading to project declination.

In Proposal	Actual
Rapid closure of lagoon	not rapid, will not close
Lagoon fisheries are doomed	fisheries may be increased following expansion of intertidal vegetation
Estuarine fisheries unrelated to vegetation in estuary or Cilacap fisheries	related and, therefore, affect the Cilacap fisheries
Settlers want to leave	stay when offered entitlements and emotionally express desire to remain
Official statistics are accurate	not always true, particularly for subsistence agriculture and artisanal fisheries
Maintenance costs are stable	anything but stable
Fisheries declining	not declining, but stable
Health would be improved	may have improved anyway (no malaria reported in 1983)
Yields from small ponds equals that of freshwater reservoir	higher in small ponds

Table 6. Unexpected results following project declination

Conflicts between offshore fishermen with trawlers and inshore subsistence fishermen. Result: banning of trawling vessels.

Concern about overfishing. Result: Segara Anakan fishermen exclude fishermen from Cilacap from estuary.

Realization that mangroves on Java are being destroyed faster than understanding is being developed. Result: use of Segara Anakan as a study area by several institutions.

Small motor fleet in Cilacap developed. Result: more fishermen with better earnings and interest.

Volcanic eruption (leaving about 68.4 MCM of ash out of 201 MCM for all catchments affected by Galunggung). Result: slightly more than double the amount of annual sedimentation from landuse.

addressing issues of a local nature such as social aspects, village life, or fisheries. Second, compilation of data was, of course, difficult. This led to erroneous conclusions when extrapolations were made from incomplete surveys or from outside the study area. The science of coastal ecology was, and is, incompletely developed. In particular, too little is known about mangrove ecosystems. This meant that information transferred from study centers to field was incomplete. In contrast, the engineering and agricultural studies proposed and now being considered seem to be more firmly based in practical experience. The common result elsewhere is that the known and presumed characteristics of coastal ecological systems appear as regrettable consequences of coastal land reclamation and as characteristics which can be overcome or accepted as the price of national development. This last conclusion was rejected only after extensive proposal review and the seemingly serendipitous meeting of various consultants, agency personnel, and changes in the national economy.

The events since 1975 have brought additional changes, most of which were not anticipated by any of the parties involved in the study (Table 6). The fisheries proved to be very valuable and grew, as predicted. However, the fishing community grew with the acceptance of outboard motordriven fiberglass boats and with greater participation by people from Cilscap. When the larger trawling boats became more numerous the local fishing community using mostly small boats felt threatened. Communal conflicts resulted and the central government finally banned all offshore trawling vessels from Indonesian waters as of 1983 (a few exceptions were granted for the Arafura Sea). To compensate for the expected decline in harvest, a massive shrimp culture intensification program has been initiated (Djajadiredja and Daulay, 1983). This will result in the cutting of more mangroves throughout Java.

A second unpredictable change was the volcanic eruption in 1982. The Citanduy River and Nusawuluh diversion might, or might not, have been in place. It is possible that the freshwater lagoon might have been filled irreversibly, thus ruining the proposed irrigation and drinking water supply system. In retrospect, another earthquake like the one that once destroyed the Cilacap jetty might have severely affected the earth levees enclosing the proposed reclamation zone.

A more predictable change since 1974 is the use of the area as a natural laboratory. The Segara Anakan is now the only major stand of mangroves on the most populated Indonesian island, and is within one day's drive of the nation's capital and the major management institutions and universities. In hindsight, it seems a natural development in a country with such ambitious plans to manage and develop its coastal zone. One might ask where else would a natural laboratory come from. As such, it is the focus of several agencies, students are being trained, and knowledge about Indonesia is being collected by Indonesians. It may be one of the most cost-effective benefits of leaving the estuary as a fisheries reserve. The information and experience gained there applies to other regions in Indonesia and serves to develop expertise in a country where basic training in coastal ecology is simply in very short supply.

In brief summary, the Segara Anakan estuary contains the largest contiguous intertidal swamp on the densely populated island of Java. This estuary supports a sustainable regional fisheries and a more local subsistence culture which resists change. The proposed massive ($26 million) land reclamation plan to convert it into ricefields was well-prepared and well-intentioned, but ultimately rejected in what now appears to be a sensitive and substantiated management decision. The issue of what else can or should be done to manage the estuary is unresolved.

3. BANJARMASIN

3.1 Introduction and Area Description

This second case study concerns the management of an enormous tropical deltaic plain on the sparsely populated island of Kalimantan. Recently migrated and traditional farmers are exploiting the extensive and long-standing agricultural developments sponsored by the central government. First, the area, farming practices, and soils are described. The history of government sponsored transmigration programs are then outlined in view of national and local economic and social issues. Lastly, the future of the present management is discussed in terms of 1) the cumulative impacts on soil properties, 2) cost-effectiveness, 3) long-term sustainability, and 4) issues to address development continues or is reevaluated.

The river delta Pulau Petak is located between the South Barito and the South Kapuas rivers, west of the city of Banjarmasin, on the south-eastern coast of Kalimantan, on the island of Borneo (Figure 11). It is one of several tidal swamps among an estimated 18.7 million ha of swamps in Kalimantan. Perhaps 20% is potential agricultural land. Eight rivers, from east to west, flow into the sea amid 24,000 square kilometers of coastal swamps: the Barito, Kapuas, Kahayam, Katingan, Metanya, Seuyan, Kumai and Arut. The total area of swamp land considered suitable for agriculture in South and Central Kalimantan amounts to 560,000 ha and 1,550,000 ha, respectively. Most of the total is coastal swamps and being considered for reclamation as rice fields. In 1974, 110,000 ha were rice-fields (Noorsyamsi and Hidayat, 1974).

The Pulau Petak delta has an average width of 15 km and length of 70 km. It forms part of the broad coastal sedimentary plain extending along the south coast of Central and South Kalimantan. It was submerged after the Pleistocene glaciation until being filled over by deposits from the Pre-tertiary and Tertiary formations in Central Kalimantan (Schophuys, 1936; cited in Noorsyamsi and Hidayat, 1974). River levees form hydro-logic barriers isolating the inter deltaic riverine swamps where drainage is slow and interdistributary lakes form. Tides are in evidence up to 100 km inland. Below and above ground salt water intrusion occurs up to 60 km inland during the dry season.

The topogenous swamp forest located between river levees is often convex and acidic as are most swamps in Borneo (Anderson, 1964; Wall, 1964). In general, the peats are up to 2 m deep and often overlie acid sulphate soils (Driessen and Rochimah, 1976). Figure 12 presents a general soil/vegetation map of the area before extensive transmigration began.

3.2 Farming Practices

Four vegetation zones are recognized and farmed according to the timing, length and depth of flooding (Table 7; Figure 13). The hydrologic regime is a major factor determining harvest success and selection of the numerous local or international rice varieties. Hydrologic modifications are thus a major consideration for both farmers and planners.

Drainage of the tidal swamp began with the Dutch system of linking two major tributaries by means of an artificial canal constructed at right angle to riverflow. The forest is cleared, usually by burning, and 2- to 3-

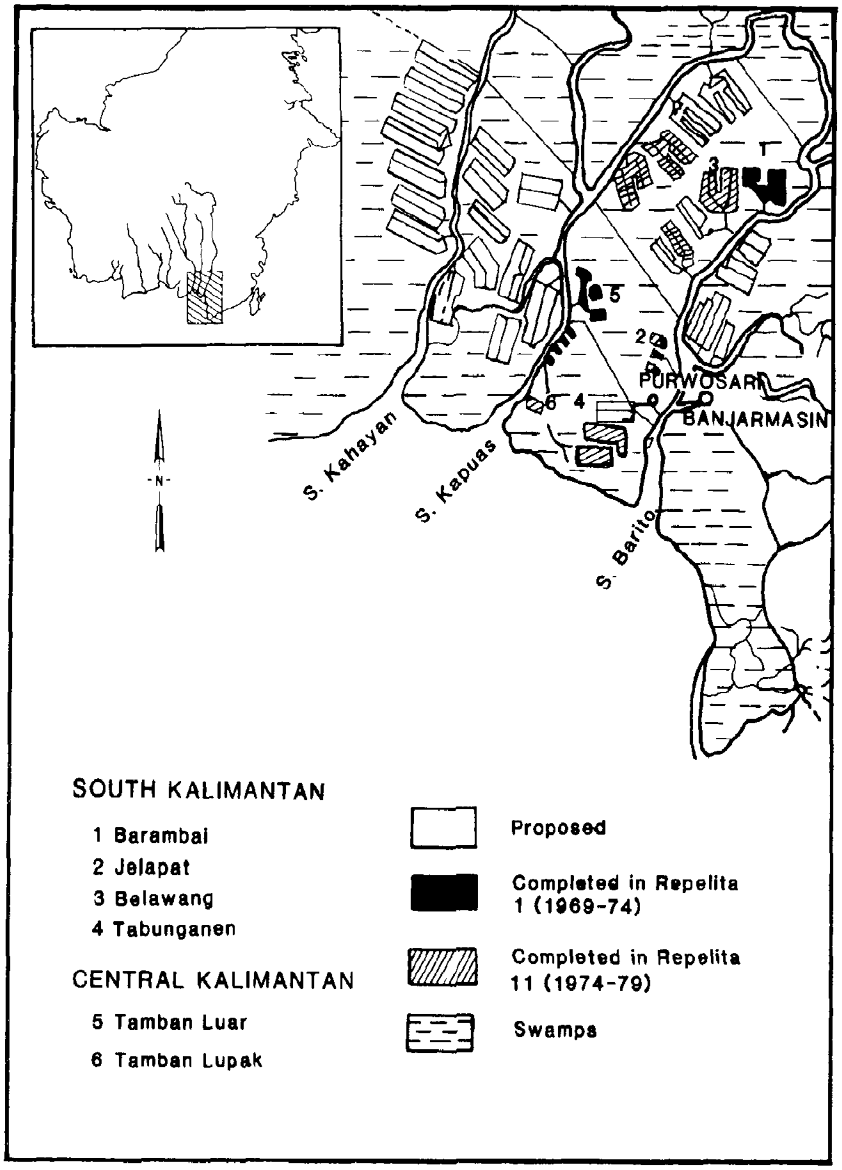

Figure 11. The development of South and Central Kalimantan from 1880 to 1978 (adapted from Koesoebiono et al., 1982; and from the Bogor Soil Research Institute maps on vegetation, agriculture, land use, and hydrologic structures).

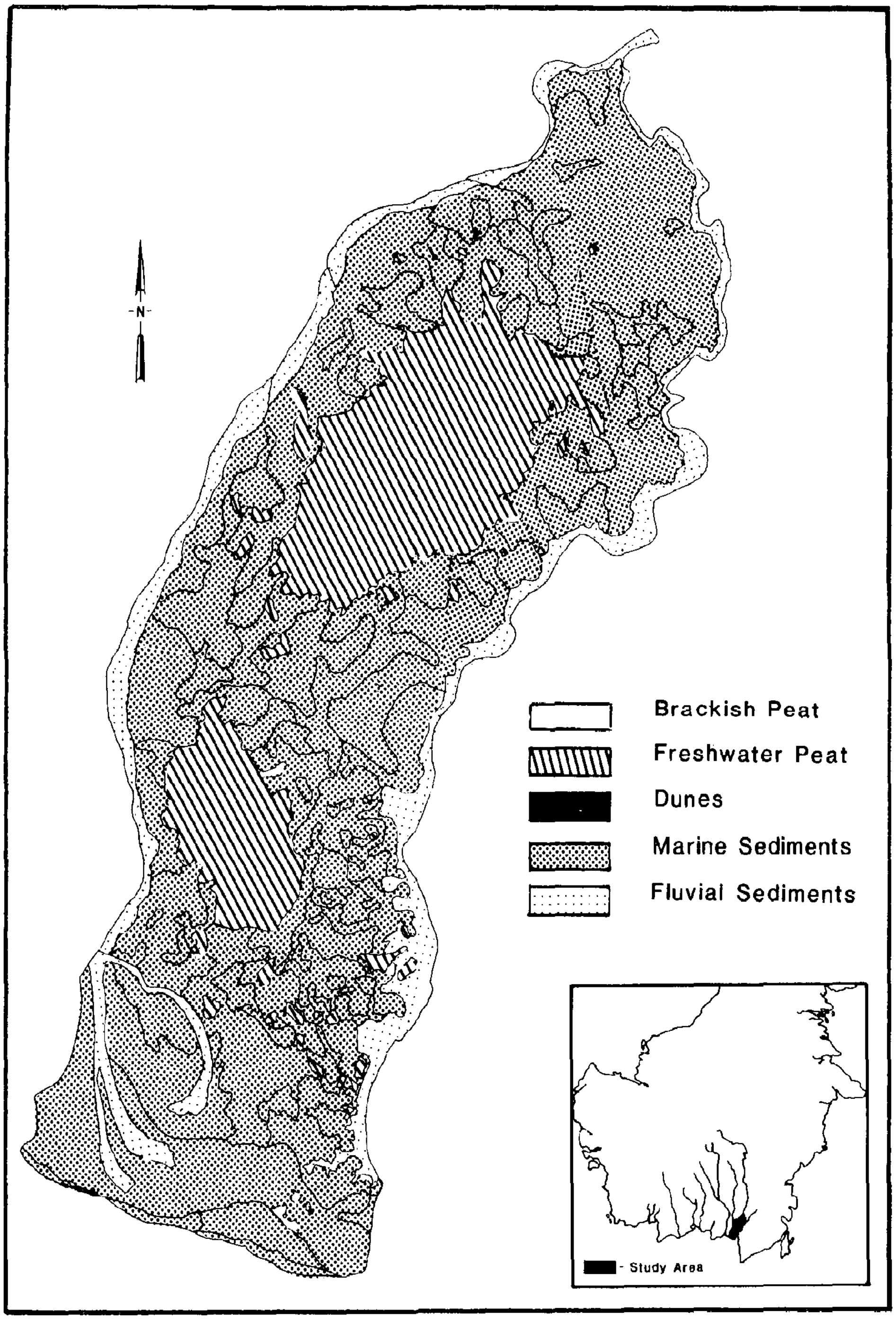

Figure 12. The vegetation zones of the delta Pulau Petak, Kalimantan, (from Lembaga Penelitian Tanah Bogor, 1973).

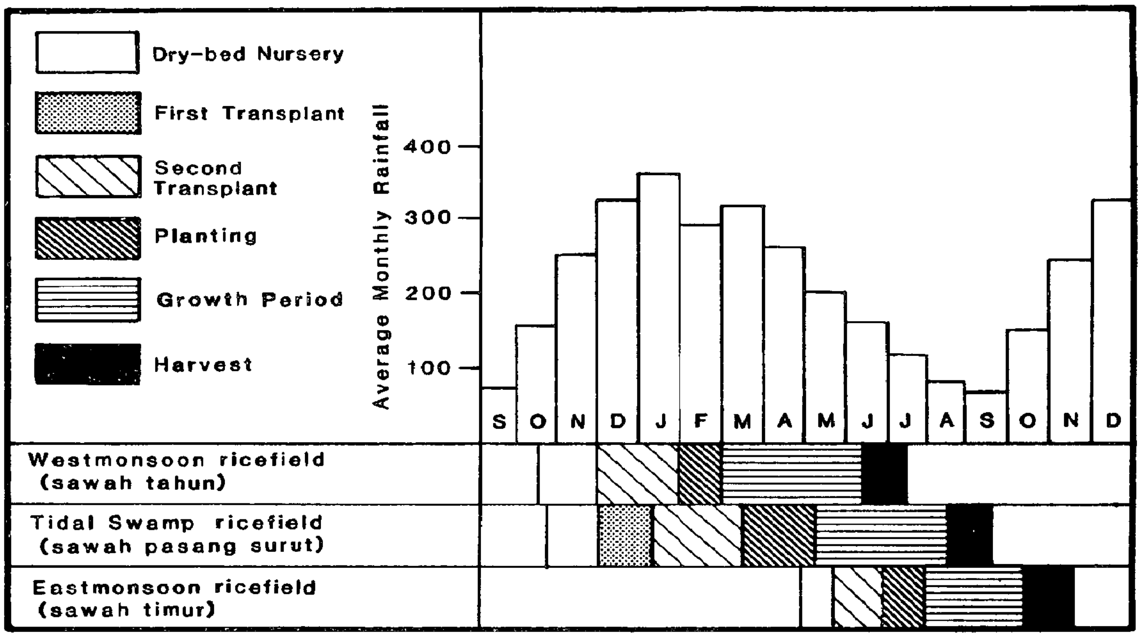

Figure 13. The planting schedule of several types of rice fields in South and Central Kalimantan (from Noorsyamsi and Hidayat, 1974).

Table 7. Vegetation zones' hydrologic regimes and farming practices in Pelau Petak (adapted from Noorsyamsi and Hidayat, 1974).

Vegetation zone	Farming practice
Tidal swamps, where flood hazards are negligible and subject to seasonal winds and tides.	late maturing rice varieties; sown in October/November
Monotonous swamp area, drainage is poor, water level high and tidal influence low.	only 'sawah surung', or deep-water rice culture is possible
Lake region, where tides are felt only during the dry season and the main factor influencing flooding is seasonal monsoons.	rice culture possible only during the dry season "sawah timur" early maturing rice varieties
Plains or lowland area, where there are valleys and hills tidal influence is negligible and flooding entirely due to seasonal monsoons.	rainfed 'sawah barat' lowland rice culture only

Table 8. Yield of sample plots on peats of different depths (from Notohadiprawiro, et al., 1981)

Peat thickness (cm)	Yield (kg per ha; local variety)
0-25	4.54
26-50	3.20
51-100	2.55
101-200	2.38
200-	1.37

meter wide perpendicular secondary and tertiary canals are dug 75-100 cm into the mineral soil. Rainwater leaches some toxic materials out of the soil.

The quality of soil depends on the previously deposited surface soils and their underlying strata and on previous farming practices. Notohadiprawiro et al. (1981) described the three basic soil types in Kalimantan: entisols, inceptisols, and histosols. When the underlying mineral layer contains pyrites, drainage and subsequent diffusion of oxygen transforms pyrite into sulphate acids. The suphuric acid moves vertically by capillary action and poisons plant roots. Some layers may develop a pH as low as 2. When this occurs the original soil is then transformed into a nonutilizable 'cat clay' or acid sulphate soil. In addition, aluminum toxicity may accompany either high salinity or high acidity because aluminum solubility increases on either side of pH 6.5, and in the presence of chloride ions which are in seawater. Primarily peat soils contain few minerals and may also be acidic. In spite of these problems some tidal swamp ricefields established on peats have produced very respectable yields for more than 20 years and without fertilizers. In Barambai the yields first increased then leveled off; in Tamban the yields first decreased, then leveled off. In general, thick peats result in lower yields (Table 8).

Successful harvests require attention to proper land preparation and planting of the seed beds, transplantations from seed bed to primary or secondary fields, application of fertilizers, pesticides and herbicides, and labor for weeding and harvest (Figure 14). A type of compost pile, a 'puntalans', of field vegetation is piled up after the cut plants are allowed to rot for 2 weeks in standing water. The ripe organic mass is applied to fields prior to planting. Plowing and harrowing are not usually practiced. Weeding is generally unnecessary for the first 3 months after planting since the fields are flooded. Holding water in the field is important and extra levees may be built during a dry season. The fields are gradually drained after 3 months. Some plant pests and viruses attack plants, and rat infestation is a local problem which the farmers respond to with pesticides.

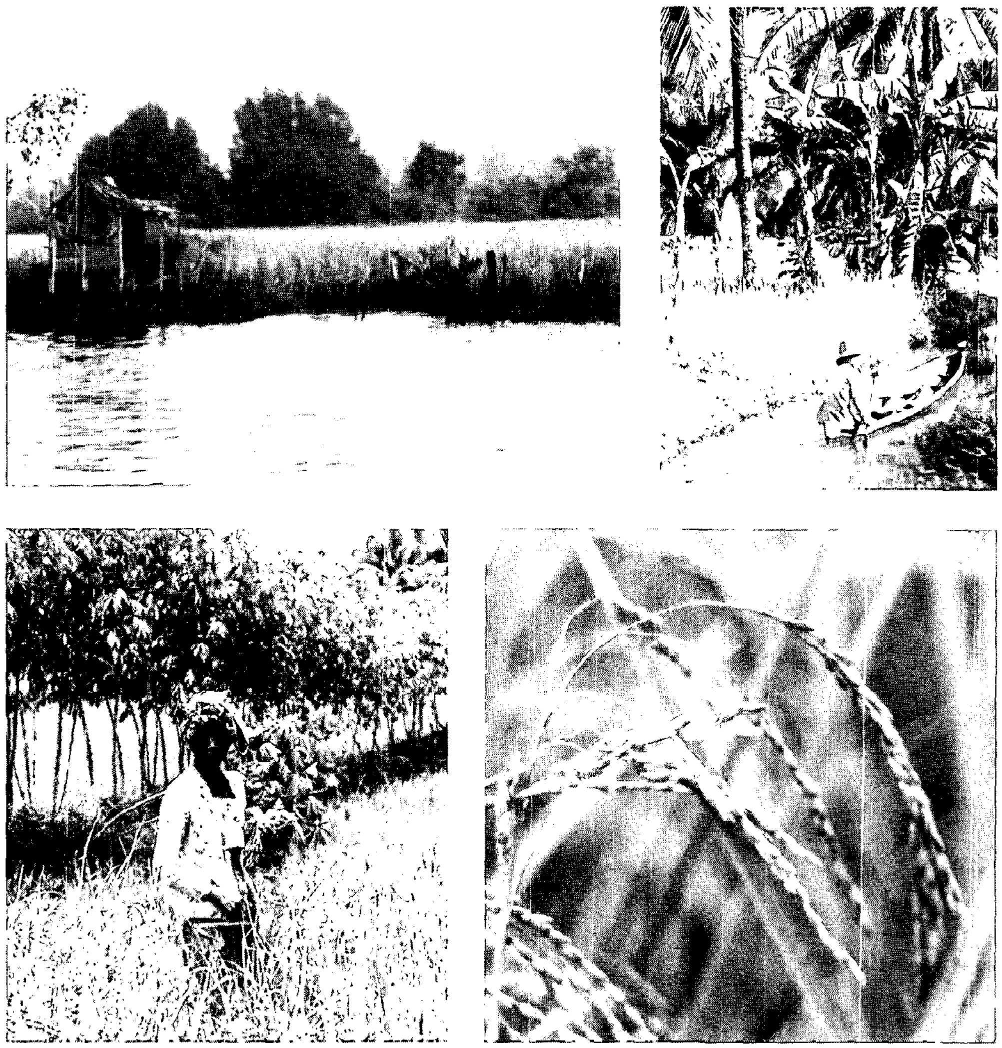

Figure 14. Farming in the Pulau Petak delta. Top left: some ricefields are adjacent to the Barito River, on levees, where drainage is good. Top right: between major levees are less well drained rice fields with raised coconut beds and smaller tertiary canals. Bottom left: harvesting is entirely by hand. Bottom right: production in some areas has continued for 20 years.

3.3 Populating the Land

Said (1973) outlined six development concepts that the South Kalimantan Planning Board, BAPPEMDA, wanted to introduce simultaneously: 1) the swamps and lowland region were to be further developed for agricultural projects, 2) the offshore zone searched for oil, 3) the coastal swamps developed as fisheries zones, 4) the inland grasslands (alang-alang) developed for cattle raising, 5) some lowland areas to remain as timber production areas, and 6) a forest conservation zone in the mountains maintained to protect the hydrologic cycle. These six geographic zones were each proposed as single-use development boundaries. These plans apparently originated from the inspiration of Mr. P. M. Noor when considering the Tennessee Valley Authority, U.S. (Said, 1973). A hydroelectric dam and improved harbor facilities were thought necessary to carry out the plans. With a density of 1.7 million people on 3.7 million ha of land, South Kalimantan needs people to implement these plans. Transmigration is therefore heavily supported by local officials. Based on their personal experience, BAPPEMDA recommended: better integration of agency efforts, importation of transmigrants (but not without support), central planning through BAPPEMDA, and total planning from hospitals to farming implements, and from roads to manpower training.

The major development efforts occurring until now include, almost exclusively, agricultural development through transmigration programs. The area has undergone rapid tranformation as various populations have entered to exploit these new agricultural opportunities. The historical attempts to encourage migration to Kalimantan are outlined in Table 9. A canal was built during 1880-1890 between the Barito and Kapuas rivers near Banjarmasin. Other canals built later resulted in the opening up of vast areas for agriculture by the local Banjarese. Dutch scientists surveyed Kalimantan before World War II to determine its potential for agricultural expansion (Schreuder, 1932; Wijk, Van, 1951). Sponsored transmigration began in 1937 when the Purwosari project site was opened up by the Dutch. Transmigrants cleared their own land, built their own houses, and dug the secondary canals. The government built the main canal and provided food and materials for the first 18 months. Farming consisted of harvesting rice for 3-4 years, intercropping with coconuts for a few more years, and then growing only coconuts as additional new land was cleared. Both price

Table 9. Chronology of off-Java coastal swamp planning and development affecting Kalimantan from 1890-1976 (from Koesoebiono et al., 1982).

Year	Event
1880-1890	The opening of the first in a series of canals in South Kalimantan for navigation through swamplands, which provided the Banjarese with access to new agricultural land through simple drainage systems emptying into the main canal.
1914-1922	Rice shortages during and after WWI focused colonial government's attention on outer island land potential. Some developments started by 1920 in Kalimantan.
1935	Further improvement of the original 1880 canals in Kalimantan and further settlement in the immediate vicinity.
1936-1940	Extensive feasibility studies and soil surveys for massive agricultural development and transmigration occurred. The purpose was to turn the Kalimantan swamplands into a 'rice bowl' in which mechanized agriculture would play a substantial role. The first transmigration project was initiated in 1937.
1948-1952	Kalimantan Polder Plan developed under the direction of Dr. Ir. H. J. Schophuys and agreed to by the Government of Indonesia. Over a 15-year period 840,000 ha of swampland would be reclaimed with proper drainage and pumping systems. A pilot canal development was initiated in 1950 on 4 areas totaling 40,000 ha which was to be conducted through regional Polder Corporations directed by the government.
1953	The first 5-year plan was to begin in Polder development. By 1970 only 2 pilot projects totaling 8,700 ha were near completion.
1957	The Ministry of Public Works announced a tidal irrigation project to convert 1.5 million ha of Kalimantan and Sumatra coastal swamplands to ricefields over a 5-year period. Minister P. M. Noor had formerly been directly associated with the Polder plan but shifted emphasis from pumping systems to lower cost open systems in which the Ministry of Works would plan primary and secondary canals in areas under the influence of tidal back-up. A 700-km canal was proposed for Kalimantan.
1960-1963	Kalimantan development project as supported by government decrees including the 1963 Presidental decree declaring it a vital state project. Actual implementation was limited to minor developments in Kalimantan and, in 1963, the project area was reduced.

Table 9, continued

1964-1965	A work committee for tidal and polder systems was established by the Minister of Public Works which resulted in the publication of 'Proyek Kanalisai'. Among other projects proposed was a canal running most of the length of Sumatra.
1967-1968	The Ministry of Public Works announced a new tidal irrigation project to open up 5,250,000 ha of land over 15 years. There was considerable exploratory work on possible projects by foreign consultants working for private companies and FAO.
1969-1974	The Public Works tidal irrigation project was reduced to 500,000 ha over a 5-year period (REPELITA I). The actual area opened was 13,198 ha for 7,180 transmigrant families. Three sites were developed in Sumatra and three in Kalimantan. Indonesian universities became involved in planning and design in 1969.
1974	By presidental instruction, a plan developed by the Ministry of Public Works to open 1,000,000 ha of coastal swampland between 1974-1979 (REPELITA II) was adopted. Survey activities, training and massive equipment purchases were quickly initiated.
1975	Canal excavation started next to REPELITA I pilot projects.
1976	The land opening projection was revised downward to 250,000 ha by 1979.
1975-1979	The World Bank request for design and survey assistance resulted in US$3.2 million loan for studies on 300,000 ha at two sites in Sumatra; it was complemented by a $3 million hydrological study and training from the Netherlands.

stability and income were achieved and with less labor than from rice out-line alone.

After World War II hundreds of thousands of hectares were planned to be opened up under very ambitious plans. Spontaneous migrants, however, were moving in faster than the sponsored transmigrants. During REPELITA I (1969-1974) only 18,000 ha were opened up of 500,000 ha planned for transmigration.

3.4 Spontaneous And Government Sponsored Migrants

Migrants are now a mixture of spontaneous migrants (mainly Banjarese but also some Buginese and even Dayaks) and government sponsored migrants (mostly from Java, Madura and Bali). Government sponsored migrants move to newly opened areas because their living conditions at home are poor. The government's offer of land, even if only one or two hectares, is attractive to what are mostly landless laborers. But settlement is generally possible only in areas where the locals have not settled, and therefore of low quality, or where the government sponsored irrigation projects open up new land. The relative success of the spontaneous and government sponsored transmigrants has been studied at Barambai by Soeratman, et al. (1977).

Barambai is the government sponsored transmigration center in the north of Pulau Petak. A survey of farmers by the faculty of Gadjah Mada University reveals numerous strengths and weaknesses in the transmigration program (Suratman and Guinness, 1976, 1977). Transportation, housing, farming implements, training and supplies are supposed to be provided for the first 18 months of settlement. However,

> Settlements are severely handicapped by shortage of staff, particularly agricultural officers, health workers, teachers and social workers, and those officers who are resident on the projects often have neither the time nor the skills to guide transmigrants adequately. The officer's own position is weakened by poor communications between the project, the provincial government and the central government. (Suratman and Guinness, 1977, p. 92).

Work outside the farming area is often necessary because a land clearing is difficult and slow and government rations are often inadequate. Living there is not easy. Farmers interviewed by this author near Barambai said their wives cried for all of the first three years of settlement. A turning point occurs when rations stop and the farmer must become entirely self-reliant. Commodity prices may tumble drastically (by as much as one-third) when the harvest is quickly sold to pay the heavy pre-harvest debts farmers traditionally accumulate against the harvest, including at Barambai. Government efforts to stabilize prices have, to date, been ineffective.

The transmigrants form social groups which are most often isolated from the indigenous populations. Balinese, who are Hindu, are encouraged to cluster so as to avoid confrontation with the local Moslem population over pig raising. The Balinese appear to be relatively successful in adapting to the new land. At Barambai, Balinese settlers excel in cultivating rice under difficult circumstances, in initiating wild pig hunts, in marketing, and in exhibiting good communal harmony. They also meet monthly to discuss social or agricultural issues. Work and celebrations are considered obligatory.

Relations between the numerous new arrivals and the few indigenous families are not always satisfactory. However, at Barambai compensation is made to the indigenous Banjarese when traditional lands are confiscated for more intense use. Banjarese are also encouraged by government officials to open up land elsewhere and to use the newly opened facilities. Whereas the government may hope that the locals will learn new farming techniques, it is often the successful transmigrants who learn from the locals about how to grow cash crops or use the local varieties. Intermarriage and regular cooperation are, however, rare between locals and transmigrants.

The Gadjah Mada University Test Farm at Barambai and Bogor Agricultural University have proven quite effective in pioneering irrigation systems and transferring techniques to farmers directly through experience. Introduction of two crops of rice and diverse cash crops has occurred. Farmers are also experimenting on their own with fish ponds, fruit trees and new variaties of rice.

The most successful settlers are those spontaneous migrants who have had to settle among the local population and negotiate for land and learn the local farming techniques. Compared to the government sponsored migrants, they have more capital, more hope, and better relations with the locals. Many successful local operators are expanding their operations.

In Kalimantan an estimated 165,000 ha of land have been opened up by them at no expense to the government (Collier, 1979). By comparison, only 13,198 ha opened up under the government program from 1969 to 1974.

3.5 Future Concerns

Hanson and Koesoebiono (1977) point out how "The settlement of Indonesian swamps is one of the most significant environmental transformations likely to take place in Indonesia. It is one of the world's major experiments in marginal land utilization and a classic case for creating resource and environmental strategies " (p. 7). Although different approaches are being tried, major questions arise about the future condition and management of the areas which must be answered if long-term stability is to be achieved. These questions involve soil development, cumulative impacts on fisheries, health, hydrology, crops, and stability to withstand perturbations from drought, disease, pests, and social unrest (Figure 15).

3.5.1 Soil Problems

Soepraptohardjo and Driessen (1976) list the following major problems affecting agricultural reclamation of Indonesia's peats, including the Pulau Petak delta:

1) High subsidence after drainage and vegetation removal.
2) Locally rapid horizontal hydraulic conductivity or extremely slow vertical conductivity.
3) High heat capacity and low thermal conductivity (as an insulator) which results in great temperature variations at the surface.
4) Locally low level of organic material decomposition and/or high wood percentage.
5) Low weight-bearing capacity of the soils; many crops, particularly tree crops such as papaya, tend to topple over.
6) Rapid oxidation of organic material after drainage.
7) Irreversible shrinkage which causes adverse water retention characteristics and increased sensitivity to erosion.
8) Low nutrient content.
9) Often overlying marine sulphate bearing soils.
10) Isolation from transportation networks.

Perhaps the most important impact for the farmer is the possibility of declining yields and income, and resulting unrest. Pest and weed infestations are other major problems. Additionally, there are periodic droughts and difficulties with drainage. Local inhabitants leave the land fallow at regular intervals or shift to other crops. There is too little long-term data to support the qualitative or quantitative appraisals of yields among the spontaneous and sponsored immigrants. In general, however, the spontaneous migrants have higher yields and the yields of the sponsored migrants decline after a few years (Collier, 1979; Collier et al.; in press; Driessen et al., 1976). This is partially the result of spontaneous migrants usually settling the preferred levee land which is naturally drained, and has better soils. The sites between levees are more likely to be the site of government projects. Even if that soil is relatively good, its properties change with tillage. There are numerous examples from the tropics documenting soil fertility losses following cultivation (Sanchez, 1976; Flaig et al., 1978; Ewel and Conde, 1980). Weed infestation usually accompanies the decline in soil fertility, thus hastening abandonment.

Tillage, drainage, and fire reduce both peat and mineral-bound organic matter. The loss of organic matter is important because organic matter:

1) Supplies most of the cation exchange capacity of the soils.
2) Increases soil aggregation and improves its physical properties.
3) Complexes with micronutrients.
4) Soil pH values increase after burning because of the incorporation of basic cations and gradually decrease with cultivation.

The individual farmer may thus expect to face more, not fewer, problems with soil fertility if he survives the first 5 to 10 years. Individual and group farming skills, or management, must eventually make up for the loss in natural productivity over long periods of time.

3.5.2 Cumulative Effects

The cumulative impacts of large-scale reclamation have hardly been examined. The major areas of concern are 1) the cumulative impacts on fisheries, 2) population expansion within existing family units when no nearby uncultivated land is available, 3) water quality, and, 4) the geologic/hydrologic modifications of the deltaic soils. With increasing population, Rotan and Nipa supplies (used for housing, nets and furniture) and fishing may be declining in Sumatra and the traditional management unit, the Marga, is losing control of resource management (Hanson and Koesoebiono, 1979). Coastal wetlands and estuaries are, by their very nature, intimately involved in the ecology of the shallow coastal zone where the most lucrative fishery enterprises are usually located (Turner et al. 1979a, b). The loss of intertidal land, either by reclamation or by hydrologic isolation from the main channels, will ultimately reduce the potential for increased fishery enterprises. Fishing at the Pulau Petak villages is now as close as the nearest canal. But the fish market is stocked with those fish which are customarily considered estuarine and wetland dependent (Figure 15). At some point the negative impacts of land reclamation on fish stocks will result in less fish than can satisfy a growing local demand. It seems no small coincidence that areas of major fishing grounds in Indonesia are also nearby the areas of coastal swamps and marshes (e.g., Doty and Soegiarto, 1970).

Relationships among the various migrants are likely to deteriorate when new farming areas are no longer available. The present farm family growth rate means the farms must be divided among family members until too little is left. Even now there are problems as the area is being populated.

Water quality problems will inevitably develop as more people use more pesticides on more fields. Intestinal diseases are the number one cause of mortality, because the drinking water supply is also the medium of waste disposal, irrigation, washing and transportation.

A potentially very serious long-term impact is the continued subsidence of the peat combined with the sinking of land relative to sea level. In a geologically similar delta, the Mississippi River delta, Louisiana, sea level rise (12 cm per century) is minor compared to natural subsidence and that caused by man-made hydrologic modifications. The Mississippi River deltaic soils are not accumulating sediments and organic materials at a rate equal to the compaction of the underlying sediments (Craig et al., 1979; Scaife et al., 1983; Turner and Neill, in press). A

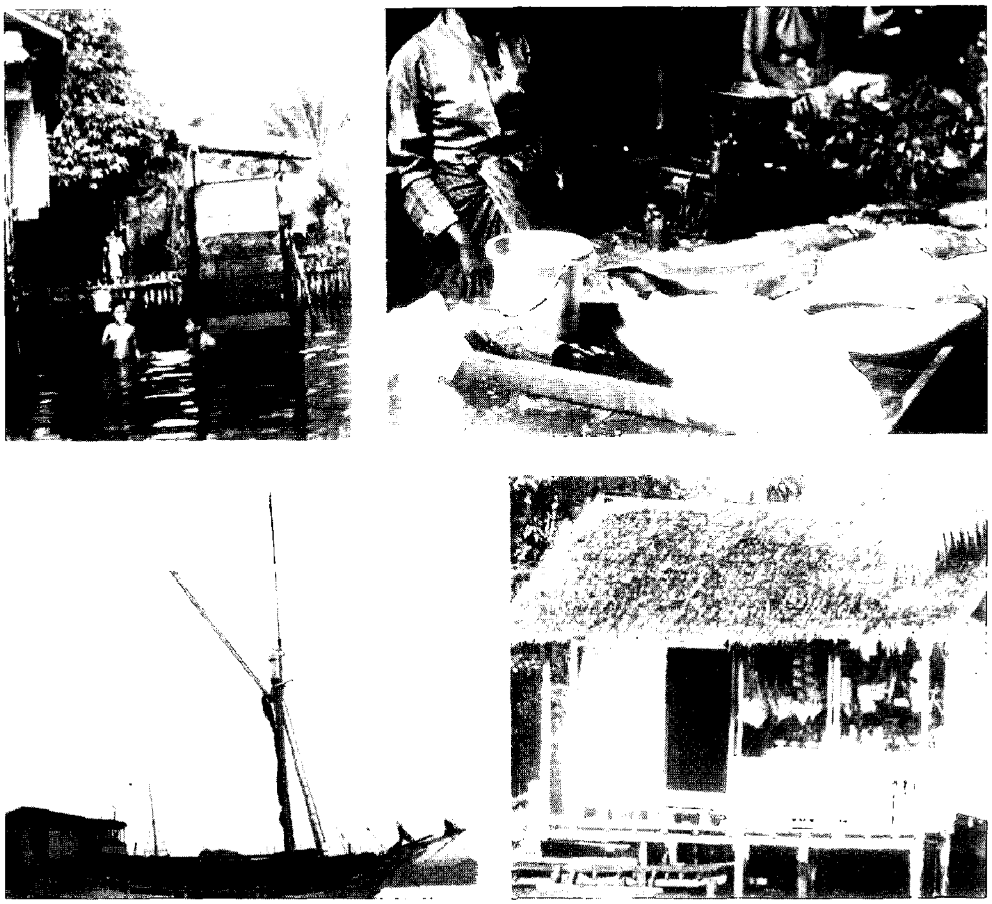

Figure 15. Life around Banjarmasin is affected by cumulative impacts. Top left: the canals serve as bathing sites, for washing and for waste disposal. Top right: the fish market in Banjarmasin has a variety of fish and shrimp, which are dependent on natural intertidal vegetation. Bottom left: transportation is mostly by waterway. This prahu is loaded with planks from timber harvested upstream. Bottom right: a 'country store'. Photographs by the author.

primary reason for the massive erosion rates (now approaching 1% annually) is the man-made modifications in the coastal swamps and marshes. It took 40 years for the impacts to become visible, and state officials are now desperately trying to grasp both the magnitude of the problem and what to do. In the same way, what if the land in Kalimantan which is presently being drained or irrigated is 50 cm lower in 50 years? We simply don't know the actual subsidence rates for this type of experiment yet. But at the present rate of development most of the land will be occupied in 50 years. Will it not be even more marginal as farmland if subsidence is significant and won't the drainage difficulties during the occasional drought or very wet year then push farmers into ruin? This is a problem that is slow to develop and devastatingly disruptive when it occurs. With the present emphasis on agricultural production, to the exclusion of the wider issues underlying Said's (1973) development plan, it is unlikely that these questions will be recognized or addressed. What Vayda (1979) said about some other development projects may soon apply here: "these examples illustrate the dangers of developing programs for particular groups without taking into account the larger systems within which those groups will have to operate."

In brief summary, the Pulau Petak deltaic swamp of South Kalimantan is undergoing a major transformation from low-density traditional farming into a government sponsored agricultural community. Significant obstacles to establishing a sustained agricultural system naturally arise in ambitious projects like this. However, the short-term success of a significant percentage of settlements is an established fact despite social tensions, difficult colonizing conditions, the presence of soils sensitive to hydrologic manipulations, economic uncertanties and labor and health issues. The success of sustained and further single-issue development is less clear because of 1) the cumulative impacts of settlement on the total ecosystem and on health and economics, and 2) the long-term changes in soil fertility and land subsidence. Presently needed are long-term comparative studies of the present results and greater emphasis on the relative merits of alternative and/or complimentary land use management.

4. LESSONS LEARNED

The term 'coastal zone management' implies a perspective larger than individuals and villages, though not exclusive of these. It involves a regional perspective, implicit in the term 'coastal zone' and time elements long enough to influence or otherwise manage the region. Though 'management' involves individuals, it has a geographic aspect since regional geologic, biologic and hydrologic history usually influence, if not determine, the possibilities for management and for development. The discussion below of the 'lessons learned' therefore emphasizes the broader aspects of these two case history studies. For each lesson a simple concluding statement is made and then followed by examples and discussion.

4.1. Local Participation

Local participation in management is absolutely essential. The villagers live where decisions are felt, they must share in the disappointments, and they share first in whatever management occurs. If decisions do not make sense to villagers then management coordination is eventually impossible and chances for successful implementation will be slight.

Management must integrate commonly accepted values to succeed. In Indonesian society the term 'mushawarah' is the idea of communal 'non-authority'. Mushawarah contrasts with the individual or state development of centralized planning, implementation, and enforcement. For example, it is common to have team reports rather than single author reports, and for individuals to feel uncomfortable expressing opinions forcefully at staff meetings. A parallel example is the idea that consensus, or 'mufakat', not a simple majority, determines successful completion in decision making. The mutual bearing of burdens, or 'gotong rojong', is part of this willingness to both participate and share in the outcome of whatever happens. There is also an acceptance of personal difficulties as something that can be improved upon; e.g., a criminal might be considered tolerantly (and guardedly, of course) as "not yet Javanese" (Geertz, 1971, 1973). Directly opposing or ignoring such strongly accepted attitudes invites an equally significant rejection of outside management.

Attempted regulations should pay attention to local laws. 'Adat' law is the assemblage of customary rules that usually govern village life in a subsistence economy. They may be considered rules which encourage the village's survival with optimal comfort in the natural environment. Violators of national law in conservation zones often defend themselves by reference to adat rights. Adat law may be invoked for personal gain, but historical implementation meant that some understanding of the environment was felt by the local community (Rijksen, 1982). Interviews with fishermen in Segara Anakan revealed that they understood the idea that shrimp and fish in Segara Anakan require mangrove detritus to survive. The 'nursery ground' concept was not as clearly expressed. Nevertheless, they had the understanding necessary to plan and follow management plans which attempted sustained use of the mangroves for fisheries. The villagers also were enforcing a sense of territoriality by keeping Cilacap fishermen out of the estuary. The villagers cannot, however, prevent the central government from completing large scale hydrologic modifications nor understand what agencies are planning until it is probably too late (Velasco, 1979).

In South Kalimantan, some shifting agriculturalists plant trees in planned transmigration areas with the sole purpose of retaining rights to their fallow fields. Government authorities do not always recognize title to lands without permanent crops and the extra work of planting trees establishes claim to land which is otherwise vacant (Dove, 1983). Management imposed from outside will be circumvented in similar ways.

4.2. Natural Resource Agency Support

National development agencies must have sufficient resources to develop existing expertise, and to find new, or better, technologies and management perspectives that, in turn, make possible sustainable development.

The Directorate General of Fisheries receives much less support, as evidenced in the salary scales of field workers, than do, for example, workers with similar training at the Directorate of Forestry or Agriculture. BAPPENAS channels money for research on mangroves into the Directorate General of Forestry, not the Directorate General of Fisheries (Burbridge, 1982), despite a fisheries industry valued at $192 million (U.S.) in 1978 which depends on mangroves (e.g., McNae, 1974; Martosubroto and Naamin, 1977; Turner, 1977). At Banjarmasin there is one small fisheries office. In contrast, there are two major field stations for agriculture, and much support for the forestry officials. One wonders what improvement in fisheries understanding and harvest would occur with a larger effort for the fishing enterprises. If there had not already been an existing fishing effort and port in the Cilacap region, it is obvious that the reclamation project in Segara Anakan would now be complete. Agricultural reclamation, which has not to date gained ground there, gave way to an established industry. In Banjarmasin, the reverse has occurred. With few people already there, what might be a major fishing zone, as other deltas are, has become a major agricultural zone for thousands of newly arrived people.

4.3 Information Gaps

Too little is known about mangroves and fisheries and sustained agricultural developments in swamps to justify either extreme praise or condemnation.

This lesson is perhaps best illustrated by what has happened to a swampland agricultural systems in the past few thousand years and also by what we now know of mangrove ecosystems now. Denevan (1970) concluded from a survey and research on numerous Central American wetland agricultural systems of now collapsed societies that population pressures preceded over population on well-drained land, which led to use of marginal lands that then failed either to sustain fertility or to offer enough time for the population growth to stabilize. These are also the present symptoms of land use on Java.

The second illustration concerns what we do not know about coastal swamps. Two common management issues are the following (modified from several sources, including Burbridge, 1982; Burbridge and Koesoebiono, 1981, 1982; Lugo and Snedaker, 1974; Odum, 1970; Snedaker, 1982; Soemarwoto, 1974; and Velasco, 1979.

1) Should comprehensive and total swamp development be favored over partial and slow development with conservation? Response: In general, no. A wise inspection of unknown quantities does not result in the loss of parts before the whole system is understood. Enough mistakes and accomplishments have been made to justify a cautious approach if sustained development is the goal of management.

2) What is the minimum area of mangroves necessary for ecosystem functions? Is the question even justified? What is the comparative advantage of different uses of mangrove, e.g., ponds vs. natural? Response: In general the whole mangrove and saline and brackish water intertidal community should be conserved intact.

The arguments over the size of the protected zone around mangroves now involves two main agencies, the Department General of Fisheries and Department General of Forestry. The fisheries department considers fisheries' yields of paramount interest and is seeking to have forestry operations reduced or eliminated for mangroves. There is logic to this conclusion since the value of mangrove lumber products is no more than 36 million dollars (U.S.) in 1978 while the mangrove-dependent fisheries catch was worth 194 million dollars (Burbridge and Koesoebiono, 1982). Additionally, shrimp which depend on the mangroves have an export trading leverage 22 times greater than imported rice, when expressed as protein equivalents (Turner and May, 1979). In other words each kg of shrimp exported pays for an equivalent importation of 22 kg protein as rice.

Alternative estimates of the value of mangrove as tambak culture show similar results. In general, for each ha of mangrove converted to tambak, a net fisheries loss of 467 kg occurs (Turner, 1977). Additional calculations would be worthwhile on the basis of energy, labor, and social stability.

The current interest in the vegetated buffer zone, the 'greenbelt', is important because it highlights issues of national concern. However, the discussions could be usefully broadened to include the total services of mangroves (e.g., erosion control, water quality, storm buffers). Evaluations based only on fisheries or only on forest values neglect the multiple values mangroves have in water quality, erosion control, subsistence firewood gathering, medicinal products, native food, and building materials. Preservation of greenbelts does not isolate functions. Instead, it gives a false hope of sustained development. If there is one thing learned in the last 10 years of environmental research it is that coastal ecosystems are strongly coupled within a hydrologic unit. Arbitrarily slicing off one part of the ecosystem for management purposes will not preserve functions in isolation of changes occurring in the connected components. Shrimp are not found only near the edge of part of the mangroves. Changing water flow patterns or forest vegetation outside the greenbelt will affect the greenbelt itself. The implications are that mangrove zones should be managed as entities for the total values of their services, not as pieces.

4.4. Ecological Planning

Environmental planning should begin when development projects are first conceived, and continue during project analysis and through development. Nations with limited capital are the ones that can least afford to misuse or degrade their natural resource capital.

It is possible to make mistakes planning and developing agricultural projects. Developing tidal swamplands is very susceptible to mistakes, particularly hydrologic errors. Social cohesion may collapse before corrections can be made, leaving abandoned projects behind. This has already happened in some areas near Banjarmasin. At times this planning practice can be rather simply accomplished. Rather than considering the local population as a barrier to development, it can be seen as a source of local consultants on the best practices for use of marginal land.

The value of coastal ecosystems cannot be entirely expressed in economic terms, not because they provide no services, but because the discipline of economics generally ignores the free services they provide. As their services become scarce their value increases. These externalities are discussed in greater detail by Burbridge (1982) and Snedaker (1982). How to evaluate the externalities is the central issue. In Segara Anakan the smaller fishermen perceived the threat to mangroves as affecting their subsistence way of life, which an economic analysis could not evaluate. The conflicts between local fishing interests became a political issue involving a Presidential Decree. A simple economic analysis is likely to be insufficient for determining the probability of sustainability.

4.5. Mid-course Corrections

Changes from the expected results will arise and should be met flexibly. Monitoring the project is necessary to minimize the magnitude of the impacts and to learn from them to avoid problems later.

Two good examples of this attitude were evident in these Indonesian case studies. First, BAPPENAS was flexible when dealing with the proposed agricultural developments in the Segara Anakan. This sparked further general interest in coastal management issues. The area is now a natural laboratory for study of how to manage estuaries. It thus becomes very useful to set aside natural areas in the immediate vicinity of projects in order to monitor what is happening and to preserve options for future development.

Second, massive increases in the use of pesticides in order to control brown hoppers (a swampland rice pest) resulted in reductions in the traditional ricefield harvest of fish. However, breaks in planting schedule followed by synchronous planting have helped to reduce the size and severity of the outbreaks.

Social institutions should be monitored too. The traditional village welfare system based on sharing of harvest and labor is disappearing together with the communal village rice stores (Conway and McCauley, 1983). It remains to be seen if the central government can act as efficiently in this regard as the village-based institutions.

4.6. Complete Project Analysis

> "Careful attention must be paid to the contribution of the natural ecosystems in sustaining long-term development in tropical countries. Projects that appear economically sound in the short term may actually be economically burdensome over time because of initially unrecognized environmental costs. Holistic planning is one way of identifying wise alternatives for economic growth and development." (National Research Council (U.S.) Committee on Selected Biological Problems in the Humid Tropics, 1982).

The development of tidal swamps for agriculture implies that all other uses have a lower priority. This is not necessarily always the case. However, tradeoffs cannot be effectively evaluated without a broad spectrum of information. Burbridge et al. (1981) argued that comparative studies which include the external, free services of natural tidal swamps indicate that some swamps should not be reclaimed. In some cases, e.g., Jakarta Bay, tambak construction in mangrove zones leads to the eventual destruction of those ponds, resulting in the loss of both ponds and mangroves (Bird, 1980; Bird and Ongkosongo, 1980).

Social interactions should be included as part of the analysis. It may be absolutely essential to do so. There is much good work in this area (see examples in the bibiliographies of Guinness, 1977; Meyer and MacAndrews, 1978; Watson, 1983) and it should continue to receive support. Suratman and Guinness (1977), point to several factors which have determined the success or failure of transmigration schemes in Indonesia:

> Agricultural and soil surveys enquiries into land rights and the culture of the indigenous people are required before final selection is made. Although some surveys have been thorough, particularly those conducted by overseas financing bodies or by local university teams in conjunction with the Transmigration Department, there has been a tendency in most pre-settlement surveys to make only a cursory inspection over a period of one or two months without attempting to provide a firm base on which later agricultural development and inter-ethnic relations can be established. As a result, after several years of settlement, crops fail, soil fertility declines and land disputes with local villagers continue to disrupt farming activities. (Suratman and Guinness, 1977; p. 90).

The whole issue of promoting artisanal fisheries faces similar problems (e.g., Sidarto and Atmoswasono, 1977; Collier et al., 1977) as does mangrove management specifically. See Christensen (1982) for a wide-ranging presentation of current mangrove uses in Southeast Asia.

4.7. Interagency Cooperation

The more informal and formal cooperation between personal, regional, national and international agencies, the better the transfer of information, training, education, experience, and ideas.

Agencies have difficulty transcending their single-minded mission orientation to work on multiple resource issues because they are not expected to do so. Attention to fisheries, mineral recovery, or forestry alone will not provide optimal coastal resource use. In settlements the strategy is to turn over control to the local authorities within 12-18 months leaving inexperienced and newly arrived settlers to manage fairly complex issues together while addressing their definite problems encountered in just surviving during the first few years. Little coordination is possible in such an environment.

Hanson and Koesoebiono (1977) suggested that in Indonesia the Department of Agriculture should be the one agency to coordinate long-term planning of living resources. They proposed regional resource management centers, not single-purpose research stations and provincial extension offices which cannot offer specific advice for a broad range of coastal problems. The involvement of so many foreign consultants and national university groups is an indication of agency needs in this area. The region planning bureau, BAPPENAS, might also review and track existing development plans and activities, with the intention of reviewing and modifying them as need for new information is discovered.

Finally, there is a sincere interest in Indonesian agencies and those of other countries to promote development programs with long-term stability. As evidence of their intent regional planning and comprehensive project planning are often already in place. The goals are to establish a sustained agricultural base, a healthy human environment, and reasonable and fair resource use. The list of agencies involved with swampland development is therefore long and complexly related (Figure 16). Ultimately, however, population growth must be stabilized. If population growth does not stop soon coastal management will be increasingly more difficult and eventually impossible. Meanwhile, there is still time to consider the best of the available options and to plan and to work for the future with some hope of contributing to progress. The historical example is that the Indonesian culture is willing to work with nonaggressive and constructive attempts to sustain a humane human society (Figure 17).

5. GUIDELINES

The following guidelines are based on the review of the two case studies, literature review, and the author's inference based on personal experience. Some specificity was sacrificed to broaden applicability over a wide geographic area. Principles of coastal ecosystem management are first stated then followed by discussion and then by example. There is naturally some overlap among guidelines. Broadly stated their summary purpose is to establish 1) a mechanism to prepare proper development by allowing for analysis of choices, implementation, and change on an individual project basis, and 2) a monitoring program which preserves a sense of agency openness both in addressing new issues on a broad level and in testing hypotheses about long-term sustainable development and project impacts.

1) Mangrove ecosystems should be designated for multiple use for fisheries reserve, erosion control, and subsistence village use rather than single-purpose agricultural zones. Converting mangrove ecosystems to

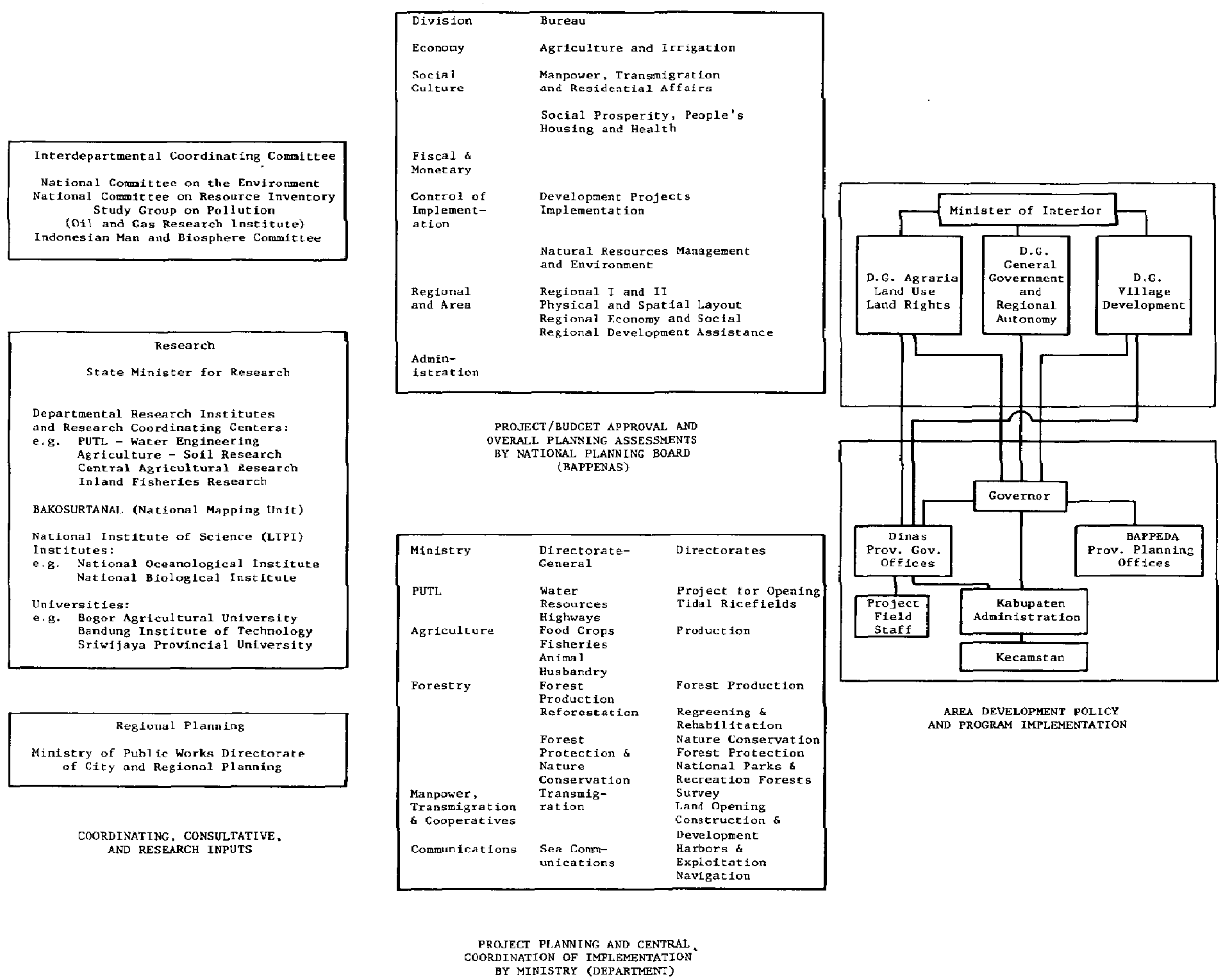

Figure 16. The agencies involved in swampland development and management in Indonesia (adapted from Hanson and Koesoebiono, 1979).

Figure 17. A student of traditional Javanese dance practicing on the grounds of the Sultan's Palace in Yogyakarta. He is learning to put finger, wrist, elbow, shoulder and torso in balanced and precise coordination under the guidance of a dance master (not shown). As the student moves about the courtyard the teacher follows with gentle reminders, humor, and straight-forward examples. The student will eventually have the natural grace and dignity which Indonesians hold in high regard as representative of an enlightened and courtly civilization.

agricultural lands or single-purpose lumber concessions will usually result in a net loss of export dollar earnings, protein production, and perhaps employment. The spontaneous use of mangroves for subsistence (firewood, medicinal products, building supplies, food, and small-scale farming) cannot, in all probability, be regulated properly by any group other than villagers themselves. That type of management therefore requires local education to improve conditions. At the other extreme, large-scale development projects are manageable at the regional and state level. Analysis can and should proceed before irreversible momentum gathers for exploitation. For that analysis managers should consider the following points about mangroves: (1) Many developed and underdeveloped fisheries are entirely dependent on mangrove ecosystems. This dependence seems to be especially pertinent for penaeid shrimp stocks captured far from the mangroves. (2) Mangroves protect shorelines against waves, tides, and storms. Agriculture ponds and lumber harvest should therefore not occur within 500 m, or farther, of the coastline in order to preserve them. (3) Mangroves provide a vast array of products and services to the local villages. (4) Mangroves are generally self-sustaining and require little, if any, economic management to be sustained.

2) Coastal management of estuarine zones should be organized at hydrologic, or watershed, level. Ecosystems are natural organizations of parts joined together in active interactions. Developing or managing one ecosystem part will therefore affect other parts simultaneously. For example, upstream land use practices affect estuarine water quality, sediment loading, and migration of some freshwater prawn stocks (e.g., the malaysian prawn, *Macrobrachium* sp.). Traditional management customs often reflect this level of management and might be utilized usefully in development implementation. Economic and transportation linkages as well as traditional village political economics also reflect such geographic boundaries. The tendency of land use in a coastal watershed to follow natural hydrology is illustrated by three examples. First, inland riverine zones may have higher tidal fluctuations than at the river mouth because of river channel geomorphology. Specific varieties of crops are therefore planted late in the wet season in back swamp areas but early in the season at less frequently inundated higher elevations. Second, unusually wet or dry years affect marginally successful agriculture along

well-defined hydrologic boundaries. Third, important natural forest commodities, such as some specialized building materials, are naturally dense or planted only in specific hydrologically defined swamp forest zones. Therefore, organize engineering measures, policy planning, and especially regulation around hydrologic units.

3) Use villages to build consensus for management. Villagers are too often ignored in planning and development. Their sustained participation is a sign of good planning; their nonparticipation may indicate either serendipitous events or poor vision of what development means. Exploiting one part of village management (structure) for a specific development goal may mean the elimination of a village's adaptation to a general and larger issue of cultural identity and value, seasonal labor supply, or obtaining building supplies (functions). Therefore, include in management the equivalent of fisheries and agricultural extension agents, rural sociologists, natural history biologists, as well as broadly trained scientists, academics, and administrators. These people should have individual contact with the villages. Also, include village elected representatives in the project planning, construction, and management. Build up the village's ability to manage natural resources as a whole rather than dismember it and then replace it with single-purpose management.

4) Only selected areas should be developed. Not all agricultural zones or fisheries stocks are equal. A peculiar anomaly in one location may result in over-extended exploitation elsewhere. Ambitious single-minded development of all of South Kalimantan, for example, would unnecessarily ruin vast areas for light agriculture or destroy potential development of, for example, local fisheries. It's necessary to preserve watersheds for healthy water supplies, diversify agricultural cropping and land uses, and set aside nondeveloped areas for future development as buffers for development-induced expansion and to learn from mistakes.

5) Incorporate traditional agriculture, husbandry, or fishing practices where possible. Experienced farmers and fishermen are rich sources of technical information necessary for planning, development, re-evaluation, and alteration. If rice is not grown, fishing vessels are few, or coconut trees are sparsely planted then find out why before exploring possibilities for expansion. Introduce changes (new varieties,

techniques, or equipment) directly to the villagers, as happens in Barambai, to observe their problems and successes immediately. If fishermen do not fish on specific days, then perhaps their usually harvested species are spawning. Therefore, gather information on success and change in order to monitor unexpected adaptations and efficiently discover opportunities.

6) Strong actions should be based on good information. Irreversible damage may occur without proper pre-planning inventory and assessment. Large-scale burning of large tracts of land in clearing will waste lumber but also reduce peat thickness, perhaps enough to affect crop productivity. Harvesting by timber mechanically is a significant capital investment and may help offset development costs, but it may also compact the soil enough to reduce future crop yields and alter groundwater hydrology. Five or ten percent of a development budget is not too much to spend to ensure project sustainability. Particularly important are 1) factors that have multiple impacts (e.g., hydrology or present social structure); 2) trial and error field studies; 3) long-term monitoring of changes; 4) inventories mapped at 1:24,000; 5) field interviews; and 6) multidisciplinary teamwork. This means that though periodic multiple-agency review of the results may be painful, at times it is absolutely essential.

7) Integrate management by sustaining and building linkages between and within natural resource agencies, participants, and discipline interest. Proper support for natural resource management requires not only the obvious needs for trained staff and good administration but also formal and informal linkages within and among all interest groups. Just as the environment is self-integrated so must management be self-integrated. These interest groups should include government agencies, educational institutes, and nongovernmental organizations (NGOs), for example. The purpose of this guideline, then, is to discourage unnecessary bureaucratic overlaps, to reduce tensions between conflicting interest groups by addressing areas of conflict, to upgrade general staff awareness of broader perspectives, and to provide better analysis.

Each country has individual requirements and obstacles to overcome to implement this guideline. Specifics are not possible to present in this format. There are five areas of successful effort possible or exemplified in southeast Asian coastal management: in education, participation by NGOs, salary equitability, introduction of techniques advancing integrative approaches, and administrative encouragement. Education is important because it broadens participant perspectives, skills, and experiences. This integrates management by means of the individual. Educational support might include multi-national or regional training centers such as Biotrop (Bogor, Indonesia) and environmental studies centers like those being established throughout Indonesia (Hanson and Koesoebiono, 1979). These research centers are important to the country because they emphasize training of adequately prepared nationals and long-term association with foreign educational facilities, and encourage broad rather than narrow research and teacher training.

For countries like Indonesia, virtually 100% of the foreign-trained students return home to work immediately on major environmental issues. They bring back both formal and informal connections with the rest of the world. Exchange programs within and among countries can be further encouraged by providing long-term support for major regional journals, providing partial salary support for an English translator/editor, or buying extra distribution copies. The effect would be to stimulate dissemination of information among those who are open to learning in this format, to encourage local scientists to share and preserve information in a readily available format.

Nongovernmental organizations such as the International Union for the Conservation of Nature, national public-interest groups, professional societies, and, at times, large donors and grantors (e.g., the World Bank and foundations) can be extremely useful through administrative review of issues and programs or providing funding. Smaller regional groups usually require only a little encouragement to grow and participate. Sometimes phone calls, speeches and committee work are enough stimulus. In Indonesia the necessary field work under difficult conditions is encouraged by providing salary incentives. Some workers earn up to 50% or more of their annual salary from extra compensation for field work.

New technologies require integrative linkages in training and administration to be developed. They therefore encourage linkages when introduced to the host country. Administrators should recognize and support the multidisciplinary nature of technologies such as remote sensing, statistical analysis, and computer use.

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Case Study Six

CATCHMENT LAND USE AND ITS IMPLICATIONS FOR COASTAL RESOURCES CONSERVATION

Random DuBois with Leonard Berry and Richard Ford

SUMMARY

The objective of this case study is to demonstrate the cause-and-effect linkages which exist between inland land use and tropical coastal areas. Kenya's Athi River catchment, a predominantly semi-arid basin characterized by zones of widespread human-induced erosion, was selected as the site for the study. The selection was based on previous personal experience as well as written accounts which linked erosion and downstream sedimentation with large-scale coastal changes. The approach followed in this study was to document coastal resource changes attributable to upland phenomena, distinguish between natural and human-induced sources of coastal changes, document the economic and ecological significance of these coastal changes, suggest possible corrective actions, and discuss the potential coastal implications resulting from newly proposed upland basin development activities. The methods employed to collect the required information were a review of the literature, interviews in Kenya, site visits throughout the catchment, observations recorded from an aerial overflight at the coast, and use of SCUBA to make underwater observations.

The results of the case study demonstrate that human activities which disrupt the existing steady-state equilibrium between upland and coastal portions of a catchment can result in significant coastal changes. Many of these changes, depending on their nature and extent, can result in considerable economic and environmental costs. Due to the general lack of data characterizing tropical coastal ecosystems and the absence of environmental monitoring programs, coastal modifications are often initially difficult to discern. Generally, attempts to mitigate negative impacts associated with coastal changes are most successful when applied at the source responsible for the changes. Long-term resolution of upstream-coastal conflicts may require expansion of authority of an existing government institution or the creation of a new agency to provide the jurisdictional scope needed to address basin-wide issues. The case study concludes with a set of guidelines for coastal planners and managers which recommend means to identify, monitor, and mitigate the coastal impacts resulting from upland land alteration.

1. INTRODUCTION

Evidence is increasing that unsound, unplanned, inland land-use practices are significant causes of change in coastal areas. In part, this can be attributed to a growing understanding by researchers of the physical relationships which exist between the coast and inland regions. This knowledge has facilitated the documenting of linkages between coastal impacts such as fish kills and habitat degradation with a range of inland sources including dumping of toxic wastes and deforestation. This case study presents a detailed example demonstrating cause-and-effect linkages which exist between inland land use and coasts characteristic of tropical areas. It documents the economic and environmental costs associated with coastal degradation which accrue when these linkages are not accounted for in land-use planning and development. It attempts to convey the difficulties which coastal land managers face when attempting to resolve inland land-use issues affecting the coast. Finally, it suggests possible institutional mechanisms which may overcome some of these difficulties.

Specifically, the case study attempts to answer the following questions:

- What coastal resource changes can be attributed to upland phenomena?
- To what extent do these changes result from upland agriculture and other human land-use practices as opposed to natural causes?
- What is the economic and ecological significance of these modifications?
- What means exist for corrective action?
- What are the coastal implications resulting from proposed upland basin development activities?

This case study focuses on coastal impacts resulting from upland land uses in the Athi-Galana-Sabaki catchment (watershed) in Kenya. The decision to use a catchment to illustrate several examples of cause-and-effect relationships was based on the following arguments: first, a catchment serves as a convenient natural ecological unit for development planning and implementation; second, a number of nations throughout the developing world are forming organizations for the development and management of river basins; third, natural resources planners are becoming increasingly aware that coastal zones are affected by upland agriculture and industrialization via river flow; and fourth, the U.S. Agency for International Development (USAID) and other donor organizations are showing increasing interest in watershed management as a means to incorporate natural resource considerations into development planning.

Kenya's Athi-Galana-Sabaki catchment (Athi for short) was proposed by the author as a suitable site for the study's objectives for meeting the following selection criteria: the coastal portion of the Athi's catchment and its estuarine and marine resources have been and continue to be modified as a result of upland land use; the nature and extent of these modifications have resulted in both positive and negative impacts on present coastal uses, some of which come at considerable economic costs; reasonably good documentation is available; Kenya offers a good, though recently developed, institutional framework to provide support for such an inquiry; and finally, the Athi River case study represents a set of issues which are presently, or soon will be, faced by other African nations as well as tropical developing coastal countries from other regions.

The methods employed in preparing the case study included: a review of the literature; interviews with individuals in Kenya; site visits throughout the catchment; observations recorded from an aerial over flight at the coast; and the use of SCUBA to make underwater reef observations.

Unfortunately, data gaps prevented complete documentation of the Athi catchment's recorded history. In part, this was due to our failure to obtain older specific documents which would have been valuable for comparative purposes. More importantly perhaps, some types of data were absent because studies had never been conducted in the region. In cases where important data were lacking, our field observations had to suffice. These data constraints made it particularly difficult for us to distinguish the degree to which coastal resource impacts were attributable to natural as opposed to human-induced causes.

This case study, like the others in this series in which the author participated, could not have been completed without significant investments of time and energy from a number of individuals. I wish to thank officials of the Tana and Athi River Development Authority, in Kenya, particularly Mr. Gerishon Gichuki (Director) and Mr. John Kimani (Director of the Athi River Development Authority). I am indebted to Mr. Hebel Nyamu (Director) and Paul Mungai (Chemist and Pollution Control Specialist) in the Ministry of Environment and Natural Resources, National Environment and Human Settlements Secretariat (NEHSS). Tom Downing (NEHSS) must also be singled out for making all of the local arrangements as well as for providing substantive support. Rita Bowry and Tom Gilbert of the Environmental training and Management for Africa Program were also instrumental in providing back-up support.

I must mention John Clark of the U.S. National Park Service, whose patient and constructive comment in the review of the manuscript provided much needed quality control. Finally I wish to acknowledge those additional individuals too numerous to cite who contributed to the success and completion of the study.

2. STATEMENT OF THE PROBLEM

2.1 Overview

Renewable resources of the coastal area (defined here as that transition zone between terrestrial and marine components of the environment) are often vulnerable to human activities which take place at inland sites (Table 1). Due to the indirect nature of their impact and distant location from the coast, these inland activities represent a major problem for coastal users and managers alike. Impacts which may be significant when measured in terms of ecological and economic costs often prove difficult to detect in their early stages. Even when impacts have been identified, connecting them with their respective inland sources can be a complicated task. Finally, the time-consuming process of impact detection and source identification often creates delays which allow the problem to reach a magnitude beyond the resources of the coastal manager.

Inland sources of coastal impact associated with unpredictable events such as natural hazards allow few means for resolution other than preventative and contingency planning for these emergencies. More tractable are predictable events which can be anticipated though often proving difficult to discern for several reasons which include inadequate detection and monitoring capabilities, ignorance of the sources of the impacts, and failure to understand the underlying processes and linkages through which the cause-and-effect relationships manifest themselves.

Even where the relationships are understood, appreciated and detected, most countries lack an adequate institutional framework to implement corrective actions. In the absence of such a framework, ad hoc corrective measures can lead to inconsistent and inefficient solutions to deal with the problems. Inadequate institutional responses are of special concern when the coastal impacts include irreversible resource degradation such as often occurs in cases of habitat destruction.

To illustrate some of these issues and provide some guidance to their possible resolution, the Athi catchment is described in some detail below.

Table 1. Examples of catchment development activities which affect the coastal environment.

Human-Induced Activity	Physical Result	Interim Step (1)	Interim Step (2)	Coastal Effect (Principal)	Significance (Major)	Source
Overgrazing of steep catchment slopes	Devegetation	Accelerated erosion	River-borne sediment transport	Increased sedimentation in coastal waters	Coral reef die-off	Chave and Maragos (1973)
Urban development	Increased impervious surfaces	Increased erosion and water run-off	Increased volume and velocity of river flow	Altered hydrologic regime	Fish kill	Banner (1968)
Dam construction	Water impoundment	Reduced flow	Reduced nutrient inputs	Reduced productivity	Fish production declines	Fahim (1981)
Irrigation development	Water diversion	Reduced flow	Reduced nutrient inputs	Reduced productivity	Seagrass degradation	Thayer et al. (1975)
Irrigation development	Stream channelization	Increased flow	Increased volume and velocity of river flow	Altered hydrologic regime	Seagrass degradation	Thayer et al. (1975)
Industrial development	Thermal effluent	Increased ambient temperature (stream)	No step	Increased ambient temperature (coastal waters)	Seagrass degradation	Roessler and Zieman (1969)
Industrial development	Chemical pollution	Freshwater contamination	Contaminant deposition and resuspension	Contaminated coastal waters	Fish kill	Wahby et al. (1978)
Agriculture development	Pesticide run-off	Freshwater contamination	Contaminant deposition and resuspension	Contaminated coastal waters	Fish kill	Randall (1972)

2.2 Athi Catchment (Kenya)

Kenya's Athi River Basin is the country's second largest catchment, draining an area estimated to be 70,000 km^2 (Figure 1). The basin's principal river, the Athi, also known as the Galana and Sabaki in its lower reaches, terminates at the edges of the Indian Ocean in a small delta composed principally of sandbars running parallel to the coast (Figure 2). Physically, the river drains a broad range of ecological and climatic zones extending from Kenya's highlands to the coastal plain. Present land-use patterns are diverse, ranging from expanding cities to shifting pastoral use. At the base of the catchment lies Malindi, one of East Africa's oldest settlements. The city, presently one of Kenya's most active centers for coastal tourism, is located less than 10 kilometers south of the mouth of the Sabaki (Athi) River. Some of East Africa's most diverse and attractive coral and marine grass bed communities occur offshore. In 1968, to protect this rich marine life, the Kenya government created tropical Africa's first marine park, Malindi Marine National Park. The Park and surrounding waters have since been designated a UNESCO World Biosphere Reserve.

There is a growing body of evidence that the amount of river-borne sediment reaching the coast has increased dramatically in recent years and that this sediment is resulting in the degradation of nearby coral reefs and coastal beaches (Pertet, 1982; Finn, 1982). This destruction of the region's natural beauty in turn adversely affects tourism, at considerable economic loss to the community. Other economic losses partially or wholly attributable to increased sediment loads include the cost of construction of sediment settling ponds to assure the quality of Malindi's water supply and the apparent recent marked declines in fish catches.

Several studies have identified one or more sources explaining the apparent increased sedimentation. The principal causes cited include natural phenomena, devegetation and non-sustainable agricultural and livestock land-use pressures (Ongweny, 1980; Dunne, 1977; NSCR, 1974). While most researchers agree that a problem exists there appears to be a lack of consensus on which connective plans should be implemented toward its resolution (TARDA, 1981; NSCR, 1974; Delft Hydraulics Laboratory, 1970).

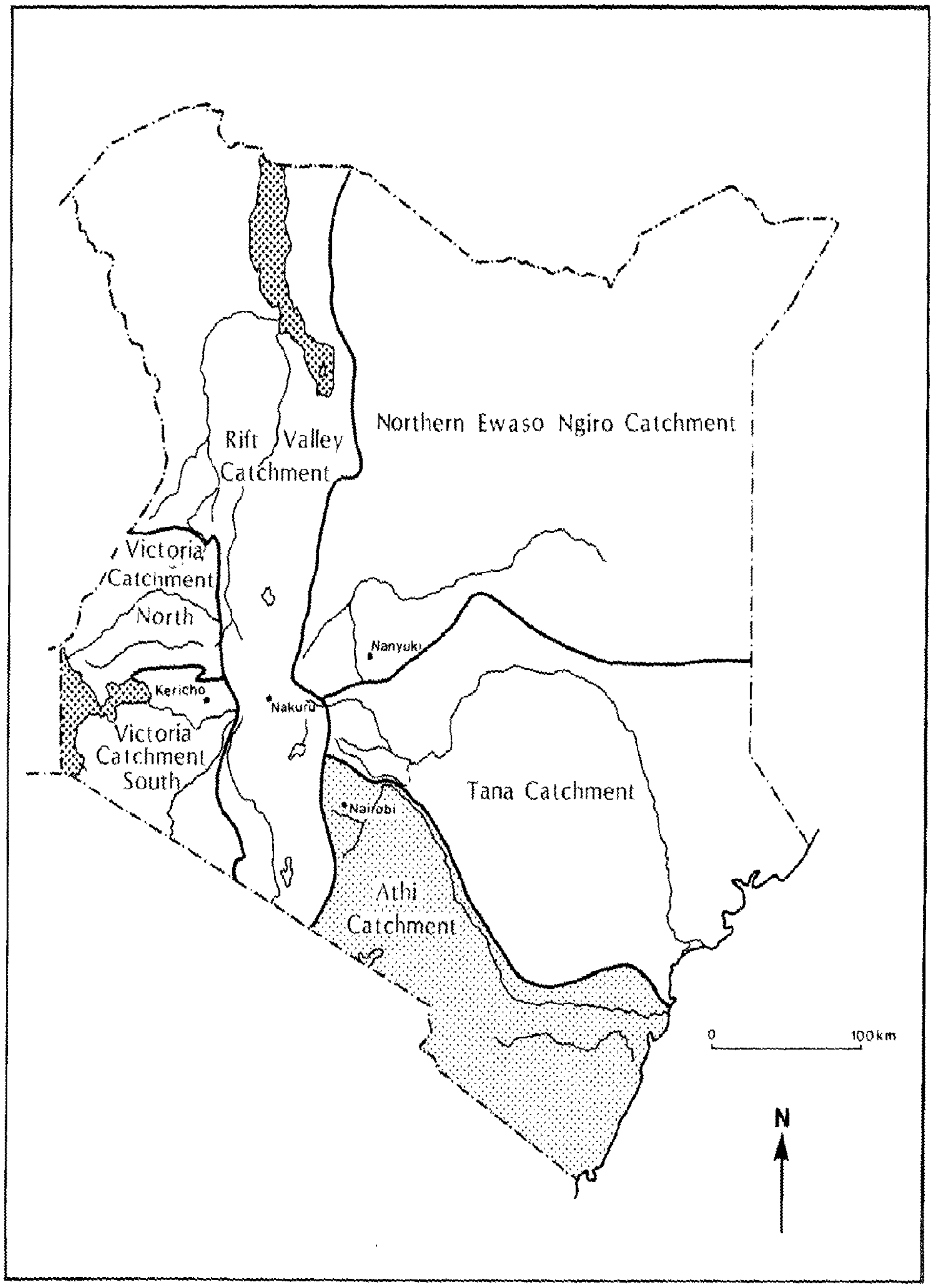

Figure 1. Kenya's Athi River catchment (Source: Survey of Kenya, 1969).

Figure 2. Mouth of the Sabaki (Athi) River, Kenya (source: photo by DuBoils).

The first national response to the Athi River sedimentation problem came in 1973 with the creation of the National Sabaki Committee. Though the Committee proposed a series of recommendations, none was ever fully implemented (see section 7.6). Then in 1974, the Tana River Development Authority was created to oversee the development of the adjacent Tana River catchment (which parallels the Athi) flowing into the Indian Ocean. In 1982, the Athi River was added to the jurisdiction of the Tana River Development Authority to create the Tana and Athi River Development Authority (TARDA). TARDA has proposed a number of development schemes, including hydroelectric and irrigation activities of the Athi catchment, which have served to renew concern over the basin's sedimentation problem. The significance of these proposed basin development activities to the coastal area will be more fully discussed in section 8.

3. COASTAL CHARACTERIZATION

3.1 Kenya's Coast

Kenya's coastline extends approximately 400 km, from 1.6° south latitude to 4.6° south latitude, bordering a portion of the western Indian Ocean. The area surrounding Malindi marks a general boundary between two predominant coastal morphological types. To the north lie broad alluvial plains, extending up to 80 km inland, while south of Malindi the plain narrows to as little as 5 km, often rising steeply to coastal hills as Pleistocene reef rock becomes increasingly apparent (Schroeder et al., 1974). Offshore, Kenya's continental shelf area measures approximately 10,000 km^2 (to 200 meters in depth) and is generally narrow except in the south where it broadens to form the Kenya Banks (Kollberg, 1979).

3.2 Sabaki (Athi) Coastal Area

In the area immediately adjacent to the Sabaki river mouth (Figure 3), large dune ridges reaching 25 meters in height run parallel to the coast. From the south of these ridges to Vasco da Gama point, the coast features wide, flat beaches exposed to incoming swell. Farther to the south, offshore reefs and tidal flats act as buffers against incoming waves. These reefs modify beach profiles on the nearby shore, resulting in increased slope and reduced breadth.

Near Malindi the most prominent marine feature is the extensive fringing reef which begins south of the Sabaki River mouth and intermittently continues down into Tanzania. The outer or windward reef slopes in this portion of East Africa show the development of "spur and groove" formations which function to help sweep back water piled up on the reef by incoming waves (Hamilton and Brakell, 1984). On the landward side of the reef, extending up to 100 meters in width, a platform composed of consolidated Pleistocene reef, recent rubble and living reef is characteristic. Other prominent features inside the reef include extensive marine grass beds, small patch reefs and well developed tidal flats, often separated from each other by a lagoon and numerous small tidal channels (Figure 4).

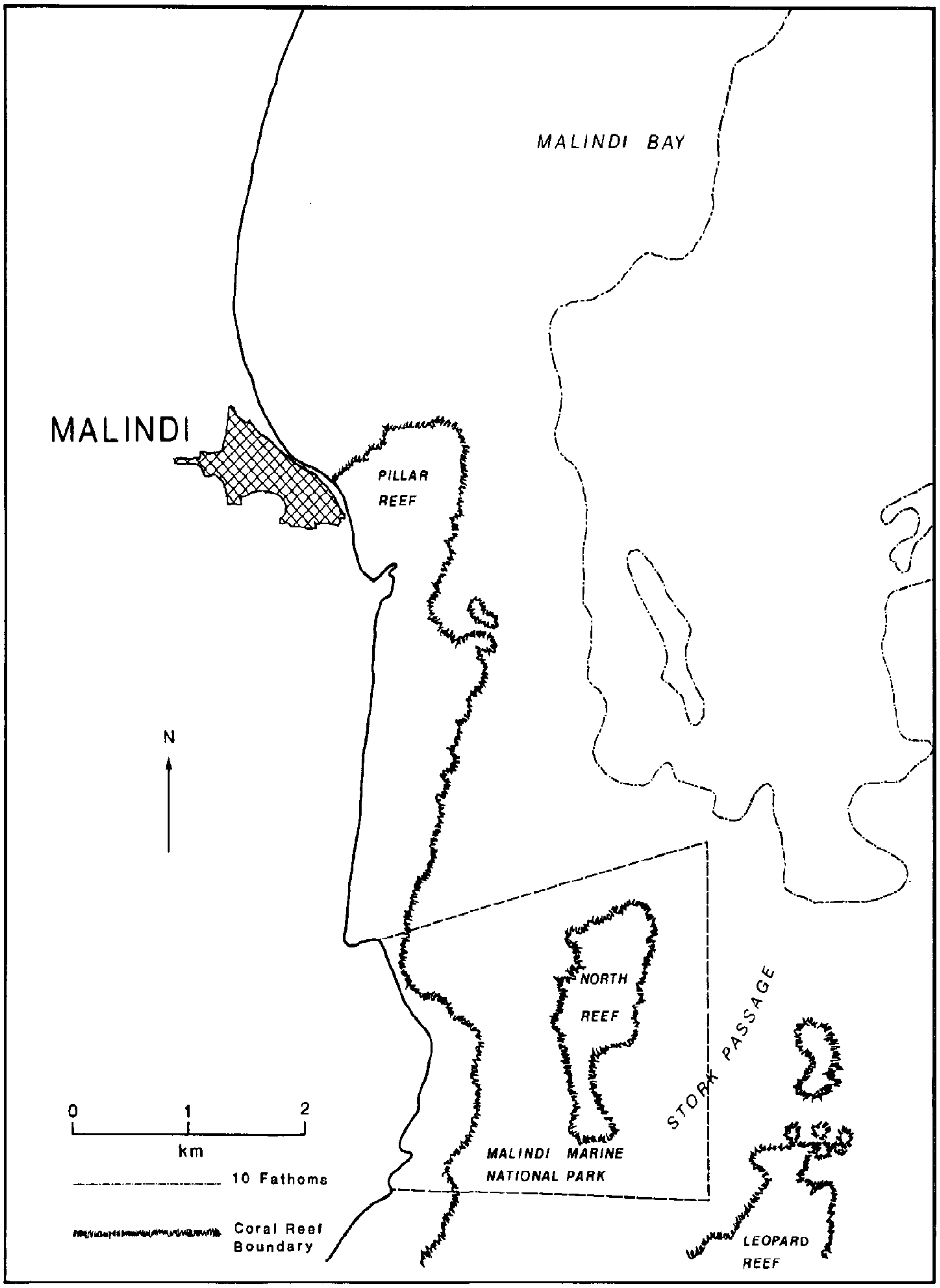

Figure 3. Malindi and its coastal environs (source: Delft Hydraulics Laboratory, 1970).

Figure 4. Offshore fringing reef and tidal flats (source: photo by DuBoils).

3.3 Malindi Town

3.3.1 History

The Sabaki River empties into the Indian Ocean near the ancient Arabic town of Malindi (Kilifi District). The town dates back at least to the 13th century when a flourishing trade developed across the Indian Ocean and along the Arabian cost. Malindi is also near the site where the Portuguese explorer Vasco da Gama, on a voyage which had brought him around Cape Horn, came ashore in 1497. The Portuguese, desiring to tap into the local lucrative trade markets remained in the area and built trading facilities within the next few years. This Portuguese presence eventually led to the establishment of a regional headquarters near Malindi responsible for governing all of Portugal's northeast African possessions (Martin, 1973).

Since these early times, the town's history has been uneven. The following phases can be discerned: early pre-European prosperity; its demise under sporadic Portuguese suzerainty; a brief period of an Arab-dominated plantation economy employing local slave labor; use as a leisure resort retreat for retired vacationing post-WWII British colonialists; and most recently a thriving international tourist attraction, especially popular with German tourists.

3.3.2 Economic Base

Today the economy of Malindi and its environs is based on three principal sectors: agriculture, fishing and tourism.

Agriculture has several components. The traditional sector produces maize, sorghum, millet, cowpeas and rice while cotton and cashews dominate the cash sector. The cattle industry recently has assumed importance and continues to expand, especially because demands for meat are increasing to supply tourist hotels.

Fishing has been important to Malindi residents for centuries. However, only at the end of WWII did the industry develop into an economically viable one of regional importance. Fish landings grew from an estimated 190 metric tons in 1948 to a peak of 1,547 metric tons in 1972, before going into decline (IDS, 1979).

At present the most important coastal fishing areas in Kenya are to the north in Ungwana Bay and offshore near Lamu, some 20 and 80 km respectively from Malindi (Figure 1). However, due to the absence of adequate landing facilities and ground transportation infrastructure in these localities, Malindi continues to play an important role as an off-loading site for transport of fish catch to Mombasa. The future of this role, which once appeared secure due to the extension of Malindi's pier to serve deeper draft fishing vessels, is however now threatened by sediments filling in the bay which could jeopardize the project's intended purpose.

The evolution of Malindi's tourism sector has been described in some depth by Martin (1973). According to this source, the growth of modern tourism can be traced back to the construction of the town's first hotels in the 1930's. Even at that time the industry was based on the area's assets of tropical climate, sand beaches, coral reefs, cultural attractions and its proximity to the large inland game reserves.

While Malindi's tourism industry catered primarily to the European settlers in East and Central Africa in its early days, the introduction of European-oriented package tours created a vast new market by the late 1960's. In the interim, the two original hotels had grown to five with internationally acceptable standards (Achieng, 1978). In the period between 1964 and 1978 alone, Malindi's total number of tourist beds increased from 234 to 1150 (Norconsult, 1981). Martin (1973) estimated that the burgeoning tourist industry with its accompanying related goods and services sectors was the largest single employer in town.

The rapid growth of Malindi's tourism industry was, in part, a result of the creation of East Africa's first marine park at Malindi in 1968. The primary justification for park designation was to conserve a representative example of Kenya's coastal and marine communities including beaches, coral and marine grass bed systems and mangroves. Today, the combined system, known as the Malindi and Watamu Marine National Parks and Reserve, consists of two core parks surrounded by a reserve measuring a total of 240 square km (Figure 5). The reserve acts as a buffer zone where subsistence fishing, prohibited in the park, is allowed (Pertet, 1982).

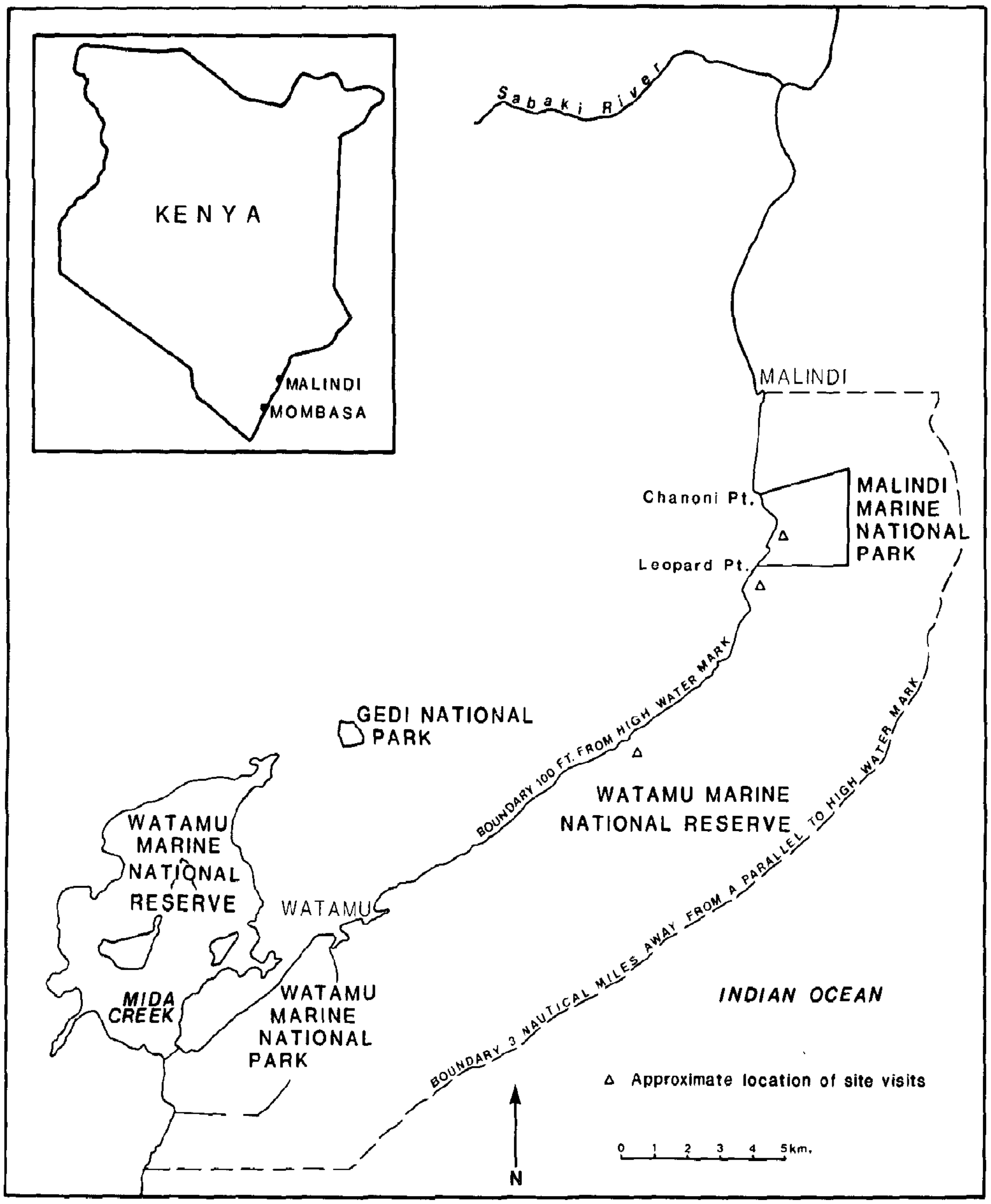

Figure 5. Malindi and Watamu Marine National Parks and Reserves (source: Ray, 1968).

Total annual visitors to Malindi's marine park grew from 18,840 in 1969 to 47,389 in 1979. While this represents a relatively small percentage of visitors in comparison to the rest of the country's game parks (5% vs. 95%), its contribution to Malindi's tourist economy is important (Pertet, 1982).

3.4 Coastal Wind and Current Regimes

To understand the role of the Athi River and its effects on the beaches of Malindi, a description of the dynamics of the coastal and nearshore portions of the Athi catchment is warranted.

3.4.1 Indian Ocean Monsoons

The two principal factors governing East Africa's coastal water currents are the southeast trade winds and the location of the Indian Ocean monsoon. The southeast trades serve as the principal driving force behind the South Equatorial Current (Figure 6). Off the coast of Tanzania, near 10°S, the current divides into northeasterly (East African Coastal Current) and southwesterly components (Mozambique Current). During the months June to September, solar heating of the Asian land mass creates a massive low pressure cell which results in prevailing southwesterly winds (SW monsoon). These winds drive the East African Coastal Current (EACC) up to the northern tip of Somalia before veering away toward the east (Kollberg, 1979).

During the winter cooling of continental Asia, the SW monsoon is replaced by the NE monsoon and the wind patterns reverse themselves. Northeasterly winds off Somalia drive the Somali current in an opposite direction down the East African coast where, upon meeting the remnant of the EACC, an easterly flowing current is created (The Equatorial Counter Current) at approximately 2°S (Kollberg, 1979).

3.4.2 Coastal Currents

The effect of these seasonal wind and wind-driven current changes is easily discernible off the Malindi coast. Current observations taken some 10 kilometers offshore indicate that it sets constantly in a north-northeasterly direction with a velocity as high as 3 knots during the SW

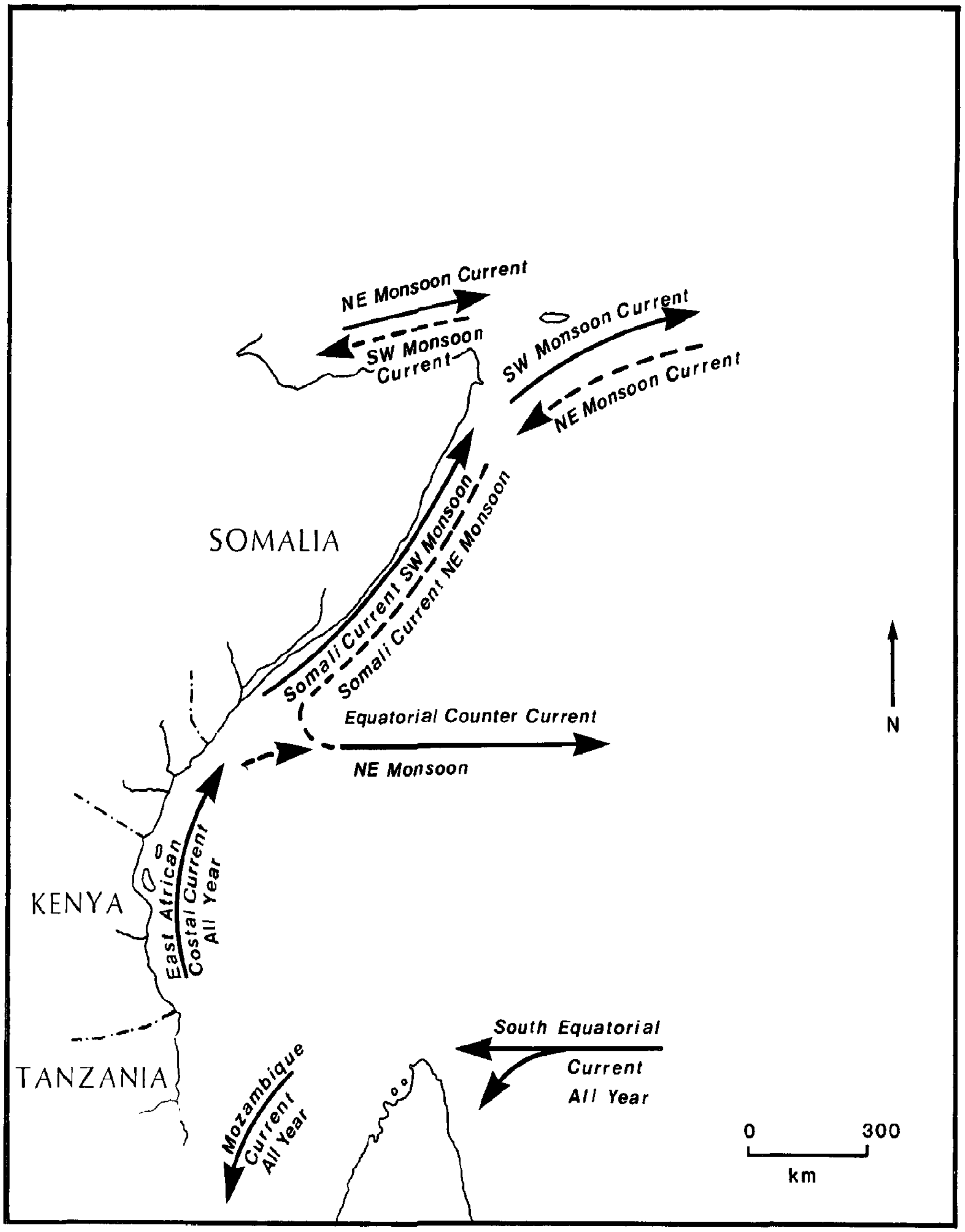

Figure 6. Current system of the North and Central Western Indian Ocean (source: Kollberg, 1979).

Monsoon. During the NE Monsoon, current speed is reduced to 1-2 knots. Closer to shore, however, an effect of the NE Monsoon can be a southerly counter-current which appears to be most persistent during the months of November and December (British Admiralty, 1939; USDMA, 1978). These observations are further substantiated by recent field measurements which recorded southern setting currents of three-fourths of a knot during the same period (Delft Hydraulics Laboratory, 1970).

The significance of a southwesterly current near Malindi becomes obvious when sediment plumes emanating from the mouth of the Athi are mapped (Figure 7). These observations made over two monsoonal seasons clearly document the southward transport of sediment past Malindi into the extensive coral reefs located in the marine park.

While the transporting current described above may only be seasonal, over the long term it has been extremely effective in distributing river-borne sediment to areas south of the river's mouth. Hove (1981) identifies the two principal sources of beach and nearshore sediment in the Malindi area as clastic quartz sands (primarily terrigenous in origin) and biogenic carbonates formed from the offshore grassbed and coral reef communities. Based on analysis of nearshore sediment samples collected from the Sabaki River south to the Watamu area, Hove (1981) demonstrated the presence of a strong gradient in the percentage of quartz composition, ranging in values greater than 95 percent near the river mouth but declining proportionately with distance from the river's mouth. Since the Athi River is the obvious source of these quartz sands (eroded from inland sources) the gradient in quartz sand to the south demonstrates how important the river is in providing sediments to the nearshore environment.

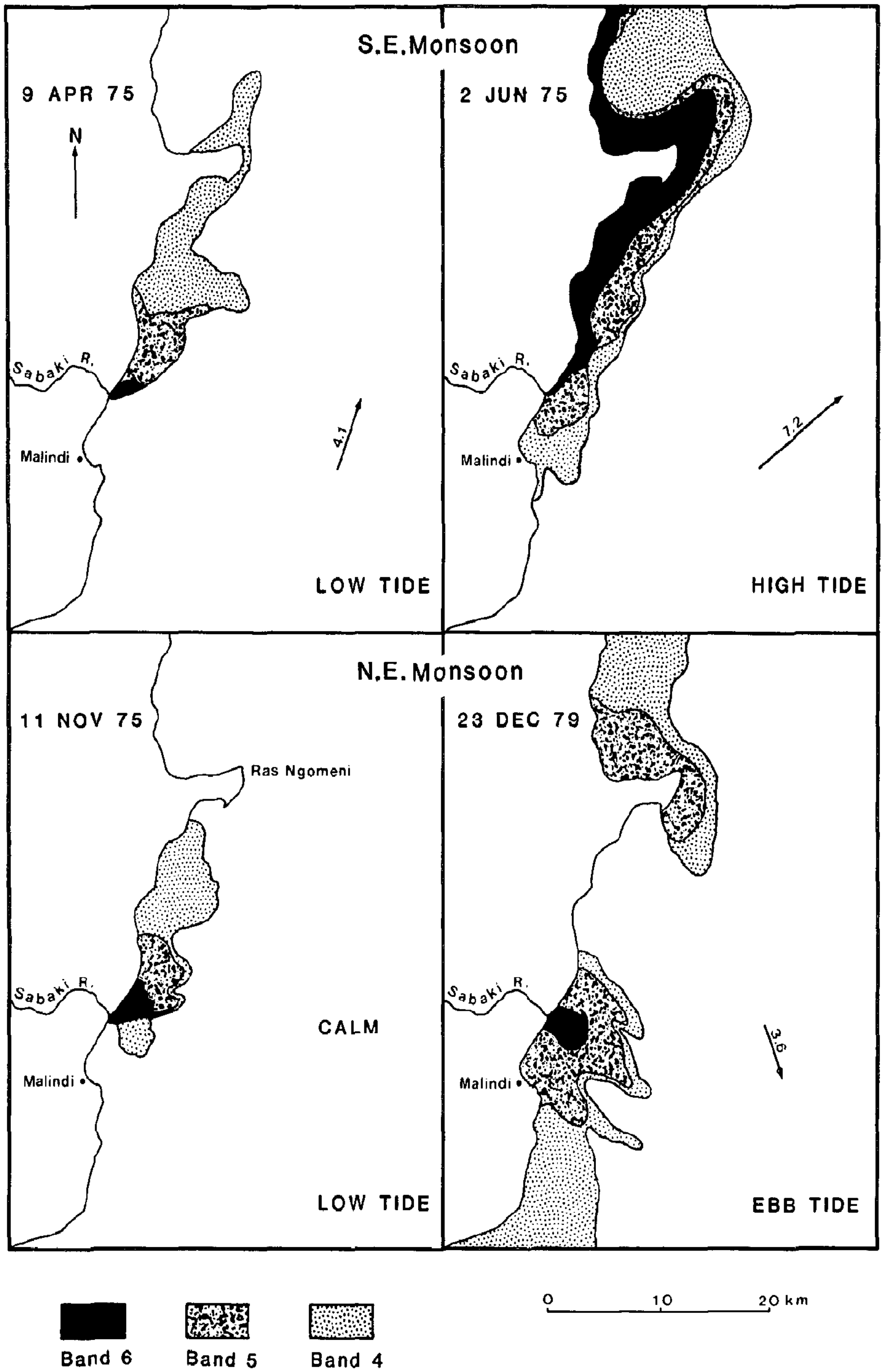

Figure 7. Comparative dispersion of sediment plumes from the Sabaki River for the S.W. and N.E. monsoon (source: Brakel, 1983).

4. CATCHMENT CHARACTERIZATION

The foregoing descriptive account outlines the basic coastal transport mechanism which carries river-borne sediment (as well as fresher water, nutrients and pollutants) into the area adjacent to and south of Malindi. Section 3 also documents the Athi's sediment contribution to the beaches of the area and describes the shelf area's sediment composition. It does not, however, examine the origin and transport of sediment from inland areas to the coast and the role of human activities in sediment production or how that role may have changed over recent years. To address these questions we must turn to the source areas of sediment and examine the causes for its production.

4.1 The River Corridor

The Athi River (Figure 8) extends more than 650 km in length including known sources of headwaters and drains an area estimated to be 70,000 km^2 or 12 percent of the country (NCSR, 1974). The river begins in the small creeks and streams of the Ngong Hills located to the west and southwest of Nairobi. As these tributaries merge they form a south to north flowing river in a valley which cuts across the general trend of topography. The south-southwest trend of the drainage is resumed just south of the Yatta Plateau and forms an increasingly narrow basin as it approaches the sea. In name, the river is known as the Athi until reaching the confluence of the Tasvo River where it becomes known as the Galana. This, in turn, changes to the Sabaki when reaching the coastal floodplain (Figure 8).

As might be expected, with the change in elevation from over 2,400 meters to sea level the river passes through (and drains) lands with varying physical, climatic and vegetative characteristics.

In the higher reaches of the river, the catchment alternates between hills and valleys characterized by steep slopes, with generally thick and fertile soils and plentiful rainfall. In the middle reaches, however, the surrounding landscape comprising over 60 percent of the catchment is an arid and semi-arid core. This middle portion of the basin gradually makes

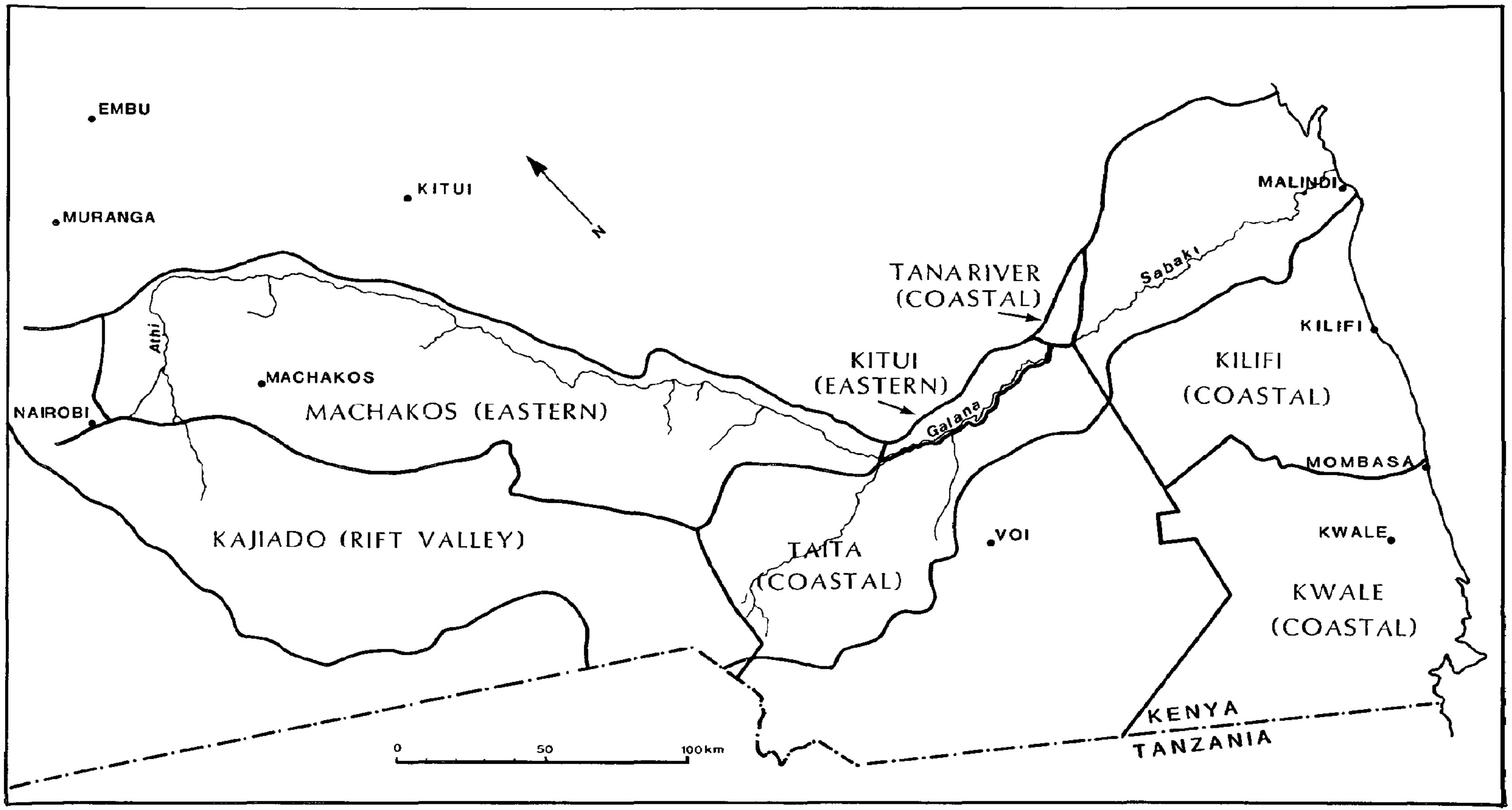

Figure 8. The Athi River catchment (source: TARDA, 1981).

the transition to a broad alluvial floodplain, extending up to 80 km in width in some portions (Schroeder et al., 1974).

4.2 Geology

Three major geological formations underlie most of the Athi catchment: volcanic rocks mostly occurring in the upper reaches of the catchment, granitic and metamorphic rocks in the ancient basement complex exposed in the central catchment area, and sedimentary rocks characterizing the floodplain (TARDA, 1981).

Volcanic rocks range in age from tertiary to recent. They appear to have extruded in association with massive earth movements which led to the formation of the Rift Valley to the west. The volcanic outpourings were greatest near the margin of the Rift. In the upper Athi catchment, isolated volcanic cones rise above deposits of lava several thousand feet thick. These lavas provide good reservoirs of sub-surface water in some localities. In the middle catchment, the lavas which now form the Yatta Plateau form a topographic barrier which plays a large part in creating the "one-sided" river basin (TARDA, 1981).

The granitic rocks of the Machakos Hills and the metamorphic rocks of the basement underlie most of the central part of the basin. They tend to weather into quartz-rich sandy soils and are easily eroded. These rocks provide only local sources of sub-surface water. Run-off percentages are higher than in the upper catchment. This middle region of the catchment appears to be the primary source area of sediments reaching the coast (NCSR, 1974).

The karroo sedimentary rocks (fine-grained sandstones) together with the coastal tertiary sediments occupy the lower Athi basin. As the valley is quite narrow in this area they have less influence on total river and sediment characteristics. As much of the karroo beds are made up of sandstones and grits, they weather slowly in contrast to the more friable (easily fragmented) calcareous tertiary materials.

In summary, the geology of the basin is very important both for its hydrology and for its sediment yield. In the wetter upper catchment, volcanic rocks promote some infiltration resulting in a more even flow of water. In the central catchment, the geology promotes more rapid run-off and a higher sediment yield. The lower catchment, covering only about 7 percent of the total drainage area, is less important than either of the other two parts of the basin.

4.3 Climate

Over 50 percent of the basin receives less than 500 mm of rainfall and is considered to be a region characterized by semi-arid conditions (Mansell-Moullin, 1973). However, a combination of higher altitudes and maritime influences from the Indian Ocean causes relatively high levels of annual precipitation in two areas: near the coast and at the base of the Aberdares (Figure 9).

Due to the moisture-laden eastern winds associated with the Indian Ocean monsoons, two seasonal rainfall peaks occur in the basins: March to May (known as the "long rains") and October to December (the "short rains"). Ertuna (1979) points out that these names may be inaccurate since those described as "short" can often be of longer duration than the long rains.

The "short rains" season is particularly relevant to this case study since it coincides with the November-December southerly-flowing currents off the Malindi coast, i.e., the time of maximum transport of sediment south along the coast to the coral reefs. Njuguna (1978) estimated that a lapse of two to three weeks occurs between upland precipitation and the arrival of the resultant run-off at the coast, leaving ample time for the two conditions to coincide.

Because of the strongly seasonal pattern of rainfall and the considerable influence of direct run-off in the basin, there is high variability in the volume of river flow. In the highlands, flows can range from torrents during the wet season to only a minimal base flow draining off the lower slopes of the Aberdares. In the arid middle reaches of the river, where intensive human land use has reduced infiltration ratios, the land's capacity to absorb rainfall, recharge the water table and maintain a year-round river flow is also minimal or may even be absent until reaching the confluence of the Tsavo River. This tributary is fed by drainage from the

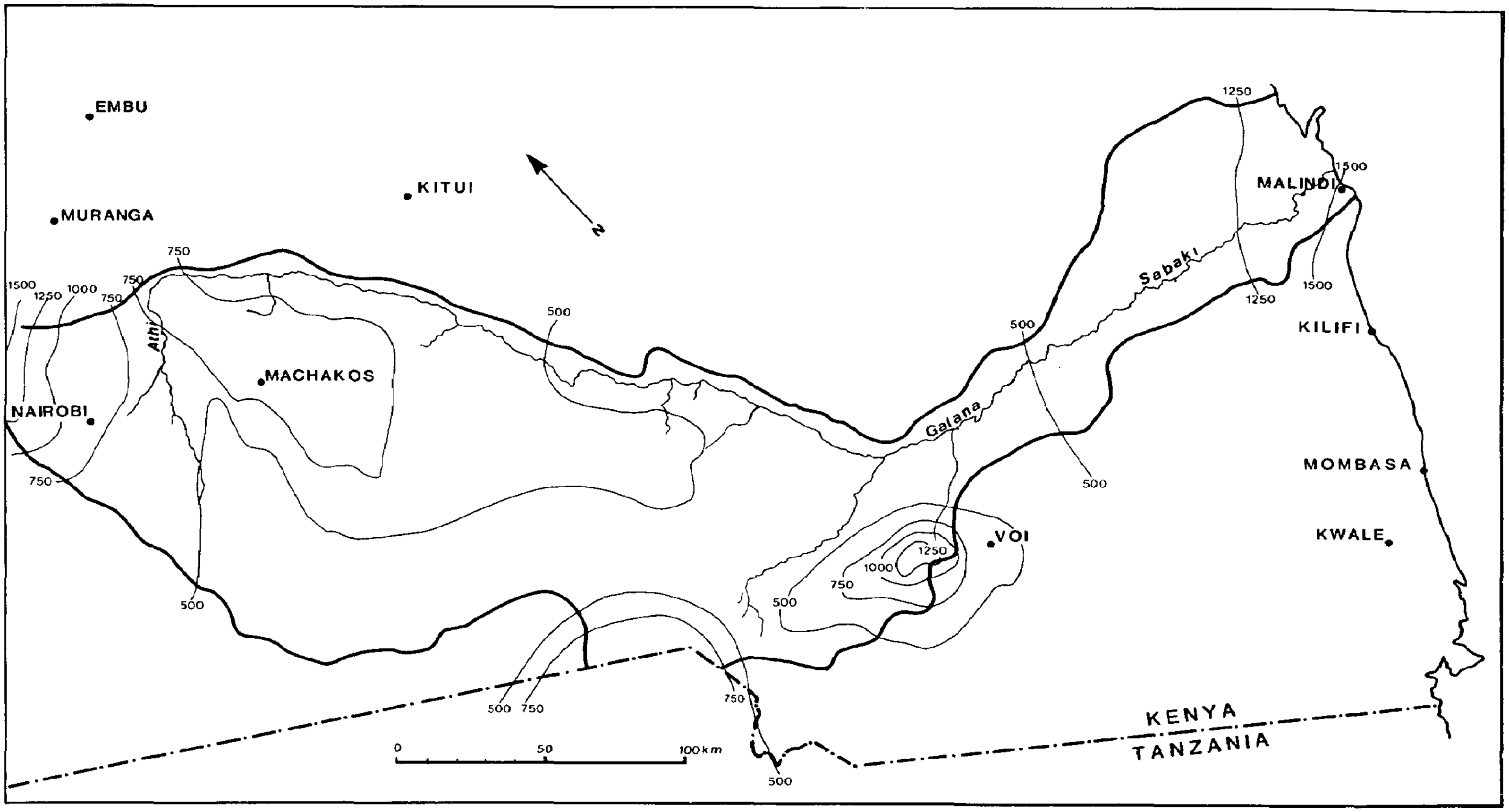

Figure 9. Mean annual precipitation, in millimeters (source: Mansell-Moulin, 1973).

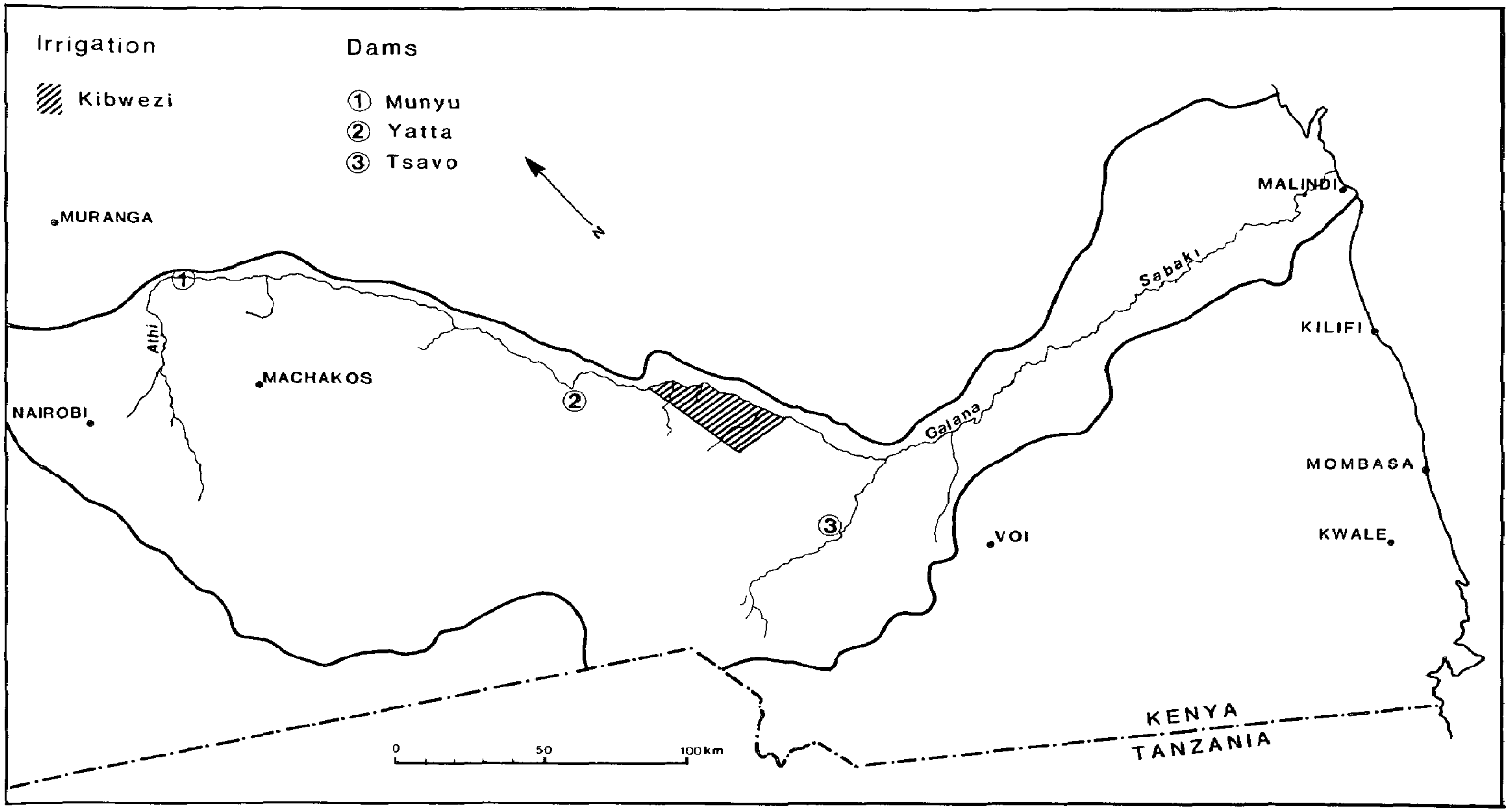

Figure 10. Proposed dam sites and projects for the Athi catchment (source: Kenya, 1969).

volcanic soils of the Chyulu Hills and has a small but reliable base flow. In the lower catchment there are no well-defined tributaries. There, the run-off pattern is erratic and is largely dependent on local storms in this area of the catchment (TARDA, 1981).

4.4 Human Population

The population of the Athi basin was estimated at 2.9 million (18 percent of Kenya's total) based on a series of assumptions. The following assumptions were used: figures for districts wholly or very nearly within the boundaries of the basin (Nairobi, Kiambu, Machakos) were accepted with no modification, the population figures for remaining districts were scaled to their approximate geographic proportion falling inside the catchment (33 percent for Kajiado and 50 percent for both Taita and Kilifi), and Kitui and Tana River Districts were not counted (see Figure 8).

The two most heavily populated rural districts are Machakos (1.02 million) and Kiambu (686,000) though their order is reversed when calculating population densities (having areas of 72 and 266 km^2 respectively). The catchment also contains the country's largest city and capital, Nairobi, with an estimated population of 838,000. (As a comparison, Mombasa, situated on the coast to the south and outside of the Athi catchment, is Kenya's second largest city with a population of approximately 342,000.)

Comparing the Athi's present population with the 1.9 million inhabitants recorded in the 1969 census (employing the same assumptions noted above) the estimated rate of growth is calculated to be 4.2 percent annually. This unrelenting increase in population has resulted in growing human pressures on the land which, in turn, appear to be contributing to accelerated rates of erosion and high downstream sediment loads.

4.5 Land Use and Its Potential

Outside the urban areas of Nairobi, Thika and Malindi, most inhabitants of the basin earn their livelihoods either as agriculturalists in the moderately to highly productive upland areas or as pastoralists and subsistence farmers in the semi-arid regions (Maritim, 1981).

Almost all cultivated areas in the catchment are rainfed. Predominant subsistence crops include maize, sorghum, beans, cowpeas, pigeon peas, cassava and an assortment of vegetables and fruit trees. The more important cash crops are coffee, sugar cane, tea, pyrethrum, sisal and cashew (TARDA, 1981). The size of agricultural holdings falls into two categories: the plots of small land holders, typically varying from 1 to 3 hectares; and the large plantations and estates, which may reach several tens of thousands of hectares.

Livestock production is important for much of the catchment's population. Three distinct livestock regions can be identified in the catchment: areas of high agricultural potential characterized by small herd size due to competition with crop production, the arid and semi-arid land dominated by the subsistence pastoralists, and coastal ranching. Even though the efficiency of livestock production in the catchment is poor, livestock will continue to be an important land use, especially in semi-arid areas where crop production is poor (TARDA, 1981).

Substantial portions of the central catchment area are included in the East and West Tsavo National Parks. Many of the parks' more scenic physical assets are located in the Athi basin and play an important role in water recharge (Mzima Springs, Chyulu Range). The parks are a major tourist attraction in Kenya and account for more than 100,000 visitors annually (Ecosystems Ltd., 1982).

A recent assessment of land-use potential, using the Kenya Soil Survey agro-climatic classification scheme, judged 45 percent of the basin (and the continuous coastal lands to the south) unsuitable for crop production (TARDA, 1981). An additional 40 percent was considered only marginally suitable with high risk for crop failure. The assessment further noted that the classification scheme does not account for local soil conditions which could further reduce the extent of arable land.

4.6 Water Use

The most important human uses of the catchment's surface waters are for public water supplies (Nairobi, Mombasa and adjacent coastal area), small-scale irrigation (in the upper reaches) and various rural water development schemes (TARDA, 1981). At present, an estimated 19 percent of Nairobi's water supply is met through surface water extraction from the Athi with the remainder satisfied through transfers from the neighboring Tana catchment. For the immediate future, growing demand in Nairobi will be met by increasing transfer loads resulting in increased waste water discharge into the Athi below the city (TARDA, 1981). In the long term, however, as these transfers become increasingly expensive, alternative sources will be provided by the construction of the Munyu regulatory dam on the Athi River (Figure 10).

Downstream, Mombasa's principal source of water has been from the Mzima pipeline (drawing off water from springs feeding the Tsavo River). More recently, the construction of the Baricho weir on the Sabaki has doubled Mombasa's water supplies (40 million m^3/year) of which 83 percent is derived from the Athi or its tributaries (TARDA, 1981). Future demand is expected to be met by the construction of a second pipeline from Mzima Springs, possibly in association with the construction of a storage dam on the Tsavo River to maintain the Baricho intake (TARDA, 1981).

In a 1977 survey of groundwater use, an estimated 2,000 boreholes, or over 50 percent of the national total, were located in the catchment, the majority in the Nairobi area. Despite the relatively high numbers, when averaged out, basin-wide groundwater extraction is relatively insignificant (TARDA, 1981).

At present, most irrigation activity is confined to the upper reaches of the river where permanent flowing rivers and springs exist. Most diversions are small-scale endeavors and serve as a supplemental water supply to the frequent rains.

Due to the high percentage of dry lands in the catchment and growing population pressure, the development of irrigation schemes appears to be a highly desirable solution to meet future human needs (TARDA, 1981).

However, despite the attraction of irrigated development only an estimated 80,000 ha of irrigable land is thought to exist in the catchment. Of that total, practical water constraints limit irrigation potential to 30,000 to 40,000 ha (TARDA, 1981).

Of the several proposed irrigation schemes, now under government consideration for topography, soils and climatic attributes is the Kibwezi project (Figure 10). Present development options range in size from 6,000 to 29,000 ha.

An initial cost-benefit analysis of the potential for hydro-power development on the Athi indicated that it was only economically feasible when incorporated into a multi-purpose development scheme (TARDA, 1981). With that in mind, the government is currently considering the Munyu Dam site as a possibility for power generation in conjunction with its other uses such as water storage and flood control.

5. HUMAN ACTIVITIES IN THE UPLANDS CAUSING COASTAL CHANGE

5.1 Sources of Erosion

The scarcity of arable land and high population densities have created intense pressures on the basin's arable land. The arable zones under the greatest pressure are the Ngong Hills, the Aberdares, the Taita Hills in Machakos and the coastal region (TARDA, 1981).

In the relatively fertile regions of upland Kiambu District which drain the base of the Aberdares, over 50 percent of the land is moderately to steeply sloped. Due to the high priority which farmers place on coffee and tea production, (with an estimated 36 thousand hectares in production) the most suitable land has been rapidly put into these lucrative cash crops. This has forced many small-holding farmers to migrate progressively upslope and into drier regions to put new land into domestic food production. The resulting clearing on these marginal lands (steep slopes sometimes surpassing 45° inclinations) has been a major cause of slope failure and has contributed to observed increases in rates of erosion (Lewis et al., 1983) (Figure 11). Other major sources of erosion and stream sedimentation are gully erosion (caused principally by road development), quarry erosion (mining), and sheet wash erosion (agricultural activities), as noted in Lewis et al. (1983). There is little information regarding the absolute amount of eroded sediment which reaches the Athi's upland tributaries although the steep slopes and high precipitation of the region provide classic conditions for severe degradation.

However, the portion of the catchment with the greatest soil losses appears to be the semi-arid and arid Machakos region. By comparing air photos taken between 1948 and 1972 of the Wamui River subcatchment in Machakos, Thomas (1974) documented an increase in "severe" erosion area from 26 to 37 percent. The increase was attributed principally to increased crop production and overgrazing, much of it occurring on slopes of greater than 16°. Thomas also noted major geomorphological changes commonly associated with accelerated erosional processes including loss of vegetative cover, filling in of springs and streams and increases in complexity of drainage networks resulting from gully development. In a second catchment, the Iiuni, Thomas et al. (1981) estimated that 7 percent of the area was poorly cultivated (farming steep

Figure 11. Slope failure in Kiambu District (source: photo by L. Lewis).

slopes, poorly protected terraces, evidence of erosion) and an additional 37 percent was degraded pasture land resulting from overgrazing.

Moore (1979) observed several overgrazed sites in the Machakos Hills and calculated rates of erosion to be as high as 10 mm/year or roughly 60 tons/ha. He predicted that the soil would be totally depleted within 100 years.

Lower in the Athi basin, near the Tsavo confluence, minor sources of sediment have been attributed to the loss of lacustrine (river side) vegetation due to floods in the large Tsavo game parks combined with the effects of wildlife which caused bank collapse (Wain, 1982).

These and other data have been compiled by Dunne and Wahome (1981) to produce a map illustrating the estimated range of rates of erosion in Kenya's arid and semi-arid lands. These values, determined through the use of a generalized soil loss equation, are presented for areas within the catchment in Figure 12.

5.1.1 Sediment Loads

River transport of sediment occurs through one of three mechanisms: suspension, saltation (skipping or bouncing over the bottom), and bed load or gradual rolling and sliding of sediment along the river bottom (Gottschalk, 1964). In most attempts to monitor sediment load, suspended sediment is the only parameter observed, due to ease of measurement. This results in underestimates of total transport.

While it is unclear how much of the eroded sediment actually reaches the Athi's tributaries, the results from two studies indicate the accumulation can be significant. In the Iiuni subcatchment, sediment samples indicate that approximately 535 tons/km^2/year were reaching the principal tributary of which 90 percent was thought to be transported by bed load (Thomas et al., 1981).

For in Kajiado District, Dunne (1977) calculated erosional losses of 2.5 thousand tons/km^2/year of which 358 tons/km^2/year reached the catchment's tributary feeding into the Athi.

Documentation is similarly poor for the amounts of sediment actually transported by the Athi River. However, data from two additional sites in the upper and middle reaches of the Athi provide some indication of load

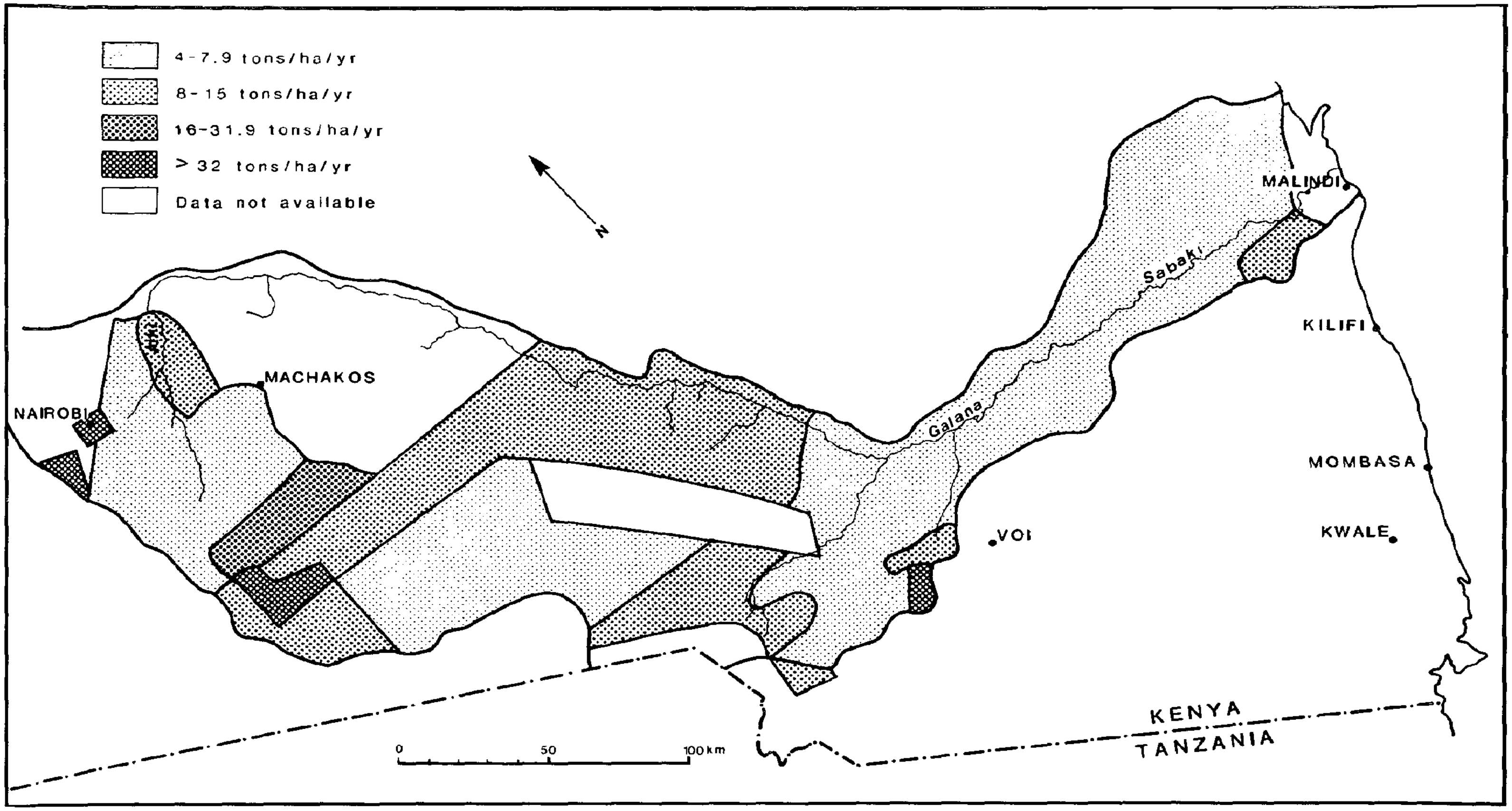

Figure 12. Values of soil erosion for arid and semi-arid lands in the Athi catchment (source: Dunne and Wahome, 1981).

levels. In 1980 and 1981 the Hydrology Section of the Ministry of Water Development initiated a sediment monitoring program for two potential water storage sites: Munyu and Mavindini. Based on their observations, Wain (1982) calculated average annual suspended sediment loads of 0.66 and 6.44 million tons respectively, for the subcatchment's principal arteries.

Based on comparisons between these and earlier results, Wain noted that suspended sediment yields had increased at both locations (possibly by a factor of two for Munyu). He also observed that the yield from Machakos bed rock (predominantly granitic) was an order of magnitude greater than yields from the upper Athi characterized by volcanic substrata.

Wain further noted that slowly flowing waters (e.g., less than 10 m^3/second), which occur more than 50 percent of the time, accounted for only 1 percent of the total suspended sediment transport (TSST) while fast flows (between 100 and 1,000 m^3/second), occurring 14 percent of the time accounted for 63 percent of the TSST. This finding highlights the importance of heavy seasonal rains in transporting the bulk of suspended sediment downstream.

In the absence of calculations for bed load for these sites, these figures are considered minimal. By using standard conversion tables to estimate total loads, new provisional figures were calculated for these two sites and the lower Sabaki (TARDA, 1981). These were: Munyu (.9 million tons/yr, Mavindini, 8.5-13.6 million tons/yr, Sabaki, 9.2-14.3 million tons/yr. These figures confirm that the heaviest sediment loads occur in the middle and lower portions of the river, consistent with our earlier description of these areas as the most altered and highly erosive sections.

5.2 Pollution

The primary sources of contamination of the Athi's waters are concentrated in and around the Nairobi-Thika area. These sources, common to most urbanized zones, include domestic sewage and commerical and industrial effluents (TARDA, 1981).

Secondary sources of pollution include those of the Kiambu area (principally fertilizers, pesticides and pulp wastes) associated with tea and coffee production and Machakos town, which contributes domestic and commercial effluent into the Athi by way of the Thwake River.

Several treatment facilities exist in or near the major urban centers, but most appear to be in varying states of disrepair or are overloaded, causing the dumping of raw sewage downstream (Njuguna, 1978). In a two-year study of the upper Athi, Njuguna (1978) monitored several water quality parameters including pH, biological oxygen demand, dissolved oxygen, nitrates, nitrites and phosphates. His results documented the presence of contaminants in river water ranging from 20 to 65 km downstream from Nairobi (Fourteen Falls) during low water-flow periods. These parameters were observed to return to expected normal levels in the middle and lower portions of the river regardless of season. No attempt was made to analyze heavy metals or other toxic materials.

6. COASTAL ENVIRONMENTAL IMPACTS

6.1 Sedimentation

Any discussion of siltation impacts at Malindi should take note that erosion, transport and deposition of sediment are natural processes, which can and do vary according to many physical, biological, chemical, and climatic variables. One can reasonably assume that over geological time, and prior to recent human settlement those processes had reached a stable or equilibrium condition to which all processes had adjusted. That is, coral reefs and sea grass beds existed in a pattern and state of health that reflected a long-established stable pattern of sediment discharge. In the case of the Athi, however, the evidence suggests that such stable conditions have now been disrupted; upland erosion and downstream deposition have dramatically increased and coastal systems (beaches, reefs and grass beds) are now in unstable states as they try to reach new points of equilibrium.

Sediment has been discoloring Malindi's waters at least since 1948. Elspeth Huxley visited the area in that year and described the beaches and waters colored by "...millions of tons of up-country topsoil...disgorged by the Sabaki River...covering the area with...a wide stretch of chocolate-red silt...to such a degree that...bathing is out of the question" (Martin, 1973). We also know from Moore's account (1979) that reports of major soil erosion in the Machakos area date back to the 1930's.

Despite these early records of sediment-laden waters, our interviews with local Malindi residents revealed general consensus that the problem was tolerable until 1961. Om that year an unprecedented flood covered most of Malindi's beaches with a veneer of fine sediment approaching the consistency of mud. The 1961 flood also coincided with the high tourist season. Reports from Tsavo East National Park indicated that devastation of lakeside vegetation washed soil, trees, and smaller vegetation downstream in great quantities (Mansell-Moullin, 1973).

Due to high water velocities, floods also transport large volumes of heavier materials down to Malindi that can only be moved by "bed load transport," further congesting the shore and coast. Dunne (1977) has described the existence in river channels of large reservoirs of eroded sand measuring up to three meters in depth and capable of remaining decades before transport, as from heavy floods, carries them downstream.

In visible terms the most dramatic change resulting from sediment deposition has been the modification of Malindi's beaches. Beach-width expansion of up to 200 meters or more has occurred to the south of the Sabaki River mouth, especially adjacent to the beach frontage of Malindi's major tourist hotels. Figure 13 shows a view from one of the hotel's original seawalls to provide a point of reference to compare the previous shore line with the present day beach. This accretion results from an average annual deposition of Malindi's beaches estimated to be 5 million m^3 (Delft Hydraulics Laboratory, 1970).

6.2 Coral Die-Off

Although less visually dramatic, the continuing die-off of coral reef both inside and outside the marine reserve must be considered as an equally serious impact. Several reports have described the impacts of sediments and vegetative debris from various sites in the Malindi reef complex (Delft Hydraulics Laboratory, 1970; NCSR, 1974; Kenya Wildlife Planning Unit, 1981). Discussion with local recreational divers and observations on dives made by the author substantiate these reports (Figure 14). Two areas particularly affected are Pillar Reef and the landward portions of North Reef (Figure 3).

The high degree of susceptibility of living corals to damage by sediment relates to several critical characteristics of the group. Perhaps the most significant effect of sediment is the role it plays in suffocating the coral. Corals which form reefs are actually colonies of living tissue supported by skeletons of calcium carbonate. Respiratory gas exchange and particulate feeding processes occur through a thin film which covers the colony. When sediment accumulating on the surface of the coral exceeds the ability of the coral to cleanse itself, feeding and respiration activities are impeded, which can result in death (Motoda, 1940).

Reef-building corals are also light-demanders. In part, this is due to the presence of symbiotic unicellular algae imbedded in the living

Figure 13. Old seawall at Eden Roc Hotel, Malindi, in right foreground; ocean at upper edge (source: photo by DuBois).

Figure 14. Underwater photo taken off Casuarina Point showing dead coral smothered by terrestrial vegetative debris and sediment (source: photo by W.J. Mussett).

problem in Malindi. Nevertheless, the author's field observations together with other reports of reef die-off confirm the seriousness of the situation. Data gaps identified in this case study illustrate the need for a thorough inventory of the parks' resources which can serve as a baseline for future comparisons and monitoring trends in community status.

6.3 Pollution

The Athi, by draining the country's capital city and largest industrial center, represents the country's primary recipient of urban and industrial wastes. Malindi's location at the base of the river directly exposes the town and adjacent waters to persistent pollutants transported from upstream sources by the river. The threat of coastal contamination is further increased due to Malindi's location down current (approximately 10 months of the year due to current reversals) from Mombasa. The use of the river to discharge waste together with Malindi's location make the absence of data concerning coastal pollution in the area particularly alarming.

In general little is known of the long-term effects of pollution on tropical marine ecosystems. Endean (1976) notes the results from various studies measuring the effects of chlorinated hydrocarbons and heavy metals on corals have been generally inconclusive. The vulnerability of grassbeds to pollutants, however, appears to be better understood. Studies by McNulty (1970), Hammer (1972) and Taylor et al. (1973) have linked reductions in seagrass density and coverage to various pollutants including domestic and industrial effluent discharges.

The effects of pollutants on reef fish populations have been well documented. Localized fish kills have been associated with insecticides (Randall, 1972), pesticides (Bourns, 1970) and high chlorine levels (5 mg/1) associated with power plant outfall (Marsh and Gordon, 1973). In some cases, contaminated fish can reach the human consumer, resulting in sickness or even death (Bourns, 1970).

In light of the potential ramifications of the pollution issue for Malindi's coastal and marine ecosystems, there appears an urgent need for data collection (and monitoring) of water quality from both source areas and coastal waters alike. This is particularly important as a means to establish a data base prior to the implementation of the proposed irrigation development schemes mentioned earlier, which could serve as additional sources of contamination from fertilizers, pesticides, herbicides, etc., transported in run-off.

6.4 Reductions in Sedimentation Rates

Although several problems associated with accelerated rates of sediment deposition have been raised thus far in the case study, a different set of issues emerges when sedimentation is reduced. One potential source of reduction might be through constructing a dam such as the one under consideration near Munyu. A dam, especially if backed by a long impoundment, serves as an effective sediment trap. Instead of Malindi's beaches expanding, a cutoff of upland sediment would probably result in a net loss of beach material. Reduced beach size is as great a threat to the tourist industry as is the present problem of accretion and of muck and ooze filled sands.

Sediment reduction might also reduce the nutrient potentials for coastal aquatic life. Few examples support this point more dramatically than Egypt's Aswan High Dam. Entrapment of nutrients and sediments were identified as the principal cause of the decline of the country's sardine fishery, an activity which had accounted for landings estimated at 8,000 metric tons per year (Fahim, 1981).

In consideration of these related aspects of catchment developments one goal of sound coastal management may be the stabilization of sediment load to allow the affected coastal ecosystem to achieve a new equilibrium rather than to attempt to end sedimentation entirely.

7. COASTAL ECONOMIC IMPACTS

There can be little doubt that declining water quality and resource conditions (whether actual or perceived) have extracted an economic price as well as an ecological one.

7.1 Tourism

In the tourist industry, Malindi's growth was dramatic between the mid-1960's (when package tours were first introduced) and the early 1970's. Since that time growth has leveled off and there has been no new major hotel development. In the last two years, tourist arrivals in Malindi have declined precipitously (Personal communications, Malindi Hotel Association, September 1983).

This decline has been attributed, at least in part, to the area's growing reputation for dirty water and mucky beaches. A manager of one tourist hotel (The Eden Roc) felt obligated to include a disclaimer in the hotel's brochure, noting the possibility of mud and silt during certain times of the year.

A second common complaint heard by hoteliers is the additional distance tourists are required to walk to the water's edge due to the beach's recent accretion. While some managers consider the continually widening beach as a declining tourist attraction, others appear to have accepted it stoically and developed it into small parks in front of their hotels. These newly created areas are currently the target of a legal controversy between the government and the hoteliers over ownership of the new beaches.

Operators of sight-seeing glass-bottom and snorkle boats licensed to visit the reefs in Malindi National Marine Park also appear to suffer economically. Business apparently declines from January to March due to muddy waters and poor visibility (NCSR, 1974). It would be an oversimplication to assign full responsibility for Malindi's current tourism declines to the sediment problem. Other factors mentioned in the course of interviews include periodic recessions in Europe (the trade's chief source of business), a poor airport, poor roads, the development of alternative coastal tourist centers north and south of Mombasa, and a growing reputation among the hotels for catering to young singles rather than families (which had been the traditional market), causing members of the latter group to go elsewhere.

Though it is difficult to isolate the relative importance of each factor, hoteliers agree that the ecological problem is an important component. The problem apparently has reached such proportions that hoteliers have reduced their rates to stimulate business (Finn, 1982).

7.2 Water Treatment

Malindi's development both as a commercial center and a tourist destination was at least in part made possible by exploitation of the Sabaki's fresh water for public consumption in this water-poor northern coastal region. The present pumping station was completed in 1961. However, as a result of continued changes in the river channel, partly attributable to shifts in river bottom and increased flooding, the station was forced to build a new intake in 1974 and is considering the possible construction of a third one in 1984.

Increased siltation has also caused filling and clogging of the station's sedimentation tanks and sand filters, forcing temporary closure of the treatment plant. These continued disruptions of the Malindi water supply necessitated costly construction of pre-sedimentation ponds in 1975 (Figure 15).

7.3 Increased Flood Risk

The relationship between stock overgrazing and increased run-off has been well established. Compaction of soil results in a reduced capacity of the land to absorb rainfall, therefore speeding run-off and increasing the chances of downstream flooding (Musgrave and Holton, 1964; Slatyer and Mabbutt, 1964). In the Athi catchment, reliable estimates for flood prediction do not exist due to the absence of accurate measurements (Mansell-Moullin, 1973). The failure to predict floods attributable to the river-breached banks and storm run-off is critical to the Malindi area where periodic flooding has resulted in studies examining various flood-water

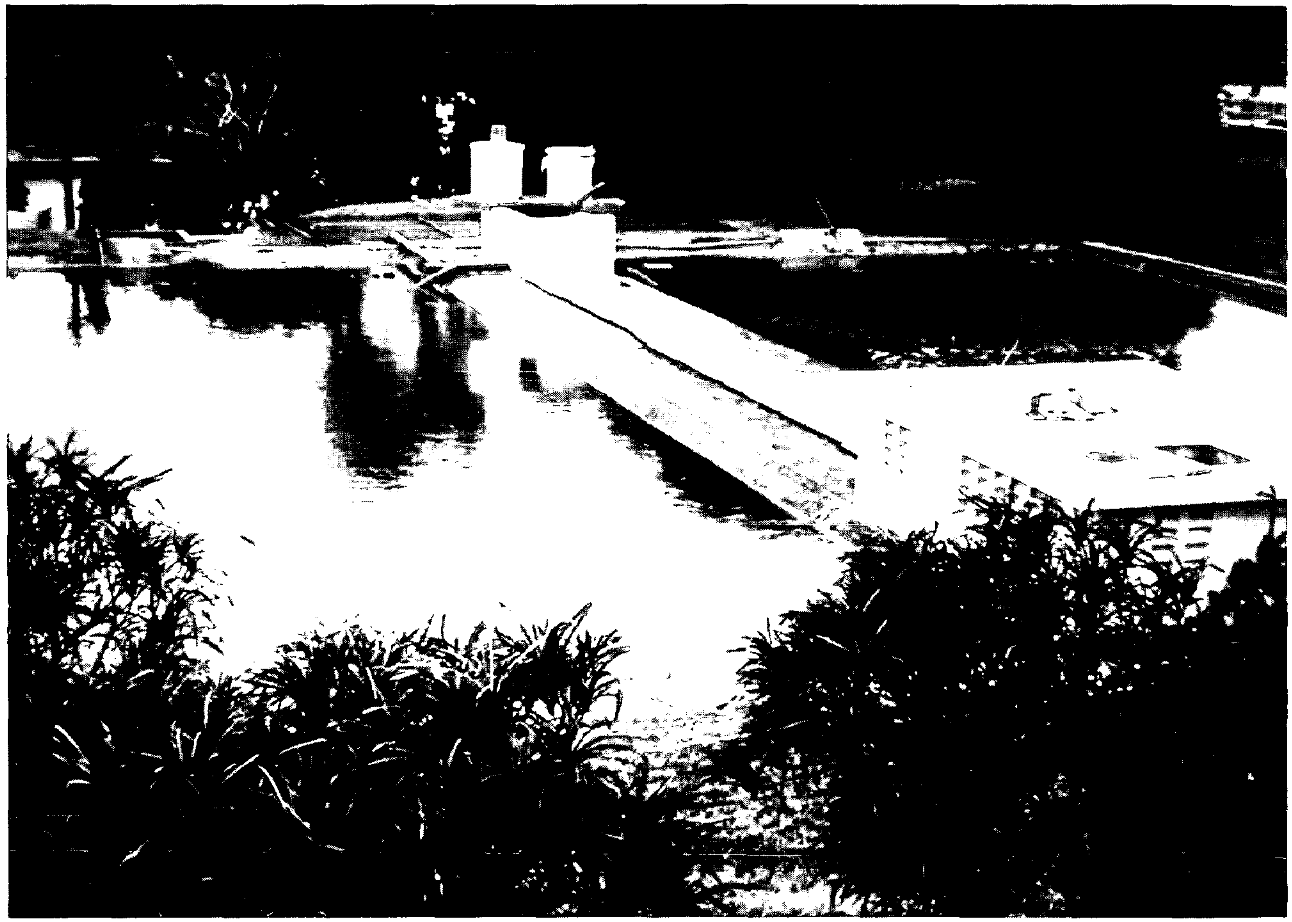

Figure 15. Pre-sedimentation ponds at Malindi pumping station (source: photo by T. Downing).

discharge schemes to reduce economic and personal risk (Norconsult, 1981).

7.4 Pollution

No reliable water quality data could be obtained from the two principal water treatment facilities in the river's low reaches (Baricho and Malindi). While water quality results from Njuguna's study (1978) indicate that normal conditions exist in waters some 65 km. downriver from Nairobi, they do not take into account toxic substances like pesticides and heavy metals. Of equal concern is the apparent failure in government-funded studies to address possible downstream impacts associated with proposed irrigation schemes and their effluent return discharges to the river (TARDA, 1981). The socio-economic costs stemming from contaminated water supplies, toxic fisheries and polluted coastal waters in an area where tourism and fish are integral components of the economy could prove devastating to Malindi.

7.5 Fisheries

The impact of sediment deposition on Malindi reef fisheries is difficult to analyze because marine park regulations prohibit fishing in major portions of the reef (Figure 5). Areas surrounding the two parks are protected by reserve status but do allow fishing with restrictions. The economic importance of Malindi's fisheries is further obscured since no record is made of the geographic origin of catches landed at Malindi.

Malindi's marine fishery, like that of most of coastal Kenya, is confined largely to inshore waters and is concentrated on the reef and its protected inner waters. In addition, catches from nearby reefs and landings of commercial importance from the Ungwana Bay and Lamu areas pass through Malindi to take advantage of ground transportation links to Mombasa. While bottom-dwelling species such as snappers, grunts, and parrot fish predominate in quantity, the more economically important species landed in Malindi include spiny lobsters, prawns and crabs.

Based on various earlier reef fishery studies along the Kenya Coast, Gulland (1979) estimated the current catch from northern Kenya reefs to be approximately 4.9 tons/km^2. Treating his data as if they were catch estimates in different stages of development from the same fishery, and using available effort and intensity data, he concluded that maximum sustainable yield from coral reefs along this portion of the coast was approximately 5 tons/km^2. This falls in the upper range which Stevenson and Marshall (1974) derived from analysis of harvests from reef fisheries from sites including Bermuda, Jamaica, Mauritius and Lamo Trek Atoll. To put these figures in perspective, harvest from the Georges Bank area, one of North America's richest fish grounds, generally falls below 5 tons/km^2 (Clarke, 1946). Though we have no specific catch information for Malindi's reefs, we assume that at least where the reefs are still healthy catches are on this order.

Using the yield figures cited above, Smith (1978) calculated that the annual potential harvest of the world's reef fishery could be approximately 2.7 million tons. Marshall (1979) pointed out that potential yields of such magnitude are especially significant since reefs occur in areas where the need for food is greatest. They are accessible to small-scale fishermen and often remain the exclusive domain of the small operators. While we cannot demonstrate the specific economic importance of Malindi's reef fisheries, Marshall's description appears to be applicable to northern Kenya.

For Malindi, the question remains, however, whether reef die-off associated with sedimentation (or other agents) is specifically and significantly affecting fish yield. While no adequate series data exist for Malindi by which comparative assessments can be made, studies by Barnes (1966), Chesher (1969) and Brock et al., (1966) indicate that migration of many elements of the fauna associated with reefs (including fish) usually is observed after severe reef degradation. Out-migration of fish has an obvious effect on reef fish standing stock and subsequent fish yields in the affected area. Such migrations can be especially critical where a fishing fleet consists of small boats which have limited capacity to fish distant waters.

7.6 Port Development

Malindi's development as a landing center for fish to be shipped to Mombasa for export and local consumption is presently under way. The existing pier is being extended at a cost of approximately one million U.S. dollars. Increased rates of erosion upstream in the catchment could result in a rate of deposition at Malindi's port exceeding natural removal, causing bay in-filling. This in turn would prevent deeper draft boats from reaching the pier, thus negating the advantages of pier extension.

Due to the history of harbor siltation in Malindi, there have been several attempts at finding solutions. In 1969, at the invitation of the Ministry of Tourism and Wildlife, a French consulting group (SOGREAH) was requested to identify an ideal site in Malindi to build a harbor for promotion of fishing and recreational boating activities. In their preliminary study the consultants proposed that such a harbor was feasible. They recommended that it be protected by a breakwater designed to create a north-flowing current driven by breaking waves near the Pillar Reef area. The purpose of this artificially created current was to create a silt-free harbor.

In 1970, Delft Hydraulics Laboratory of The Netherlands carried out field measurements and evaluated the French proposal. Delft concluded there were only two viable alternative approaches to the siltation problem: deal with it at its upriver sources, or invest in a large-scale engineering project designed to direct the incoming silt away from the coastal areas. Delft rejected the former for the following reasons:

- A long period of time would be required before obtaining tangible results.
- There would be high associated costs.
- Ot might cause reduction of sand supplied to beaches from upland sources, threatening their stability.
- It would not be efficient in actually stopping siltation.

In examining options under the large-scale engineering approach, Delft considered:

- Diverting the lower course of the Sabaki toward the next bay north (Formosa Bay).

- Construction of a retaining wall in the bay of Malindi to direct river discharge beyond the influence of coastal currents.
- Creation of an artifically induced northern current off Pillar Reef, similar to the SOGREAH proposal.

In February 1974, the Minister of Finance and Planning created the National Committee on Sabaki River/Malindi Bay Siltation, composed of an ad hoc group of scientists charged to examine problems caused by siltation of the river and propose recommendations for their alleviation. They in turn created a subcommittee to review the SOGREAH and Delft proposals and make comments and recommendations, as necessary.

The subcommittee's report questioned the objectives of the harbor development project and proposed that a complete investigation of the coastal currents and sand transport regimes be made before making any decisions.

In November 1974 the full committee issued its report which recommended that:

- "Downstream" solutions--those focused on the coast--should be rejected as too costly.
- Soil conservation measures should be taken at the source to solve the problem, e.g. one project achieved concrete results in reducing erosion from the Tana River catchment after only 12 months.
- Government should estabish a silt monitoring unit for sampling river waters.
- A marine research program should be initiated in the Malindi area to focus on socio-economic aspects of development of the bay, development of the bay's fishery potential, and the geology and ecology of Malindi's reefs.

8. SOLUTIONS

The Sabaki Committee's central conclusion--that the long-term solution to Malindi's sediment probem must be dealt with at its source--appears sound for the following reasons. (1) Addressing the cause of Malindi's problems rather than its effects coincides with the national government priority of reducing declining land productivity attributed to improper land use. The coincidence of these objectives provides the incentive to pool resources and develop a coordinated approach to seeking a common solution. (2) The technical arguments for construction of a large-scale coastal work provides no real guarantee that the effects of sediment can be mitigated. Further, it is not a dynamic response, failing to account for future changes in sediment loads and their underlying causes. (3) Finally, the validity of the downstream solution must be questioned in the larger context of other present and future upstream-downstream conflicts. In the absence of a comprehensive management framework, the inhabitants of the coastal portion of a catchment will always be vulnerable to the actions of upland residents. The resources diverted to address an endless series of impacts with upland roots could be more effectively used toward developing a coherent, political, legal, and institutional response oriented toward conflict resolution and preventive measures.

Several studies previously cited in this paper support this conclusion. Ferguson Wood and Johannes (1975) reviewed the literature addressing the effects of erosion and sedimentation on coral reefs and concluded that marine scientists themselves have no means to counter the effects of bad land management upstream caused by pressures of population growth and land-use intensification in developing countries. Odum (1982) addressed this specific issue as it applies to marine fisheries. Noting that many seashore fish species pass critical stages of their life cycle in coastal and estuarine areas, he concluded that the optimum management solution is to protect the total range of fish habitat. Sound management of this area, defined by the salinity gradient, protects the fish species and their coastal habitats and livelihood systems which the resource base supports.

For East Africa, Finn (1982) cites several sets of examples of coastal problems caused by external or upstream sources. Some of these are tourist issues similar to those described for Kenya (Madagascar): increased coastal flooding (Rufiji River, Tanzania), declines in fishery production (Zambesi River, Zambia), and loss of navigability (Madagascar). It is clear that sources affecting coastal change can be serious and often occur outside of the control of the people at the coast. What the Athi example demonstrates is the need to expand Odum's solution from the coastal area defined by the presence of saline waters to a catchment-wide basis. Yet in a recent Kenyan executive policy change, responsibility for rural development planning has now been shifted away from central government to the districts. Increased decentralization unfortunately does not appear to be the answer to problems which clearly transcend each district's political and ministerial boundaries (Kenya, 1982). Thus, amended existing or new structures complementary to the district jurisdiction must be called upon.

The primary responsibility of TARDA is to advise the government of Kenya on all matters affecting areas under its control, including the apportionment of water resources, the development and revision of long-range development plans, and the coordination of activities of all agencies concerned with the use of the catchment's water (Maritim, 1981). Similar development authorities exist for major catchments in other countries in the region, such as Tanzania and its Rufiji Basin Development Authority (RUBADA). Similar examples occur in Rwanda, Burundi, Somalia, Uganda, Ethiopia, and Zimbabwe.

Although these examples appear institutionally attractive, they are in fact largely advisory in capacity, with budgets often insignificant in comparison to such traditional ministries as those for agriculture, water, livestock or industry.

These constraints can be serious deterrents to effectively responding to problems normally managed by the main ministries. However, the catchment authority can exercise its greatest influence when the basin's development is still in planning and design phases, and the makeup of a project and its levels of commitment are still flexible. Where the catchment has already undergone large-scale development (such as Kenya's Tana River) the authority must find a series of informal means to influence remedial actions in other institutions.

In the absence of basin-wide development authorities, alternative institutional options exist. Examples of these include the creation of temporary or permanent multi-institutional committees, such as the Sabaki Committee, or employing an existing planning or environmental secretariat. In most cases, these commissions not only suffer from the same problems as the catchment authorities, but they also carry a broader portfolio of responsibilities which serve to dilute their effectiveness in basin development.

Thus far, the most significant step taken to prepare for the Athi catchment's future development has been a detailed report (Athi River Basin Pre-Investment Study) prepared for TARDA that identifies development options which would fit within the government's stated terms of reference for the basin. These options will subsequently serve as a basis for proposals generated by TARDA to be presented to various assistance agencies for funding.

In the Athi example, the four objectives identified by the government for development of the catchment are to increase food production, provide opportunities for agricultural land use, expand employment, and develop and maintain secure water supplies.

Based on these objectives, it was obvious that the focus of planning activities should be on the development of rainfed agricultural opportunities and the development of water resources. Regarding the latter, the report concentrates on three principal sectors: water supply, irrigation, and hydro-power.

The report, while recognizing the need for hydrological monitoring in the development project, made no provision for determination of coastal impacts in or near Malindi. In fact the only coastal component in the development package was to make an assessment of the economic benefits associated with reducing or eliminating the siltation at Malindi. The irony in this approach is that several of the presently proposed activities may create problems of equal or even greater magnitude than those which presently exist in Malindi.

The sources of these potential problems include reduction of nutrient inputs and charges in the hydrologic regime (Munyu dam) and polluted irrigation run-off (Kibwezi irrigation scheme). Rather than fund a cost-benefit analysis of sediment mitigation options it would be preferable to conduct a resource inventory and study of the bay's dynamics as a precursory step to project implementation in order to assess implications of the projected changes as they might affect the coast. The study should be conducted over a period of at least a year, making provision for possible follow-up activities (e.g., monitoring studies). Mapping of coastal and nearshore marine communities should be made a priority, giving particular attention to the location and description of environmentally stressed communities. Current and water quality monitoring studies are the keys to understanding the bay's dynamics and the determination of effect and extent of sediment (and other potentially harmful substances) on the area's marine communities. In Kenya, the institution most competent to conduct such a survey is the Kenya Marine and Fisheries Research Institute.

TARDA in this situation is in an excellent position to influence the process by providing additional guidelines which should call directly for these types of evaluations. TARDA can also call for additional studies to examine critical areas in the watershed which may be affected (not always negatively) by potential developments. Finally, TARDA is in the position to influence other government agencies to re-direct their own resources to problem areas within the catchment that directly threaten the success of the project's activities.

9. LESSONS LEARNED

The physical processes which characterize an undisturbed river catchment--and the coastal area near the river's mouth--represent a steady-state condition which has evolved over geological time. Human activities in the uplands can disturb this steady state and result in significant changes downstream and in coastal areas as these latter systems try to readjust. While erosion, transportation and deposition of sediment in the Athi catchment are in fact natural processes, the evidence is clear that land-use practices in upland areas of the basin have accelerated soil loss rates. The increased volume of sediment carried down river has resulted in changes in coastal land form and ultimately contributed to reef die-off. Other proposed activities in the Athi catchment which could further disrupt the steady state include water diversion, extraction and impoundment schemes.

Upland discharges of urban and industrial wastes can have significant effects on coastal communities. Even though precise data are lacking for the Athi catchment, the location of Nairobi and other industrial areas in the upper portion of the basin is reason for concern about possible transport of industrial and urban pollutants to the coast.

Economic costs associated with coastal changes attributable to upland land-use activities can be significant. Dirty, unattractive beaches, sediment-laden waters, and degradation of the marine parks and reserves appear to have played important roles in the decline of the Malindi area's tourist industry. Increased sediment loads have also created a need for pre-sedimentation tanks to protect and purify Malindi's water supply. Other less easily documented changes with potentially high economic costs include increased flooding frequencies and rapid bay in-filling. From a positive perspective, expanding beaches in the Malindi area provide an added buffer against offshore storms and offer additional non-beach recreational development opportunities.

Absence of baseline information throughout a river catchment area prevents later comparisons to identify trends in resource status. Despite an intensive effort to collect data for the purposes of this Athi case study, the absence of earlier studies or invalid historical data sets made earlier definition of precise linkages between land use, increased sedi-

sediment loads, and reef die-off impossible. This deficiency also precludes clear identification of trends associated with these linkages.

Due to the complexity and magnitude of the issues involved in catchment land use, solutions--especially after development is already under way--often prove elusive, expensive, and time-consuming. Despite acknowledgment that Malindi's coastal sedimentation problem extends back to the 1930's, creation of several organizations and committees and contracts awarded for various alternative solutions, no satisfactory resolution of the problem has yet been achieved.

Resolutions to downstream and coastal problems can be directed either at the upland sources or coastal manifestations. Of the two alternatives, the former is far more logical and appears to have the greater possibility for success, though initial costs may be high. The Sabaki Committee acknowledged the difficulty and expense of reducing erosion at its upland source, yet also concluded applying coastal solutions was even more expensive; it's recommendation: that primary attention go to solving the sedimentation problem at its source.

Failure to act on previous recommendations to collect data or undertake surveys seriously hinders successful project design and future implementation. Despite the Sabaki Committee's 1973 recommendations to establish a sediment monitoring unit and to encourage a marine survey of the area adjacent to the river, follow-up activities were never implemented. The absence of the survey has resulted in a data base inadequate for the catchment's pre-investment development study. Poorly monitored erosion rates make it difficult to predict success for several elements of a proposed watershed development project.

Even catchment development and management projects which purport to be fully comprehensive may still fail to address coastal and nearshore marine considerations in their development, design or assessment of impacts. The only coastal component which the Athi catchment pre-investment study addressed is the proposed determination of costs and benefits associated with upland erosion controls with respect to mitigation of coastal impacts.

Existing institutional arrangements may not be optimal for effective development and management of an entire catchment. In the Athi example, the institution whose jurisdictional boundaries correspond with the watershed is principally advisory; it lacks a mandate to manage the watershed. The institutions which actually have a mandate and resources to implement change lack the necessary watershed-wide political jurisdiction. New management strategies must be developed and implemented to reconcile such jurisdictional issues.

10. GUIDELINES

Planners and managers of coastal areas vulnerable to the effects of inland catchment alterations should consider the following actions:

(1) Define the boundaries of the coastal and nearshore marine areas influenced by catchment processes. These boundaries should specifically include the zone influenced by fresh water, by river borne pollutants and terrestrial sediment runoff, making ample allowances for prevailing current patterns, seasonality, and other physical factors which influence the extent of the zone.

(2) Identify in order the critical coastal and marine resources in the affected area. This process should attempt to address the present and future socio-economic importance of the resources, the degree to which they can sustain probable impacts attributable to inland sources and their present status.

(3) Carry out baseline studies within this zone including resource surveys, status assessments, and description of the physical environment and the processes which shape it. The studies should also assess the nature and quantity of inputs from inland sources which enter and influence the zone.

(4) Implement a monitoring program including systematic observations of "key" inputs influencing the zone (such as freshwater flow, suspended sediment, selected nutrients, selected contaminants, dissolved oxygen). Periodic visits to vulnerable areas (such as reefs, beaches, seagrass beds) should also be included to collect the data required for trend analysis. Where a monitoring program already exists within the catchment, coastal and marine components should be integrated into the existing work.

(5) Once key inputs have been identified, establish the threshold levels required to maintain the coastal/marine resources and processes identified above. This can be done through review of existing literature, visits to comparable sites where such inputs have already been altered, and establishing in situ experimentation plots and testing programs.

(6) Where harmful inputs entering the coastal area have been observed, identify their source and upstream location(s). Once this information is known, an evaluation of available corrective measures should be completed and selection made accordingly. Complex large-scale source problems such as deforestation may limit coastal area management responses

to temporary remedial measures directed at the affected coastal area until the appropriate institutions and resources can be mobilized to address the underlying causes.

(7) Where mitigation activities at the upstream source are already under way, consider opportunities to coordinate and complement them through existing efforts. Mechanical means to control soil loss have made substantial beginnings in upstream areas, especially through the Machakos Integrated Development Project (MIDP). Even though more resources are required to gain control of soil loss, there are lessons to be learned from small-scale successful interventions including construction of bench terraces, cutoff drains, and small check dams as well as through better land management such as reforestation, controlled grazing, and improved cultivation. These activities should be reviewed, and, as appropriate, expanded.

(8) Where possible, consider in upstream water management the negative impacts of downstream sedimentation. As new dams and new irrigation schemes come onto line in the Athi basin, potential soil loss problems should become a basic consideration in determining water management practices. Water storage cycles should be geared to restrain soil loss; water discharge from irrigation schemes should be timed to minimize sedimentation downstream; small holding dams should be considered to reduce sedimentation in the river bed itself.

(9) Establish systematic procedures to evaluate coastal implications of proposed development activities (or other intervention) in the catchment area. One common approach to institutionalize these procedures is to empower an appropriate government agency with the right of review. The agency should be either a body responsible for coastal affairs or one which is multi-jurisdictional in nature with a coastal component. In either case it should possess or have access to technical expertise to assist in proper evaluation of the proposed activities.

(10) Where key inputs may be altered by development proposals and therefore pose a threat to threshold limits of coastal resources, make the appropriate modifications in development design. Where modification is precluded, a complete social and economic assessment of costs and benefits and other techniques should precede final authorization of the development

activities, taking into account coastal impacts and considering costs of foreclosed future opportunities.

(11) Examine appropriate institutional mechanisms for their capability to develop, manage, and monitor catchment-wide activities, including the coastal and marine components. Where gaps in administrative jurisdiction occur, appropriate measures should be taken through creation of inter-agency committees, organization of new administrative units, or related institutional responses.

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Case Study Seven

IMPACTS OF RIVER FLOW CHANGES ON COASTAL ECOSYSTEMS

Sawar Mahmud

SUMMARY

This study reviews pertinent literature documenting the damages caused by human and natural changes in the freshwater flow regimes of eleven selected rivers of the USA. Within the scope and limitations of the project, the author has qualitatively summarized the lessons to be derived from past experience in modifying freshwater flows upstream on coastal resources. In many instances, these factors were common to several rivers.

After reviewing the individual rivers, the author tabulated the lessons learned, with a view to compile a list of hydrologic changes and the resultant impacts on coastal ecosystems. The main objective of the study was to prepare a single source of information which could be consulted and used by water resource planners in the lesser developed countries (LDCs) of the world in helping them preserve their valuable coastal resources. It is anticipated that they may be able to find numerous similarities betweeen the rivers in their countries and the American rivers, which could help them in their future water resources management plans.

Finally a set of guidelines have been proposed, briefly outlining how the managers in the LDCs might be able to extrapolate data from the American rivers/estuarine systems to address and solve their coastal zone problems, which may be similar to those found in some of the American rivers. It might be appropriate to conduct further studies to make a comparative analysis between specific rivers in the developed nations and similar river systems in a selected LDC, to demonstrate the value of such an approach. It is believed that the use of simulation and extrapolation techniques can be of considerable value in filling data gaps that may exist in hydrologic and ecological information readily available to LDC managers and planners.

1. INTRODUCTION

1.1 General Background and Justification

"WATER IS THE BASIS OF ALL LIFE. . ." (The Holy Quran). This simple yet potent message from the Islamic Scriptures reminds humankind of the fundamental role of freshwater in all forms of life. The steady expansion of the world's population and the ever-increasing demand on limited supplies of available freshwater make it imperative to consider the downstream impacts of upstream hydrologic regime modifications. This concern is especially significant where rapid development and population growth occur simultaneously--particularly in most of the developing nations of the world.

In the technologically advanced nations there is an emerging consensus of public and scientific opinion that the effects of upstream freshwater modifications on the downstream estuarine ecosystems are of considerable significance. Scientists throughout this country have spent decades in documenting the changes of freshwater inflows into the coastal regions and the resultant deterioration in estuarine ecosystems.

This paper presents the results of a literature review on the effects of inland river modifications on coastal ecosystems, and suggests how the lessons learned from the research on selected American rivers may be used to help develop freshwater management strategies in developing nations.

Water resources managers in most developing nations, facing increased demands for freshwater supplies, are often compelled to divert significant volumes of freshwater to meet urgent agricultural, urban and industrial development needs. They rarely have the time, technical or financial resources to study the long-range consequences of their actions on the delicate balance of the coastal ecosystems. Many of them believed that freshwater discharges into the saline oceans were an enormous waste of a valuable resource which could be more beneficially utilized to meet the essential needs of the human race. Thus, in order to meet their immediate needs, they neglected to consider the long-range detrimental consequences of such inland water development activities.

The complex relationships between the nutrient cycles and food webs operating in estuaries and their importance to humans has now been recognized by many analysts and the need to protect coastal zone environments has gained impetus. Planners now realize that comprehensive environmental considerations must form an integral part in the overall planning and implementation of water resources development. Research indicates that seemingly innocent human alterations of river systems, combined with unusual chains of natural events, have often generated complex problems of varying degree and magnitude. Since the mid-1960's numerous studies have been completed in various degrees of detail on several U.S. rivers; yet for many rivers we lack essential information. Figure 1 (Water Resources Council, 1976) clearly shows that under severe drought conditions total water demand exceeds available supp in over 95% of the continental USA. (Second National Water Assessment)

This study has documented two prevalent research approaches. One group of researchers has evaluated the physical and chemical changes brought about by inland freshwater modification while a second group of researchers focused attention on biotic degradation observed in different estuarine habitats. Yet it is not alwasy easy to accurately correlate the impact of any specific hydrologic modification to a particular coastal zone degradation problem. Past research indicates that a balanced intermingling of freshwater and saline ocean water is essential to maintain a high level of estuarine productivity. Figure 2 shows the general relation between coastal zone productivity of freshwater inflow from river systems.

1.2 Brief Historical Perspective on the Role of Freshwater Inflow to Estuaries

The essential role of freshwater inflow to estuarine ecosystems has been well documented in numerous studies published by several eminent scientists (Benson, 1981; Snedaker, 1977; Rauschuber, 1981; Odum, 1974) and many others.

Benson (1981) projects that:

> Over 55% of the United States' commercial fish and shellfish catch is dependent on estuaries for spawning and nursery functions, but these estuaries cannot function ecologically without an adequate volume, seasonal inflow, and high quality of freshwater from inland rivers.

Major inland development projects such as the construction of dams, reservoirs, levees, dredged navigation channels, freshwater diversions for agricultural, industrial and urban development, as well as storm water and sewage effluent disposal systems, all seem to contribute to coastal ecosystem disturbances of different types and magnitude.

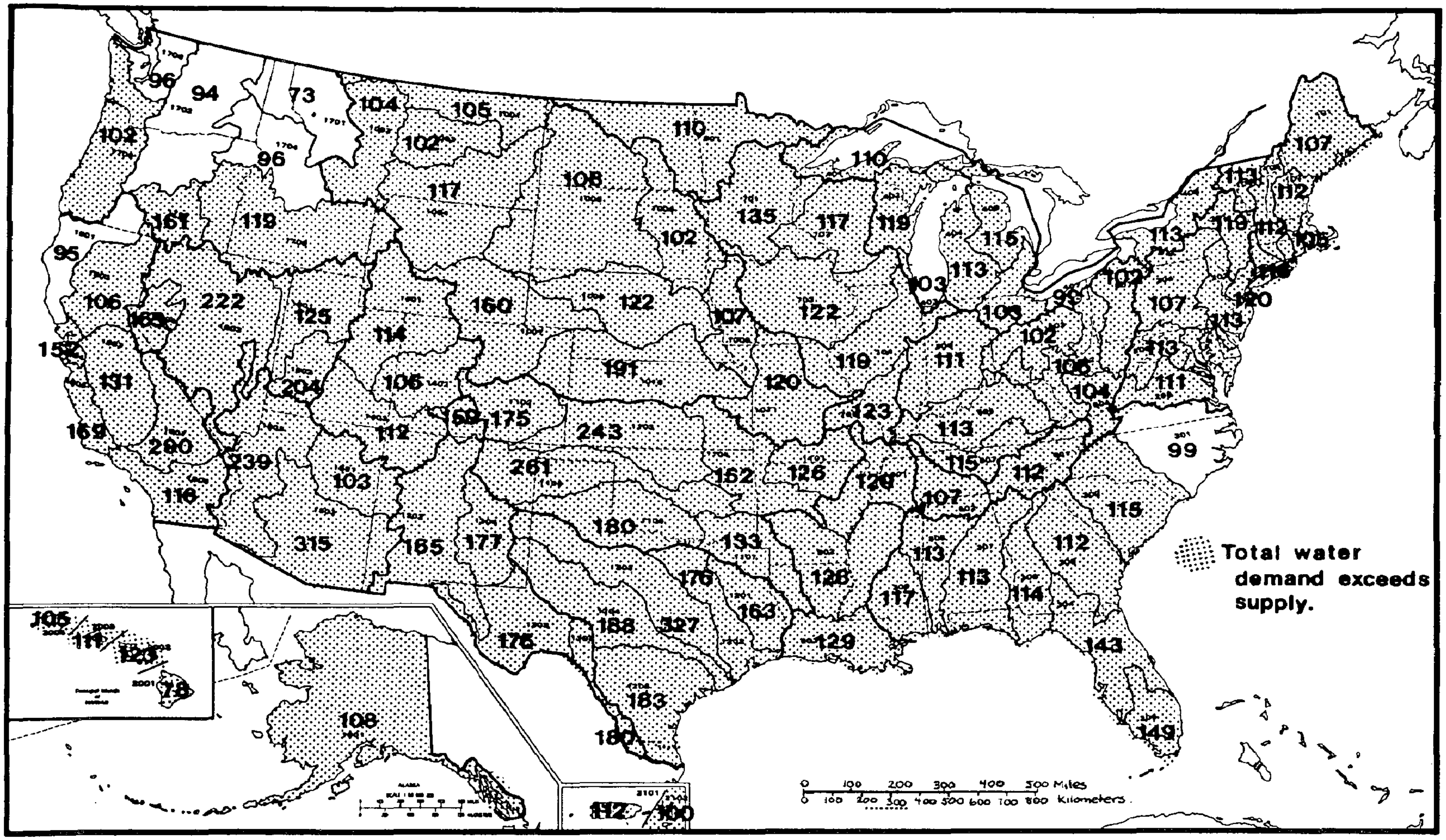

Figure 1. Map of the U.S.A. depicting the areas in which the 1975 water demand exceeded available dry year surface water supply. Figures indicate percentages. (Source: Water Resources Council-Second National Water Assessment, 1976)

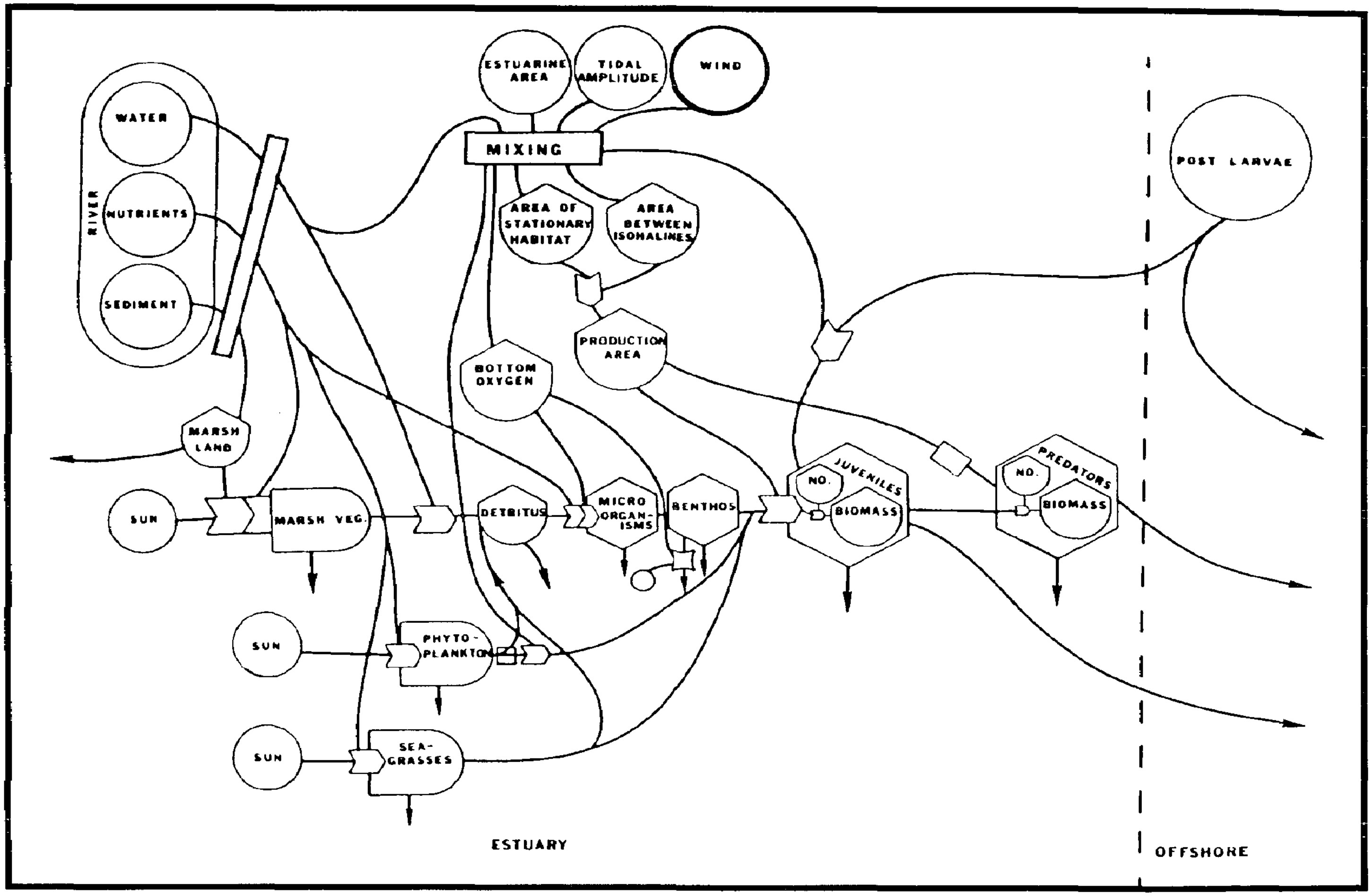

Figure 2. Energy-flow diagram showing pathways of potential effects of river inflows on production of fishery stocks. (Source: Odum and Odum, 1976)

Benson (1981) has stated that the problems of the Atlantic estuarine system are basically functions of reduced water quality, increased runoff and in some cases lower flow quantities. On the Pacific Coast, drastic reduction in both flow quantities and water quality are the major problems, while estuaries along the Gulf of Mexico have shown serious losses of productivity due to decreases of freshwater quantities and navigation channel diversions.

The Fish and Wildlife Service (Office of Biological Sciences), the National Coastal Ecosystem Team, the U.S. Army Corps of Engineers, the Conservation Foundation, the National Oceanic and Atmospheric Administration (NOAA), along with analysts from various academic institutions, have published extensive literature on this subject.

Snedaker et al. (1977) have published a "Bibliography on the Role of Freshwater in Estuarine Ecosystems," and Hopkins (1973) prepared an extensive work for the Corps of Engineers entitled "Annotated Bibliography on the Effects of Salinity and Salinity Changes on Life in Coastal Waters."

The importance of the estuarine ecosystems to the nation's economic well-being is reflected in a number of federal laws and executive orders which have been promulgated over the past several years:

- Coastal Zone Management Act, 1972
- Coastal Zone Management Improvement Act, 1980
- Fish and Wildlife Coordination Act
- Fishery Conservation and Management Act, 1980
- Endangered Species Act, 1973
- Marine Mammal Protection Act
- Marine Protection Research and Sanctuaries Act, 1972
- National Environmental Policy Act, 1969
- Estuary Protection Act, 1968
- National Flood Insurance Act, 1972
- Federal Water Pollution Control Act, 1972, 1977
- Federal Clean Water Act 1972, 1977
- Safe Drinking Water Act, 1974
- Outer Continental Shelf Lands Act, 1976

Yet despite the number of federal laws, executive orders, and state regulations, the multifaceted problems faced by the nation's estuarine ecosystems are being resolved at a painfully slow pace. Clashes between powerful interested developers and environmentalists are a common occurrence.

1.3 Economic Importance of Coastal Ecosystems

In the Proceedings of the National Symposium on Freshwater Inflow to Estuaries (1981), Ozmore made several key observations on the economic value of coastal resources along the Gulf Coast.

> In 1979, Texas shrimpers landed 41,604,000 pounds . . . worth \$153,115,000 ex-vessel . . . worth about \$500,000,000 retail. Louisiana fishermen . . . ex-vessel value of \$115,282,000 or \$345,000,000 final value . . . while the other three Gulf of Mexico states . . . ex-vessel value of \$109,245,000 or \$327,600,000 retail value . . . total landings from the entire Gulf of Mexico coast was worth boatside of over \$377.6 million or \$1,133 billion. Sports fishing alone is capable of generating expenditures of over \$75.2 million annually in the State of Texas. (Ozmore, p. 7)

The contributions of estuaries to the overall economies of inland regions underscore the importance of protecting coastal zone resources by maintaining an acceptable level of freshwater inflow in the estuaries. However, coastal zone inhabitants have little, if any, political strength to fight for their share of freshwater, as compared to the powerful inland agricultural, industrial and urban development interests.

Statistics compiled by UNESCO (1974) show that freshwater inflow into the nation's estuaries have in some cases dropped at the alarmingly high rate of 62% or more. Declining freshwater inflow is often accompanied by a higher input of treated sewage flows through the river basins. Increased salinity levels often reach far inland. Figure 3 (from UNESCO, 1974) presents a map showing estimated freshwater flows into the oceans through the major rivers of the conterminous United States, as of 1970.

The author has developed a conceptual matrix, which could be refined and used as a design tool to correlate the impacts of upstream hydrologic changes with coastal ecosystem degradation. Table 1 depicts this concept which can be readily modified to reflect the actual conditions observed in any drainage basin or river system. This matrix (or a similar tabulation) may help coastal zone resources managers and identify and address the negative impacts of inland freshwater flow modifications fairly expeditously. On the basis of such an analytical review, water resources managers can develop optimal strategies to ensure a better balance of inland and coastal freshwater distribution and usage.

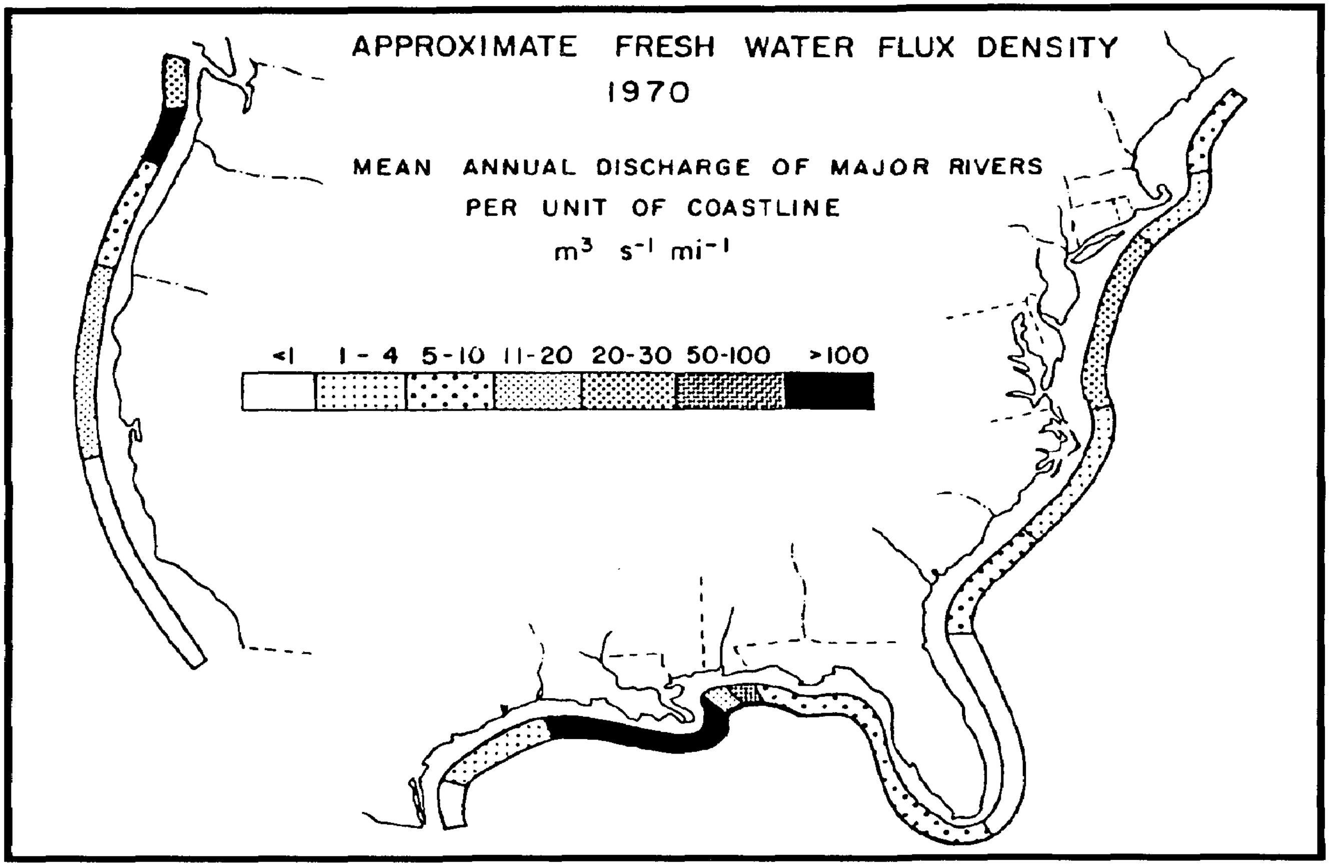

Figure 3. A rough approximation of the flux of freshwater from major rivers along the coast of the coterminous United States. (Source: UNESCO, 1974.)

Table 1. Conceptual matrix showing correlation between man-made changes in upstream hydrologic regimes and changes in downstream coastal ecosystems.

TYPICAL ACTIONS EFFECTING FRESHWATER FLOW MODIFICATIONS	TYPICAL COASTAL ECOLOGIC PROBLEMS ENCOUNTERED OR OBSERVED							
	Erosion & sedimentation	Changes in thermal gradients	Salinity increases & saline intrusion	Nutrient-level modification	Pollution			
					Organic	Inorganic	Metals	Other
1. URBAN DEVELOPMENT • Deforestation for homes, highways, roads, etc.	High	Lo-Med	Lo-Med	Lo-Med	Lo-Med	Med-Hi	Lo-Med	
• Consumptive water supply (dams, reservoirs)	Lo-Med	Lo-Med	High	Med-Hi	Lo	Lo	Lo	
• Sewage treatment and disposal	Lo-Med	Lo-Med	Lo-Med	High	Med-Hi	Lo-Med	Med-Hi	Algal Blooms
• Flood control structures	Lo-Med	Lo-Med	Med-Hi	Lo-Med	Lo	Lo	Lo	Biota Changes
2. AGRICULTURE • Forest clearing & land grading, roads, etc.	High	Lo-Med	Lo-Med	Lo-Med	Lo-Med	Lo-Med	Lo-Med	
• Pesticides & Fertilizers	Lo-Med	Med-Hi	Lo-Med	Med-Hi	Lo-Med	Lo-Med	Lo-Med	
• Agricultural wastes disposal	Lo	Lo-Med	Lo-Med	High	Med-Hi	Med-Hi	Lo	
• Irrigation Demands	Lo-Med	Med-Hi	High	Med-Hi	Med-Hi	Lo-Med	Lo	
3. INDUSTRY • Transportation -Navigation	Med-Hi	Lo-Med	Med-Hi	Med-Hi	Lo-Med	Lo-Med	Lo	River course changes
-Bridges, dams, other diversions of water	Lo-Med	Lo-Med	Med-Hi	Lo-Med	Lo	Lo	Lo	Shoals sandbars
• Manufacturing -Chemical	Lo	Med-Hi	High	Med-Hi	Lo-Med	High	High	Potential toxicity increases
-Power plants	Lo	Med-Hi	High	Med-Hi	Lo-Med	Lo	Lo-Med	
-Raw mat'ls recov.	Med-Hi	Lo-Med	Low	Lo-Med	Lo-Med	Med-Hi	Med-Hi	
-Fossil fuels: coal, oil & gas	Lo	Lo-Med	Lo-Med	Lo-Med	Med-Hi	Lo-Med	Lo	

Note: The severity of ecologic impacts is widely varible and subject to site-specific parameters.

1.4 Methods of Investigation and Analyses

The original goal of this study was to compile an annotated bibliography of relevant literature describing the impacts of diminished freshwater inflows on coastal ecosystems. This goal was changed to develop a more objective and focussed review of eleven selected American rivers. The rivers selected for the study represent a variety of coastal ecology problems. An attempt was made to identify resource conflicts and management issues and to determine the relevance of adapting U.S. problem-solving techniques to river systems in lesser developed nations.

Time and fiscal constraints of the study severely limited the scope and extent of the analysis, and ruled out the possibility of investigating major river systems or complex drainage basins. Thus, a brief and expedited review was conducted on the eleven rivers for the case study.

During the course of the investigations, it was observed that the following major categories of research were documented in the mass of literature identified through library and computer searches:

- Reports emphasizing purely hydrologic and hydraulic engineering elements of different river systems and estuarine environments.
- Articles documenting the impact of freshwater inflow modifications on the variations in the occurrence or depletion of specific coastal resources.
- Detailed statistical, mathematical or computer-aided analyses of physical and chemical changes observed at different coastal resources.
- Papers addressing the impacts of upstream freshwater flow changes on coastal ecosystems, but generally without concentrating on specific regions or species.

The literature review revealed that diverse groups of researchers seem to approach estuarine problem-issues with considerably different perspectives. Federal agencies (such as the U.S. Army Corps of Engineers or the USDA Soil Conservation Service), local government agencies (such as county planning offices), and private industrial/commercial groups (mining, commercial or urban developers) tend to view their upstream freshwater usage as having minimal downstream coastal zone impacts. Such inland and upriver interests seem to restrict their environmental impact assessments to only the immediate vicinity of their projects with little regard to the cumulative effects of several such projects on downstream coastal environs.

Inhabitants of the coastal regions, together with serious conservationists, often consider that inland freshwater users are responsible for most of the disastrous, long-term degradation of their valuable and fragile coastal resources. Coastal residents, frustrated by their inability to influence or moderate some of the upstream freshwater withdrawals made by many inland water developers, feel helpless and angry.

The key articles referenced in this study were derived from a select group of sources. It was not feasible to review the large number of publications dealing with this subject. These include:

- Proceedings of the National Symposium on Freshwater Inflows to Estuaries. Volumes 1 and 2, prepared for the National Coastal Ecosystems Team, Slidell, La., ed. by Ralph D. Cross and Donald L. Williams of the University of Southern Mississippi, Hattiesburg, MS, Oct. 1981.
- Coastal Ecologic Systems of the United States, Volumes 1-4, ed. by H.T. Odum, B.J. Copeland, E.A. McMahan, published by The Conservation Foundation of Washington, D.C., June 1974.
- Freshwater Needs of Fish & Wildlife Resources in the Nueces-Corpus Christi Bay Area, Texas: A Literature Synthesis by Don E. Henley and Donald G. Rauschuber, for the U.S. Fish & Wildlife Service, Biological Services Program, March 1981.
- Trinity-San Jacinto Estuary: A Study of the Influence of Freshwater Inflows, by the Texas Department of Water Resources' Staff, April 1981.
- Instream Flow Methodologies for Regional and National Assessments: Instream Flow Information Paper No. 7, by Keith Bayha of the Cooperative Instream Flow Group, U.S. Fish & Wildlife Service, Fort Collins, Colo., December 1978.
- Bibliography - Role of Freshwater in Estuarine Ecosystems, by S. Snedaker et al. University of Miami, Rosenstiel School of Marine and Atmospheric Science, 1977.

From an original list of 22 U.S. rivers, 11 were chosen that exhibited coastal zone problems associated with freshwater inflow changes:

Name of River	Receiving Water Body
Appalachicola River	Gulf of Mexico
Atchafalya Bay (Mississippi)	Gulf of Mexico
Colorado (Main) River	Pacific Ocean
Colorado (Texas)	Gulf of Mexico
Nueces River (Neuces Bay)	Gulf of Mexico
Pee-Dee (Yadkin) River	Atlantic Ocean
Potomac River	Atlantic Ocean
Sacramento River	Pacific Ocean
Santee/Cooper River	Atlantic Ocean
Susquehanna River	Atlantic Ocean
Trinity River	Gulf of Mexico

Relevant papers describing coastal environmental issues pertinent to each of the river systems were reviewed, and the lessons learned were derived from the research conducted. Finally, a set of guidelines have been formulated to assist water resources developers avoid or minimize damage to valuable coastal resources.

In concluding this section, the author wishes to record the valuable assistance provided in the initial stages by Dr. Samuel Snedaker of the University of Florida, Miami; and Dr. Ray Hicks, Jr., of the University of West Virginia.

2. THE EFFECTS OF FLOW CHANGES IN SELECTED RIVERS ON COASTAL ECOSYSTEMS

The eleven rivers selected for this study have the following characteristics.

- Five of the river systems discharge into the Gulf of Mexico, and their coastal zones are generally influenced by temperate to tropical climatic conditions.
- Four of the rivers discharge into the Atlantic Ocean, mainly associated with somewhat cooler temperature climatic environs.
- Of the two rivers discharging into the Pacific Ocean, the Sacramento River flows through the San Francisco Bay and Delta in the cooler northern latitudes, while the Colorado River flows through the Gulf of California further south, into a warmer aquatic environment.

As a matter of convenience, the sequence of discussions is presented in accordance with the principal receiving bodies rather than with respect to the alphabetical listing of the rivers. Hence, the Gulf Coast rivers and estuaries are discussed first, and this is followed by discussions of the rivers flowing into the Atlantic and Pacific Oceans.

2.1 The Apalachicola River and Bay System

Situated in the western part of Florida, the Apalachicola River forms the principal drainage system draining the watersheds of the Chattahoochee River and Flint River systems of Alabama and Georgia, below Lake Seminole and Woodruff Dam, before emptying into the Gulf of Mexico.

Figure 4 (NOAA, Coastal Zone Management, 1979) depicts the general watershed of the combined Chattahoochee, Flint and Apalachicola Rivers draining into the Apalachicola Bay.

Browder and Moore (1981) have shown that the Apalachicola Bay system is one of the most productive estuaries in Florida and contributes substantially to the economy of Franklin County. It supports a large recreational fishing industry and a commercial fishery for oysters, shrimp, blue crabs, and several fish species. The oyster industry alone is responsible for 50 percent of county income (Boynton et al., 1977).

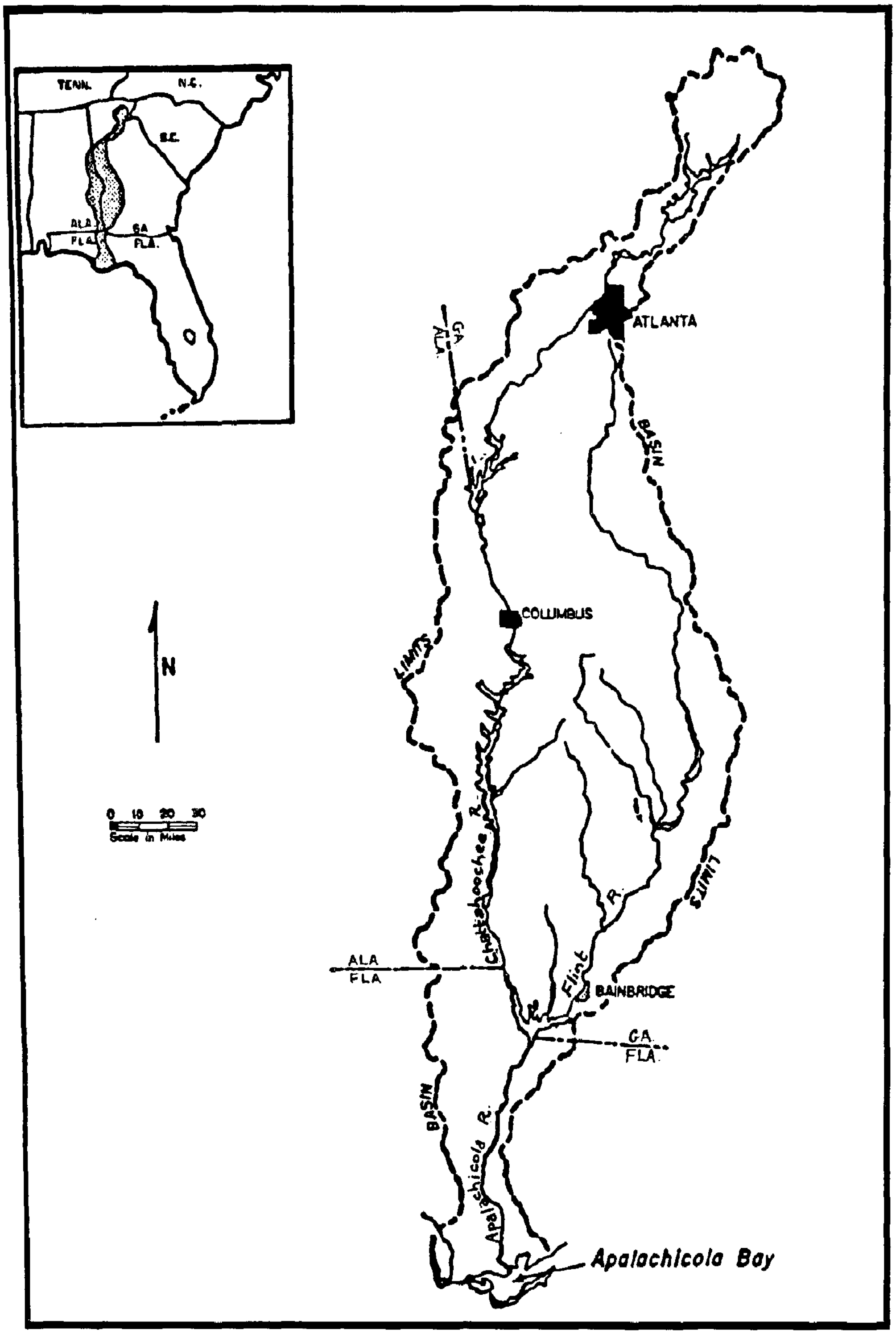

Figure 4. General location of Apalachicola, Flint and Chattahoochee River Basin. (Source: NOAA, 1979.)

The Apalachicola estuary is a shallow, bar-built system of 549 km^2, which receives freshwater runoff from a 7,530 km^2 watershed in Florida, Georgia, and Alabama. Average depth of the estuarine system at mean low tide is 2.7 m. The usual tidal range is 0.5 to 0.7 m. The Apalachicola River, with an average flow rate of 540.7 m^3/s, provides the major input. Local runoff from 1,295 km^2 of swampland also influences the estuary (Livingston et al., 1974).

The bay is characterized by low light penetration, considerable oyster bar development, and low primary productivity from bottom-living plants (Livingston et al., 1978). Although Livingston et al. (1978) reported that there is usually little vertical or horizontal variation in temperature, this bay does stratify, and tongues of highly saline water often extend into the bay along the bottom through passes (Livingston et al., 1974).

Apalachicola Bay is receiving runoff from a dammed river. The Columbia and Bartlett Ferry dams on the Chattahoochee River are used for generating hydroelectric power. Cattle ranching and forest management activities such as clearcutting, ditching, diking, and road construction also have affected freshwater inputs. Studies have been made of the long-term and short-term dynamics of chemical and biological factors in the bay and the effects of watershed alterations. Meeter et al. (1979) determined that upriver alterations have thus far not substantially altered long-term river flow patterns but have affected short-term flow patterns, particularly during periods of low flow. Until now, the dams have had little impact on the pattern of flow (Boynton, 1975). However, further changes in the periodicity of the flows into the Apalachicola estuary could result in significant degradation of the coastal ecosystem.

Lowered water quality has resulted from the cattle and forestry operations also. Effects of the forestry operations in Tate's Hell Swamp are particularly well documented (Livingston and Duncan, 1979). Each aspect of the clearcutting jobs tended to increase the rate of response of local runoff to ra fall, which increased the amplitude and decreased the duration of runoff events. This caused abrupt changes in the levels of salinity and nutrients in the vicinity of the swamp drainage. Sudden increases in water color and decreases in both dissolved oxygen and pH in upper portions of the bay were associated with periods of high runoff from the altered swamp. These events coincided with periods when the upper bay is utilized as a nursery ground by fish and invertebrates. Runoff from clearcut areas significantly reduces the water quality, and, in turn reduces the number and biomass of white shrimp in upper portions of the bay. Dissolved oxygen and pH levels increased in clearcut areas of the swamp after regrowth of a covering vegetation, suggesting that swamp vegetation can offset the changes in the water quality of the river (Livingston and Duncan, 1979).

Livingston (1981) has expressed concern regarding proposed major freshwater diversions upstream from the Chattahoochee River to meet the increasing demands of the rapidly expanding Atlanta Metropolitan region. Such diversions exceed several millions of gallons per day. He notes that the Apalachicola Bay, (the largest federally designated estuarine sanctuary in the nation), can be easily damaged if significant alterations to the upstream hydrologic regime are not rigidly controlled and existing freshwater inflow into the system is not carefully balanced.

2.1.1 Lessons Learned

- Marshes, swamps, lagoons, embayments, deltas and other related coastal physiographic features need to be protected from degradation or dimishing freshwater inflows. These areas provide the breeding, hatching, spawning, nursing and feeding grounds for a wide variety of coastal organisms. Such rich faunal and vegetal resources are the prime source of considerable economic and social benefits to large human settlements established along the entire length of a river and its principal tributaries.
- One promising mechanism to ensure the continued protection of most coastal ecosystems is by the establishment of national sanctuaries. Such efforts can be enhanced by the combined efforts of local, state, and national authorities, supported by widespread public participation. Strict enforcement of environmental and water resources standards and regulations helps preserve such sanctuaries.
- Interregional coordination and integrated planning is essential to prevent upstream water diversions. Detailed and thorough analysis of the downstream and coastal zone impacts likely to be caused by such diversions is essential. Decisions cannot be based on just the localized environmental assessments limited to the immediate

surroundings of proposed projects.

- The Apalachicola Basin sanctuary is one of the best examples of the successful cooperation of widely divergent interests such as developers and engineers on the one hand, and conservationists, the general public and coastal zone inhabitants on the other hand. It should be adapted by other coastal states all over the world.

2.2 The Atchafalaya River and Atchafalaya Bay

The Atchafalaya River, a major offshoot from the Mississippi River, flows through Louisiana into the Gulf of Mexico through a complex system of marsh and swampland. It has undergone considerable changes over the past 140 years. Figure 5 depicts the regional setting of the Atchafalaya Bay. Cunningham (1981) has documented the above water-level land development, environmental implications and resource potential of the Atchafalaya delta. He notes:

> The Atchafalaya River was a distributary of the Mississippi as far back as the 1500s (Fisk, 1952). During the middle and late 1800s, flow from the Mississippi and Red Rivers into the Atchafalaya was increased by the removal of a natural log jam and dredging of a navigational channel. (Cunningham, 1981)

Tuttle and Combe (1981) have detailed the formation of this navigation channel as follows:

> In 1831 Captain Shreve made a cutoff in the Mississippi River across the neck of Turnbull Island (to aid navigation) which left the mouth of the Red River and the head of the Atchafalaya River in an oxbow lake with a two-way connection to the Mississippi River. The Atchafalaya, at this time, was an ineffective distributary of the Mississippi, choked by a massive log jam covering 20 miles of its length. A few years after Shreve's cutoff, local interest and later the State of Louisiana undertook removal of the raft (log jam) for the purpose of developing navigation on the Atchafalaya. Their efforts were eventually successful and the Atchafalaya was reportedly open by 1855 (Latimer, 1951). Because of a distinct gradient advantage, the Atchafalaya enlarged rapidly near its mouth causing lands previously exempt from overflow to be submerged annually by the increasing volume of water from above.

Cunningham further reports that:

> By the mid-1900s a natural channel had become so well established through the diversion that the volume of flow increased at an alarming rate. Total capture of Mississippi River flow seemed

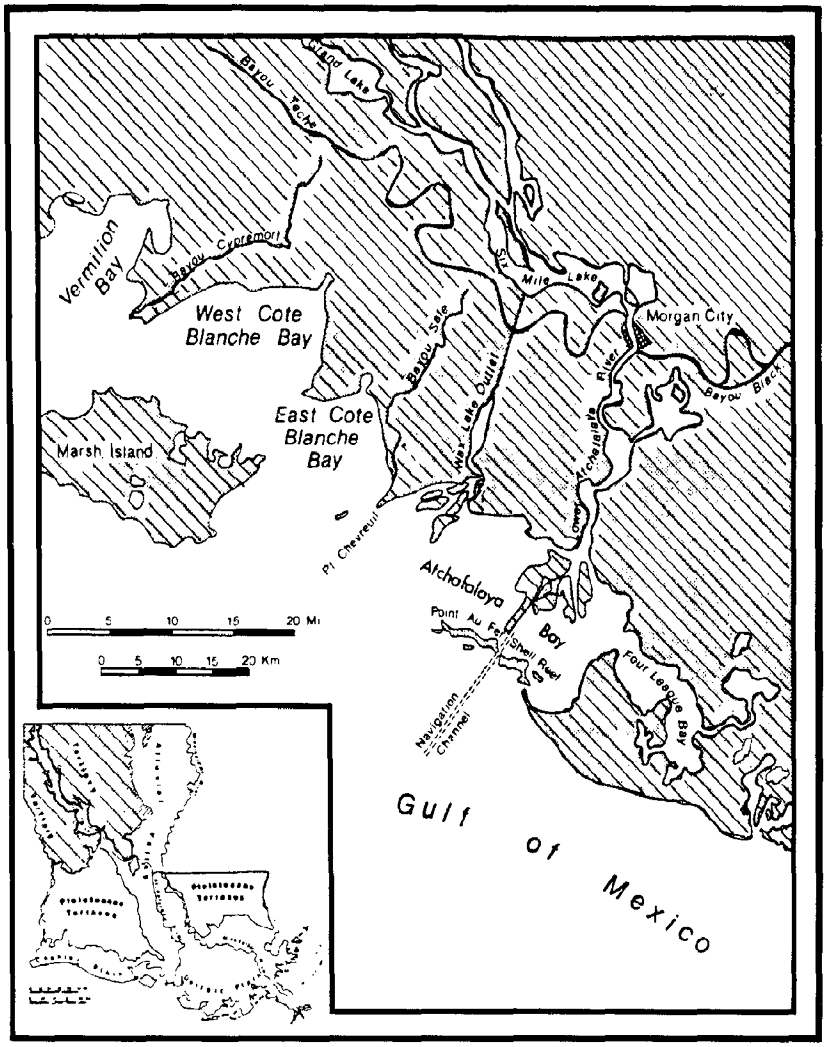

Figure 5. Regional Setting of Atchafalaya Bay
(Source: Cunningham, 1981)

inevitable because of the Atchafalaya's shorter route to the Gulf of Mexico and its decided gradient advantage. Old River control structure, built in 1963, was designed to prevent this possibility by limiting the diversion into the Atchafalaya to approximately 30 percent of the flow of the Mississippi.

Because the lower course of the Atchafalaya River contained a network of lakes and swamp catchment basins, much of the sediment load carried by the increasing flow was deposited in these areas before it reached Atchafalaya Bay.

By the early 1950s sedimentation on the coast produced noticeable effects. During the 1950s and 1960s silts and clays transported to the coast were deposited near the mouths of the outlets in the bay. By the early 1970s a thick platform of silty clay deposits covered not only Atchafalaya Bay, but adjacent offshore areas. An extraordinary increase in the amount of sand, scoured from the basin and transported to the bay, was noted during the period 1973-1977 (Roberts et al., 1980).

The heavy discharge of the Mississippi through the Atchafalaya River system inevitably resulted in heavy sedimentation, shoaling, and the formation of a new deltaic formation which gradually extended out into the Gulf of Mexico. This phenomenon was accompanied by a drastic change in the vegetation and faunal communities originally associated with the Atchafalaya Bay.

Figure 6 shows the relationship between the Atchafalaya River and the proposed Atchafalaya navigation project. Figure 7 presents a comparison of the size and shape of the Atchafalaya delta with other small new deltas of Texas.

Natural calamities such as the unusually heavy floods of 1973 and 1975 have also resulted in serious impacts on the original species, especially shellfish and finfish, in the region. The surging fresh floodwaters have had appreciable impacts on the salinities, temperatures and fauna in the bay. Hoese (1981) has discussed the effects of heavy flooding on the Atchafalaya Bay systems. His research indicates that the temperature differences, accompanied by fluctuations of the nutrient levels caused by floods, have a significant impact on the fauna. Other analysts have indicated that during prolonged periods of freshwater intrusions, marine species are often rapidly replaced by species adapted to freshwater conditions. These organisms in turn are replaced by saltwater species during times of drought or prolonged freshwater inflow decreases. Cyclic flow variations are a natural feature

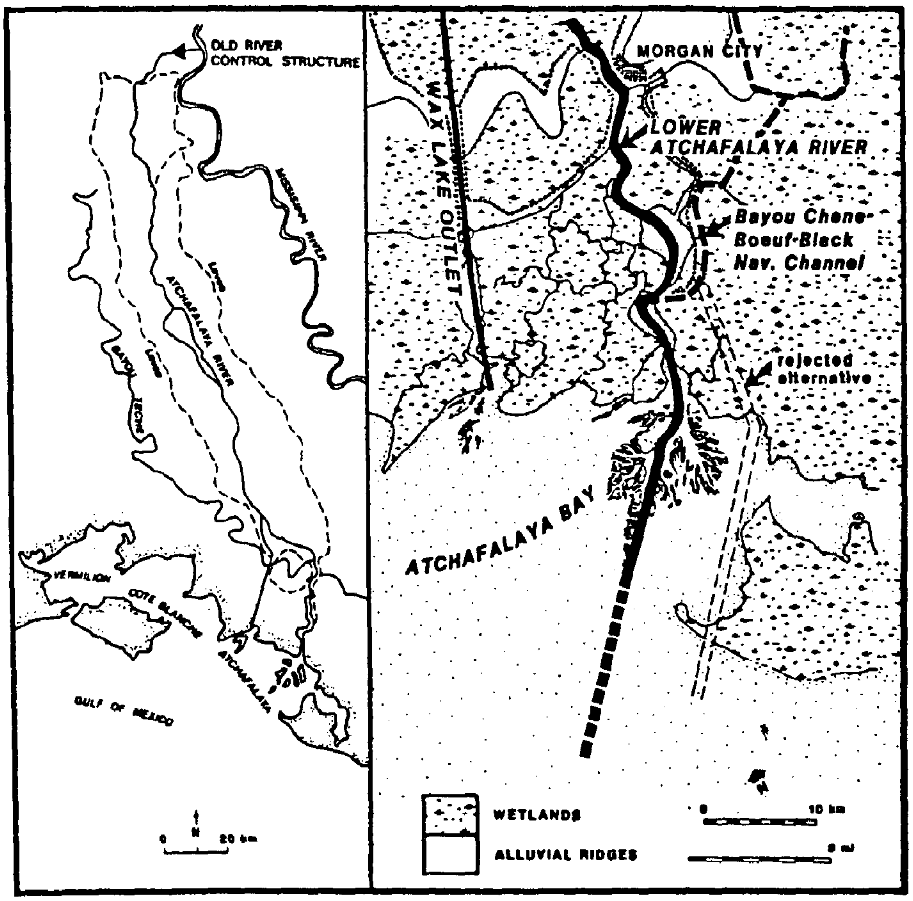

Figure 6. Atchafalaya River Basin and Lower Atchafalaya River navigation project. (Source: van Beck and Meyer-Arendt, 1981.)

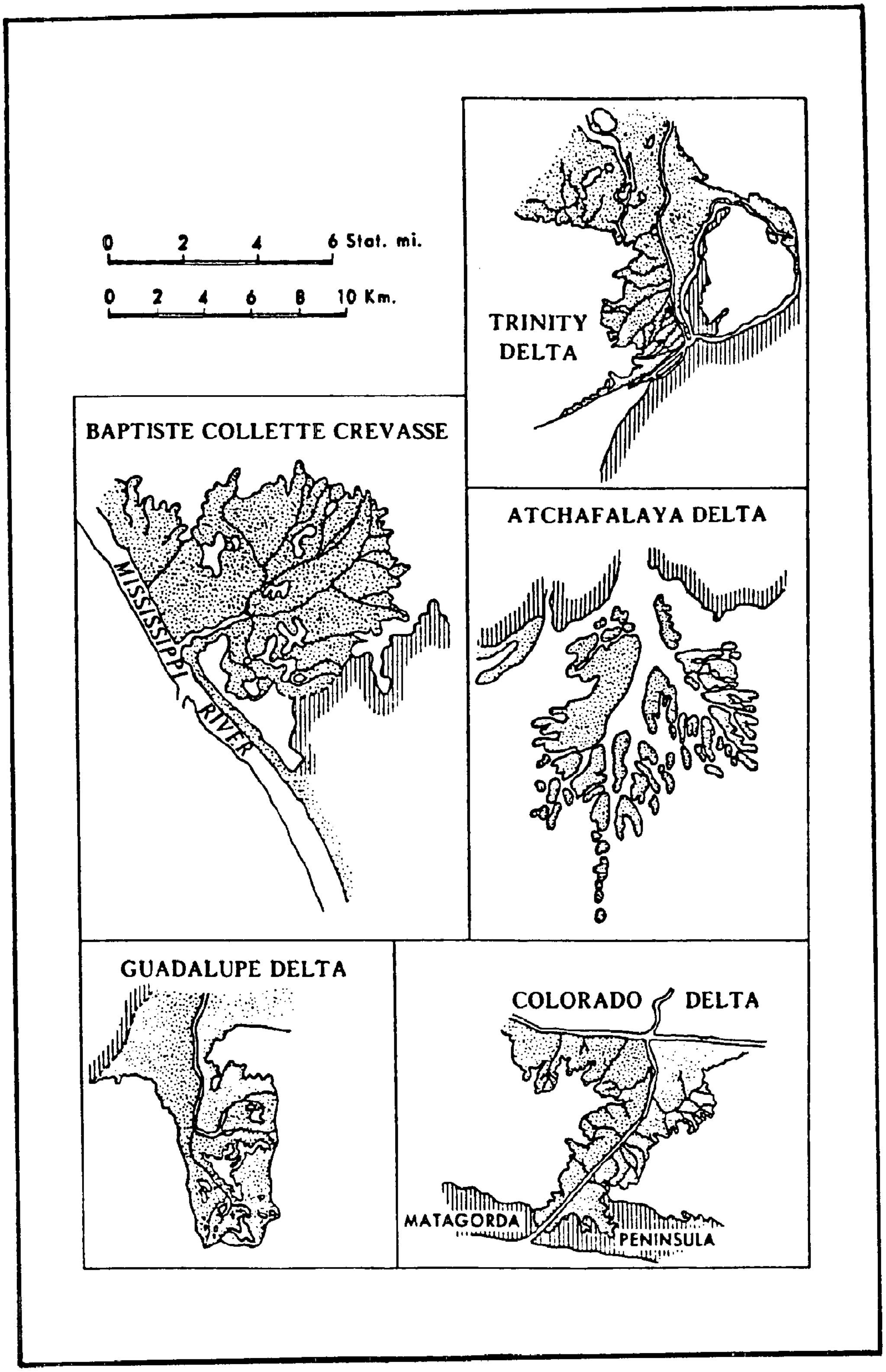

Figure 7. Comparison of the size and shape of the Atchafalaya Delta and other small modern deltas from the Texas coast, showing the result of rapid accretion. (Source: Cunningham, 1981.)

of coastal systems, but serious perturbations of freshwater flow regimes by human activities can have long-lasting detrimental effects.

2.2.1 Lessons Learned

- Even the most simple activity, such as the removal of a naturally occurring log jam can initiate far-reaching effects on the magnitude and direction of freshwater flows, and change entire coastal ecosystems and deltaic morphologic characteristics. More complex changes, such as flood control levees, dikes, etc., may increase channel scouring on the one hand along with enhanced deltaic deposition offshore on the other.
- Overabundant inflows from major flood events or surge releases from dams cause appreciable fluctuations in coastal salinity and temperature ranges, which can be destructive to nearshore biota if prolonged at times when such regions are essential to the nursery and hatchery needs of various species.
- Comprehensive and integrated regional basinwide water resources management planning and implementation, together with constant monitoring, can help prevent unwanted damage to coastal ecosystems.

State and local authorities appear to be working with conservationists to maintain the status quo of this coastal ecosystem.

2.3 The Colorado River, Texas

Figure 8 depicts the general relationship and geographic location of the Colorado River and two other Texas rivers and estuaries emptying into the Gulf of Mexico.

The Colorado River flows in a southerly direction, almost dividing the state in two parts, and after flowing past Austin, it forms an integral part of the Matagorda Bay System (Figure 9).

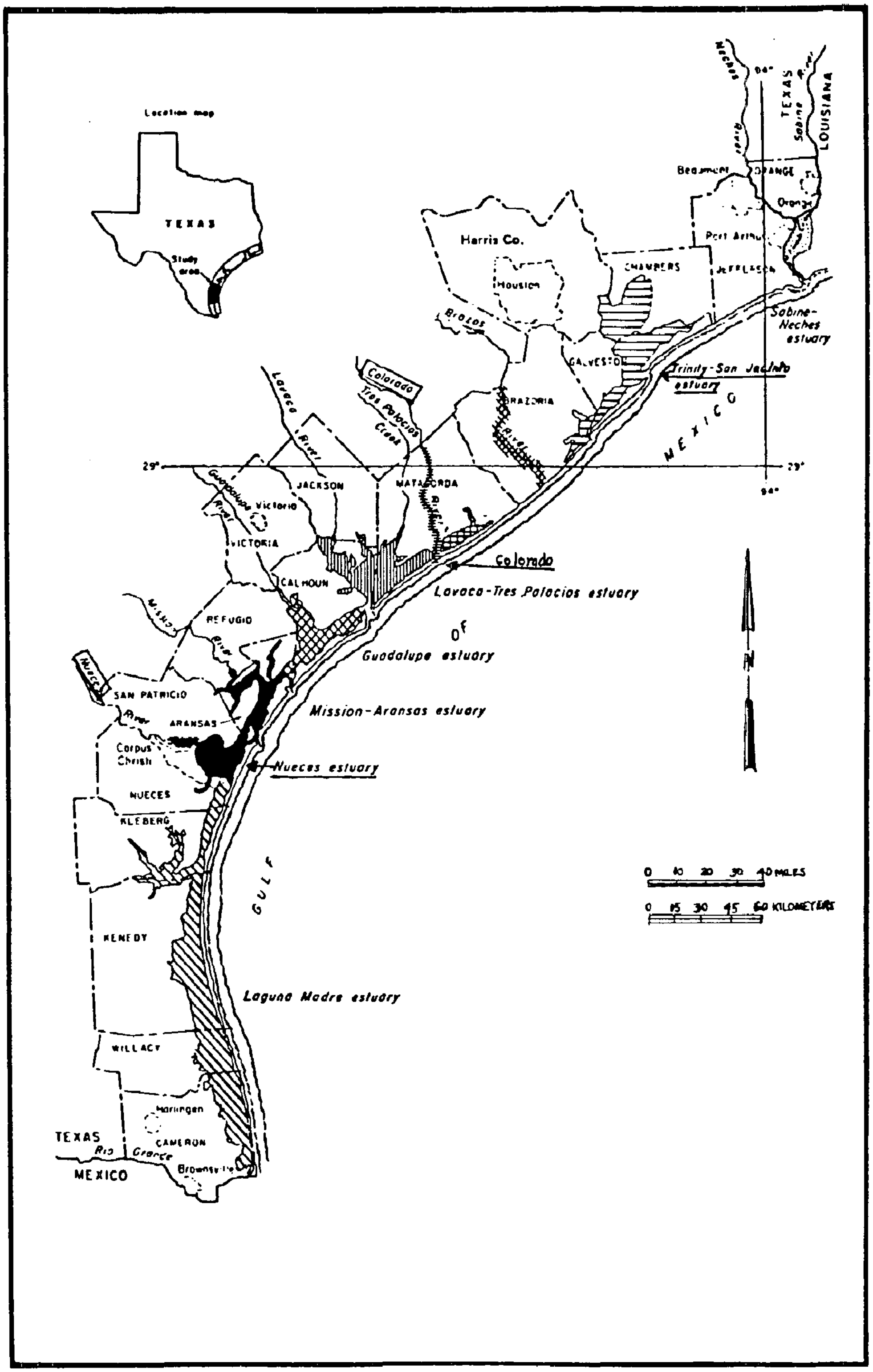

Figure 8: Location of the Texas coast estuaries. (Source: Texas Department of Water Resources, 1981.)

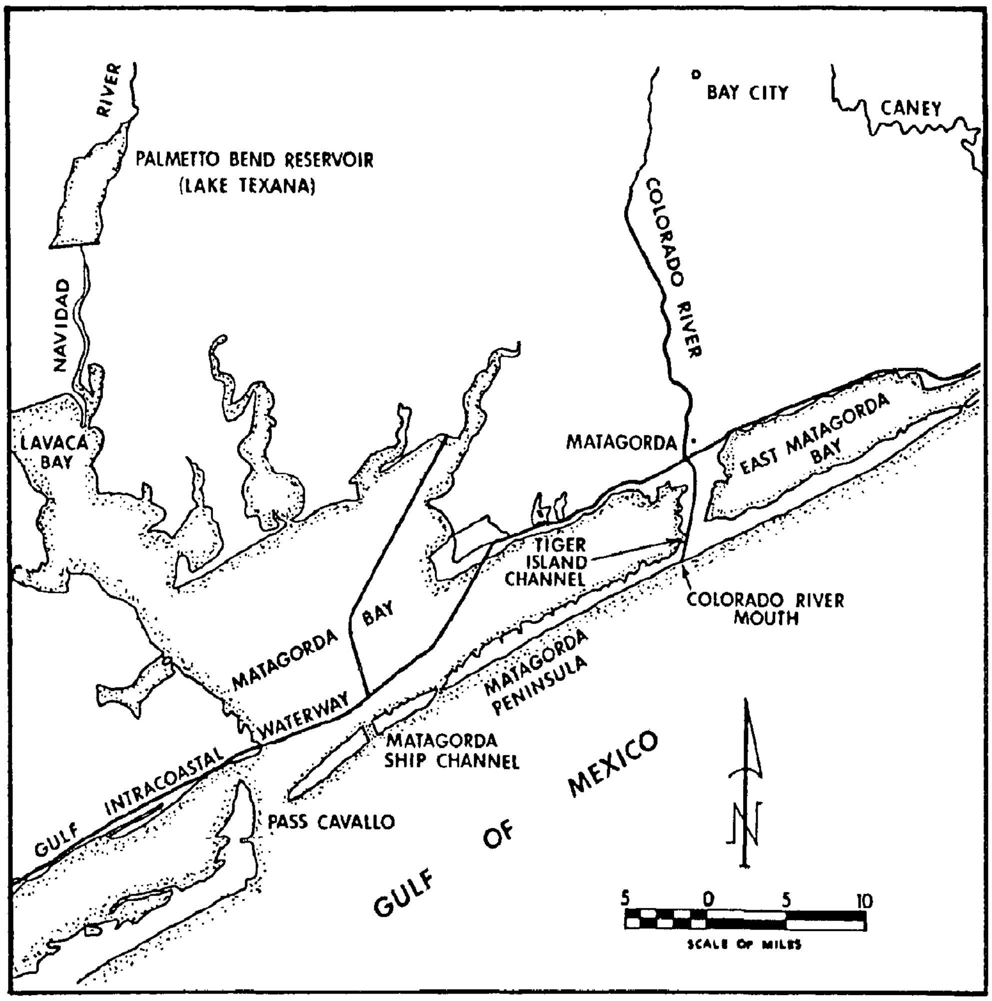

Figure 9. Location of the Colorado River in relation to Matagorda Bay. (Source: Sheffield and Walton, 1981.)

This coastal system has been the subject of extensive studies and prolonged controversy over changes proposed to be made at the mouth of the Colorado River. Its importance is apparent from the fact that the Matagorda Bay system is ranked third among the Texas bays in commercial value. Sheffield and Walton (1981) observe:

> Before 1929, the Colorado River flowed directly into Matagorda Bay near the town of Matagorda, Texas (Texas Department of Water Resources, 1978b). Removal of a large natural log jam above the town by dynamiting resulted in sudden downstream transport of great quantities of naturally trapped silt and subsequent unnatural, rapid formation of the present delta (Bouma and Bryant, 1967). Productive bay bottom was inundated, highly productive oyster reefs destroyed, and the eastward arm of Matagorda Bay was divided into two separate water bodies. The delta was channelized and Matagorda Peninsula breached so that the Colorado River was diverted from the bay, through the delta channel, directly into the Gulf of Mexico. The delta, about 4,000 acres, divided Matagorda Bay into what are now known as East Matagorda Bay and West Matagorda Bay.

The gradual development of the Colorado River delta over the past 120 years is shown in Figure 10.

Freshwater and nutrients formerly entering Matagorda Bay now pass directly to the Gulf of Mexico. The Colorado River delta marshes are now not subject to inundation and flushing by Colorado River flows except during extreme hydrological events (Texas Department of Water Resources, 1978); therefore the value of the delta for nutrient input to the bay is minimized. Some Colorado River flows now enter West Matagorda Bay through Tiger Island Cut. Studies by the Texas Department of Water Resources (1978) suggest that during periods when the mouth of the Colorado River at the gulf is not plugged by shoaling, 75 percent of river-borne nitrogen, phosphorus and organic carbon pass directly to the gulf.

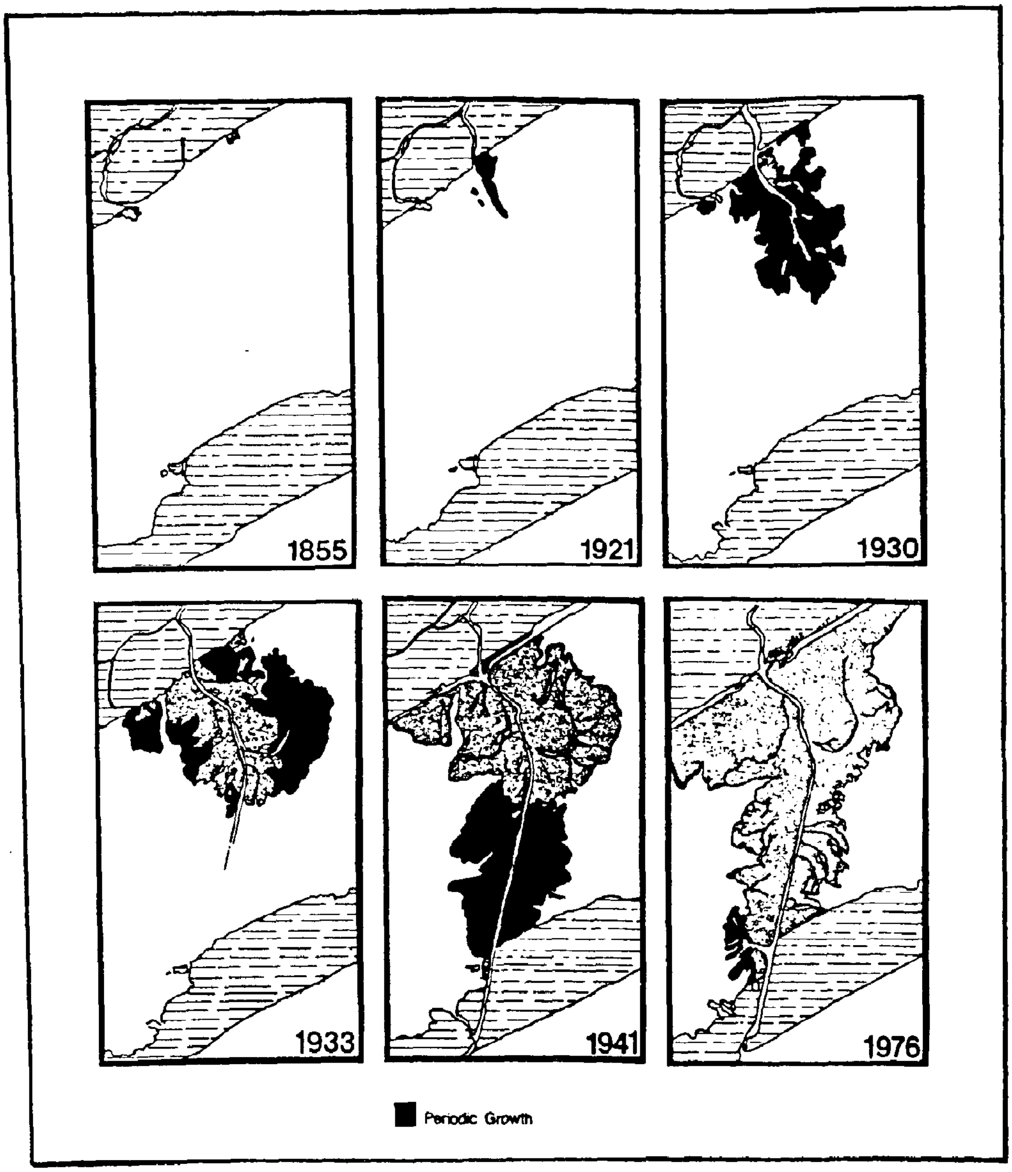

Figure 10. Delta development of the Colorado River under the influence of channelization. (Source: van Beck and Meyer-Arendt, 1981.)

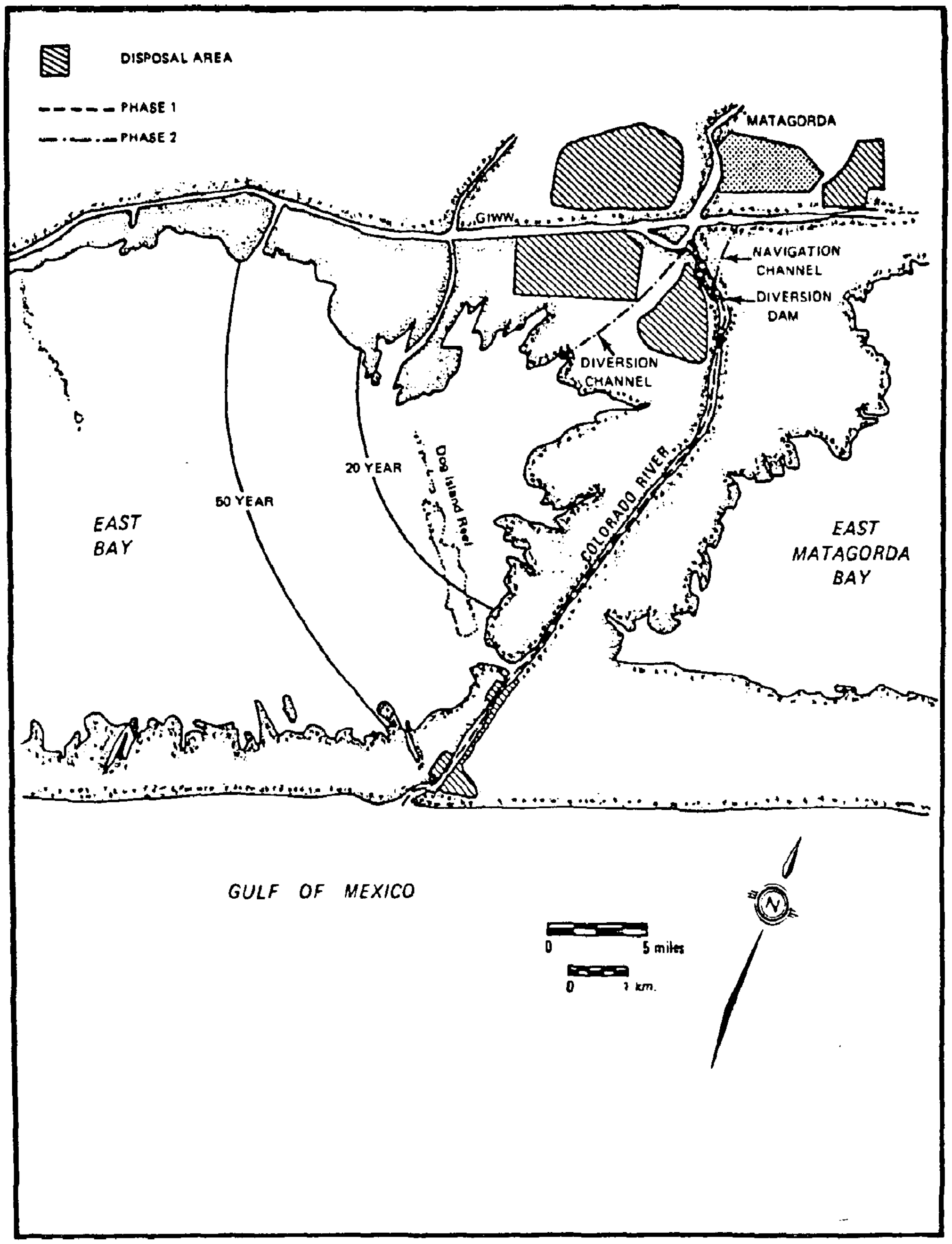

Figure 11. Proposed mouth of the Colorado River Project. (Source: Trahan, 1981.)

Reservoir development and diversions in the upper Colorado River Basin have reduced the amount of freshwater and nutrients available to the bay and altered the salinity regime (Gunter et al., 1973). The average annual discharge (1899-1936) of the Colorado River at Austin prior to regulation by upstream reservoirs was 1.964 million acre-feet but has fallen to 1.5 million acre-feet per year (1937-1977), following regulation by upstream reservoirs and increased water usage (U.S. Geological Survey, 1978).

Further drastic changes in the coastal ecosystem are likely to occur when the proposed "Mouth of the Colorado River Project" is implemented (Figure 11). Future diversions of inland freshwater flows from the Colorado River watershed, authorized by the Texas Water Resources Board, the Texas Water Commission, and the Colorado River Municipal Water District include:

- Fayette Power Plant - 48,000 acre-feet/year
- South Texas Nuclear Project - 102,000 acre-feet/year
- Metropolitan Austin/Stacy Reservoir - 113,000 acre-feet/year
- Palmetto Bend Reservoir - 92,000 acre-feet/year.

All these projects will be implemented after controversial public hearings and environmental impact statements have been finalized. However, it appears that the cumulative impact of such freshwater flow alterations are likely to be very significant and the authors report that more detailed studies over a longer time-frame would be needed to accurately predict the effects of such diversions.

2.3.1 Lessons Learned

This brief review of the Colorado River demonstrates that:

- Man-made changes of the upstream hydrologic regime have seriously affected the Colorado River's estuarine morphology and biotic systems.
- Proposed future alterations of the Colorado River flows into the Matagorda Bay, instead of the current freshwater discharge directly into the Gulf of Mexico, are likely to create considerable ecologic changes and wetlands formation further downstream.

- Water Resources Managers in LDCs should consider all aspects of their inland water resources developments, prior to actual planning and/or implementation of such projects.

2.4 Trinity River and the Trinity-San Jacinto Estuary

In their paper entitled "A New Approach to Determining the Quantitative Relationship Between Fishery Production and the Flow of Freshwater to Estuaries," Browder and Moore (1981) state:

> The Trinity-San Jacinto Estuary has slightly more than 25% of the total Texas estuarine area and leads the other estuaries in harvests of oysters, blue crabs, white and brown shrimp. Quoting D.C. Cooper and B.J. Copeland (1973), the authors state that reduction of normal Trinity River flows or addition of industrial effluents would result in decreased productivity in the Trinity Bay which is a major nursery ground supporting significant populations of valuable organisms, and thus would have a strong negative impact on the fisheries and tourism economics of the Texas Coast.

Figure 12 shows the geographic relationship between the Trinity-San Jacinto estuaries and the Galveston Bay. On the following page, Figure 13 depicts the watersheds and relationship of the major drainage basins contributing inflows into the Trinity-San Jacinto estuary.

The Texas Department of Water Resources (TDWR)(1981) has presented both historical data as well as computer simulation to document changes in the hydrologic regime. The report indicates:

> The Trinity River Basin with a total drainage area of 17,969 square miles has an average annual runoff in the Trinity River Basin ranging from 150 acre-feet per square mile in the headwaters of the West Fork Trinity to over 550 acre-feet per square mile near the mouth of the Trinity River.

During the severe drought of 1956, the average annual runoff was less than 60 acre-feet per square mile.

Altogether, 29 major reservoirs are either in existence or under construction within the Trinity River Basin. The Houston and Galveston industrial and urban areas account for a large portion of consumptive water usage not only from the Trinity River Basin, but also from deep underground aquifers. In fact, over-pumping from such deep aquifers has resulted in widespread subsidence. Figure 14 depicts the areal extent and magnitude of subsidence observed by previous researchers.

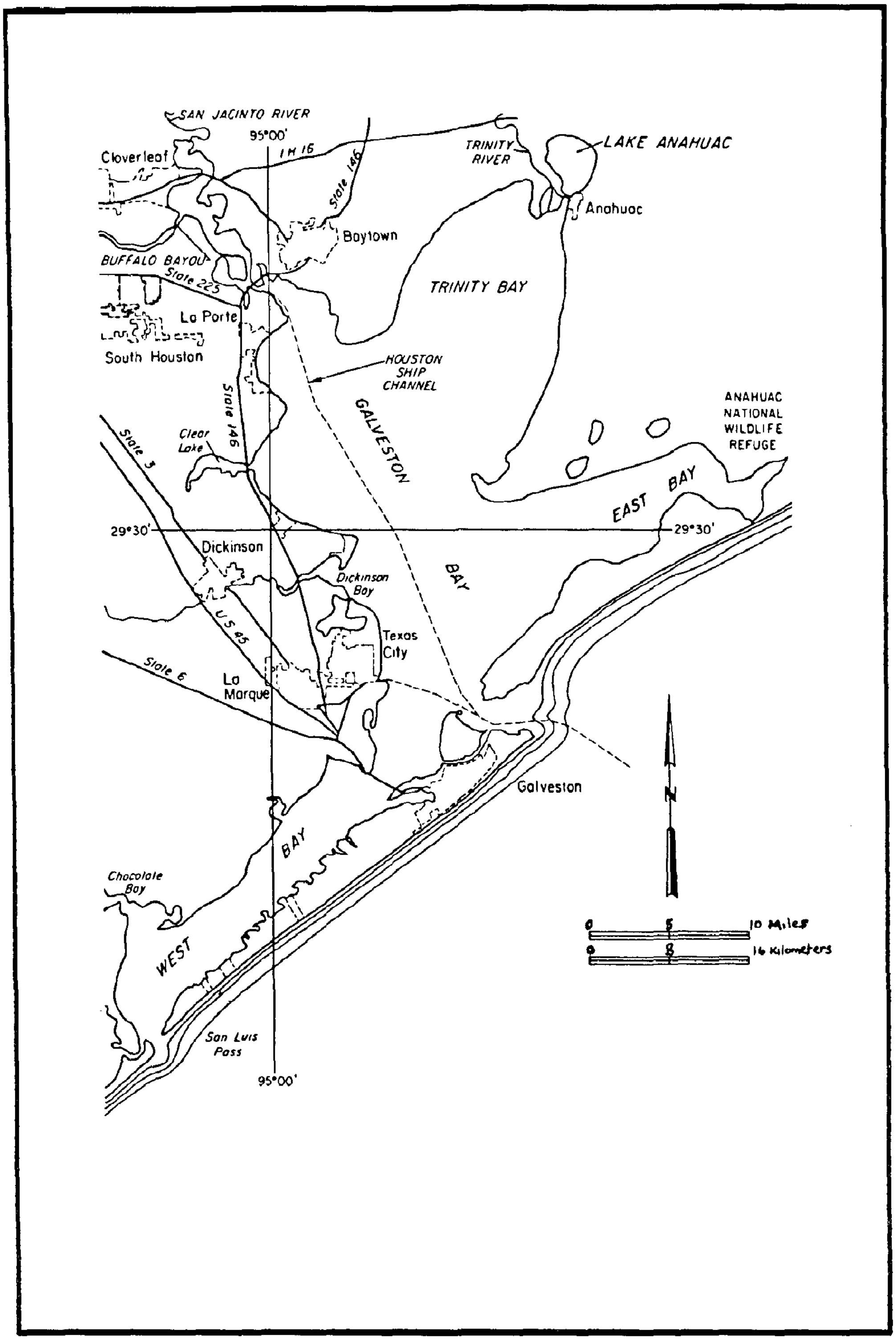

Figure 12. Trinity-San Jacinto Estuary. (Source: Texas Department of Water Resources, 1981.)

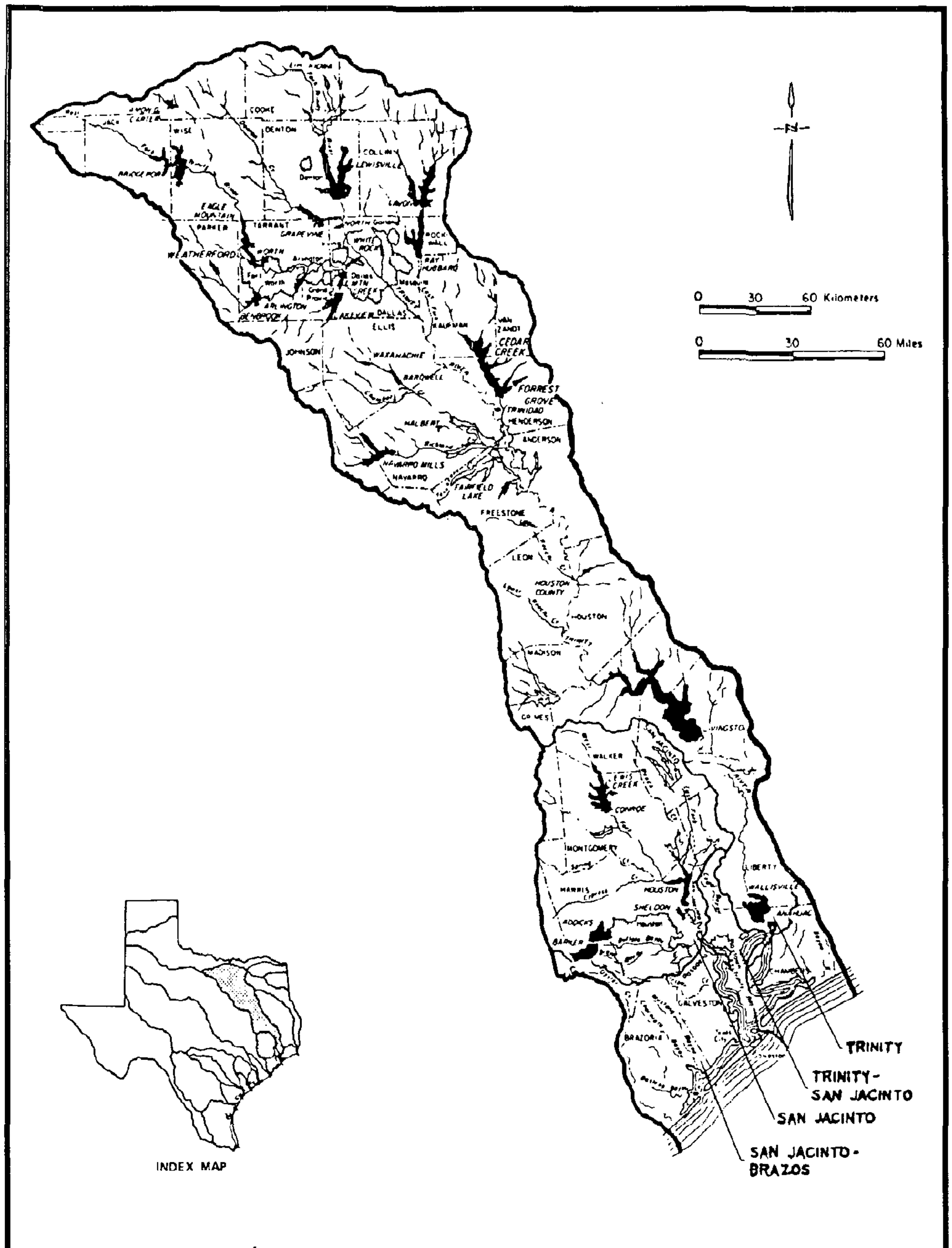

Figure 13. Basins contributing to the Trinity-San Jacinto estuaries. (Source: Texas Department of Water Resources, 1981.)

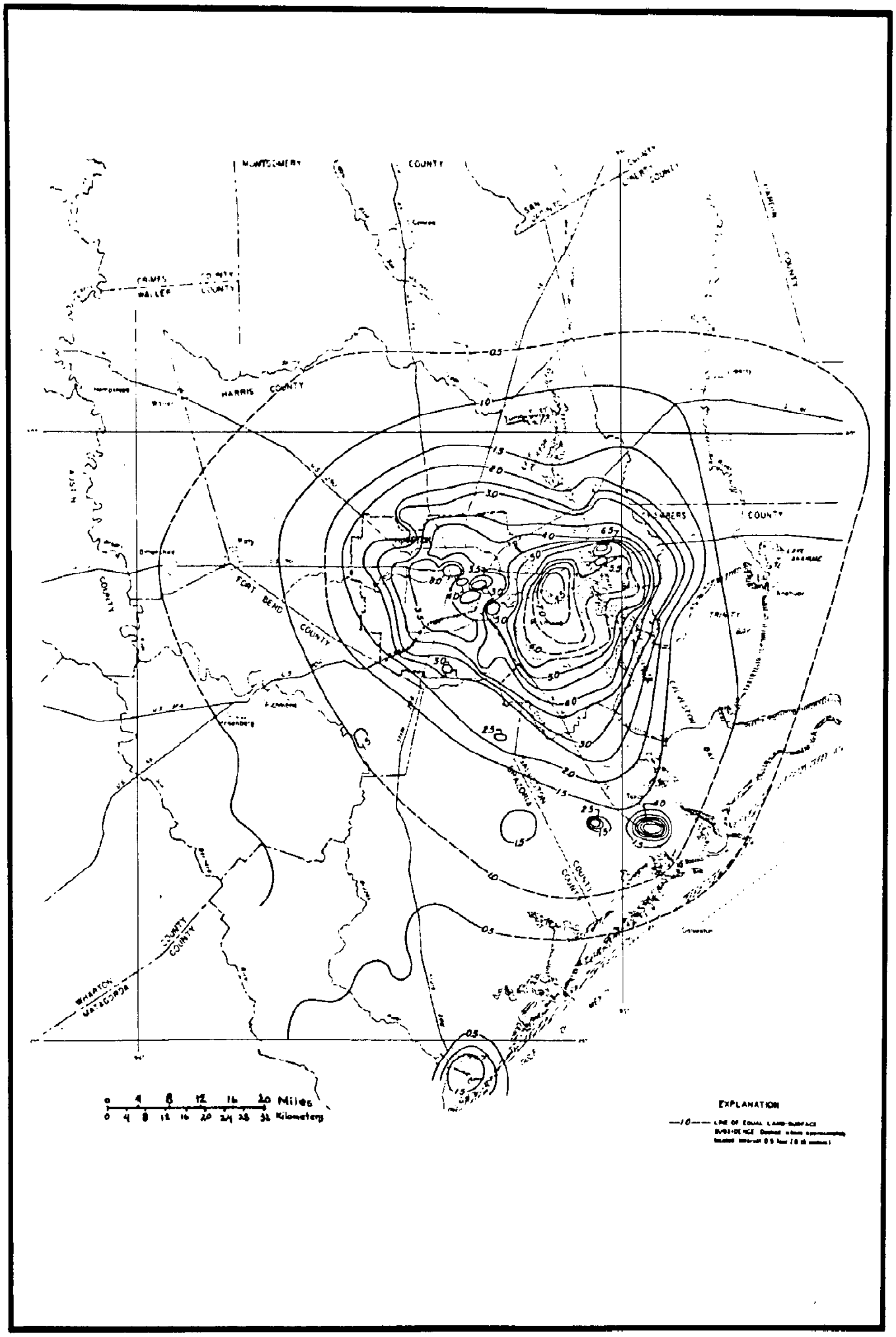

Figure 14. Land subsidence in the Houston area, 1943-1973. (Source: Brown, 1976.)

To control the rate of land subsidence limits were placed on deep-aquifer pumpage, and underground recharge and reinjection techniques, have been introduced by state authorities. These measures are offset by increasing population growth and a proportionate increase in the demand for freshwater.

Calculations reported in TDWR (1981) conclude that:

> The Trinity River delta is frequently submerged by floods from the Trinity River. Based upon historical conditions and gauged streamflow records, freshwater inflow needs for marsh inundation are estimated and specified at 750 thousand acre-feet in each of the months of April, May, and October. These volumes correspond to flood events with peak daily flow rates of 29,500 ft^3/sec.

Three scenarios of freshwater inflow needs have been estimated by TDWR researchers, who have projected the monthly freshwater inflow needs for the Trinity-San Jacinto estuary for each of three alternatives:

Alternative I (Subsistence): minimization of annual combined inflow while meeting salinity viability limits and marsh inundation needs. This would necessitate freshwater inflows totalling 6.85 million acre-feet per year.

Alternative II (Maintenance of Fisheries Harvests): minimization of annual combined inflow while providing annual commercial harvests of red drum, sea trout, shrimp, blue crab, and bay oysters at levels no less than their mean 1962 through 1976 annual values, satisfying marsh inundation needs, and meeting viability limits for salinity. This option would require annual freshwater inflows of 7.19 million acre-feet annually.

Alternative III (Shrimp Harvest Enhancement): maximization of the annual offshore commercial harvest of shrimp while meeting salinity limits, satisfying marsh inundation needs, and utilizing an annual inflow to the estuary at a level no greater than the combined individual average annual historical inflows from the contributing river basins. This alternative calls for a unique seasonally-distributed freshwater inflow of 7.02 million acre-feet each year.

The report notes that:

> A high level of variability in annual freshwater inflow occurs naturally in the Texas estuaries. The authors recommend that any estuarine management program should be capable of offsetting an increase (over historical levels) in the frequency of low inflows detrimental to the ecosystem and its resident aquatic organisms.

2.4.1 Lessons Learned

- Thorough research is necessary both to determine historical freshwater needs and to predict inflow needs of major estuarine systems. Individual river basins must be analyzed in conjunction with adjacent river basins to gauge the overall hydrologic regime affecting the entire estuary system. All too often water resources planners and managers in developing nations tend to view their developmental needs along very narrow and highly limited perspectives.
- In order to develop viable freshwater management systems, the TDWR has developed a very detailed and comprehensive data base, which includes several decades of geologic, physical, chemical, climatic and biologic studies and data collection. Few of the LDCs have the resources or techniques to achieve the objectives; it may be valuable to replicate statistical data obtained from developed nations with similar riverine and estuarine characteristics.
- While the freshwater inflow contributions of the Trinity River to the Trinity-San Jacinto Bay System is now considered to be adequate at this stage, future inland water diversions may cause adverse or negative impacts. This can only be controlled by an integrated inland-coastal zone freshwater management system. It would be useful if water resource planners in LDCs also adapt and implement integrated management systems.
- Effective control of both point-source and non-point-source effluent discharges from both municipal and industrial systems as well as agricultural development need constant monitoring and analysis in order to limit the degradational impacts of all such activities on the coastal ecosystems. This can be extremely costly and time-consuming, but is of paramount importance and suitable mechanisms to generate the requisite funds must be implemented by all concerned.

2.5 The Nueces River and Nueces-Corpus Christi Bay System

The Nueces River is one of three drainage basins providing freshwater inflow to the Nueces-Corpus Bay system situated in the south central Texas-Gulf of Mexico coast. A recent study conducted by the Office of Biological Services (OBS) program of the U.S. Fish and Wildlife Service (1981) addresses freshwater regime disturbances on the estuary.

Figure 15 illustrates the relationship between the three principal drainage systems contributing inflows into the Nueces-Corpus Christi system. The Nueces River Basin is bounded on the north and east by the Colorado, Guadalupe, and San Antonio River basins and the San Antonio-Nueces Coastal Basin, and on the west and south by the Rio Grande Basin and the Nueces-Rio Grande Coastal Basin. The basin has a drainage area of 16,950 square miles. According to the report, between 1941 and 1974, average annual gauged inflows from the Neuces River Basin averaged 628,000 acre-feet/year, while ungauged inflows averaged 77,000 acre-feet/year. This includes inflows from the two principal tributaries of the Nueces--the Atascosa River and the Frio River.

The Nueces-Corpus Christi Bay system is the smallest of the major inland bay systems of Texas with a combined surface area of only 200 square miles (including Nueces, Corpus Christi, Oso and Redfish Bays, along with 17 miles of the Nueces River downstream from the Calallen Diversion Dam). Lake Corpus Christi is the largest existing reservoir in the Nueces River Basin and the bulk of the stored water is purchased by the City of Corpus Christi. Other industrial and municipal consumers also purchase water from the Lake Corpus Christi Reservoir.

Construction of a new reservoir about 10 miles above the confluence of the Frio and Nueces Rivers has been authorized by federal authorization, and is known as the Choke Canyon Reservoir Project. This new reservoir site is about 42 river miles upstream from Lake Corpus Christi, and the Bureau of Reclamation will be responsible for the entire project. The OBS report states:

> Construction of Choke Canyon Reservoir is projected to reduce the amount of freshwater inflow entering the Nueces-Corpus Christi Bay System from the Nueces River Basin. Freshwater inflow will be reduced by 4% on an average annual basis (based on the 1941 to 1975 hydrologic period). An increase in the frequency of high salinities in Nueces Bay is also anticipated.

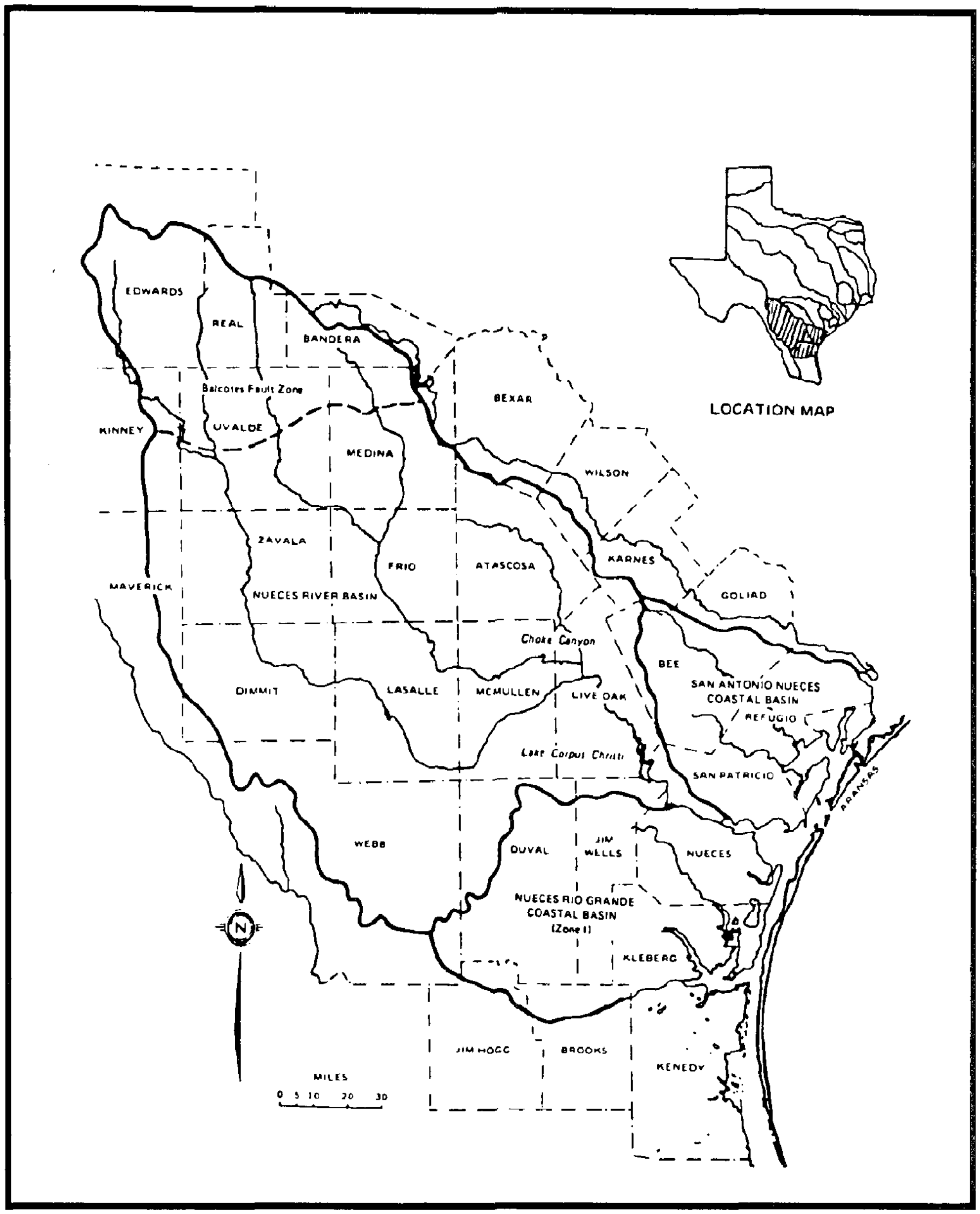

Figure 15. Three drainage basins contribute freshwater inflows to the Nueces-Corpus Christi Bay System. (Source: Fish and Wildlife Service, Office of Biological Sciences, 1981.)

Increased salinities resulting from reduced freshwater inflows within the Nueces-Corpus Christi Bay System are likely to cause a shift in vegetation species in the Nueces River Deltaic Marsh. Those less tolerant of salinity would be replaced by others with higher salinity tolerance. Biomass of animal populations within both the marsh biotope and seagrass biotope would be altered. Population changes of the key species would likely arise from altered salinity conditions within the Corpus Christi Bay systems. Losses or alterations of suitable nursery areas (marshes and seagrass beds) for the development of larval, postlarval, and juvenile forms of shell fish and finfish would be a major cause of faunal changes.

2.5.1 Lessons Learned

- Considerable volumes of hydrologic data, backed up by detailed climatic, geomorphologic, chemical, and biological information collected over the long term are essential to help guide effective planning and management of a nation's coastal resources.
- Both inland as well as coastal zone and offshore human activities can have significant impacts on coastal ecosystems as a whole.

2.6 The Potomac River Estuary and the Chesapeake Bay

Both the Potomac and Susquehanna Rivers which were selected for this case study are integral parts of the whole Chesapeake Bay System, and thus it may be pertinent to very briefly discuss various aspects of the entire bay system before turning our attention to the individual rivers. This will eliminate duplication while presenting the more relevant factors. Much of the description has been derived from Robinson (1981).

The Chesapeake Bay is the largest estuary of the United States and one of the more important estuaries of the world. It is about 200 miles long and varies in width from 3 miles to about 30 miles at its widest point near the mouth of the Potomac River. It has a free connection with the waters of the Atlantic Ocean at its southern extreme. The tidal shoreline of the bay and its tributaries is about 7,000 miles long while the water surface area is about 4,300 square miles. The surface of the bay proper is about 2,200 square miles and its mean depth is less than 28 feet. The Chesapeake Bay receives water from a basin over 64,000 square miles in area (Figure 16). There are more than 50 tributary rivers with widely

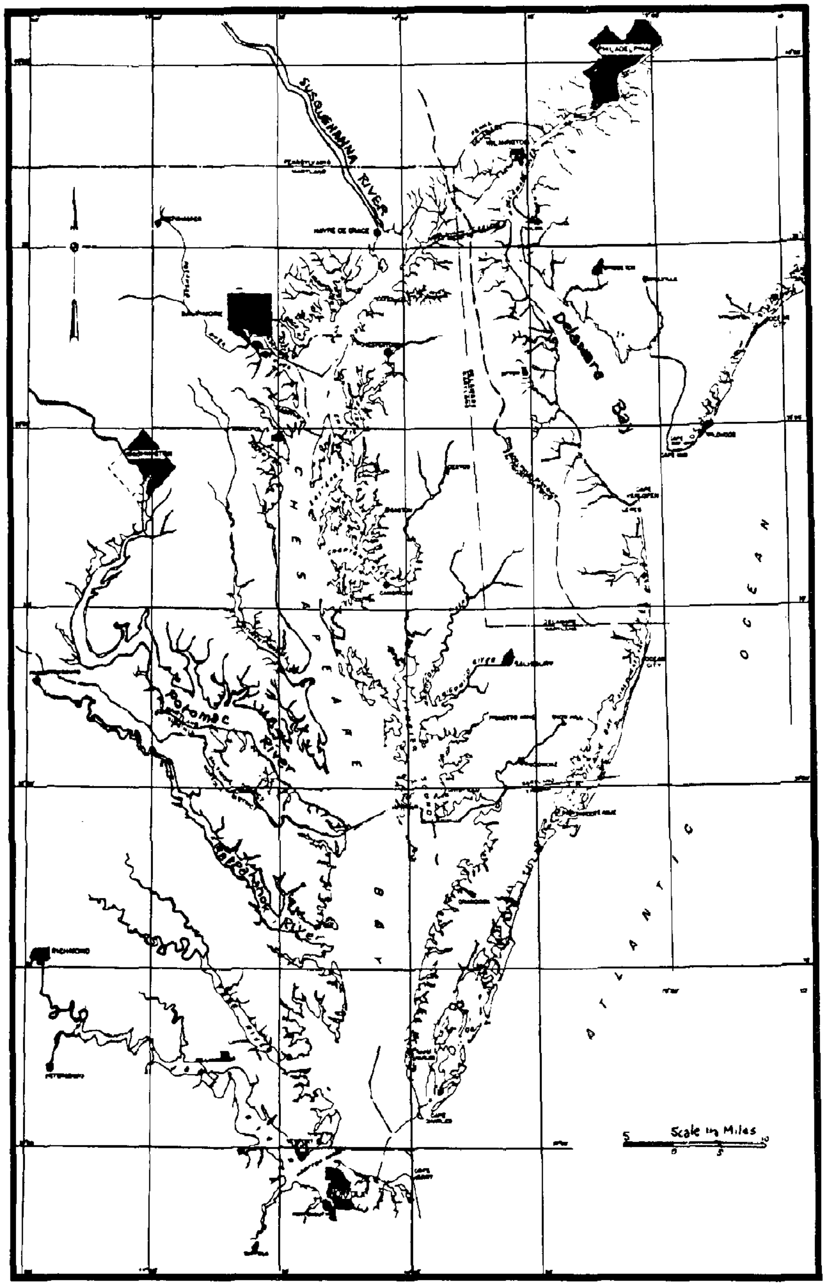

Figure 16. The Chesapeake Bay showing the Potomac and Susquehanna River Estuaries (Source: Robinson, Corps of Engineers, 1981)

varying geochemical and hydrologic characteristics contributing freshwater to it. The largest river on the east coast of the United States, the Susquehanna, drains 42 percent of the basin. The Potomac River drains 22 percent, while the Rappahannock-York-James system drains about 24 percent (Robinson, 1981).

Like all estuaries, Chesapeake Bay is dependent on the inflow of freshwater to maintain its salinity regime. The species that live in the bay year round and others that utilize it only in various portions of their life cycle are generally able to survive the natural daily, seasonal, and yearly variations in salinity. Drastically reduced freshwater inflows during droughts or reductions of less magnitude over a longer period of time can impose environmental stress. Changes in freshwater inflow can also alter existing estuarine flushing characteristics and circulation patterns. The character of Chesapeake Bay and the health and well-being of the ecosystem depend on established physical, chemical, and biological patterns in the bay.

Recent Corps of Engineers' studies (1981) was found that, if the present trend of increased water demands continue, the future quantity of freshwater flowing into Chespeake Bay could be substantially less than it is today. This predicted reduction is primarily a function of increased consumptive use of water from the bay's tributaries resulting from an increasing population, agricultural demands, and increasing use of evaporative cooling processes.

The population of the Chesapeake Bay Region is expected to nearly double in the next 50 years. The majority of these people will probably be served by central water supply systems. Typical communities usually return only 75 to 90 percent of the water withdrawn from rivers or streams. If an inter-basin transfer is involved, it is possible that none of the water would be returned.

An increasing population needs more food. Because of limited land resources and other economic factors, locally produced food will probably cause substantial increases in irrigation water demands further upland in the drainage basin. Almost all of the water used for agricultural purposes seldom returns to the hydrologic system or takes so long to return that, for all practical purposes, it is considered lost.

As economic activity expands, more water will be needed for industrial processes. This alone would result in a substantial increase in consumptive water use. There is, however, a definite trend toward an increased use of processes such as cooling towers, which involve the evaporation of water. Utilities are required to minimize the extent of their aerial discharge plumes, and can achieve this goal by use of enclosed cooling towers or recycling the waste steam from their boilers. The consumptive use of water associated with power generation and supply is often markedly greater than some other types of processes.

Nearly every tributary to Chesapeake Bay will be subjected to the consequences of increased consumptive uses of water.

Turning now to the Potomac River estuary itself, the Corps of Engineers' analysts state:

> The problem of supplying water to the Washington Metropolitan Area is a major complication in the management of adequate freshwater inflow. The region, already water short, would have great difficulty in coping with a major drought condition.
>
> Several proposals to solve the water supply problems of the region are under active consideration. One such proposal would use the Potomac Estuary at Washington as a supplemental water supply source. But several problems have been associated with this proposal. First, although the intake may be located at a freshwater source, if large quantities of water are withdrawn during a drought, the salt wedge could move far enough upstream to contaminate water at the intakes. Secondly, large freshwater withdrawals might reverse the flow of the estuary sufficiently to cause the wastewater plume from the area's wastewater treatment plant to reach these intakes. Third, withdrawing water during the droughts could result in threats to the integrity of the coastal ecosystem.
>
> The water of the Potomac Estuary is already polluted, and it is anticipated that advanced treatment methods will be required to make it potable. Initial research and practical steps have been undertaken by the Corps regarding such advanced wastewater treatment (AWT) measures. At the same time, in accordance with active and highly effective congressional and administrative directives, a clean-up program has resulted in significant improvements of water quality in the Potomac River. Yet there is still a great deal of concern regarding the impact of pollutants (including toxic chemicals), discharges of excess nutrients (which cause eutrophication), decline of submerged vegetal growth, along with proposed freshwater regime alterations (both natural and man-induced) on the productivity of the Potomac River Estuary.

This estuary is considered one of the most important spawning and nursery habitats of the North Atlantic shad and the striped bass. Mihursky et al. (1981) have addressed freshwater influences on striped bass populations as follows:

> The striped bass is an important commercial and recreational fish native to the East Coast of the United States. It is an anadromous species that migrates during the spawning season from coastal high salinity areas to the fresh or slightly brackish spawning grounds in the upper reaches of estuarine systems. Research and management interests in this species have increased markedly in the past decade because of stock declines. Reports by Pfuderer et al. (1975), Rogers and Westin (1975), and Horseman and Kernehan (1976) indicate that the Chesapeake Bay system has been identified as the principal spawning and nursery area for striped bass on the Atlantic coast and may contribute as much as 90 percent of recruitment to the fishery in Atlantic coastal waters (Kumar and Van Winkle, 1978; Berggren and Lieberman, 1978). Given that the Potomac estuary contributes about 20 percent of the striped bass stock, the authors conclude that any significant reduction of springtime freshwater discharge into the Potomac estuary would have a serious detrimental impact on the fisheries of the region.

Shea et al. (1981) have modelled the Chesapeake Bay system using sophisticated modelling techniques. They have shown that it is possible to predict correlations between hydrologic changes and freshwater diversions of various magnitudes. Their "Chesapeake Bay Ecosystem Model (CBEM)" is a powerful and useful tool for conducting such detailed investigations of estuarine systems.

Champ, Villa, and Bubeck (1981) have traced the complex relationships between sewage treatment plant discharges, freshwater quantities, salinity levels, and nutrient level variations in the Potomac River estuary over the past several decades. This paper shows the three perpetual salinity zones recognized in this estuary.

2.6.1 Lessons Learned

- The national capital metropolitan area, with a rapidly expanding population growth, is the major source of demand for consumptive freshwater diversions from the upper reaches of the Potomac River estuary system.
- Sewage treatment plants and effluent disposal systems of the region are the major sources of nutrient modification in the estuary. Considerable pollution problems of the river waters

in the past have been successfully, though only partially, ameliorated by a concerted effort authorized by strong environmental regulation accompanied by massive funding. Reduced freshwater inflows into the Potomac estuary is likely to aggravate the pollution problems in this system.

- Only complete, integrated and continuous regional cooperation can ensure steady improvement in the quality of the freshwater inflows into this coastal ecosystem.
- Public awareness of major problems and the determination to implement viable solutions are essential elements in rehabilitating a damaged estuarine ecosystem even at very high costs. Though the costs of such rehabilitation exceeded several millions of dollars, the end result has improved the quality of the Potomac River estuary. Yet it appears from the recent newspaper reports that a great deal of additional funds and effort are still needed to minimize the level of pollution in the Potomac River.
- Recent reports (Washington Post, September 3 and November 11, 1983) indicate that high phosphate discharges from the Blue Plain Treatment Plant in Washington, D.C., and the Virginia Wastewater Treatment Plant near Quantico may have been responsible for unusally rapid algal blooms, recorded during the late summer and fall of 1983, extending all the way down to the Tidewater area of the Potomac estuary. Hence, the phosphate levels discharged into the Potomac by both Washington and Virginia wastewater disposal authorities must be significantly reduced.
- Despite the beneficial results achieved in the Potomac water quality through the expenditure of billions of dollars, any relaxation of effluent discharge standards, whether intentional or not, can rapidly destroy such benefits and cause unnecessary ecological damage.

2.7 The Susquehanna River Segment of the Chesapeake Bay System

The Susquehanna River is the largest river on the East Coast and drains about 42% of the 64,000 square mile basin draining into the Chesapeake Bay (Robinson, 1981). High density of industrial concentration along the upper reaches of the river are potential sources of chemical and thermal pollution. Industry, combined with a growing population and increased consumptive freshwater demands, could pose serious ecologic damage--particularly during drought seasons and other low water flow periods. Robinson (1981) has presented some interesting statistics on the recorded low water flows and projected consumptive water demands. Table 2, from his report, indicates the magnitude of consumptive uses of the Susquehanna River waters. Actual discharges of the Susquehanna River during August, September, and October of the drought year, 1964, compared with anticipated consumptive uses of water through the year 2020, present real cause for concern. These reduced inflows have been adjusted to reflect the influences of several dams constructed since 1964 and the discharges from wastewater treatment plants.

Under low flow conditions these consumptive uses often constitute a considerable portion of the natural flow in a river. For instance, the losses in the Susquehanna River during this dry period constitute from 24 percent to 66 percent of the natural river flow. A very comprehensive "Low Freshwater Inflow Study" by the Corps of Engineers is still being conducted to help determine the best means to meet the minimum freshwater requirements of the estuarine ecosystem while serving the consumptive upstream needs.

The major problem lies in identifying or quantifying such "minimum" ecosystem needs, and then determing how to curtail upstream freshwater diversion during peak low flow conditions. Shea et al. (1981) discuss their studies on low inflow studies and the various modelling techniques being used to provide answers to the problems.

Numerous studies and reports have been published on different aspects of the Susquehanna River, and the Susquehanna River Basin Commission has actively supported research in this field. Riddesill and Senko (1979) have evaluated the impact of the three hydroelectric facilities--Conowingo, Holtwood and Safe Harbor plants--on the Lower Susquehanna River Basin. The dissolved oxygen concentrations were subject to significant fluctuations on account of these plants.

Coelen et al. (1977) reported on the feasibility of transferring up to 400 cubic feet per second (cfs) of freshwater from the Susequehanna River Basin to the Delaware Reservoir System, including nine alternative water supply schemes to augment

Table 2. Chesapeake Bay low freshwater inflow study. Susquehanna River weekly average low freshwater inflows with and without consumptive losses (in cubic feet per second). (Source: Robinson, 1981.)

Week Ending	Recorded Flow	Consumptive Loss (2020)	Reduced Flow	Percent Reduction
5 Aug 64	5087	1751	3335	34
12 Aug 64	7155	1752	5403	24
19 Aug 64	4900	1752	3148	36
26 Aug 64	3968	1752	2216	44
2 Sep 64	3955	1632	2323	41
9 Sep 64	3182	1632	1550	51
16 Sep 64	2613	1632	981	62
23 Sep 64	2415	1632	783	68
30 Sep 64	2466	1632	834	66
7 Oct 64	3980	1600	2380	40
14 Oct 64	3182	1600	1582	50
21 Oct 64	3462	1600	1862	46
28 Oct 64	3223	1600	1623	50

NOTE: The 1964 figures were chosen as being representative of drought period conditions.

the New York City area water requirements. While it was found to be economically and hydrologically feasible, the impacts of reduced flow conditions in the Lower Susquehanna Basin may not be acceptable.

2.7.1 Lessons Learned

- The Susquehanna River Basin is the principal source of freshwater inflows into the Chesapeake Bay System and is subject to abnormally high losses during extreme low flow or drought conditions. During normal seasons, the impacts of sedimentation are fairly well controlled, but unpredictable tropical storms have drastically increased sedimentation problems on several occasions. Low flow conditions have also caused serious damage to the coastal ecosystems.
- Flowing through highly industrialized sections of Pennsylvania and Maryland, the Susquehanna River is likely to impound or withdraw to meet upstream freshwater demands. Dams and hydroelectric power plants already in operation along the length of the river appear to have stabilized freshwater inflows into the Bay. Impacts of additional changes in the hydrologic regime on the coastal ecosystems must be carefully evaluated before they are implemented.
- Optimal conditions can be maintained in the coastal ecosystems only if human activities can be made to conform with and/or augment existing natural processes, rather than going contrary to such processes.

2.8 The Yadkin-Pee Dee River System

Originating on the southeastern slopes of North Carolina's Blue Ridge Mountains, the Yadkin River becomes the Pee Dee River in South Carolina, draining an area of about 18,000 square miles of both these states, along with a small part of southeast Virginia, before flowing into the Winyah Bay near Georgetown, South Carolina (Figure 17). It is the second largest river basin on the Atlantic coast. Clark (1980) and the U.S. Water Resources Council (WRC), 1981, have described the hydrology of this river system.

The flow of the Yadkin-Pee Dee River essentially consists of the runoff from 44-56 inches of annual rainfall distributed over the entire basin.

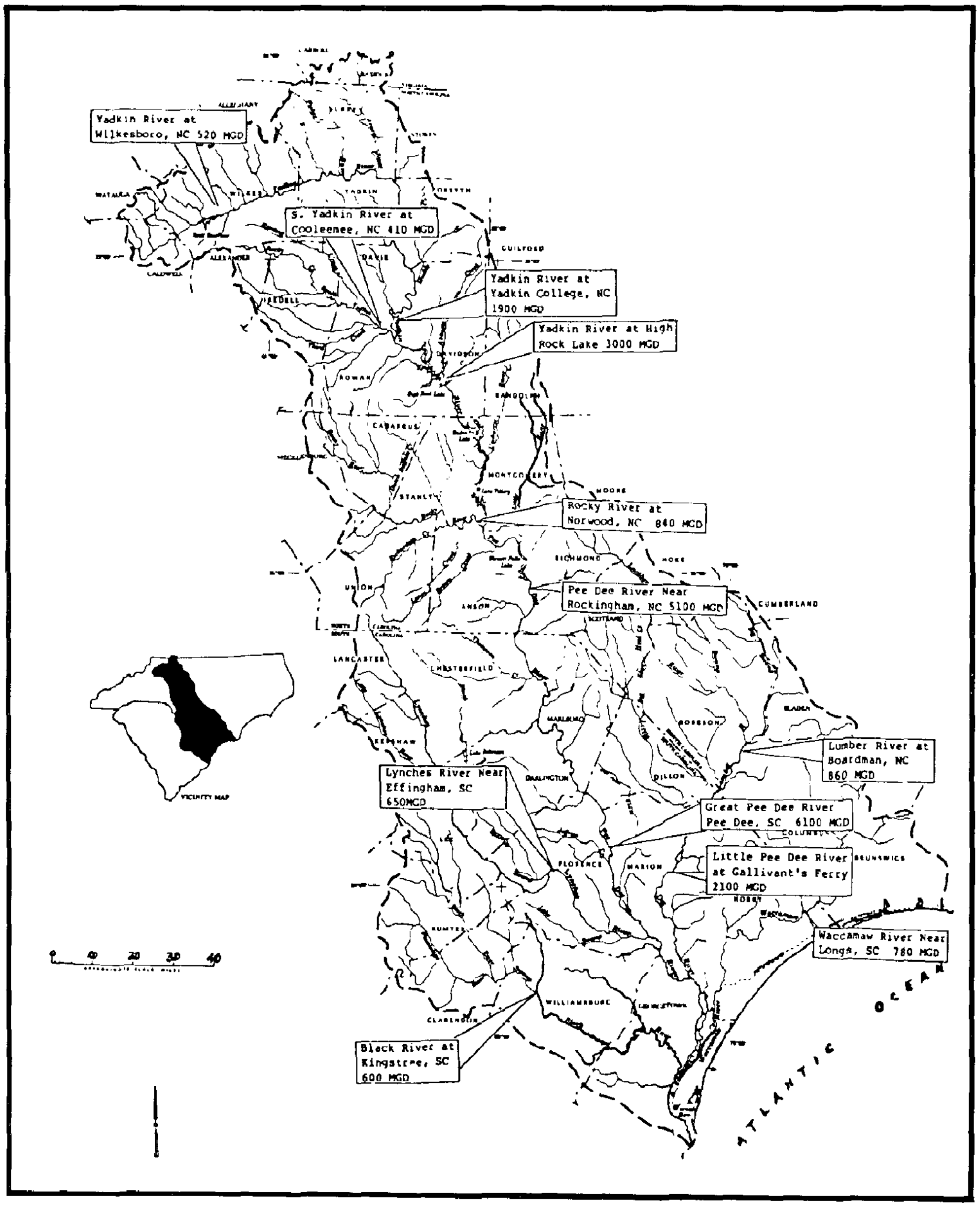

Figure 17. The Yadkin-Pee Dee River Basin (Source: Clark 1980.)

An average discharge of 13,700 cfs flows into the Winyah Bay (WRC, 1981). About 60% of the basin is forested, while 31% is devoted to agricultural cultivation, over 6% to urban development, and about 3% is put to other uses.

Significant growth is projected in urban development activities over the next several decades. If this growth materializes, it will result in a substantial increase in the demand for consumptive freshwater withdrawal from the river system. Urban and industrial wastewater and sewage disposal problems will also increase. These will place a severe ecological stress on Winyah Bay.

Clark (1980) has dealt with the existing problems already being evidenced at the mouth of the Yadkin-Pee Dee River system, and has strongly cautioned against rapid and improperly planned developments in both the coastal regions and inland. His reconnaissance survey of the Winyah Bay ecosystem shows that sedimentation, along with urban, industrial and agricultural pollution, has already caused some serious environmental degradation which includes restriction or banning of shellfish harvesting in sections of the bay. Even this reconnaissance of the Winyah Bay ecosystem indicates that proposed industrial development in the region could lead to disastrous results. The studies and alternatives suggested in the Conservation Foundation report, as well as the Yadkin-Pee Dee River Basin Plan, highlights the prevalent gaps in data essential to make planning decisions. Upstream non-point-source pollution control measures, accompanied by sedimentation entrapment schemes and very careful development plans, seem to be the most feasible means of preserving the delicate coastal ecosystems.

2.8.1 Lessons Learned

- Integrated basin wide freshwater management techniques involving active participation at local, state and federal levels are absolutely essential to prevent unacceptable damage to the coastal ecosystem of the region.
- Cooperative data collection and dissemination methods should be developed by both North Carolina and South Carolina to achieve maximum economic benefits for both states. Hence, interregional and interjurisdictional planning combined with extensive public participation are the most efficient means to achieve optimum results.

- Establishment of heavy industrial complexes with new harbor and navigational facilities south of Georgetown, South Carolina, may cause a great deal more environmental, social and economic damages in the long run, as compared to the projected short-term economic advantages that may be derived from such developmental plans.
- Both North and South Carolina must work together to study and develop adequate data bases on surface water and groundwater hydrology in order to establish minimum inflow requirements for ecosystem maintenance.

2.9 The Cooper and Santee River Estuaries

Two rivers of South Carolina are of considerable interest to engineers, physical scientists and coastal ecologists, mainly because of the potential impacts of the proposed Santee-Cooper Rediversion Project, authorized by the River and Harbor Act of 1968. They gained considerable significance shortly after the initial impoundment and diversion of the bulk of the Santee River waters to the Cooper River Basin to support hydroelectric generation way back in 1942.

Barclay and Burrell (1981) document the diversion of an average of 15,600 cfs into the Cooper River (up from an average of 72 cfs), at Pinopolis Dam (Figure 18) as a direct result of the construction of the Santee-Cooper hydroelectric plant. At the same time the project reduced the average flow in the Santee River from about 15,500 cfs to about 2,230 cfs.

The net result of the 1942 diversion was a drastic, totally unanticipated shoaling in Charleston Harbor. The authors report:

> Increased shoaling in Charleston Harbor was an unanticipated result of the Santee-Cooper diversion project. The average annual amount of material dredged from Charleston Harbor increased from 500,000 cubic yards before diversion to 10,000,000 cubic yards a few years after the project was completed. Studies since 1942 have revealed that the greatly increased inflow of freshwater to the harbor interacts with the tidal inflow of saline water from the Atlantic Ocean to form density currents which entrap sediments and create vast shoals. This large increase in shoaling resulted in a tremendous increase in maintenance dredging requirements for Charleston Harbor. Thus, in 1966 the Corps of Engineers proposed to reduce the shoaling problem in Charleston Harbor by rediverting most of the original Santee River flow back into the Santee Basin.

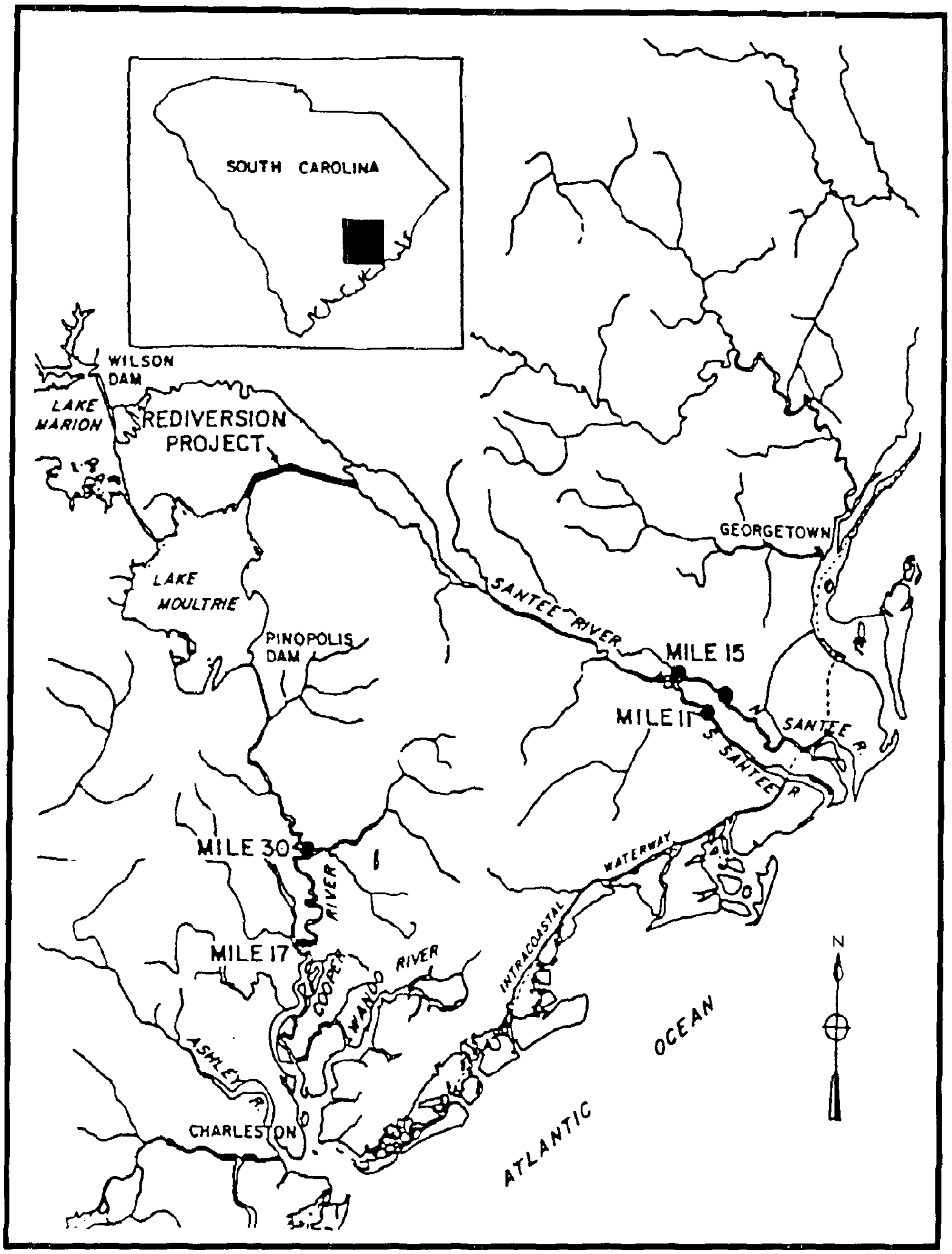

Figure 18. The Cooper and Santee estuaries, South Carolina, showing areas affected by the rediversion project. (Source: Barclay and Burrell, 1981.)

After the passage of several decades, the coastal ecosystems appear to have stabilized to an almost total adjustment to the changed flow conditions. The Santee River bifurcates near river mile 15 from its mouth and allows 85% of its freshwater flow drain through the north branch, which has lower salinity levels than the southern branch. The Santee-Cooper Rediversion Project proposes to reduce shoaling in Charleston Harbor by rediverting water to the lower Santee River so that flows in the Cooper River are limited to a weekly average of 3,000 cfs, an amount determined by Corps of Engineers' sediment modelling studies to be insufficient for the formation of density currents and the entrapment of sediment. The potential ecologic impact on the Santee River estuarine habitat is still a subject of considerable controversy.

Nevertheless, the exorbitant dredging costs associated with maintaining navigational facilities at Charleston Harbor make it imperative for some drastic action to save the region's economic viability. This must in turn be weighed against potential economic losses of lucrative fish and wildlife resources, now well-established along the Santee River estuary. The interested reader is referred to numerous papers dealing with various aspects of this problem--many for, and many against the proposed rediversion project.

Given the limitations of this study, it may suffice for our purposes to point out some of the lessons learned from this brief review of the Santee and Cooper rivers.

2.9.1 Lessons Learned

- By authorizing and implementing engineering projects to enhance apparently immediate short-term benefits, a coastal community may suffer from long-term adverse consequences--particularly if careful integrated regional planning is disregarded.
- It generally requires decades to establish a totally new and modified ecosystem properly adjusted to man-made changes. Another change in the opposite direction can lead to disastrous ecologic damages, which may often be irrevocable. The best results are often attained when human activities are geared in a manner to enhance natural processes, rather than to go against them.

2.10 The Sacramento-San Joaquin Estuary

Turning to the West Coast, with its mild climate, seasonal rainfall, and high density of population in the coastal zone; stresses on the estuaries are evident in high salinities, agricultural and industrial pollution and constantly diminishing amounts of freshwater inflows into the coastal estuaries.

Papers by Herrgesell et al. (1981) and Kjelson et al. (1981) are useful in understanding the problems of the Sacramento-San Joaquin estuary.

The Sacramento, the largest river of California, drains the Sacramento Valley between the Coastal Ranges and the Sierra Nevada Mountains and parts of the Central Valley before joining the San Joaquin River. The San Joaquin in turn drains most of the southern part of the Central Valley. The confluence of Sacramento and San Joaquin river systems forms a complex estuarine system characterized by numerous interconnected embayments, slough, marshes, channels, and distributaries (Figure 19). A large lowland area formed by the junction of the rivers, the Sacramento-San Joaquin delta, forms the eastern-most portion of the estuary. The Sacramento River bounds the delta on the north, while the San Joaquin flows by the south. Suisun and San Pablo bays are located to the west of the delta. These carry the freshwater through the San Francisco Bay via the Golden Gate. Herrgesell et al. continue to state:

> The estuary receives runoff from a 63,000 square mile drainage basin which covers 40 percent of the land area of California (Conomos, 1979). Inflow into the system is highly seasonal and is composed primarily of rain runoff during winter and snowmelt runoff during early summer. The annual natural flow through the estuary would average about 27.6 x 106 acre-ft. Ninety percent of the fresh water that enters the bay passes through the delta (Porterfield et al., 1961) and Carquinez Strait.

According to Kjelson et al. (1981):

> Presently, water is exported to the south by pumping plants in the southern delta [Figure 19] operated by the Central Valley Project (CVP) of the Federal Water and Power Resources Service and the State Water Project (SWP) of the California Department of Water Resources. Typical export rates substantially exceed the flow of the San Joaquin River, hence most of the San Joaquin flow goes to the pumps. Remaining export needs are met by diversions from the Sacramento River.

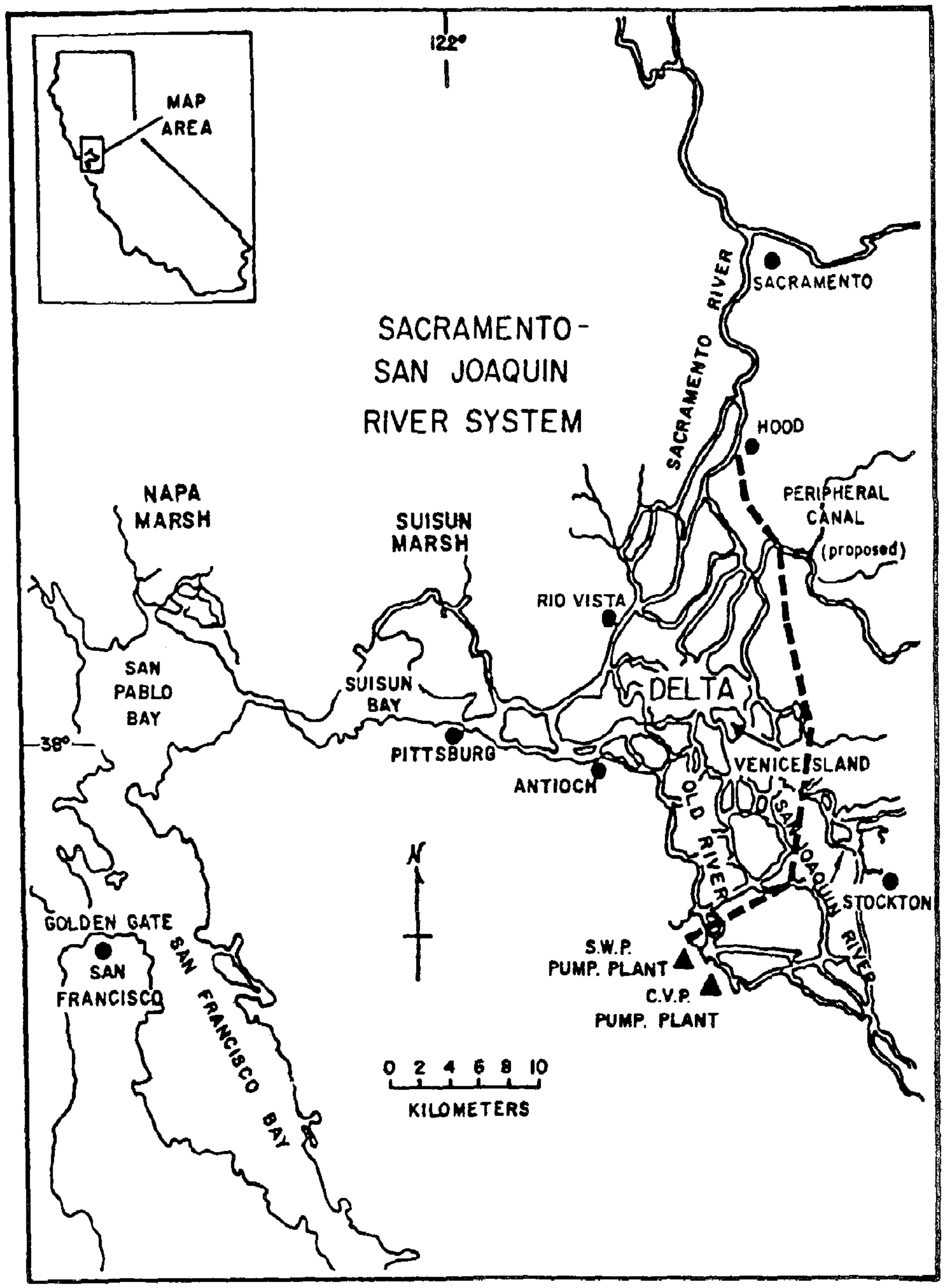

Figure 19. The Sacramento-San Joaquin estuary, California. (Source: Hergesell et al., 1981.)

Water development projects in California have caused major changes in the flow patterns within the estuary and the amount of flow entering the ocean. One result of upstream development is that the average annual freshwater flow to the ocean from the Sacramento-San Joaquin system has been halved since the 1800's. Most of the water in the San Joaquin system is captured and utilized in upstream areas, while development on the Sacramento has been designed for both upstream use and the transport of water through the delta to more southern parts of California. Ninety percent of the freshwater inflow to the estuary is from the Sacramento River. Future water development plans, as authorized under recent State legislature (Senate Bill 200, signed July, 1980) include construction of additional upstream storage reservoirs and a peripheral canal. The Peripheral Canal Project is designed to divert water at a maximum of approximately 23,000 cfs from the Sacramento River at Hood and transport it around the eastern edge of the delta to the pumps in the southern delta.

2.10.1 Lessons Learned

- Despite considerable damage to coastal ecosystems, freshwater needs for human developmental activities appear to supersede the freshwater needs of the ecosystems in California's prevailing water management policies. The main question is whether water managers can balance the upriver consumptive needs adequately enough to prevent complete degradation of the coastal zone resources. So far, the California state authorities seem to be succeeding in maintaining this minimal delicate balance, as evidenced by the size of the salmon and bass populations in the Sacramento-San Joaquin Estuary region.
- Excessive diversion of the currently adequate Sacramento River inflows much beyond the already much-reduced historic flow regime may, however, lead to further severe degradation. This may be controlled by augmenting estuarine freshwater inflows through other alternatives.
- Thorough analyses conducted over the long term combined with sophisticated modelling and simulation techniques may have helped the California water resources managers maintain the estuarine ecosystems at their current delicately balanced levels.
- The Sacramento-San Joaquin estuarine problems are typical examples of the growing conflict between the effort to establish sensible coastal zone management techniques and attempts to satisfy

burgeoning population demands for limited water sources in semi-arid regions. Such conflicts are widely prevalent in many of the developing nations of Asia, Africa, South America, and the Middle East.

2.11 The Colorado River System

The Colorado River, along with its major tributaries, the Green River, Grand River, Gilla River and other smaller streams, can best be described as the 'jugular vein' sustaining life in areas of seven of the eleven arid western states: Wyoming, Colorado, Nevada, Utah, Arizona, California and New Mexico. It is also the most fought-over, heavily depleted American river. Most of the freshwater in the river (82%) is completely utilized in the United States, before the balance carrying high concentrations of salt and agricultural runoff crosses the border, to be utilized by the Mexican authorities before reaching the Pacific Ocean through the Gulf of California. Figures 20 and 21 illustrate the regional setting of the Colorado River and the seven states dependent on the waters of the Colorado River basin.

The river drains almost 242,000 square miles of U.S. territory, and about 8,000 square miles of Mexico, before dropping 14,000 feet in elevation during its 1,700-mile journey from its headwaters to the sea. Flows in the Colorado River have varied between 50,000 and 100,000 cfs, but these quantities of water are heavily controlled by no less than eight dams and reservoirs. Every drop of runoff from the meagre rainfalls and snowmelt in the higher elevations is almost totally exploited. California, with its densely populated southern region accounts for a significant proportion of the freshwater diversion from the Colorado River Basin. International treaties with Mexico guarantee a fixed share of the Colorado waters at a certain level of salinity. But given peak drought conditions and heavy upstream demands, deviations from the norm are likely to occur.

Through a set of unique water resources management techniques developed and strictly enforced by the eleven major western states after decades of intricate water-rights litigation, a compromise situation now exists. The intricate water allocation formulae and the tomes of judicial decision would boggle the minds of most laymen. The Western States Water Resources Council, along with the powerful Water Engineers of the seven concerned states, zealously

Figure 20. The Colorado River Basin and seven western states sustained by the river. (Source: Fradkin, 1981.)

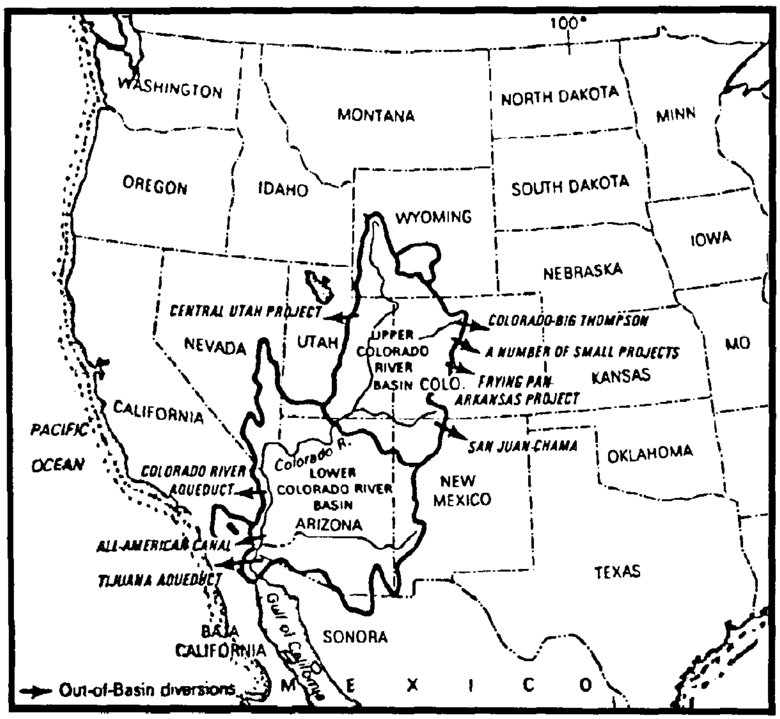

Figure 21. Regional setting of the Colorado River basin. (Source: Fradkin, 1981.)

guard and enforce the interstate, intrastate and international water use codes thrashed out after years of acrimonious and bitter strife, while minimizing most forms of federal intervention.

Fradkin (1981) describes detailed historical, social, economic, political, environmental, and legal issues associated with the Colorado River at great length. According to this author the Gulf of California has been deprived of any freshwater inflow during the past twenty years. Hence, it appears that the coastal ecosystems have somehow adapted to the highly saline conditions created by human activities.

Fradkin also draws an analogy between the Colorado River and the Nile River in Egypt, as well as other ancient river systems where entire civilizations have been wiped out or have disappeared, partly because of such relentless withdrawal of fresh waters from those rivers by rapidly growing populations. His book appears to sound a stern note of caution against the dangers of uncontrolled freshwater consumption from a river flowing through a predominantly arid region. The irrevocable damages caused by such activities to coastal ecosystems cannot be overly emphasized.

2.11.1 Lessons Learned

- This system may be regarded as one of the most extreme examples of how not to manage a river, if a nation is to have any regard for coastal ecosystems and the valuable resources provided from the coastal zone. It also seems imperative that such a total withdrawal should be avoided.
- It appears that judicious allocation of meagre water resources in arid and desert environs of the world can help furnish substantial economic benefits, even if only for limited periods of time. National leaders are often faced with a very difficult choice between trying to preserve valuable coastal zone research or benefiting upstream water users. The Indus River basin of Pakistan provides a similar example for such a tough decision-making process.
- Despite the most advanced technological breakthroughs, a time and point will come when one must decide on the next step for survival after completely utilizing readily available water resources. Only severe controls and strict enforcement of established regulations can ensure the possibility of bare survival.

- There are dangers associated with over-exploitation of non-replenishable groundwater resources upstream. Depletion of such resources will take its toll on downstream water inflows.

3. SUMMARY OF LESSONS LEARNED

Certain important facts were discerned during the review of papers by marine biologists, hydrologists, ecologists, conservationists, fishery specialists, coastal zone managers and developmental engineers. A brief summary of observations on the eleven selected rivers is presented here.

- With increasing population growth and accompanying freshwater demands, coastal zones will continue to suffer from decreasing freshwater inflows despite any array of rules and regulations. To meet the increasing inland water, coastal ecosystems will be stressed to varying degrees and drastic changes in nearshore biological populations are likely to occur. Many species will migrate, or become extinct, while others may adapt to modified conditions.
- Decreased freshwater inflows into coastal estuarine systems cause several major problems. Reduced inflows cause rapid fluctations in the salinity levels of estuarine zones and disruption of the fragile freshwater-saltwater interface. Heavy natural floods and human-induced wet weather discharges will push this interface farther offshore, while dry season withdrawals will result in detrimental inland saline intrusions. Changes in periodicity of flows in estuarine regions are often detrimental to coastal biota.
- Human activities such as construction of dams, levees, flood control structures, urban and agricultural developments, dredging of navigation channels, and other related functions often result in drastic changes of the sediment load discharged by most rivers into the nearshore coastal environment. Heavy sediment discharges usually result in shoaling, siltation, loss of dissolved oxygen, and high turbidity. Other inland structures retain large volumes of sediments and associated mineral nutrients which are essential for the survival of coastal ecosystems. The life-systems of marshes, swamps, lagoons and other coastal features are heavily dependent on periodic or seasonal flushing. Hence, upstream modifications of the hydrologic regime of most drainage systems often affect the coastal zone ecosystems in an adverse manner.

- Nearshore and upstream agricultural, urban and industrial developments tend to increase estuarine pollution through increased sewage and chemical disposal. Many of the polluting elements have been found to be toxic to plants and animals. Yet the sources and long-term detrimental impacts on coastal biota have only been discovered long after the damages have occurred. Regular and constant monitoring of water qualities in a river system, while expensive, helps to ensure prevention of coastal zone degradation.
- Power plants and other industrial cooling systems cause great temperature fluctuations in water entering the receiving bodies. Sudden heavy flooding and reservoir spillway discharges can result in sudden lowering of water temperatures often to appreciable distances offshore. Such drastic temperature variations are often detrimental to the coastal ecologic regimes.
- The overall damage to coastal ecosystems results in significant societal and economic losses of an extremely vital and essential resource base.
- Despite the array of federal and state legislation enacted in the United States over the last few decades, several factors impede the reversal of the previously-caused damage to major river-estuarine systems. These include insufficient coordination between various concerned agencies, lack of jurisdictional control and enforcement powers, lack of sufficient knowledge and a universal shortage of funds.
- Environmental assessments, impact statements, and other localized measures taken to alleviate environmental damage, tend to be extremely limited in their scope and extent. Water resources managers are apt to underestimate the cumulative effects of their project activities, and may tend to neglect the overall regional effects of their site-specific activities. Hence greater interregional coordinations and interagency cooperation becomes imperative if damages to coastal ecosystems are to be controlled or minimized.

The author recognizes that it would not be feasible to make a comprehensive evaluation of all coastal ecologic problems caused by human activities modifying the hydrologic regimes in upstream regions of the selected rivers. Table 3 attempts to depict a cause-and-effect relationship noted during this investigation.

Based on the lessons learned, a series of guidelines have been developed and presented in the subsequent section.

Table 3. Impacts of flow changes in selected U.S. rivers on coastal ecosystems.

CANDIDATE RIVERS OR ESTUARY SYSTEMS	RECORDED TYPES OF HYDROLOGIC MODIFICATIONS	IMPACTS ON COASTAL ECOSYSTEMS
1. Apalachicola River & Bay System (Flows through Georgia, Alabama, & Florida **Main Tributaries** Flint River & Chattahoochee River **Receiving Body:** Gulf of Mexico	• Bartlett Ferry & Columbia Dams on the Chattahoochee River • Several smaller reservoirs & flood control structures on both Flint and Chattahoochee Rivers • Forestry & cattle ranching projects in Tate's Hill Swamp • Designation of Apalachicola Bay as National Sanctuary	• Abrupt changes in salinity and nutrient levels • Lowered light penetration due to increased runoff from altered swamp condition • Lowered water quality, pH and dissolved oxygen • Substantial reduction in white shrimp harvest
2. Atchafalaya River & Bay (Flows through Louisiana) **Main Tributaries** This is a distributary of the Mississippi **Receiving body:** Gulf of Mexico via Matagorda Bay	• Removal of natural log jam at offshoot point from Mississippi • Lengthy navigation channel inland from the bay • Flood control levees & dikes • Old river control structure	• Increased diversion of Mississippi River flows • Increased channel scouring • High sedimentation of coastal swamps and lakes • Fluctations in salinity in nutrient and salinity levels during high floods/surge releases • Rapid deltaic land accretion
3. Colorado River (Texas) (Restricted to the State of Texas) **Main Tributaries:** No major tributaries of significance **Receiving Body:** Gulf of Mexico	• Removal of major natural log jam • Important navigation channel • Few flood control and water supply structures • Proposed mouth of the Colorado River Project	• Loss of nutrients, nitrogen, phosphorous and organic materials directly into the gulf • Inundation and flushing of deltaic marshes during flood events • Altered salinity regimes and decreased freshwater inflows due to upstream reservoirs

Table 3. (Continued)

CANDIDATE RIVERS OR ESTUARY SYSTEMS	RECORDED TYPES OF HYDROLOGIC MODIFICATIONS	IMPACTS ON COASTAL ECOSYSTEMS
4. Trinity River and Trinity-San Jacinto Estuary (confined to Texas) Main Tributaries No major rivers Receiving Body: Gulf of Mexico	• 29 reservoirs of various sizes • Substantial groundwater withdrawals & heavy pumpage • Significant industrial and urban center development with high loads of treated wastewater discharges	• Decreased productivity in the Trinity caused by decline in nutrient supply • Widespread land subsidence in Houston-Galveston area due to excessive groundwater withdrawal
5. Nueces River and Nueces-Corpus Christi Bay (Texas) Main Tributaries Frio River, Atascosa River Receiving body: Gulf of Mexico	• Several major reservoirs and dams upriver--including the Corpus Christi Reservoir and Cuallen Dam • Agricultural & industrial waste streams • Proposed Choke Canyon Reservoir to be built 42 miles upriver from Corpus Christi	• Not much impact as yet • Anticipate medium to high stress on coastal ecosystem when Choke Canyon Reservoir Project is implemented
6. Potomac River and Chesapeake Bay (Drains West Virginia, Maryland, & Virginia Main Tributaries Shenandoah Receiving Body: Atlantic Ocean	• Numerous water supply and flood control structures • Several large wastewater treatment plants discharge into the Potomac • Industrial waste streams & power-plant cooling tower discharges	• Heavy pollution and high phosphates causing dense algal blooms • Contamination of shad and other fish • Decline of undercoater vegetal growth • Decline of striped bass population

Table 3. (Continued)

CANDIDATE RIVERS OR ESTUARY SYSTEMS	RECORDED TYPES OF HYDROLOGIC MODIFICATIONS	IMPACTS ON COASTAL ECOSYSTEMS
7. Susquehanna River and Chesapeake Bay (Drains: Pennsylvania & Maryland) **Main Tributaries** **Receiving Body:** Atlantic Ocean	• Many large dams reduce dry season inflows by 25%-65% • Hydroelectric plants and major industrial units in Pennsylvania & Maryland contribute to high pollution • Heavy urban and commercial development with high consumptive water use	• Unusually high dry season inflow losses • Decline in fisheries harvest
8. Yadkin-Pee Dee River System (Drains southwest Virginia, North & South Carolinas) **Main Tributaries** **Receiving body:** Atlantic Ocean	• Several water supply reservoirs & flood control structures structures • Proposed development of heavy industrial complex and new harbor south of Georgetown, S.C.	• Restriction/ban placed on shellfish harvesting in Winyah Bay • Loss of navigational facilities near Georgetown, S.C., due to heavy shoaling & high dredging
9. Cooper and Santee River Estuaries **Main Tributaries:** **Receiving Body:** Atlantic Ocean	• 1942 Diversion of Santee River water to Cooper River via Lake Marion & Lake Moultrie • Large hydroelectric power plant • Proposed Santee-Cooper Rediversion Project	• Drastic shoaling in Charleston Harbor, S.C., due to formation of density currents & sediment entrapment • Rediversion Project likely to cause drastic habitat changes in Lower Santee River

Table 3. (Continued)

CANDIDATE RIVERS OR ESTUARY SYSTEMS	RECORDED TYPES OF HYDROLOGIC MODIFICATIONS	IMPACTS ON COASTAL ECOSYSTEMS
10. Sacramento-San Joaquin Estuary Main Tributaries Receiving Body: Pacific Ocean	• Complex system of water and irrigation supply withdrawals, causing 100% flow diversion of San Joaquin River • Considerable pollution from agricultural, industrial and urban discharge • Proposed Central Valley Project would further decrease Sacramento River inflows to the estuary	• High degree of salinity encroaching into the bay system • Salmon fishery not yet effected • Considerable ecosystem damage anticipated if the Central Valley Project is implemented
11. Colorado River Main Tributaries Green River Receiving body:	• Several major dams in the USA & diversion structures in Mexico • Industrial, agricultural & urban water supplies are often beyond safe limits	• Highly saline and mineralized inflow into Gulf of California almost to the point of no flow at all

4. PROPOSED GUIDELINES

The following set of guidelines may be implemented by water resource managers in developing nations experiencing similar coastal zone degradation and freshwater inflow problems to meet their specific requirements. These guidelines are not listed in order of priority, nor will they be applicable to all circumstances. The guidelines should be implemented or modified to suit the particular needs of each individual coastal region.

(1) Efforts should be initiated immediately to collect and compile baseline data on individual river distributary or regional estuarine systems. Such data should include essential hydrologic and ecological parameters based on historical and present-day conditions. Basic hydrologic data should include those delineating watersheds and drainage basins, those on precipitation runoff, seasonal variations, consumptive demands and uses by different sectors, natural losses through evapotranspiration and other essential statistics. Fundamental ecologic data should include information on the freshwater needs of plants, fish, animals, birds and human beings frequenting the region, on optimum salinity tolerances of coastal faunal and floral species, and on periodicity of demand and human consumptive needs. Where such data are not readily available, it may be possible to use simulated data extrapolated from rainfall runoff calculation tables developed by the Soil Conservation Service of the U.S. Department of Agriculture. Or, reference may be made to coastal zone management techniques developed by several American research agencies, such as the Corps of Engineers, NOAA, the Fish and Wildlife Service and others.

(2) Using such empirical, factual or extrapolated data, minimum freshwater inflow needs of various ecosystems must be established on a national or regional basis. When rivers drain watersheds extending beyond national boundaries, international agreements are needed to establish inflow needs. Both hydrologic and ecologic parameters must be considered in any such evaluation. Criteria for establishing national or regional inflow needs should include demographics, agricultural and industrial factors, urban and rural configurations, inland and coastal resource availability, hydrologic regimes (past and present), number and variety of coastal flora

and fauna, and many other relevant parameters.

(3) Water rights and riparian allocation decisions must be based on the actual and essential economic needs of coastal as well as inland water users. When rivers cross national boundaries, upstream and downriver water users often present conflicting demands for limited water resources. Unfriendly neighbors question the reliability of the data presented by specialists of either country. Each upstream nation insists on its perogative to meet the water needs of its own region before considering the downstream country's water requirements. Each group claims that they have the right to a greater share of the available resources on the basis of antiquated water rights laws. Hence, cost-benefit analyses based on available empirical data must be well documented and accurately developed to permit a comparative analysis with inland water development, cost-benefits, and subsequent establishment of water use priorities. The example of the western states of the United States agreements on sharing scarce water resources may provide valuable guidelines for the use by planners in other arid or semi-arid regions of the world.

(4) Research and management of rivers and watersheds should be coordinated with similar national or regional plans for protecting the resources of coastal zones and estuaries. In any case, total water resource management should be on a regional rather than localized basis. Hence, environmental assessments pertaining to upstream development projects should also be on a regional rather than localized basis, and such projects should consider long-term, downstream impacts likely to be caused by water use.

(5) Effective regulatory agencies with adequate institutional infrastructures, ample funding and enforcement authorities must be established to ensure compliance with the established standards and prevent irreversible ecologic deterioration. Available data collected from studies on some European and Russian river systems appear to indicate that freshwater flow reductions exceeding 25% to 30% of the net total flow of a river generally result in disastrous coastal ecologic consequences. These figures could vary in different geographical regions, but are generally applicable in temperate latitudes. Hence, freshwater planning, allocating and management agencies must have the requisite authority to enforce stopping of future inland development activities when established flow standards may be exceeded by such actions. This can best be accomplished by integrating

water allocation for natural systems before a confrontation arises between proposed new development and natural systems water needs.

(6) Several alternatives for water development projects should be considered in the planning stages. Such alternatives should be oriented in a manner to take maximum advantage of natural processes, rather than attempting to work against such processes. Compatible and harmonious blending of human activities with existing environmental conditions can be highly beneficial to all concerned and will help prevent undue ecologic perturbation. This permits a balancing of economic and ecologic considerations, allowing selection of the final option with minimal ecologic damage. This is particularly significant in coastal zones where population pressures often trigger plans to "reclaim" marshes and swamps to provide "beneficial" areas for the cultivation of essential food grain or cash crops (high yielding varieties of rice or jute/cotton.

(7) A centralized authority solely responsible for controlling all water-related activities and watershed management may be more effective than numerous different agencies with overlapping responsibilities or terms of reference. If several agencies must have specific water resources management functions included in their mandated duties, formal agreements should be implemented to forge the maximum cooperation between such agencies and eliminate the duplication of overlapping functions.

(8) Labor-intensive field operations should employ local residents of fast-growing rural and coastal communities to contribute reliable data collection efforts. College or university students with time and dedication to assist in ecologically sound national development plans could readily acquire data collection skills and provide a valuable pool of skilled researchers. Simplified training techniques can effectively build up a large cadre of qualified workers capable of collecting and compiling vital information and statistics. Their work should only be spot-checked by technically-trained field supervisors. Field data could be transferred to a central data gathering center on a set periodic schedule. These simple steps would help create a comprehensive and valuable data bank.

(9) In transferring sophisticated modern water and ecologic research technologies to the underdeveloped countries, emphasis must be placed on a simplified approach with stimulating audio-visual aids in the local language and/or dialect, to ensure effective communications with rural populations

with low levels of literacy. Local artists and painters can depict graphics with appeal and impact in many LDCs.

(10) To appeal to the poorer rural inhabitants of the LDCs, it is essential to stress the benefits that are to be derived by the application of new techniques. Old customs and proven ways are difficult to modify without strong fiscal, emotional or social incentives. Special emphasis must be widely publicized on the benefits to be derived by implementing new techniques being advocated. Frequently sound resource management techniques can be subtly integrated with established custom.

(11) It would be appropriate to advise trainees from the LDCs on techniques for adapting sophisticated equipment and methodologies to their specific site conditions. This will enable them to utilize their newly acquired skills in the most effective and beneficial manner. Alternatively, skilled trainers from developed nations should be instructed to adapt their advanced technologies to be effective within the limitations of local skills and indigenous resources. Most AID projects include some form of training program, and invariably trainees from LDCs are brought to stateside institutions for acquiring resource management skills. Unfortunately, when these individuals return to their respective countries, they are often unable to apply the skills they have acquired due to lack of the requisite tools and equipment on which they have been trained. This becomes highly frustrating, and the benefit of such training is soon lost.

(12) Coastal zone managers and planners in LDCs should be trained to quickly identify similarities between local hydrologic and ecologic conditions and those prevalent in other countries. This will enable them to extrapolate vital information from such similar circumstances to fill data gaps in their local environs.

Only few of the main factors essential to a program for achieving the goals of balanced and equitable distribution of inland and coastal freshwater resources have been enumerated. A conceptual flow diagram incorporating these elements has been developed by the author and is presented at Figure 22. However, hydrologic and ecologic problems and solutions are more complex than those depicted in this diagram. Suitable modifications of this approach can be tailored to suit prevailing local conditions,

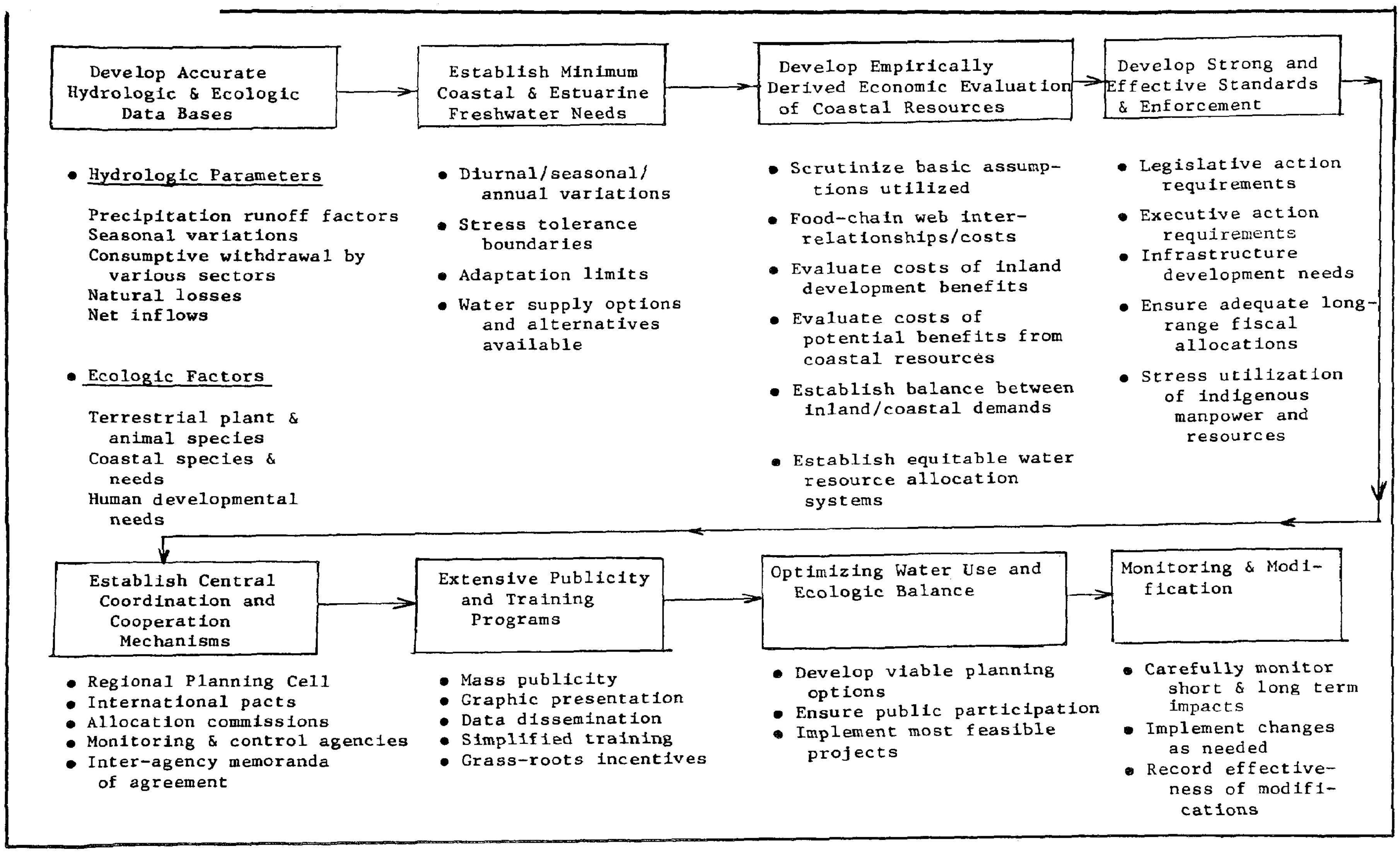

Figure 22. Conceptual flow-diagram of a mechanism for water resources development and ecosystem protection.

or may be geared to match indigenous resources and requirements. It is highly recommended that further research in this field be directed towards developing specific comparative analogies between select groups of rivers and estuarine systems facing almost similar problems, in an LDC and in an advanced nation. It is believed that this type of study may be of considerable value in demonstrating the effectiveness of data extrapolation technology transfer, and indigenous resource utilization.

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Case Study Eight

THE ISLAND MICROCOSM

Edward L. Towle

SUMMARY

This study is concerned with the coastal resources of smaller, offshore developing island systems. Perspectives on the nature, constraints, and implications of "insularity" are interwoven within an analysis of the extensive literature on islands of all types. Classification strategies regarding the island universe are reviewed, as is the possible instructional use of detailed studies of "island microcosms" as models for comprehension of larger, more complex continental ecosystems. A major conclusion is that smaller oceanic islands are sufficiently different from continental areas to require customized, carefully adapted, and more participatory kinds of resource assessment, planning, development and management strategies, especially since islands tend to be far more dependent on coastal and marine resources than continental countries. Examples of island system gains and losses from the environmental impacts of poorly planned, externally initiated development projects are presented. Summaries are given of successful "model" approaches to island coastal resource assessment, planning and management.

The analysis examines the vulnerability, dependency, stability, and ecological integrity of islands, principally within the context of externally induced, rapidly implemented, and sometimes inappropriately scaled and designed development initiatives that are often stimulated by outside interests and factors. The significance of island coastal zones and the use of their marine resources, along with the evolving theories and practices of resource management, are reviewed. An attempt is made to analyze and document the way in which insular systems respond to stress and their customarily very short list of true options.

Study findings suggest the need for serious modifications of standard continental approaches to coastal resource management if they are to be applied to tropical islands.

ISLANDS: FUTURE AND PAST

In the event of a nuclear Armageddon,
islands may well be mankind's only hope
for a future as the continents
will be uninhabitable.
(Anonymous, 1984)

The sea has long dominated the history of the Virgin Islands. It has, until the advent of the air age, been the only route to the outside. It has also been a constant source of food and recreation. The threshold to the sea that surrounds us is the shoreline. The shorelines of the Virgin Islands have in the past been used freely by all residents and visitors alike. The seashore has been a place of recreation, of meditation, of physical therapy and of rest to Virgin Islanders, past and present. To fishermen the sea and its shores are a way of life. The second half of the twentieth century has brought adverse changes to the Virgin Islands shorelines. There has been uncontrolled and uncoordinated development of this area.

(Open Shorelines Act, Title 12 of the U.S. Virgin Islands Code, 1972)

The tidal wave devours the shore
There are no islands any more.

(Edna St. Vincent Millay, 1940)

In everything, respect the genius of the place.

(Alexander Pope, <u>Essays on Man</u>, 1733)

1. INTRODUCTION

1.1 Continental Perspectives on Islands

In man's imagination, islands have always been lands of promise--promises of escape from the mundane to high adventure or an unknown delight. Sir Thomas More located Utopia on an island in mythical seas. For those who live on continents, the greatest attraction of the world's oceanic islands is their detachment, both from the mainland and from mainland routines. Crossing water to reach an island becomes a symbolic act of leaving behind too familiar activities and unsolved problems.

Islands can be fun. They tickle the imagination; they conjure up fantasies and dreams. They are wonderful places to visit, to study, to poke about, and to write about. They are also fun to read about (remember Defoe's Robinson Crusoe, The Swiss Family Robinson by Wyss, Goldings' Lord of the Flies, Hemingway's Islands in the Stream and Melville's Typee, among others). Tourists by the tens of millions search for them and artists and writers retreat to them, while ocean-going yachtsmen and cruise ship passengers collect them as log or diary entries, and natural scientists and anthropologists find them ideal "mini-laboratories"--neat, clean, comprehensible and Eden-like, with endemic, symbolic "apples" ripe for academic picking from the insular tree of knowledge! A genuine discovery perhaps awaits the intrepid island investigator.

However, not everyone cares for islands. There are at least two that Napoleon was not happy with (recall his: "...able was I ere I saw Elba"!), and Papillon could have done without his private room on that special green island in the sun off the coast of South America. Columbus, too, was displeased when he found that islands had an annoying habit of getting in his way en route to Cathay.

Similarly, larger, continental nations do not really appreciate them because they are so small and "clutter up" the United Nations and other international fora; the UN, in turn, has often found islands a troublesome lot, pleading special case circumstances, isolation factors, and smallness as a disadvantage and arguing they are "different".

Nevertheless, with a few exceptions, islands remain a source of enjoyment available to everyone, especially since there are so many of them --500,000 "islands, isles and islets" according to the U.S. Department of State (Hodgson, 1973)--seemingly enough to go around to meet everyone's fantasies and dreams of paradise, for exploration, study, or escape. But things are not quite that simple--ask any islander about these continental perspectives on his or her insular home for a contrary point of view!

The flippancy of the above paragraphs is deliberate because it reflects the often equally flippant, if not frivolous and wrong-headed perspective of many continental people regarding the nature of islands. How, they question in a condescending manner, can a small vacation spot in the middle of the ocean or even along a coastline be a "country"? A Club Med, yes; exotic, idyllic, nostalgic, backward, traditional, remote, yes. But a real country, a full-fledged nation--impossible!

To a large degree, smaller oceanic and coastal islands have been traditionally perceived by continental peoples as interesting but only satellite appendages, frontier outposts, or recreational sites. Whether colonial, territorial, or even politically independent, most smaller islands are viewed by continental powers as marginally valuable and marginally viable--as difficult, but exploitable geographical hybrids. Islands of all types (coastal, oceanic or grouped as an archipelago) have, therefore, historically been treated in a cavalier, even callous, manner and have frequently been administered with general disregard for the "niceties" of prevalent democratic theory, political morality, social ethics, and--more recently--environmental principles or standards.

There is, unfortunately, in the mind's eye of many "mainlanders" only a fuzzy, artificial island construct--part metaphor, part myth, part fiction, part caricature that obscures, distorts and even, on occasion, blinds the observer about what an island (or insularity) really is and how it "fits" into the rest of the world.

For this reason alone, islanders are always at risk. The continental's skewed perception or island expectation model constitutes a one-sided, conceptual barrier which further skews any transactional process linking or involving the island system and the larger continental system.

There are other dysfunctional imbalances that characterize the large vs. small or continental vs. insular relationship (which will be discussed later in this study). Yet this particular problem is sufficiently pervasive and on occasion pernicious enough, when development planning and resource management are addressed, to require an early cautionary note for the reader. It may account for why island systems literature and documentation, in the aggregate, is so diverse and inconsistent and lacks both a unified theoretical and empirical base. There has been little consensus.

1.2 Contemporary Pressures on Island Systems: An Overview

At the present time, thousands of islands are experiencing strong development thrusts based chiefly on tourism, on extractive enterprises, on their use as nodes for international air transportation and satellite tracking networks, and on the increased demands for and upon local resources generated by rising affluence and expectations among rapidly growing island populations. Additional driving forces include continentally based initiatives seeking waste disposal sites, deep-water petroleum transhipment sites, cruise ship ports, offshore banking centers, low-cost labor for materials processing and assembly, and expanded supplies of harvestable high-value marine species (like tuna, lobster, conch, and certain seaweeds). The availability of multinational and bilateral aid programs has also contributed to accelerated development activities.

One by-product of this current development phenomenon has been a dramatic deterioration of island coastal environments, accompanied by a decline in the quality of life on islands, as measured by means other than such traditional economic indicators as gross national product (GNP) and average per capita income. On islands, as elsewhere, progress has its price. As insular smallness confronts continental bigness in its various manifestations, what are the prospects for islands and island people? The pessimist well may say there is no hope, for island cultures, environments, and ecosystems will be overwhelmed and fundamentally changed if not destroyed. But for those who can say of an island (as once did Rupert Brooke), "This is my home, my native land," the values of smallness, isolation, self-sufficiency, and the insular condition have a special meaning and promise. If islanders are uneasy, it is understandable. And if the process of change is to be managed and sustainable island ecodevelopment is to become a reality, then the skills, expertise and accrued learning of islanders, continental scholars and development specialists need to be applied in the search for island growth, resource management and survival strategies.

How urgent is the task? "Maybe you can afford to make a mistake on a continent," warned Ray Fosberg. "The thing you damage or destroy probably exists in two or three other places but almost every island has something unique on it. Anything you do on an island makes a difference. You just can't always tell what the difference is going to be" (Gosnell, 1976). Aldo Leopold once reflected, "One of the penalities of an ecological education is that one lives alone in a world of wounds. Much of the damage inflicted on land is invisible to laymen." Unfortunately, in the special case of the world's oceanic and coastal islands, much of the damage being inflicted is invisible to almost everybody involved--except the islanders themselves. As in the case of the old saying, "out of sight, out of mind," insular remoteness obscures from all but a few persons the burgeoning impact of contemporary continental pressures and well-meaning but often ill-designed international development strategies on small insular systems, their associated terrestrial and coastal environments and their human production systems.

Twelve years ago, an island biogeographer, Sherwin Carlquist, observed (1972), "Access to islands is far easier than it has ever been, and island biotas, many relatively intact now, are going to be devastated soon to the point where all we will have to study are shreds of the marvelous fabrics of evolution that inspired Darwin and Wallace...." "There is plenty of evidence," according to Bill Newman, Professor of Oceanography at Scripps, "that almost anything we do on islands makes them worse" (Gosnell, 1976).

The stresses and pressures of rapid population growth, unrestrained development, and modern technology are partly responsible for the decline of the environmental quality of island systems and their littoral zones and for coastal zone competition and conflict among traditional and prospective users. Another increasingly apparent cause of the decline is a serious methodological failure in the omission of environmental resource values in planning and development strategies. The principal question now is how to incorporate environmental criteria to a far greater degree in the modernization of island communities, as they are shaped by local forces, transnational corporations, external market factors and by development agencies involved in or responsible for external financial and technical assistance in islands. A derivative of this has been the procedural and technical failure of the development planning process to comprehend or deal specifically with island coastal zone or marine resources, use opportunities, conflicts, trade-offs, and externalities (see Section 6.3).

1.3 Study Objectives

The primary objectives of this extended case study are to address the questions of the verifiability and utility of the island microcosm concept, to explore the theoretical and empirical underpinnings to the concept of both island ecosystems and an island model or paradigm, and to develop from the extensive literature and from several site specific analyses an updated set of rules for the design and implementation of development projects in small island systems.

1.4 Antecedent Methodological Considerations

A "microcosm" is a diminutive representative world or system analogous to a much larger system. It is not so much dwarf-like as it is a miniaturized replicate in substance, structure, and process. Assuming for the sake of argument that islands are in fact a microcosm, a number of questions arise. The most important one is, microcosms of what? Are they microcosms of continents? Of man-environment interaction on continents? Can a smaller island be seen as a microcosm of other larger islands? Are they microcosms of closed systems or open systems (most islands are viewed as closed systems but are they in fact open systems)? Are they only microcosms of smaller, continental microstates, as Dommen

(1980b) and Jones-Hendrickson (1979) have argued? Or are they microcosm models of the development and resource management process and therefore to be seen as artificial or genuinely real laboratories of one or both processes? Is the whole idea of microcosm simply an analog, a way to describe the target area, a vehicle for analysis and evaluation, or is it the result of a standard (perhaps naive) continental view of islands as smaller, discrete systems that are more manageable for the resource planner, the conservationist, or the development change agent? Alternatively, are islands a true archetypal form of global real estate that is only artificially and perhaps inaccurately assumed to be a microcosm of other systems, whatever those systems might be?

If one assumes that, for whatever definitional, hypothetical or strategic reason, some kinds of islands are a microcosm of something larger (insular or continental), then one also has to address the question of how then to classify islands as microcosms. This immediately raises the issue of an island taxonomy; and matters of size, of levels of development, of economic structure, culture, ethnicity, dependency, complexity (a single island vs. a multiple island grouping), linkages to adjacent islands, archipelagic status, population, GNP, and other parameters become important in some yet to be determined fashion.

This in turn raises other questions. Are islands really different? What makes them so? Are the differences significant or secondary constraints regarding model transfer? Does the existing literature which suggests they are scientifically and ecologically "different" (especially when considered within that portion of the ecological framework called biogeography) constitute a sufficient differentiation to require different approaches in development strategies, different approaches in conservation strategies and different approaches in coastal resource management within such island systems?

If there is an argument for substantive differences, then how does one conceptualize the development paradigm for islands? Do we have one --or more? Should it focus on structural factors, on process, or on intervention strategies to address the problems that have arisen from the applications of continental development paradigms (like the market system, central planning, free trade, or protectionism) to island areas? Are the larger continental systems development models and practices truly applicable to the insular microcosm? Is the relationship symmetrical or not? If not, can we assume that the assymetry is disadvantageous to islands (for example, through the one-way "brain drain" factor or tilted terms of trade in commodities, technology transfer or economies of scale and capital-intensive resource development, which all tend to favor the more developed and/or larger system or country)?

Regarding islands' vulnerability or victimization, are these derived solely from insular status? Is there a way to document (as per Hamnett et al., 1981) a unique insular system vulnerability factor and to document island victimization, dependency, and exogenously imposed limits on options?

The island "coastal" model is obviously unlike all continental "coastal" models (considered holistically). All islands have circumferential (surrounding) sea-land boundaries or coastal zones, whereas continental microstates do not. Is this "surrounding sea" an important or vital variable? What does a surrounding sea or marine environment do to an insular microstate model that it cannot do to a continental coastal model? Lastly, how does the microstate model for an island affect the treatment of satellite mini-islands on the periphery?

This litany of queries is not a checklist of what follows but illustrates some of the complexities of what appears to be a simple assumption--that islands are microcosms (of something) and that, by implication, some lessons learned in one or more islands are transferable to someplace else. Since paradigms as approaches are less rigid than models (and therefore less island-type specific), we put forward the a priori assumption that the microcosm concept may lead to more effective customized models (for analysis or management), but that only the currently emerging, more holistic, still transitional island paradigm can put the "microcosm" hypothesis to a proper test regarding both its validity and utility.

1.5 Case Study Methodological Design

Behind the title of this case study, "The Island Microcosm," there are two hidden assumptions. The first is that islands are microcosms of some larger system (whether insular or continental is neither explicit or proven). The second assumption is that any "microcosm" studied in detail might offer some lessons that could be applied to islands, presumably larger, or part or all of a continental system. There is some question about whether or not islands can be models, in a microcosmic sense, for continental areas (at least it has not been proven yet and is only an hypothesis). It seems more likely that small islands might be microcosms of larger islands. These in turn might be microcosms of continental areas.

We have elected to focus on islands that exhibit characteristics of true insularity in the form of isolation and smallness: smaller oceanic islands. We choose this focus, recognizing that if the hypothesis that islands are microcosms of continents proves invalid, there may still be a high probability that the findings from the smaller island microcosm universe could provide a model for larger island systems that are, in turn, closely linked to continental systems. We have elected to study the problem from the bottom up since medium to large size islands could only be microcosms of continents, but small islands could be microcosms of both larger islands and continents. Our principal focus is on developing oceanic islands smaller than about 10,000 km^2, approximately 4,000 mi^2 (the size of Jamaica). We have excluded all the developed coastal islands, like Great Britain or Japan, all very large islands like New Guinea and Cuba and the larger conglomerates of multi-island systems, like Indonesia and the Philippines.

A second rationale for selecting smaller islands is that the perceived environment is totally insular, since there is no "interior." In an island of approximately 10,000 km^2 there is no point that is more than approximately an hour's drive from the sea. The entire island and the sea are closely linked under these conditions.

There are four separate elements involved in the following case study analysis and report, the first of which is an historical overview that examines the universe of islands, their characteristics, attempts to classify them and conceptual problems in studying them. The second element is to extract from site-specific examples what has been learned from experience. The third is an overview of technical problems and advances in insular resource assessment and coastal zone management. The final element explores and evaluates the evolving experimental approaches that have emerged over the past decade, leading toward a new island paradigm (or a theory of insular systems development) that could be empirically tested in the future.

This case study utilizes a variety of data sets: the existing published literature on islands and island systems, only a small portion of which has been cited and included in the bibliography; reports and counsel from various expert consultants; direct site visits to St. Lucia, the Virgin Islands and Fiji; and the extensive island reference files (documents, reports, correspondence, maps, photos) maintained by the Island Resources Foundation.

The principal sources for literature reviewed were the U.S. Virgin Islands (Island Resources Foundation Library), St. Lucia (the St. Lucia National Trust and the St. Lucia Central Planning Unit), Hawaii (the East-West Center), Fiji (the University of the South Pacific, UNDP/CCOP/SOPAC, and the National Trust), and Washington, D.C. (the Library of Congress and the headquarters of the U.S. Man and the Biosphere Program). It should be noted that although the literature available on islands, published and unpublished, is rather voluminous, it is heavily biased on the side of science and natural history material, and is more or less deficient in areas of the social sciences.

The author would like to take this opportunity to make special acknowledgment of contributions made by the following persons: Mr. Robert Devaux of the St. Lucia National Trust (an engineer), Mr. Steven Koester (an anthropologist), Dr. Jerome McElroy, (an economist from St. Mary's College, formerly of the College of the Virgin Islands and the Department of Commerce, U.S. Virgin Islands), Dr. Michael Hamnett from the East-West Center, Mr. William Beller (engineer and chairman of the U.S. Man and the Biosphere Directorate on "Islands and the Rational Use of Island Ecosystems"), Mr. Cruz Matos (engineer and present director of the CCOP/SOPAC group based in Fiji), Dr. Uday Raj (director of the Marine Resources Institute, the University of the South Pacific, Fji), Mr. Birendra Singh (environmental planner, Fiji National Trust), Mr. Allen D. Putney (principal investigator of the Eastern Caribbean Natural Area Management Program, St. Croix,), Ms. Judith Towle (public administration specialist on international development, Island Resources Foundation), Ms. Fran Roberts (who handled the onerous task of manipulating the word processor to produce this report), and the World Wildlife Fund-U.S. for its logistic support.

2. STATEMENT OF THE PROBLEM

2.1 Dimensional Considerations: The Universe of Islands

In the normal scheme of world politics, islands--especially small islands--have traditionally lacked sufficient area, population, resources and geopolitical leverage to count for very much. Although all of the world's islands taken together have a combined land area of about three million square miles (not including Greenland with 840,000 square miles), they constitute only about five percent of the earth's total land area. However, forty three, or approximately one-quarter, of the world's independent states (with membership in the United Nations and other international bodies) are wholly insular. Most of these (Table 1) are developing countries, with thirteen concentrated in the Caribbean, ten in the Pacific, and seven in the Indian Ocean/Persian Gulf.

Table 1. Independent island countries.

1. Antigua-Barbuda	16. Iceland	30. Sao Tome and Principe
2. Bahamas	17. Indonesia	31. Seychelles
3. Bahrain	18. Ireland	32. Singapore
4. Barbados	19. Jamaica	33. Solomon Islands
5. Brunei	20. Japan	34. Sri Lanka
6. Cape Verde	21. Kiribati	35. St. Christopher & Nevis
7. China, Republic of	22. Madagascar	36. St. Lucia
8. Comoros	23. Maldives	37. St. Vincent
9. Cuba	24. Malta	38. Tonga
10. Cyprus	25. Mauritius	39. Trinidad and Tobago
11. Dominica	26. Nauru	40. Tuvalu
12. Dominican Republic	27. New Zealand	41. United Kingdom
13. Fiji	28. Papua New Guinea	42. Vanuatu
14. Grenada		43. Western Samoa
15. Haiti	29. Philippines	

There are sixty two islands with areas greater than 4,000 square miles, and 126 islands with areal dimensions larger than 1,000 square miles. However, some very important islands are much, much smaller, and many of these smaller, formerly colonial island territories and associated states have over the past decade or so opted for independence or are moving in this direction and thus represent new factors on the international scene.

There are very few island countries that are essentially single islands like Barbados, Sri Lanka, St. Lucia and Nauru. Some come in major pairs like Trinidad and Tobago, St. Kitts and Nevis, Antigua and Barbuda. Some occur in single country clusters or arcs or archipelagos like Fiji with 322 islands or Tonga with 150. Others, as in the case of the Lesser Antilles in the Eastern Caribbean, represent a multi-state cluster with eight independent island nations in an area about the same size and with the same number of individual islands as Fiji. The Seychelles in the Indian Ocean has a hundred volcanic and coralline islands spread over a distance of 1,000 km. The Maldives has a thousand islands, sub-clusters of 19 atolls spanning an arc of 800 km, while Kiribati has 33 islands but they are spread over five million square miles of the Central Pacific. The Marshall Islands in the Pacific Trust Territories, with 1,156 islets, have a combined land area of only 70 square miles (smaller than St. Croix in the U.S. Virgin Islands), each averaging only 39 acres. By way of comparison, some continental countries also have extensive insular resources. The United States has 29,000 islands, of which 6,000 are in Alaska and 2,000 in the Pacific Trust Territories. Panama has 700 (about the same number as the Bahamas); New Zealand has 500.

But for all of these and others, this is a time of change and transition. Within just the past two decades, the advent of jet air service, containerized cargo technologies, mass tourism, satellite communication links, television, multinational corporations, and geopolitical considerations have each contributed to a rising level of interest in islands among continental business circles, bilateral and international development agencies.

2.2 Definitional and Conceptual Considerations

The dictionary definition of an island as being a body of land entirely surrounded by water is not of much use. Australia and Funafuti in Tuvalu both meet the definitional requirement. As a consequence, island groupings originated for convenience' sake by the user lack precision (for example, wet, dry, high, low, tropical, arctic, small, poor, French, Aegean, remote, atoll). In addition, there is a similar lack of precision which derives from a conceptual dualism; Fiji, for example, is both a discrete point on a map and a country with 322 distinct islands spread over 600 miles of ocean. The "point" approach is convenient but obscures the reality not only of internal distances separating sub-units but cultural and economic "distance" or differences as well. Secondly, the discrete-point perspective tends to emphasize the center or core island and downplay the periphery or satellite islands and how things are seen from the "out island" vantage points. In effect, the "view" of the city from the suburbs is very different from the reverse view. Two very different perspectives are involved.

Another conceptual problem arises out of the natural scientist's tendency to construct a more or less closed system model for isolated islands because of the sea barrier. Unfortunately, from the perspective of economists, planners, humanists, and other social scientists, islands are highly open systems (Brookfield, 1980; Hamnett, 1981; McElroy, 1978b; MAB, 1977; Villamil, 1971) and therefore vulnerable to numerous external factors which limit and often override internal preferences, decisions, traditional resource use practices, and strategic planning assumptions, rendering facile projections invalid.

As early as 1971 it was noted that insular open systems planning should be structured around the concept of contingency planning (Villamil, 1971). Demas (1965) in The Economics of Development in Small Countries, now considered a classic, noted the importance of modifying development planning every year to consider changes in the external sector or in the sytem's environment. This practice of course rarely happens, and there is a tendency on many small islands to consider development plans as static entities to be modified every five to ten years -whenever external aid funding is available.

The strong identity or sense of insular place which most islanders have for their homeland, surrounded by water as it is, tends to produce a collective inclination to see the island as a "closed" and secure system like the scientist's insular ecosystem, but the realities of developing islands as open systems induces an internal conceptual conflict often reflected in island politics and life.

2.3 The "Island System" Concept

Although some islands are more "open" than others, all are bounded by the sea, and the smaller they are, the shorter the time frame for interactions between human and natural ecosystems (and component terrestrial and marine ecosystems), especially when external forces induce change.

For this study, development and its associated impacts are considered within the framework of an "island system" construct, a flexible label that applies principally to islands or island groups and their associated natural, social, economic, and political systems. The "island system" concept calls attention to the following facts.

- It affirms that an island, even though it is small, is not an homogenous, discrete entity, but rather an assemblage of diverse subaerial and subaqueous ecosystems in upland, littoral, sublittoral, and outer-shelf zones; most of these, in the case of small islands, are included in the coastal zone.
- It stresses the importance of the interdependent linkages among island ecosystems: impacts in one ecosystem will have repercussions in another. Further, their areal extent will not conform to convenient geographical or political boundaries, like "land" or "sea". The concept also requires perception of each island's relationship to and within associated island groups, wherein artificial international boundaries and the downstream pollution effect create resource management problems.
- It suggests the need for a "biocybernetic" view of island growth and development, wherein multiple feedback, effect-to-cause "transformational" phenomena can be added to the more linear, more "transactional" cause-to-effect phenomena usually considered, especially in the linkages between the human and natural ecosystems.
- While technically interchangeable with the more flexible term "ecosystem," it suggests the value of seeing an island as an assemblage of ecosystems, preferring to consider multiple

island groups as clusters of island systems with a central core and peripheral satellite islands, which may differ appreciably within the cluster.

2.4 Understanding the Difference

Failure to understand distinctive differences between island and continental systems has often had unanticipated and undesireable results for both private developers and public sector funding agencies engaged in island development activities. Evidence of mistaken, ill-advised, inappropriate, sometimes naive development schemes abound in the island world. Most failed, even though similar approaches had worked well in continental systems, because of insufficient adaptation to insular conditions and constraints, and reflect an antecedent conceptual failure to see islands as different--and then to define those differences. Several examples are illustrative of this point.

- Costly groin, pier, dock and jetty facilities have been literally washed away by "unanticipated" seasonal storms (not even hurricanes). They were simply sited or designed wrong for an island environment.
- Costly sewage treatment plants, desalination plants, and diesel/electric power plants not designed for island environments have deteriorated and failed prematurely.
- Costly enclave-type tourism efforts, especially those designed as sequestered, centralized, high-rise, "Miami Beach-style" facilities, have failed to meet island development needs. They overlook local employment, ownership, cultural exchange and integration with other island economic development possibilities, and many are under increasing pressure to "decentralize" and become more integrated into island development planning strategies.
- Costly coastal zone management programs extrapolated from continental models have simply not measured up to island expectations or requirements.
- Costly beach improvement/nourishment strategies have failed

for design reasons, based on an assumption that what worked elsewhere would work in islands.

- Standard sand and coral mining efforts have seriously damaged adjacent beaches, coral reefs, and coastal environments and adversely affected other sectors like fisheries and tourism.
- Natural disaster relief activities, because of poor planning and inappropriate scales and styles of intervention vis a vis island areas, have often had a greater negative long-term impact on the island system and its capacity for survival than the cyclone, hurricane, flood or drought itself.

Most of these "failures" will resurface in more detail in later sections of this report.

3. INSULAR SYSTEMS: CLASSIFICATION AND CHARACTERISTICS

3.1 The Taxonomy Problem

The literature on islands abounds with partially completed or failed attemps to classify islands. The simpler approaches which distinguish between continental and oceanic islands, or between developed and undeveloped islands, or between wet and dry, or high and low, or large and small tend to be essentially academic exercises that are of little use to a development planner. More sophisticated approaches, which have generally dealt experimentally with island regional groupings or types focusing on various small sets of characteristics like rainfall levels, soil types, floral and faunal diversity and endemicity, population levels or densities, and ethnicity, have not been of much help either and tend to be equally academic. However, although they differ considerably, they do perhaps represent the first step in the development of a full-fledged taxonomy or classification system for islands as a unique geomorphic type and a unique resource development and management problem.

Any attempt to classify the characteristics of small developing island countries is not without its problems, especially in view of their heterogeneity and the serious shortcomings in many of the more basic statistics. But even leaving aside the statistical and descriptive information availability problems regarding islands, there still remains the separate issue of how to classify existing information about islands into some taxonomic or even tabular format that will have utilitarian value to the resource planner/manager.

As early as 1973, a thoughtful UNESCO document dealing with islands as an element in the Man and the Biosphere Program (MAB) suggested that "an elaborate land classification (evaluating fluvial and coastal geomorphology, soil and water resources, etc.) would contribute to ... planning future development of islands ... with a view to rational land use ...." (UNESCO/MAB, 1973). The report, entitled "Islands and the Rational Use of Island Ecosystems," went on to suggest four options for classification:

1) Structural types
   a) Continental islands (geologically defined)
   b) Volcanic islands
   c) Elevated coral/limestone islands
   d) Low coralline islands and reefs

2) Climatic types by temperature zones, precipitation, wind effects

3) Geomorphic types
   a) The degree of preservation of flat structural or erosional surfaces on the divides
   b) The formation of foothills and foot slopes as well as coastal lowlands
   c) The existence of reef and lagoonal systems (in tropical zones)

4) Biological types
   a) Islands situated on a continental shelf (with biota similar to the adjacent continent)
   b) High oceanic islands with unique ecological communities usually limited and vulnerable
   c) Atolls and raised limestone islands.

In the same UNESCO/MAB document (1973), an attempt was made to use a three-tier breakdown of more developed, less developed, and uninhabitated islands, but this was of limited use.

Best (1968), of the University of the West Indies, separates islands into "metropolitan and hinterland (marginal) economies"; the United Nations distinguishes between less developed and more developed island areas; some scholars separate the "core" or central islands from "peripheral" islands; and the United States government in an inventory of its 29,000 islands makes a fuzzy distinction between coastal, barrier and offshore islands (U.S. Department of Interior, 1970).

For the development planner, there is no master list or inventory of islands displaying and categorizing the comparative characteristics of island systems. There is, in effect, no universal system of classifying islands -- no taxonomy of islands. Only the 1974 UNCTAD document on "Developing Island Countries" is useful in this regard but it has not been kept up to date.

3.2 Classification Approaches

Since there is no general island paradigm, i.e., a theory embracing the nature of all insular systems, this has left the field wide open for experimentation with classification frameworks.

Natural scientists (Fosberg, 1963; Dorst, 1972; Douglas, 1969; MacArthur and Wilson, 1967; Wace, 1978; and Simberloff, 1974) generally are in agreement that all true islands, as ecosystems, are characterized by the following:

- relative isolation
- limitation in size
- restricted natural resources
- limitation in organic biological diversity
- reduced interspecies competition
- natural protection from external competition and consequent preservation of numerous bizarre endemic species
- tendency toward climatic standardization
- high vulnerability and a tendency toward equally high instability when isolation is broken down
- ecological fragility.

Similar investigations by social scientists (mostly economists and geographers) (Dommen, 1980b; Dolman, 1982; Wace, 1980; UNESCO/MAB, 1973; UNCTAD, 1974) collectively suggests the following socio-economic characteristics of smaller island countries:

- more dependent on foreign trade than large countries and have less influence on the terms in which that trade is carried on
- a narrow range of resources and, hence, specialized economies
- heavily dependent on one or more large foreign company;
- dependent for key services on external institutions such as universities, regional training facilities, banking and marketing arrangements
- a narrow range of local skills and specific difficulty in matching local skills with jobs

- difficulty in providing some infrastructure services as there may be costly diseconomies of scale in the provision of such services
- a small Gross Domestic Product and, hence, import substitution industries may face special difficulties.

All small countries face most of these problems, but they appear in an extreme form on small islands. Collectively, the characteristics can be best summarized as economic dependence, whereby external circumstances and decisions have a far greater impact on the internal system than do internal circumstances and decisions on the external system.

Little attention has been given to the following important and unique characteristics of islands--as compared to continental countries:

(1) Islands (and only islands) have a completely circumferential coastal zone and, therefore, a sea frontier and Exclusive Economic Zone (EEZ) which totally surround the entire country or territory and no land frontier. The only exceptions to this rule are occasional islands divided into political units such as Hispaniola, Borneo, St. Martin, or New Guinea. In this special case, the coastal zone perimeter boundary is always longer than the inland land boundary or frontier (the reverse being generally true for continental countries). Islands also have a disproportionate ratio--favorable to islands--of the size of the Exclusive Economic Zone (EEZ) to the island land mass itself (as compared to continental countries).

(2) Island clusters (not continents) have no internal land transport option to link the parts of the country and are restricted to sea transport and air links.

(3) Small islands (unlike continental countries) do not have an interior hinterland or central terrestrial core area that is essentially distant from the sea. Therefore, for island states, coastal resource planning and management is essentially synonymous with national resource planning and management. (See Sections 3 and 8 of the Coastal Management Case Study.)

In the above examples, islands are different in kind, not just degree, from all continental countries. Furthermore, the facts that island ecology differs from continental ecology and ecological principles derived from continental ecosystems are insufficient to explain the ecological relationships in islands have been well described by Fosberg (1963), Carlquist (1965 and 1974), MacArthur and Wilson (1967), Dorst (1972), and Mueller-Dombois (1973). Three important factors--insular isolation, size and age (geologically islands are relatively recent in origin)--in combination have biological consequences that are most clearly developed on islands because they result in many unique ecological relationships.

One unanswered question, however, is whether the island characteristics discussed above diminish or limit the prospective utility of the microcosm model. This remains to be tested.

3.3 Classifying Islands as Laboratories: The Ecosystem Model

In the world of the natural scientist, islands have long been considered ideal laboratories--microcosms of larger continental situations or systems. Within the framework of an island, "the parameters of variables can be readily defined, the behavior of variables measured, and externalities either controlled or disregarded" (Brookfield, 1980). It was the more remote islands in the Pacific and Indian Oceans that, in the 19th century, had an enormous and fateful impact on the minds of Charles Darwin and Alfred Wallace, the fathers of modern evolutionary theory. For nearly a hundred years after Darwin, however, investigations of islands remained a descriptive science, accumulating a "wealth of information on patterns of species distributions, on the composition of island floras and faunas, on the taxonomic description of insular species and subspecies and on the adaptations, often bizarre, of island creatures" (Gorman, 1979). During the decade of the 1960's, however, island studies underwent a transformation, perhaps triggered by the role islands played in World War II but more likely the result of emerging paradigms for ecosystem analysis within the natural science disciplines.

Institutionalized cooperative island study projects were mounted by UNESCO (Natural Science Division), the U.S. National Academy of Sciences and the Smithsonian Institution. In 1961, F. Ray Fosberg took the first step in generating a new synthesis by organizing a Pacific Science Congress symposium on "Man's Place in the Island Ecosystem" and, in 1963, by publishing the papers in book form under the same title. This seminal symposium and book (reprinted in 1965 and again in 1967) launched a whole new way of looking at islands, not only as "ecosystems" but as ecosystems perceived, studied, used and modified by man. It was the first step in the direction of seeing the island ecosystem as a laboratory, serving both science and man.

Island ecology was transformed into a predictive science by the publication of MacArthur and Wilson's Theory of Island Biogeography (1979), which argued that the number of species on an island is distinctly correlated and is a direct function of the island area and its distance from the nearest island or continent and that on very small islands the process of natural extinction is accelerated. More relevant to this study is their assertion that "by studying clusters of islands, biologists view a simpler microcosm of the seemingly infinite complexity of continental and oceanic biogeography. Islands offer an additional advantage of being more numerous than continents and oceans. By their very multiplicity, and variation in shape, size, degree of isolation, and ecology, islands provide the necessary replications and natural 'experiments' by which evolutionary hypotheses can be tested."

The "laboratory" notion and the "microcosm" concept, wherein islands are seen as models of a wider complexity (continents, oceans, and even the whole biosphere), are implicit or explicit in the work of MacArthur and Wilson and became recurring themes in following years. Carlquist (1974) observed that islands were both "great museums for the biologist and remain the marvelous laboratories of evolution that Darwin and Wallace found them to be more than a century ago. These laboratories, however, have hardly been used, in comparison to what they offer." When a UNESCO project on islands emerged the following year it presumed that "islands could have an important laboratory function as places where different theories of resource management are developed and tested for subsequent application elsewhere" (UNESCO/MAB, 1973). By the early 1980's, the "continentally perceived" purpose of the laboratory had changed somewhat, but Dolman (1982) suggested that small islands, for all the problems and constraints which confront them, could become the laboratory in which alternative development strategies, shaped by the notion of self-reliance, first see the light of day. The longevity of this island "laboratory" notion confirms the point made above about how many outsiders have and continue to view islands.

3.4 Changes in Focus: Islands As A "Special Case"

International concern regarding developing island countries, as a kind of "special case" of the development process, also first surfaced in a serious way in the mid-1960's when a number of international institutions began a search for a theory and a prescription for certain types of "special circumstances" (within the international organizational framework) to improve technical assistance programs to various kinds of "special problem areas." For example, international organizations began to separate out least developed or land-locked countries as needing special attention, and strategic distinctions began to appear regarding least developed, less developed and more developed countries. The concept of Third World countries came into vogue as a classification, and eventually some attention was paid to islands as a special case.

Only within the past two decades or so have most of the world's island populations begun to emerge as subjects of specialized, systematic resource analysis and of planning and management strategies, rather than adaptations of traditional, continentally focused models (Fosberg, 1963). This has involved an evolutionary process. As early as 1966 scientists working with the International Biological Program (IBP), the International Union for Conservation of Nature and Natural Resources (IUCN), and the Pacific Science Congress articulated a concern for the conservation of certain Pacific islands through a series of conferences, symposia, and resolutions which launched the "islands for science" program (Nicholson and Douglas, 1970). Subsequent IUCN initiatives at a "Symposium on Conservation of Nature--Reefs and Lagoons," held in Noumea, New Caledonia (August 1971), stressed the need for specialized ecological guidelines in island development project planning, and noted the vulnerability of island ecosystems to disturbances arising out of human activities. The specific environmental impacts of tourism development on the resources of coastal zones of certain Pacific islands were also given attention.

Shortly thereafter, one of the priority study projects listed by UNESCO's International Coordinating Council for the Man and the Biosphere Program (a follow-up to the IBP) was designated "ecology and rational use of island ecosystems" and resulted in publication of the MAB "Green Book No. 11 on Islands," published by UNESCO in 1973. About the same time a special "Group of Experts" was assembled by the Secretary-General of UNCTAD (United Nations Conference on Trade and Development) to "identify and study the particular problems of the developing island countries and to make recommendations thereon" (UNCTAD, 1974). This was the first full-scale attempt to examine the economic problems of developing island countries within an international forum. Islands surveyed ranged in size from a large archipelago like Indonesia, with about 100 million inhabitants, to very small islands with only a few thousand inhabitants. An attempt was made to classify the island countries and territories according to various significant characteristics, and a further attempt was made to identify certain key problems and the implications for development policy.

The report from the group of experts was published by UNCTAD in 1974 "Developing Island Countries" and was followed shortly by a UNDP sponsored study of coastal development problems in the Caribbean (Towle and McEachern, 1974) and by two IUCN initiatives, first a booklet on "Ecological Guidelines for Island Development" (McEachern and Towle, 1974a) and then an environmental management case study of the British Virgin Islands (Howell and Towle, 1976).

Since 1974 the available specialized literature on island resource development and management has expanded rapidly as is reflected in the bibliography section of this study. Of particular note is a UNESCO/MAB/UNFPA sponsored carrying capacity case study of the Lau sub-island group in Fiji (MAB, 1977). The study's multidisciplinary team was headed by Dr. Harold Brookfield, formerly of McGill University, and included such eminent scholars as R.D. Bedford, T.P. Bayliss-Smith, Bernard Salvat, Anne Whyte, J.B. Hardaker, R.F. McLean and other island specialists. The seven volumes of reports from this project, dealing with population-environment relations, resources, and development, were published between 1977 and 1980 (the last as MAB Technical Notes No. 13; see Brookfield, 1980). They constitute a major point of departure for any proposed insular resource management strategy in the future.

4. THE CARIBBEAN REGION: EXAMPLES AND LESSONS

Development projects, resource planning efforts and environmental management strategies have, in recent decades, had an uneven history in island systems, with fewer real successes than disappointments. The reasons behind this pattern of development and technical assistance failures lie buried in the experiences of those involved and in the historical web of changing circumstances, options, constraints, events, choices, and impacts. Post-audits can be helpful.

Two examples of coastal resource management problems have been selected from St. Lucia and from St. Thomas in the U.S. Virgin Islands group for detailed investigation. Each covers about the same span of time--1960 to 1983. One (Rodney Bay, St. Lucia) involves a large-scale development project and the effects of its induced environmental changes on people. The other (the Mangrove Lagoon, St. Thomas) involves the effects of incremental growth and people on an ecosystem. A non-governmental, regional approach to Eastern Caribbean resource "eco-develoment" is also reviewed in some detail. All three offer instructive lessons within the Caribbean context.

Stretching between the atypical, oil-rich coastal island of Trinidad (adjacent to the Venezuelan coastline) and the island of Puerto Rico (the easternmost and smallest of the Greater Antilles group), there exists an extended chain of smaller islands known generally as the Leeward and Windward Islands or, collectively, as the Lesser Antilles. Within this 600-mile arcuate-shaped linear assemblage of islands, islets, and cays, there are approximately 300 insular entities of varying types, dimensions, shapes, and levels of development. The largest is Guadeloupe at 710 square miles, but most are much smaller. Some are emergent volcanic, high and wet; and some are raised carbonate, low and dry. A few are combinations of both geomorphic types, and many are simply cays or rocks.

Within the archipelago, there are seven independent island countries (Antigua-Barbuda, Barbados, Dominica, Grenada, St. Christopher-Nevis, St. Lucia, and St. Vincent). Most of these have significant satellite or peripheral islands and cays, some of which are habited but most are not, at least on a permanent basis. Interspersed among the seven island nations are eight other non-independent islands or clusters politically linked to France, the Netherlands, the United Kingdom, and the United States.

Taken together, their cultural, linguistic, historical, ecological, developmental, and human and natural resource endowment characteristics vary enormously. All of the Lesser Antillean islands, however, are small, have lost a disproportionate share of endemic species, and most have been greatly modified by external influences (i.e., the colonial experience, the plantation system, contemporary tourism, and imported technologies).

As vestigial colonial ties began to weaken in the 1950's and island political systems gradually became more self-governing, local governmental bodies were faced with the difficult task of balancing competing pressures for change. On the one hand, expanding populations, growing unemployment, and rising social, economic, and nationalistic expectations created demands for development, employment, and services. On the other hand, a marginal natural resource base, weak monocultural export earnings, and a primitive infrastructure suggested other forms of intervention and growth were needed. Some islands, like Barbados, sought a way out of the dilemma by opting early on for independence. Others waited, seeking time and external multilateral and bilateral assistance as a "holding action." Still others took the opposite route altogether by strengthening ties with parent countries in order to obtain needed investment capital, grants-in-aid and technical assistance.

Regardless of the strategy selected, when the pace of development activity quickened markedly in the 1960's, critical land and coastal resource allocation questions arose regarding the landscape -- what and where to develop or to preserve (and how), what constraints to apply, and how to optimize growth in employment, income, exports, and earnings using the indigenous resource base in company with external involvement and capital, both public and private.

As a result, the period from 1960 to 1984 has been one of dynamic change in the Lesser Antilles--witnessing several new oil refineries and transshipment terminals, a dozen new seaports and airports, scores of new marinas, hundreds of new hotels, thousands of new cruise ship calls, hoards of tourists in the millions, tourism receipts in hundreds of millions of dollars, and petroleum production, refining, and transshipment of roughly a billion dollars. Since these are all coastal water-dependent activities and all island cities and urban centers are seaports, it is obvious that the coastal zone is the primary nexus of economic growth in the Lesser Antilles. Less obvious is the environmental price being externalized or deferred.

4.1 Rodney Bay Development, St. Lucia (1968-1984)

4.1.1 The Setting

An independent island state since 1977, St. Lucia is situated in the Windward Islands of the Lesser Antilles (between Martinique and St. Vincent). It has a total land area of 238 square miles (616 km^2), a population of approximately 124,000 persons, and in 1980 it had a gross domestic product of US$80 million or $210 million Eastern Caribbean currency (EC$2.6 = US$1). Over 30 percent of these revenues were derived from the marine sector (sand mining, fishing, transportation, and tourism) (Mitchell and Gold, 1982). It is a rugged, lush island with steep mountains, mainly volcanic in origin. Relief is broken only by a small plain in the south, eroded hills in the north, and several deep embayments and harbors on the central leeward (westerly) coast. A new international jet airport occupies the extreme southern tip at Vieux Fort and a second older, lesser air facility is located at Vigie, adjacent to the capital city of Castries.

The island possesses a relatively narrow nearshore, submerged shelf area and several coastal islets. Maria Island (12 ha), a nature reserve on the southern coast, and the former Pigeon Island (20 ha) off the northwestern coast opposite the Village of Gros Islet, some seven miles north of the capital, are especially noteworthy.

Since St. Lucia was formerly settled by the French and was captured, lost and recaptured several times by the British during the eighteenth and early nineteenth century colonial period, a French "patois" is spoken widely (although the official language is English), and customary place names are mostly French.

Traditionally, the people of St. Lucia have depended heavily upon agriculture (mostly bananas), forestry and fisheries for a livelihood. In more recent times there has been rapid growth in other sectors which draw heavily upon various marine resources, especially port-related industry, sand mining, shipping, and tourism. Growth in tourism since about 1970 has brought it from a relatively non-existent sector to one contributing approximately 18 percent of the Gross Domestic Product. St. Lucia has approximately 2,000 fishermen, although some are only part-time participants, with over 400 boats producing an artisanal catch valued at EC$45 million in 1981 and virtually all of which is consumed locally. Village units of artisanal fishermen are common along the leeward and southerly, more protected coastlines (Figure 1).

In the early 1960's, when the Government of St. Lucia sought to define a share of the Eastern Caribbean tourism traffic for itself, one of the areas selected for resort hotel development was the Bay of Gros Islet on the northwestern coast opposite Pigeon Island. At the time, the islet and its associated shallow reef at the northern end of the Bay created a superior, semi-enclosed and protected anchorage of considerable ecological diversity, historical significance, and importance as a net, lobster and conch fishing area used by fishermen of the nearby Village of Gros Islet. Pigeon Island, the namesake of the village, was studded with historical forts, batteries, and buildings dating back to the era of Admiral George Rodney.

Reduit Beach, approximately one mile long, forms the southern half of the Gros Islet Bay coastline with the fishing village of Gros Islet located at the northern beach limit. North of the village, the rugged coastline is formed by low cliffs and pebble beaches. Between Reduit Beach and the volcanic peaks well to the east, a flat swampy area of about 250 acres was maintained by surface water drainage from the surrounding hills. Natural drainage to the sea was restricted by Reduit Beach and its associated berm (Figure 2).

During World War II the United States leased and occupied the area as a seaplane base for anti-submarine patrols, and some construction and

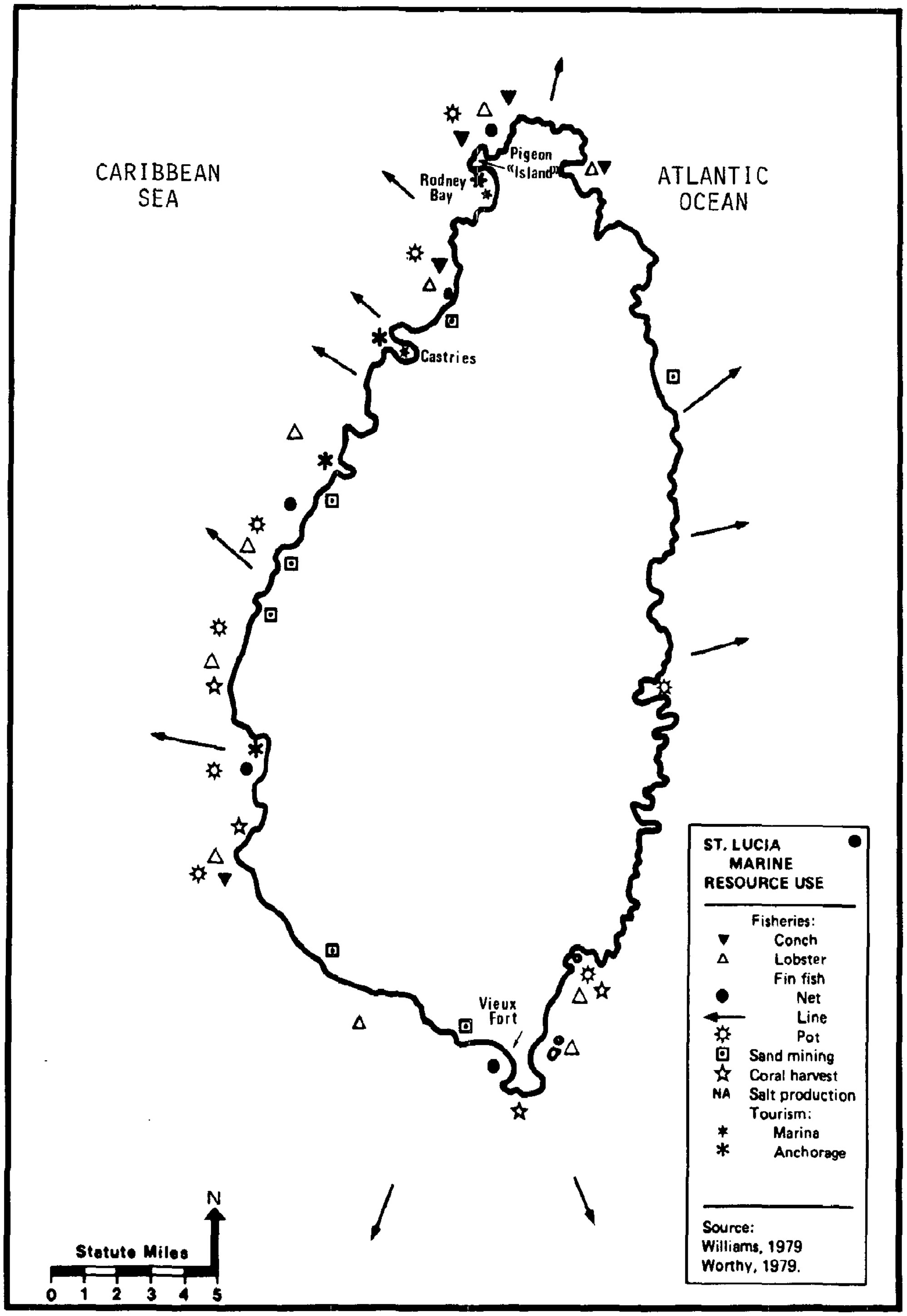


Figure 1. St. Lucia marine resource use. (Adapted from Eastern Caribbean Natural Area Management Program Resource Data Maps, 1980.)

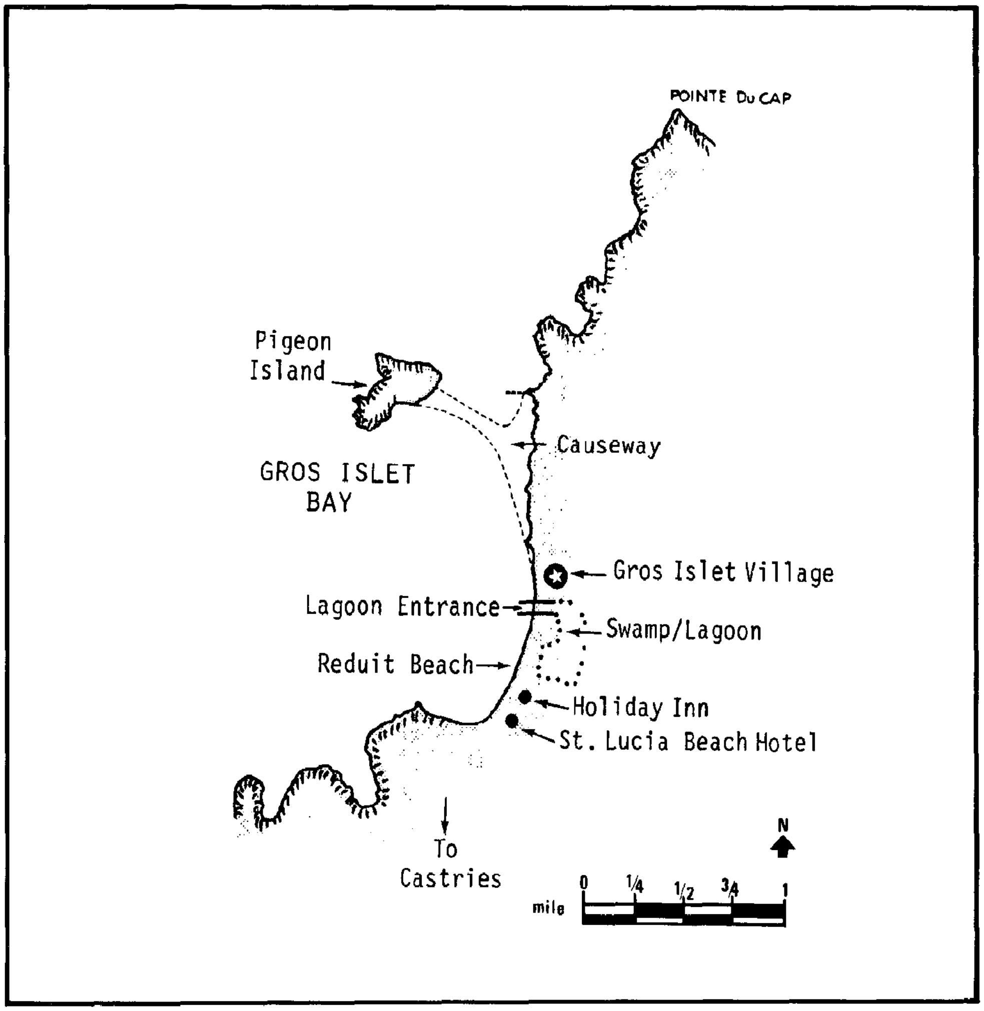


Figure 2. Location map: Rodney Bay development project at Gros Islet Bay/Pigeon Island area, St. Lucia.

considerable dredging were carried out at the site. The U.S. Navy attempted to fill the swamp with about 200,000 cubic yards of sand hydraulically dredged from an area immediately offshore at the southern end of Reduit Beach. The deep borrow pits are still visible forty years later. Because of the amount of soft silt that had built up over the years in the swamp bed, the dredging strategy did not work as the heavy sandy fill material compressed the underlying silt and gradually sank. By 1960, the area was once again a swamp.

4.1.2 The Rodney Bay Development Project

The attractiveness and development potential of Gros Islet Bay (later unofficially renamed Rodney Bay) captured the attention of a group of Canadian investors. In 1961, with government blessing, they commenced construction of the St. Lucia Beach Hotel on the palm fringed extreme southern end of Reduit Beach, as far from the Village of Gros Islet and as near to Castries and the airport as possible. The new facility was ready to open by 1962. Six years later a second Canadian-owned resort hotel (Holiday Inn) was planned for Reduit Beach--even larger than the first--just north of the existing St. Lucia Beach Hotel (Figure 2).

However, there was a problem that delayed construction of this second facility: tiny but bothersome, bloodfeeding insects known locally as sand flies or "no-see-ums." Both the St. Lucia Beach Hotel management and the prospective Holiday Inn developers complained to Government that something had to be done about the swamp to the east, thought to be the source of the sand flies. Their bites plagued visiting tourists in the early morning and late afternoon to early evening hours, causing occupancy rates to suffer. Insecticide fogging and spraying had not worked. The option of draining the swamp was raised in order to eliminate the breeding habitat of the pesty "no-see-ums" (Island Resources Foundation files; Devaux, 1983).

The Government gave firm assurance to the hoteliers that something would be done to alleviate the problem. But what and how and who would pay for it remained to be established.

Nature may abhor a vacuum, but so, apparently, do engineering contractors. By a mysterious process akin to osmosis a well-known Jamaican entrepreneur, who owned a large marine dredging and construction firm, appeared on the scene with an offer that "could not be refused." He proposed a private sector solution to the government's "bug" problem at Reduit Beach, one that would generate profits but only if his grandiose scheme was accepted in its totality (Devaux, personal communication, 1983). That plan evolved as the Rodney Bay Development Corporation with a projected investment capital requirement of EC$17,089,000. It included the following development components:

- To dredge the core of the swamp, filling border areas with sea sand and open up the new "lagoon" to the sea with a channel for yachts through Reduit Beach.
- To create 88 acres of new flat land with a new mile-long beach for additional tourist facilities by dredging seabed sand from Gros Islet Bay and emplacing it as a "causeway" on top of the shallow reef between Pigeon Island and the main island, thereby doubling the linear dimensions of Reduit Beach available for "development."
- To create and sell or lease marinas, residential and condominium units on the newly filled "waterfront" lots on the filled areas in the new lagoon (i.e., ex-swamp).
- To accomplish the above through a three-way partnership between the Government of St. Lucia, the [British] Commonwealth Development Corporation (which would cover the up-front capital costs as an "investment"), and the Jamaican entrepreneur, who would provide the expertise and dredging, road building, and other services (for which he would be paid).
- The project would comprise 1,311 acres (1,243 of which had to be purchased), consisting of 650 acres of single residential vacation/retirement housing units, 52 acres of hotels, 80 acres of condominium/apartment units,

7 acres of commercial tourist "boutiques," 10 acres of yacht club/marina facilities, 440 acres of green land, lagoon, public beaches and roads, and 72 acres for "extension" of the Village of Gros Islet.

- The project would require two years of site modification and five to seven years of lot sales and development.

The Government of St. Lucia accepted the proposed scheme; engineering studies and plans were completed by June of 1969; shortly thereafter work commenced, i.e., temporarily surcharging or covering the swamp with sea sand to compress the silty bottom, installing a rock/boulder barrier from the mainland to Pigeon Island (behind which dredged sand could later be safely deposited), opening up the swamp/lagoon by a channel cut through Reduit Beach and re-routing the existing north-south road system. But not everything went according to plan.

In 1970, as part of the attempt to create access from the sea to the swamp behind the beach berm at Reduit, an effort was made to excavate the entrance channel between the former St. Lucia Beach Hotel and the new Holiday Inn. This, however, had to be abandoned when it was discovered a ridge of hard rock extended underneath the beach berm. Blasting was unfortunately ruled out, and in 1971 an alternative strategy was selected which involved the dredging of a channel immediately south of the Gros Islet Village. The siting of the channel south of the Village ended up requiring the elimination of the bridge over the old swamp drainage outlet between the Village and its cemetery, thereby cutting the Village off from both its traditional burial ground and from direct access to the existing hotels and the new "development area." The initial rock barrier placed between Pigeon Island and the mainland, as an antecedent protective mechanism for the causeway dredge and fill activity, caused the beachfront at the Village to collapse, thus requiring "nourishment" with additional dredged material--a remedial strategy which, it will be demonstrated below, failed over time (Stevenson and Hardtke Associates, 1973; Devaux, 1983).

However, the final phases of the site preparation, including the dredging of over 2.5 million cubic yards of Gros Islet (Rodney) Bay sea-bed coral sand to construct the 88-acre causeway, were completed by the end of 1972. All that remained for the project to succeed was to sell or lease the newly created or "enhanced" waterfront properties to amortize the investment and generate new revenue. But, some fourteen years later, this has not yet occurred. Not one sale, lease or option has been finalized for the causeway area. Not one new hotel has been built. There has been no deluge of buyers or leaseholders for the residential sites in the new "lagoon", which is fairly attractive. Additional capital investment (for further site improvement and remedial environmental interventions), development, and marketing costs have mounted, and the total is close to three times the original estimate. There has been no appreciable return on invested capital, and carrying costs are estimated at about US$2,000 per day.

There were other recurring costs of a different nature accruing to the project and its environs. From an environmental impact perspective, the development scheme for Rodney Bay is a rather classic case of both good intentions gone astray and of "Murphy's Law" ("If anything can go wrong, it will"). The following section summarizes a sequence of unanticipated environmental impacts that help explain the failure.

4.1.3 The Short-Term Impacts

As part of a larger series of Eastern Caribbean investigations focusing on coastal processes, erosion, sand mining, and regional beach control, Deane et al. (1973) undertook a detailed study of the Reduit Beach area in St. Lucia from 1970-1973. In the subsequent report documents, Deane reported that the most signficant event that had occurred in this area was the closure of the Pigeon Island passage which had resulted in the following major changes in the littoral climate: 1) almost no new sediment is supplied to Reduit Beach; 2) there has been a significant reduction in the wave climate along the stretch of coastline between St. Lucia Beach Hotel and the lagoon entrance near Gros Islet Village; and 3) waves now approach the beach at almost right angles and consequently southerly littoral transport, formerly driven by waves passing through the Pigeon Island passage, has ceased. "One result of the first change is that in the long term, erosion will be experienced over the entire stretch of beach. As a result of significant changes in the direction of wave approach in the medium term major losses will be experienced in the southern half of the beach during periods of severe wave attack" (Deane et al., 1973).

In 1973 the consulting firm which had prepared the original engineering and design study for the Rodney Bay project was employed by Rodney Bay, Ltd., of St. Lucia to examine the post-construction beach stability situation at Rodney Bay. The study was prompted by various complaints about modifications that were occurring to beaches and other marine features in the area. The report by Stevenson and Hardtke Associates (1973) noted that the causeway beach will "tend to change to some degree over the next five to ten years, but this is not likely to create a problem, provided the change is allowed for in planning." Concurrently, they indicated that "regular surveys of all Rodney Bay beaches are recommended in order to insure that unexpected changes are noticed." Shore erosion problems at the southern end of Reduit Beach, according to the consultants, were solely the result of the offshore dredging carried out in 1941 and the mining of sand from the beach during the 1960's for aggregate and the removal of the sheet piling (installed by the U.S. Navy in 1941) from in front of the southern part of the Holiday Inn in 1970. The report concluded that any existing erosional problems were "not caused by the Rodney Bay construction, ... although it has markedly influenced conditions in the area" (Stevenson and Hardtke Associates, 1973, emphasis added).

What the consultants were saying, in effect, was that the previous extraction of perhaps a total of 200-400,000 cubic yards of sand and the removal of a forty-year-old sheet pile wall had more influence than the closure of the Bay entrance, the removal of 2.5 million cubic yards of sand for the causeway fill, plus the removal of more than a million cubic yards for the surcharge and fill strategies for the swamp area.

The most interesting part of the study is its endorsement of the need for costly remedial actions, involving the installation of a gabion blanket near the St. Lucia Beach Hotel costing EC$100,000, the installation of an offshore breakwater near the southern end of the Bay costing EC$300,000, possible installation of two stone groins at the point where the causeway beach and Pigeon Island connect in order to attempt the restoration of the former Pigeon Island natural beach. The study also supported the need (given the modifications in Bay circulation caused by the installation of the causeway) for any new sewer outfall serving future tourist facilities to extend at least 2,000 feet from the nearest shoreline. The outfall recommendation was deemed necessary to take account of the new flow conditions, new bathymetry, and new wave regime--yet no cost estimates were cited (Stevenson and Hardtke Associates, 1973).

By 1975 the beach at the Village of Gros Islet had deteriorated, causing the village council to protest to the Town and Country Planning Unit, suggesting that the existing lagoon entrance south of the Village was "an eyesore." The Council complained that the encroachment of the sea on the bay front created a hazard, and that the sandy beach which was expected had not materialized. In the opinion of the council, these problems were a direct result of the works carried out in the creation of the causeway (Devaux, 1983).

Changes were not limited to the main island. For more than three hundred years the westerly side of Pigeon Island had a rather beautiful 1,000-foot-long, 40-foot-wide yellow sand beach. The foundations for a rock pier constructed by military engineers in 1782 still survive and, until the causeway was built, produced a minor widening of the beach area at the point where the 1782 stone dock was constructed. In 1969, two years after a new timber-pile jetty was constructed on the eastern side of Pigeon Island as a dock for visiting boats, the rapid build-up of sand to the south rendered the jetty more or less unuseable. Rapid shoaling occurred at the extreme outer edge, indicating a sand deposition phenomenon and slow littoral sand transport from south to north in the area. By 1970 when construction activity began for the causeway, Reduit Beach began experiencing serious erosion problems. Pigeon Island was not affected by these events until the closure of the gap. However, when the gap was closed in 1971, the sand on Pigeon Island beach began to shift noticeably toward the east. At that time, accurate measurement profiles of the Pigeon Island beach were taken for the first time (Devaux, 1983). By 1972, when the causeway was completed (almost a year later), a yellow sand strip or streak began to appear along the white coral sand on the artificial causeway beach, matching the color of the sand at Pigeon Island. Within six months it had traveled 1,000 feet along the causeway toward the mainland; Pigeon Island was apparently losing its only beach to the causeway beach.

The St. Lucia National Trust, a quasi-governmental body responsible for developing Pigeon Island as an historic site and national park, was properly concerned. By 1976, however, the beach had virtually disappeared and, despite sequential protective and remedial engineering strategies (e.g., gabion baskets, groins, and armor stone emplacements), all at great expense to the National Trust, only the northerly segment of the former beach had stabilized (Devaux, 1983).

In the meanwhile, the causeway itself has been "stabilizing" (to use the consultant's term)--or eroding (to use the disinterested observer's term)--at a loss rate of 14 feet per year since 1974. The original 88 acres are now down to perhaps 75 acres. When and if it will truly "stabilize" is an unknown. Whether investors can be attracted to build hotels or condominiums on a dynamic, not yet stabilized, artificial tropical island beach is also an unknown. What has happened as a result of the causeway and associated Rodney Bay dredging activity to the adjacent artisanal fishing Village of Gros Islet, however, is not an unknown. It is a matter of record and a cause for concern.

4.1.4 Impacts on the Coastal Fishing Community at Rodney Bay

Gros Islet, St. Lucia, is a small fishing village for which there are dozens of replicates within St. Lucia and hundreds in the Caribbean region. Before the Rodney Bay project, Gros Islet bore a resemblance to coastal fishing villages on all inhabited oceanic islands, such as those in the Lau group of Fiji described in detail by Brookfield and others (MAB, 1977). To illustrate how this has all been changed, we have elected to explore in some detail the metamorphosis of the village-based fishery at Gros Islet.

Prior to the Rodney Bay project, Gros Islet had three seine nets exploiting the resources of the nearby reef and coastal environment. Each seine had a full-time crew of four to six men responsible for casting the net and maintaining it. In addition, between 15 and 20 people regularly accompanied the crew to pull. Another shifting group of approximately 15 to 20 villagers would pull on a given day in exchange for at least a substantial portion of their families' daily food requirements. A crew member's share served as his daily wage, and the shares distributed to the regular pullers were also essential sources of income. In theory, the distribution of a day's catch was: 1/4 to 1/3 to the net owner, 1/4 to 1/3 to the permanent crew and 1/2 to 1/3 distributed among those who pulled. In all, each net had between 40 to 50 people working on it daily in exchange for varying amounts of income and subsistence. The size of the work force fluctuated with the seasons, the quality of the previous day's catch, and weather and sea conditions (principally wind and swell).

With the advent of Rodney Bay Development, this fairly stable system was undermined and destabilized. Dredging the Bay, digging the lagoon channel, and building the causeway destroyed the usefulness of the seine fishermen's two principal beaches. The causeway cut the Gros Islet Beach area in half. The dredging left borrow pit edges or underwater cliffs that would snare large beach seines when cast. It also released mud and sediments into the water, destroying sea grass and coral fish habitats. The causeway also blocked off the current and, according to the fishermen, a main "path" for schools of jacks and mackerel which they previously caught.

All three seine owners abandoned fishing as a result of this drastic environmental alteration, and their cotton nets all spoiled. Eventually, one of the three experienced seine fishermen bought a nylon net and began casting at the Cariblue Beach some distance to the south. He was followed by two net owners from Anse La Raye (south of Castries) who also began fishing there.

This new arrangement left three nets (from two villages) sharing one beach and resulted in a reduced daily catch from the seines and a reduced demand for labor. Instead of three separate groups of people pulling each seine daily, only one group was needed. In addition, because the Cariblue Beach is located outside the village, a large portion of the catch no longer comes through Gros Islet but is instead shipped directly to Castries by van. Before, with three nets being used close to the village, fish were more plentiful and, with over 100 people (sometimes 150) getting a share daily, the catch was efficiently and widely distributed to meet local needs.

Gros Islet's seine fishing was also an important source of fresh bait for fishermen trolling the banks northeast of the island, especially during the bottom fishing seasons, July to November. It was common before the development to sell bait to over 20 canoes a day during the bottom season. As seine fishing has diminished in Gros Islet, these fishermen had to find more direct alternative sources for bait.

A still unfolding further development illustrates the current predicament of Gros Islet's seine industry. Until recently, one local fishermen with a "ti-seine," (small [petite] seine) had been casting his net on beaches that the larger seines cannot use, including the remaining part of the Gros Islet Beach and along part of the causeway. But even he has emphasized that net fishing was much better before. "Before we were a fishing village, everyday we were taking kawang (carang) and jacks especially in this season now but the barricade blocks off the fish" (Koester, 1983).

Rodney Bay development destroyed or eliminated the most productive parts of the seine fishermen's environment, cutting their daily production by two-thirds and diminishing the daily work force requirements by about the same amount. According to one of the net owners, "From the time of the causeway I haven't had a really good year. Before if I had a son I would encourage him to come and help me with my seine. Now I wouldn't do that. There is no future in it" (Koester, 1983).

The use of both wire and the more traditional bamboo fish pots was the second major fishing method employed by Gros Islet fishermen at the time of the Rodney Bay Development project. Some men specialized in this single technique, others combined it with additional methods and others (like farmers, craftsmen and day laborers) set fishpots as a part-time occupational pursuit. Before the development about 30 Gros Islet fishermen relied principally on setting pots inside Reduit Bay, in the area of the causeway and north of the causeway up to Cap. Setting pots on the nearby reef area and in the bay provided all fishermen with a secure inshore component to their overall strategy, thereby spreading the risk. It involved the least effort and provided sustenance and income when the sea was too rough or the weather too bad for other kinds of fishing.

The Rodney Bay Development Project adversely affected pot fishing by destroying nearby areas previously used by fishermen and by impeding their access to more distant areas they previously used and continue to use, but now at a greater cost. Dredging destroyed fish habitats where men had set pots, and the mud and fine sand particles released while dredging the bay and swamp continue to hinder the efforts of pot fishermen. The causeway itself obstructed their access to fishing areas north of the village. "The causeway kept me back a lot, I used to set pots there. Before I rowed my boat and used a sail, now I have to buy a machine to go around Pigeon Island. And its not just me, its kept back a lot of fishermen," reports one village resident (Koester, 1983).

The Rodney Bay project has therefore raised the cost and effort required for Gros Islet pot fishermen, and many pot fishermen have left fishing altogether. Some sold their boats to Frenchmen, a lot left the sea and went on shore for a job. Another concludes, "Before the causeway, I never left the sea but after that I can't depend on the sea alone."

The Rodney Bay project occurred at a time when several new fishing technologies were being introduced in St. Lucia. At Gros Islet only two men had engines; the rest were still rowing and sailing. The three seines were all cotton. There were only two bottom gill nets and no trammel nets. Only one man was diving with a tank, and the use of dynamite was infrequent. Since the completion of Rodney Bay the old technologies have given way to more modern ones. Engines are used on both canoes and chaloupes, the seines are nylon, there are more bottom nets, and diving with tanks is widespread (Koester, 1983).

When the Rodney Bay project began, some Gros Islet fishermen were able to secure jobs in its construction. For example, it was reported, "A lot of fishermen quit to work on the causeway, the whole area was white with mud, there were no fish so there was nothing else to do." This alternative, however, was short-lived. Before the Rodney Bay project over 100 Gros Islet men earned their living from the sea. Estimates of the number of active fishermen now range from 30 to 50 (and many of these are part-time). The adverse effects of Rodney Bay Development for fishing, combined with the options it offered in construction, changed the occupational focus of many Gros Islet men.

Up until the time of the development project, lobster and conch were both present in the area of the causeway and also around Pigeon Island. The Bay itself had extensive sea grass beds. The fishermen of Gros Islet and the St. Lucia fisheries office agree on this. But all three--lobster, conch, and sea grasses--have now virtually "disappeared."

Before the Rodney Bay project, tourism seems to have played a more visible and reliable role in the livelihoods of Gros Islet fishermen. Tourists were able to walk from the Reduit Beach hotels to the Village and arrange for boat tours. Somewhat nostalgically, one fisherman recalled, "We used to take tourists to Pigeon Island. We didn't have engines then so we'd row them or take them by sail. We could always make a few dollars from it. Now the tourists catch big transports [tourist buses] and drive right around us" (Koester, 1983).

Fishermen also claimed it was possible, before the project, to catch lobster nearby and sell directly to the St. Lucia Beach Hotel and the Holiday Inn. Since the development, the nearby hotels buy from all over the island because the local supply is now "unreliable."

Frequently, when discussing the causeway, the fishermen of Gros Islet Village will use the term "barricade." One fisherman reports, "Gros Islet was the net fishing center. Since after they put up the barricade the place is dead." From the perspective of the village, its cemetery has been destroyed and the channel was made in order to separate the people of Gros Islet from the tourists. "I believe they didn't want much black people to meddle with the white people. Now we can walk to Pigeon Island but before we could walk over the bridge to the cemetery but now they've built the marina there. They didn't want the people in the midst of the whites" (Koester, 1983).

4.1.5 Retrospective Conclusions

The central idea of developing the Rodney Bay area as a multi-purpose (hotel, condominium, marina) site had merit. But the development plan was fundamentally flawed and produced serious problems when implemented. The project scheme did attract external investment capital, expand the tourism industry's infrastructure base in St. Lucia, provide some new employment opportunities (although primarily short-term), and is probably economically viable for the owners or investors over time. But as designed and implemented, and in the absence of any serious impact assessment or mitigation planning (even by 1970 standards), it produced a number of serious negative effects. Far too many unanticipated social, economic, and environmental costs resulted, and the project, in retrospect, was a failure, especially since the full accounting of environmental disbenefits (losses) is not yet finished. Three fairly obvious categories of failures overwhelmed the original scheme and placed it at risk. These failures are summarized below, not to be retroactively critical but because experience is still the best teacher and there are positive lessons to be learned.

1) Conceptual Failures. There was a general conceptual failure to appreciate the magnitude and complexity of the project and its aggregate consequences if done in one "fell swoop" instead of in stages. The evidence now suggests (after the fact) that the Rodney Bay tourist facility and land development project could have been accomplished without installation of the causeway and would have produced a better outcome. The causeway "component" of the scheme was costly, has returned no revenue and has induced numerous unanticipated, negative environmental effects on the natural and human ecosystems. The Gros Islet bay, beach, swamp, and village "system" was subjected to several sequential devastating modifications, almost simultaneously, with no

attempt to assess the impact of the first stage before moving ahead on later stages.

Three distinct and major ecosystem disruptions were involved:

- conversion of the fresh water swamp to a saline system, by cutting a deep channel (it would have been better to cut not one but two) for enhanced flushing and to reduce the sand flies
- dredging of Gros Islet Bay sand for surcharging the swamp and then converting the core of the swamp to a lagoon marina system with filled shoreline areas and road access for residential and commercial use
- closure of the Pigeon Island passage and massive dredging in Gros Islet Bay for causeway fill emplacement which has had (and could have been predicted to have) fairly dramatic oceanographic, biological, and socio-economic impacts--mostly negative--on the ecosystem.

Had the swamp/lagoon modifications been followed by an even brief period to allow the system to stabilize and to allow for an assessment of impacts (providing feedback), it is likely that a decision would have been made to abandon the final "causeway stage". New market conditions and problems, community concerns, and environmental lessons learned in the first phases would have been evident, arguing against proceeding as planned with the causeway. Grand and complex schemes, hurriedly modifying equally complex island coastal ecosystems, are often pre-programmed routes to an economic failure, if not an environmental disaster.

The rule of thumb should be "when in doubt, stretch it out," even though this involves resisting the "can do" inclination of getting the job finished, producing immediate results, and moving the money--all very efficient and legitimate concerns under smaller, less risky coastal resource development circumstances.

A second conceptual failure by those who originated and sanctioned the project was their inability to perceive the marine biological system at Gros Islet Bay, the artisanal fishery, and the Village itself as "resources" which were unofficially committed to the project and which would be modified by it. The traditional users of the area became involuntary, reluctant partners in the venture because they fell within the "natural boundaries" of the project, although not within its official or legal boundaries as shown on planning documents.

In the absence of any integrated development planning protocol, this narrow perception of the project led to a failure to assess the nature and value of the resources being allocated--perhaps inadvertently and irrevocably--as an investment in the Rodney Bay development scheme. For example, the former coral reef at the Pigeon Island passage, now buried under the causeway, was taken out of the St. Lucia natural resource "bank" and invested in the project. It can only be recovered in kind, and even that prospect of re-payment is in doubt -- in part, because, after the fact, one can only infer what it was worth in terms of pounds of fish, lobster, or conch, in employment, and in natural shoreline protection (i.e., as an annually renewable free input to the economy of the Village of Gros Islet and of St. Lucia).

There were also a variety of other failures, some systemic (and those can be avoided in the future only by external compensatory actions) and some technical (that can be eliminated by modifying or applying higher or different standards or using alternative methods).

2) Systemic Failures. The political decision-making process, i.e., the political system, as an ongoing process of interactions between electorates, institutions, and leaders, is inexorably inclined to optimize short-term, sectoral development aimed at generating employment, investment and income in a problem solving mode within the shortest possible time frame. This is a simple fact of life, but especially risky when the developmental "quick fix" involves the allocation of small island coastal resources, usually involving complex, closely coupled dynamic natural ecosystems with an overlay of an equally closely coupled human ecosystem, constrained by both the insular vulnerability and limited option factors characteristic of smaller islands.

There is, however, another aspect of this systemic failure of the governance process. Insular dependency on externalities, like investment capital, technical assistance, grants-in-aid, and specialized engineering expertise (particularly marine) means that political leadership must also listen to a variety of different, exogenous drummers. The conjuries of development planning schemes and tempos (generally faster in the private sector, slower to funereal in the public) resulted in a Janus syndrome of trying to look inward and outward at the same time for signals or guidelines. In the process, coastal ecosystem development planning gets short shrift--project boundaries are too constrained, planning is both hasty and narrow, schedules are too tight to allow for feedback adjustments, resources are damaged, and costly surprises are endemic. Rodney Bay presents a classic example of this particular dilemma of "getting on with it" vs. "getting it right" (i.e., minimizing losses and optimizing gains); it is a problem that can only be ameliorated, not eliminated.

3) Technical Failures. Relying on engineers and economists to design a project like Rodney Bay was akin to planning a hospital without consulting with either the medical staff or user groups. In effect, a narrow engineering/marketing solution was sought and applied to a development task that had other equally important, non-engineering dimensions, namely, severe modifications to the natural and human ecosystems. Missing was the design perspective and technical expertise of natural and social scientists who, collectively, could and should have dealt with the unfortunately unaddressed matters of natural and human resource assessment. Issues deserving attention included documentation of traditional local uses and their economic and social significance, ecosystem characteristics, and project environmental impacts.

Other technical failures or omissions included cutting the Village off from its cemetery and its customers for tours and boat trips, dredging too close to the shoreline, not fairing the edges of the dredge borrow pits, not maintaining a beach profile monitoring program (although the engineering consultant recommended one in 1973), not working out an employment strategy for the Gros Islet villagers (who were prevented from fishing during the project), not including a proper sanitary waste water sewage outfall disposal strategy for projected tourism facilities in the planning, not anticipating the causeway erosion phenomenon, and not being responsive to obvious negative feedback signals from the disturbed ecosystem. These all were project design failures more than performance failures.

The final failure, perhaps the most significant, is really a by-product of all the conceptual, systemic and technical lacunae discussed above.

Over historical time, the Gros Islet community had struck a balance with nature. It had learned how to survive the vicissitudes of isolated island living, not just by fishing (which it did well) but also by learning to spread risk and adjust to seasonal catch cycles for various species. The community had developed ways to reduce vulnerability by internal diversification (mixing farming and fishing) and to limit dependencies on external markets by "substitution." It had developed an unwritten but proven and practical "optimum sustainable yield" resource management strategy for harvesting living marine species, which were within economic range. It embodied two or more centuries of experientially derived, collective information about the dynamics and stock of nearby coastal resources. As a West Indian community, it had come to terms with insular constraints, natural hazards (especially hurricanes and drought), and the vagaries of exogeous factors such as fish hook and net pricing, energy costs, spare parts availability, and "outside" markets for fish catch. When the St. Lucia Beach Hotel was built on the southern end of Gros Islet Bay, the community (wholly without assistance from tourism planners or commercial operators) adapted what it knew well to develop a new economic activity requiring no new capital investment, i.e., transporting tourists to historic Pigeon Island or to visit other local marine "things" within the area like the adjacent reef. Fishermen built their own boats and wove their own fish pots out of local material. In short, the Gros Islet community was a viable, fairly self-sufficient, productive fishing unit with low-level requirements for input from the state and from the external cash/market economy of St. Lucia and beyond.

Villagers had few requirements for energy, capital, and technological imports from off the island; their "dependency index" was low.

It is clear that Gros Islet was a village community which possessed its own technically autonomous culture while maintaining itself as a marine-oriented coastal society with a fairly "complex" production system. This is true, even though in a classical sense, Gros Islet was and still is a marginal and "peripheral" community vis a vis the more advanced dominant core systems in Castries or beyond. Even as a marginal or peripheral (albeit archaic) social unit, the Village was economically important (like other villages along St. Lucia's coastline) both to the national center and to other marginal units and production systems. It knew how to produce, to nourish, to sustain, to survive, and even to grow. It had established its own definition of the "rational use" of insular resources.

What the people of Gros Islet had not learned and did not know was how to deal with a Rodney Bay development intrusion. Not that they saw it as intrinsically "bad" or "good"--only that it represented a totally new threat and opportunity, frightening and promising all at once.

Island villages like Gros Islet, even in the face of development schemes like the Rodney Bay project, are not, of course, totally helpless. They may survive on their own adaptive terms as villages and as "less" productive, less efficient (more marginal) communities within the terms of national planning and development activity, but in either case they and we confront the same two questions: what of value is there already that could be lost in the process of modernization and growth, and how can the production system be sustained and losses minimized?

Failure to address these questions more often than not leads to later costly losses requiring remedial strategies and interventions. In this instance, there is no known remedial action that will recover what was lost. What was will never be again; no engineer can "fix it" or make it right. St. Lucia inadvertently sacrificed a living coastal village on the altar of tourism to exorcise a small, pesty bug. Unfortunately, there are still sand flies lurking in the bush at Rodney Bay, and the causeway remains an empty, unused expanse of sand.

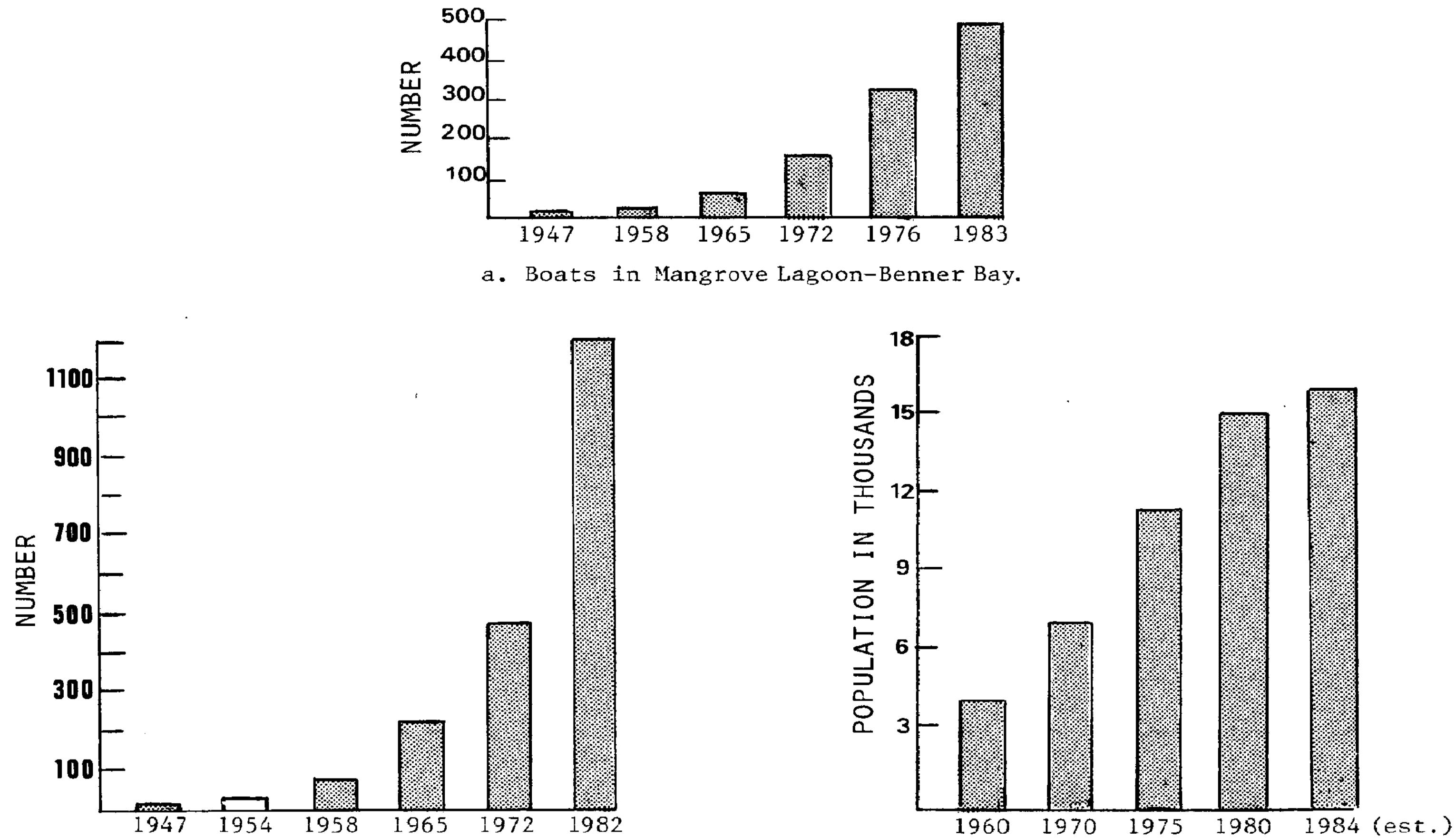
4.2 Virgin Islands Mangrove Lagoon (1967-1984)

4.2.1 Introduction

The southeastern coast of St. Thomas is endowed with a large, singularly attractive mangrove lagoon and bay of exceptional natural value. Its water, mangrove and grass bed systems traditionally provided a rich nursery area for fish and a productive habitat for benthic biota. Its mangrove fringed shores are a natural buffer against shore erosion, floods and hurricane waves. The coast's configuration provides a protective anchorage for boats and its adjoining hillsides are popular residential areas for Virgin Islanders. The area is filled with scenic contrasts, manglar islands, rocky cliffs, ponds and panoramic ridgelines. Its diverse complex of natural communities provides a recreational opportunity for Virgin Islanders. Yet these very attributes have attracted so many people in recent years that the same elements which first attracted them to the area are now being degraded.

Traditional uses of the "Mangrove Lagoon" (its official and generic names are the same) have included fishing, crabbing, clamming, the cutting of mangrove wood for charcoal and boat timbers, and serving as a protected anchorage for local boats, particularly as a hurricane refuge. Since the 1960's, however, development of the watershed and shores has proceeded virtually unchecked. Upland slopes, valleys and flood plains were bulldozed for two shopping centers, thousands of residential sites, and roads. Mangroves were cut and buried by backfill to create marinas, docks, a sewage treatment plant, roads and a racetrack. Coastal salt ponds were also filled. More people and more boats (Figure 3) created a need for new service facilities, i.e., more fresh water, more power, more roads, more parking, more docks, sewage treatment plants, and septic tanks. These, in turn, have reduced hillside vegetation and created higher residential and commercial densities resulting in more runoff, erosion and pollution. As pressures for development mounted, a series of environmental problems were created, and the Lagoon's traditional ecological values and functions were threatened.

The following are some of the stresses and impacts currently impinging on or present in the "Mangrove Lagoon."



a. Boats in Mangrove Lagoon-Benner Bay.

b. Residential units in Mangrove Lagoon-Benner Bay.

c. Population in the Mangrove Lagoon, Benner Bay and watershed.

Figure 3. Trends in number of boats, residential units, and population in the Mangrove Lagoon-Benner Bay area. (Modified from Nichols and Towle, 1977b.)

- sewage pollution from anchored boats, sewage treatment plants, local septic tanks and shore establishments

- release of toxic trace metals from a municipal dump and boat yards, and local debris scattered around lagoon margins and watershed

- discharge of petroleum products, i.e., oil, gasoline and grease from boats, shore spillage, bilge discharge

- declining water quality, i.e., high turbidity, low transparency and low oxygen content, and rising indices of coliform bacteria

- growths of filamentous algae associated with high nutrient pollution loads

- sedimentation associated with storm runoff from the watershed and shoaling of the lagoon floor with formation of a black mud blanket

- disturbance of vital mangrove habitats by bulkheads, dumping and landfill to create dock space, berthing facilities and useable land

- loss of productive inshore clam and fishing grounds and reduction in vitality and diversity of bottom biota

- restriction of drainage with loss of flushing capacity and stagnation of backwaters favorable to mosquito breeding

- shoaling in the entrance channel which limits boat traffic and, in turn, marina use and economic viability.

Figure 4 schematically displays these current stresses and impacts in relation to contemporary lagoonal uses.

What is most notable, however, is not that the Mangrove Lagoon has deteriorated in an accelerated fashion but that this has happened within the context of a full spectrum of well-funded, well-intentioned, regulatory and control mechanisms, of planning, zoning, permitting, research and environmental assessment procedures, and after 1978 a formal Virgin Islands coastal zone management program designed and funded by the U.S. federal government.

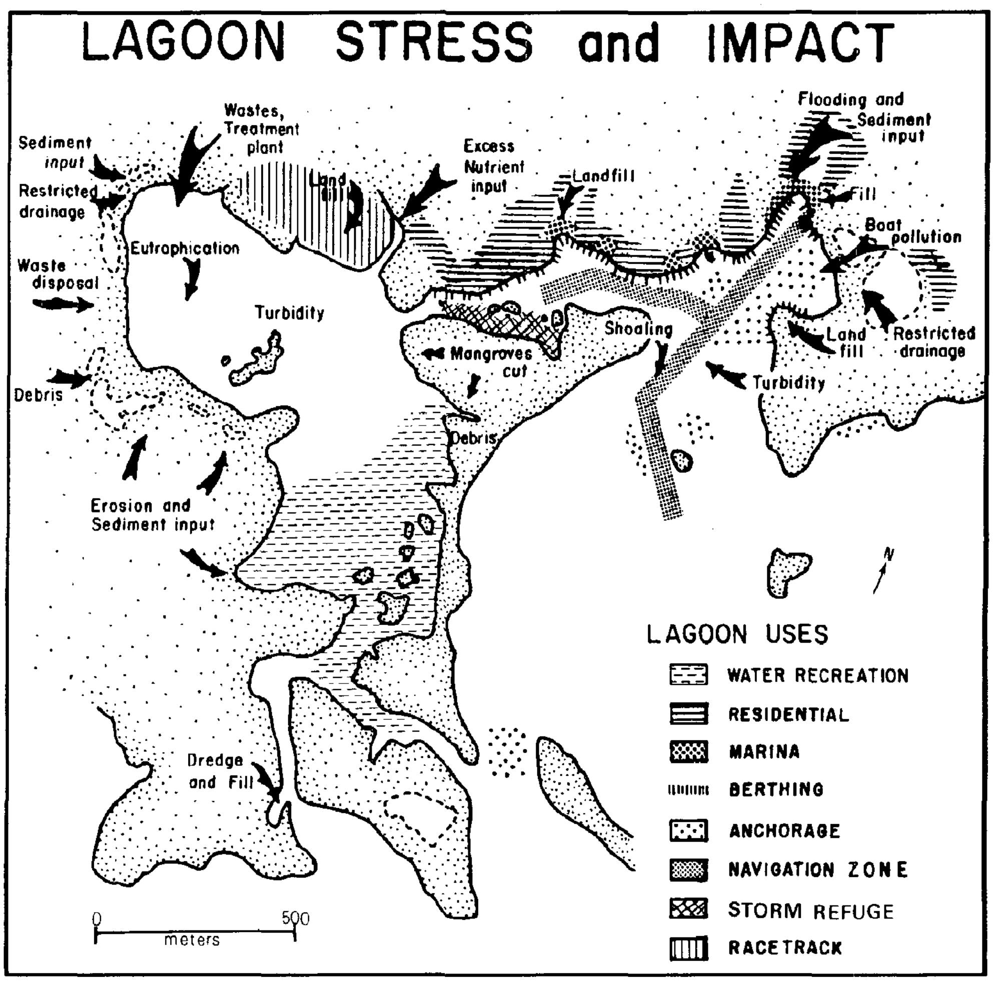


Figure 4. Schematic summary of stresses and impacts on the Mangrove Lagoon and Jersey Bay area, St. Thomas, 1983. (Modified from Nichols and Towle, 1977b.)

What went wrong? What can be learned from the labyrinth of emerging interactions between the users, the planners, the managers, the off-island exogenous factors and forces, and the natural ecosystem? It would appear that the management system was overwhelmed. Was it for internal or external reasons?

What follows is a fairly detailed description of the metamorphosis of an island lagoon/watershed system undergoing rapid change. It suggests that we can learn from experience, and it demonstrates that good intentions and local legislation, research and planning are not always enough to prevent the degradation of an island ecosystem in the face of externally generated and funded development pressures. It also stands as a kind of biography of an insular ecosystem that has inadvertently been pushed beyond its natural carrying capacity threshold into a new behavioral mode of a highly stressed, man-modified system requiring continous human management inputs of a costly and remedial nature.

4.2.2 Description of the Lagoon System

The Mangrove Lagoon with its contiguous passages, bays and backwaters forms a triangular estuarine system 2 km (1.2 miles) long and about 1.3 km (0.6 miles) wide overall. Because the shores are very irregular the average width is less than 0.5 km. The system lies in a northeast-southeast trending fault zone of sedimentary fill at the mouth of Turpentine Run, the largest perennial stream on St. Thomas. Mangrove fringed islands and shallow waters form an embayment in the coast which contrasts with the pattern of steep, rocky headlands and narrow sand or cobble beaches along the rest of the south coast of St. Thomas.

Together with Cas Cay and Patricia Cay, Bovoni Cay separates the Lagoon from Jersey Bay and the sea creating the quiet water necessary for extensive mangrove growth and the development of a safe harbor for small boats. Table 2 summarizes the geographic and hydrographic dimensions of the Mangrove Lagoon and Benner Bay.

Since the Lagoon is linked to the sea and to the watershed, contiguous upland drainage basins or "watersheds" and the waters of Jersey Bay are also considered. The standard geographic element is the ecosystem,

Table 2. Summary of geographic and hydrographic dimensions for the Mangrove Lagoon and Benner Bay systems. (Source: Nichols and Towle, 1977b.)

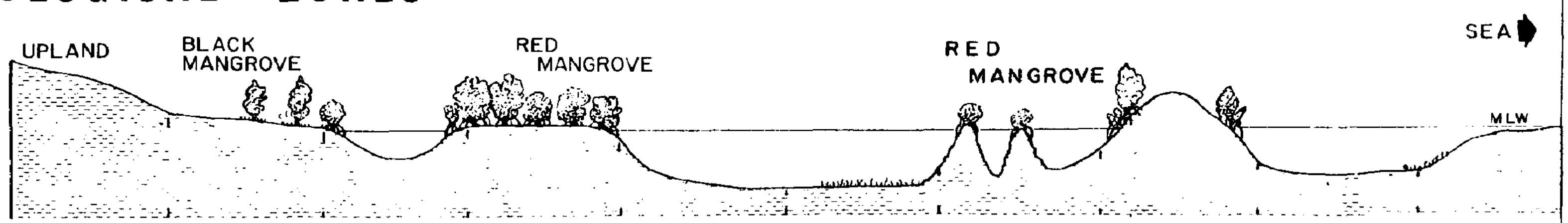
Parameter	Mangrove Lagoon (including passages)	Benner Bay
Length	1.6 km	0.4 km
Width	0.35 - 1.0 km	0.15 - 0.30 km
Water Area (Mean Low Water)	614,339 m^2	128,891 m^2
Water Area (Mean High Water)	809,471 m^2	135,607 m^2
Water Volume (below MLW)	805,675 m^3	160,394 m^3
Mean Depth Overall	1.3 m	1.3 m
Maximum Depth	3.2 m	2.2 m
Mean Tide Range	0.27 m	0.27 m
Tidal Prism	191,238 m^3	35,713 m^3
Shoreline Length (MLW)	1,374,641 m	13,201 m
Watersheds (total surface)	12.7 km^2	0.8 km^2

embracing all the biologic and physical components in the Lagoon which act together as an ecological unit; no single part of the system operates independently. The concept of a "coastal ecosystem" employed herein is that defined by Clark (1977) as including "... (1) a defined water basin (or series of interconnected basins), (2) all marginal (shoreline transition areas, and (3) all shoreland watersheds that drain into the coastal basin."

The lagoonal complex involves a series of ten ecological zones or units. These units are all linked by the flow of water and other human use. Table 3 summarizes attributes of these zones and their relative position with respect to each other, to water depth, and to distance seaward. Proceeding from greatest elevation, they are: the upland Tutu Valley area, a primary drainage basin called Turpentine Run with cactus and secondary scrub growth, the high tidal flats and salterns which are dominated by the black mangrove, the several ponds and inner lagoons which are edged by the red mangrove forest and swamp. There is also an open-water lagoon which contains turtle grass flats and manglar (barrier) cays. Between Bovoni Cay and Patricia Cay and between Patricia Cay and

Table 3. Ecological zones of the Mangrove Lagoon (from Nichols and Towle, 1977b).

ECOLOGICAL ZONES



ATTRIBUTES	DRAINAGE BASIN	HIGH TIDAL FLATS "SALTERNS"	PONDS & INNER LAGOONS	MANGROVE FOREST & SWAMP	OPEN WATER, LAGOON & BENNER BAY	GRASS BEDS (LAGOON) THALASSIA	MANGLAR CAYS	BARRIER ISLAND	PASSAGES, ENTRANCE CHANNELS	BACK REEF FLATS
AREA IN ACRES	3,334	10.7	14.34	49.9	183.0	11.0	4.5	15.3	14.8	10.4
WATER DEPTH OR **ELEVATION**	Range 0 to 260	Range 0.2 to 0.4	Range 0.1 to 0.3	Range 0 to 0.3	Mean 1.3	Mean 0.8	Range 0 to 0.3	Range 0.3 to 2.6	Range 0.2 to 3.2	Range 0.1 to 0.3
DRAINAGE OR FLUSHING	Intermittent	Partly Covered on Spring & Storm Tide	Slow	Red Mangrove. Covered with water most of year	Slow to Moderate	Slow to Moderate	Covered by Normal Tides	Rapid Drainage	Moderate	Rapid
SUBSTRATE OR BED SEDIMENT	Gravelly Clay Loam	Clay & Silt	Organic Muck	Peat	Mud, Sandy Mud, Muddy Sand	Muddy Sand Sandy Mud	Peat, Sandy Mud	Sand	Sand	Rubble, Sand
DISTINCTIVE ECOLOGICAL CHARACTER & FUNCTION	Dry Forest with Cactus, Secondary Snrub growth	Barren or Algal Covered	Bird and Wildlife Habitat	Forest Cover, Nutrient Production, Shore Stabilization	Plankton Habitat, Feeding and Nursery Area	Confinement, Nursery Habitat, Production, Nutrient Storage	Nutrient Production, Shore Stabilization, Sediment Trap	Storm Barrier, Sand Storage	Water Exchange, Feeding Area	Storm Barrier, Sediment Trap, Feeding Area

the mainland are entrance passages that lead to the back reef flats at the several "false entrances" (open but too shallow for boat traffic due to coral reefs). Much of the circulation for the Lagoon comes across these shallow reef systems in the form of wind driven currents.

The lagoon system acquires some of its water and much of its sediment from the upland watershed or drainage basin. Because the Lagoon is linked to the watershed, changes in topographic and flow characteristics of the watershed affect many functions in the Lagoon itself. Fresh water inflow governs the salinity of lagoon water which, in turn, affects the types of organisms in the Lagoon, their distribution and abundance. Additionally, the amount of sediment, nutrients, organic debris and some pollutants carried into the Lagoon is determined by stream runoff. These materials affect lagoon water quality, sedimentation rates, and plant production.

The drainage basin receives an average of about 40 inches of rainfall annually, but as much as eight inches has been recorded from a single 24 hour storm. Annually runoff amounts to only two to eight percent of the rainfall. The drainage system of the Mangrove Lagoon and Benner Bay consists of four sub-basins (Figure 5). Most stream channels are dry and carry only intermittent storm runoff. The Lagoon receives drainage conveyed through small guts or washes, through local culverts, and through a major stream channel--Turpentine Run. Most runoff in Turpentine Run infiltrates the soil and alluvium (Jordan and Cosner, 1973). Only major storm runoff, resulting from infrequent rainfalls totaling more than four inches, reaches the Lagoon as surface flow.

Intense development in the upper drainage basin of Turpentine Run (the Tutu area) has increased the potential for flash flooding into the Lagoon. By destroying the naturally absorptive soil and vegetation cover with construction of roadways, parking lots and roofs, and by lining stream beds with concrete, flood water from torrential rains is delivered to the Lagoon quickly (Nichols et al., 1979a). Most watershed sediment so supplied to the Bay is fine-grained silt and clay, and by remaining suspended in Bay waters the fines degrade water transparency.

Prior to 1968, flood drainage from Turpentine Run entered the La-

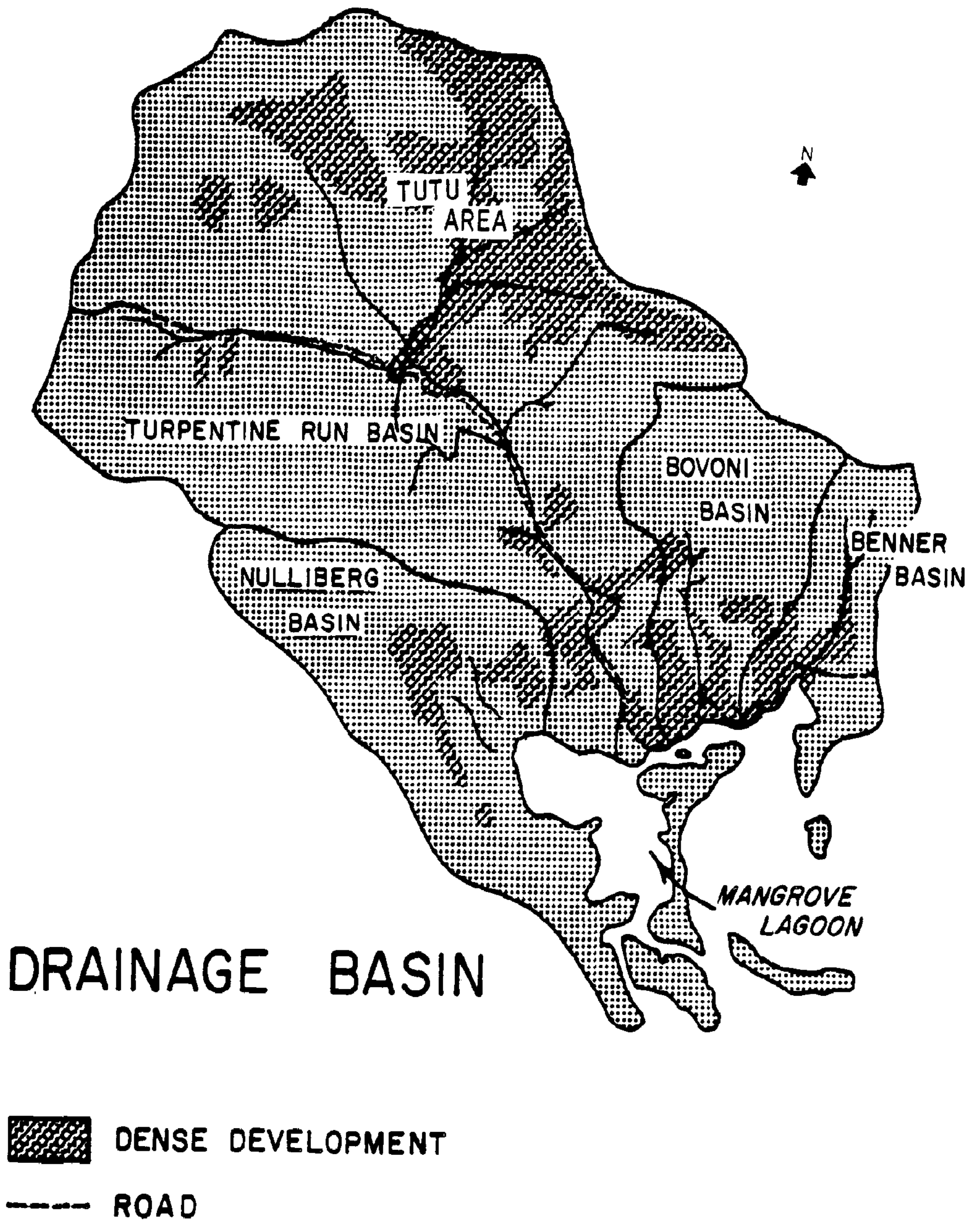


Figure 5. Drainage basins of the Mangrove Lagoon and Benner Bay, with areas of dense residence. (Source: Nichols and Towle, 1977b.)

goon through two or more vegetated distributary channels across an alluvia delta with mangroves. These shallow channels and the mangroves acted like a filter to cleanse the runoff of sediments and debris. When fill for a potential horse racetrack was dumped on the delta in 1968, drainage was short-circuited through a single channel directly to the Lagoon (Figure 6). Thus, the cleansing action of the distributaries was lost.

Some lagoonal circulation is wave driven. As waves enter Jersey Bay, they "feel bottom" and are refracted into gently curved patterns with crests more or less parallel to the bottom contours (Figure 7). Because of the narrowness of the west entrance channel and protection provided by Manglar Island and adjacent shoals, waves do not enter Benner Bay under normal conditions. Bovoni Cay excludes waves from the Mangrove Lagoon proper.

Although tidal forces are small compared to wind and wave transport over the reef, they are the most persistent force over the long term. They are also the main force during periods of light weather, a time when "worst case" conditions for exchange and flushing of pollutants develop.

4.2.3 Historical Development

The narrative begins in 1961 when the territory of the U.S. Virgin Islands entered into a dynamic period of rapid expansion and economic growth (stimulated almost exclusively by external factors) in three sectors--government operations, light manufacturing (assembly) exports, and tourism. In the case of tourism, growth rates were exponential, measured in tourist arrivals and accommodations. Massive U.S. government funding was also made available for public housing, roads, educational facilities, sewage treatment plants, health care and other human services. Additionally, U.S. tax incentives favored external investment in the Virgin Islands.

As a result, between 1960 and 1980 the population of the Virgin Islands doubled, and the employed labor force tripled. Electricity demand increased at an average of 20 percent per year. Thousands of new individual housing units were built. Public housing for 20,000 residents was constructed utilizing federal funding. A new 750 thousand barrel a

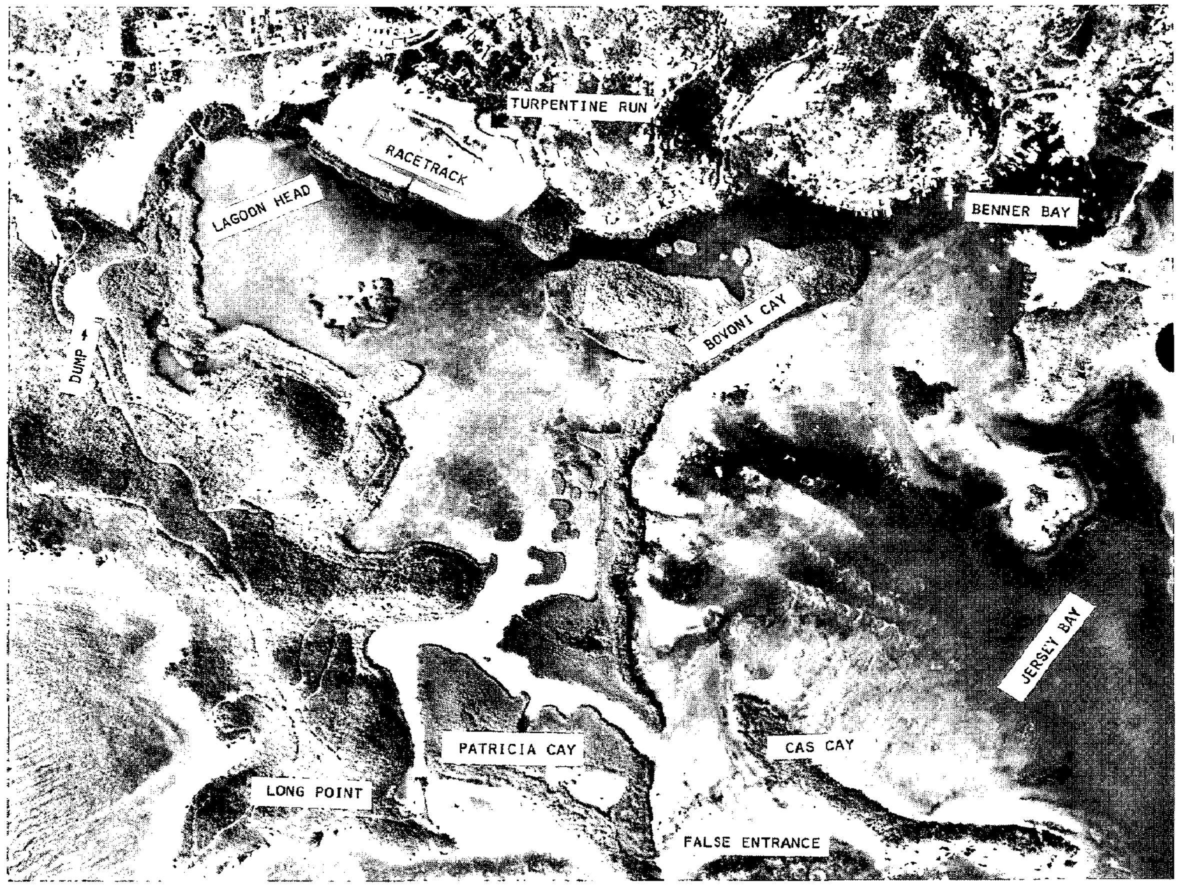


Figure 6. Aerial photograph of the Mangrove Lagoon and Benner Bay taken by the National Ocean Survey, November 23, 1972. (Source: Nichols and Towle, 1977b.)

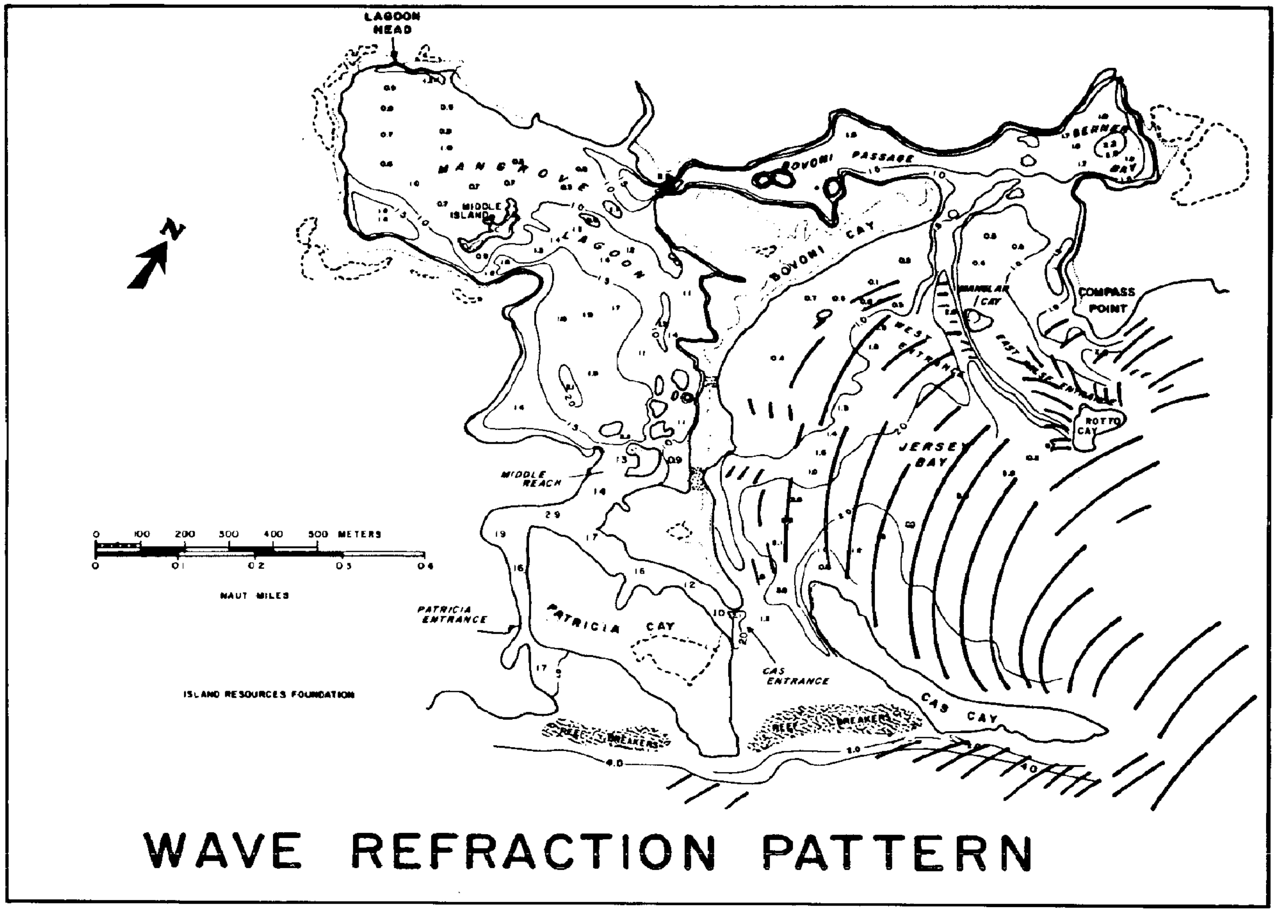


Figure 7. Wave refraction pattern for easterly swells reproduced from NOS aerial photographs of 1958 and 1974 (from Nichols and Towle, 1977b).

day oil refinery was sited on St. Croix (one of the three major islands within the territory of the U.S. Virgin Islands), adjacent to a new bauxite processing plant. Most standard indices for the Virgin Islands' economy had literally taken off, and the territory became increasingly dependent upon the mainland. As McElroy and Albuquerque (1983) have noted, "... the tourism base became pervasive ..., new ties were forged with national travel, financial, and transport interests..., federal social service and regulatory programs were institutionalized... [and] manufacturing activity (petroleum and aluminum refining) tied the territory inextricably into the global energy and raw materials markets." Although attenuated by the mild world-wide economic recession of the early 1970's, the process of accelerated growth has been sustained at only a slightly reduced level through the present time.

Sometime in 1967 the Governor of the Virgin Islands determined that the existing St. Thomas airport at Lindbergh Bay, on the island's southern coast near to the capital of Charlotte Amalie but removed from most major beaches and resort hotels, was unsafe and unsatisfactory and that a new international airport that could accommodate larger jet aircraft should be constructed at some alternative location. Engineering studies by off-island firms recommended that a new airport be constructed on the south shore of the Mangrove Lagoon on the easterly end of St. Thomas' shoreline. This would be accomplished by leveling Patricia and Cas Cays and Long Point and filling in intermediate reefs and the false entrances to build a runway which would have a more or less east-west axis, extending into 50 feet of water in Stalley Bay (Figure 8). It was a major engineering undertaking.

At the time no attempt had been made to assess the environmental impact of the proposed jet airport construction, and a bitter controversy in the community emerged which lasted the better part of two years. The resulting public debate evolved into rancorous polarization between the so-called growth vs. no-growth factions, between the environmental purists and the developers concerned with jobs, the economy, and human resource development.

Local opposition to the proposed airport resulted in the letting of

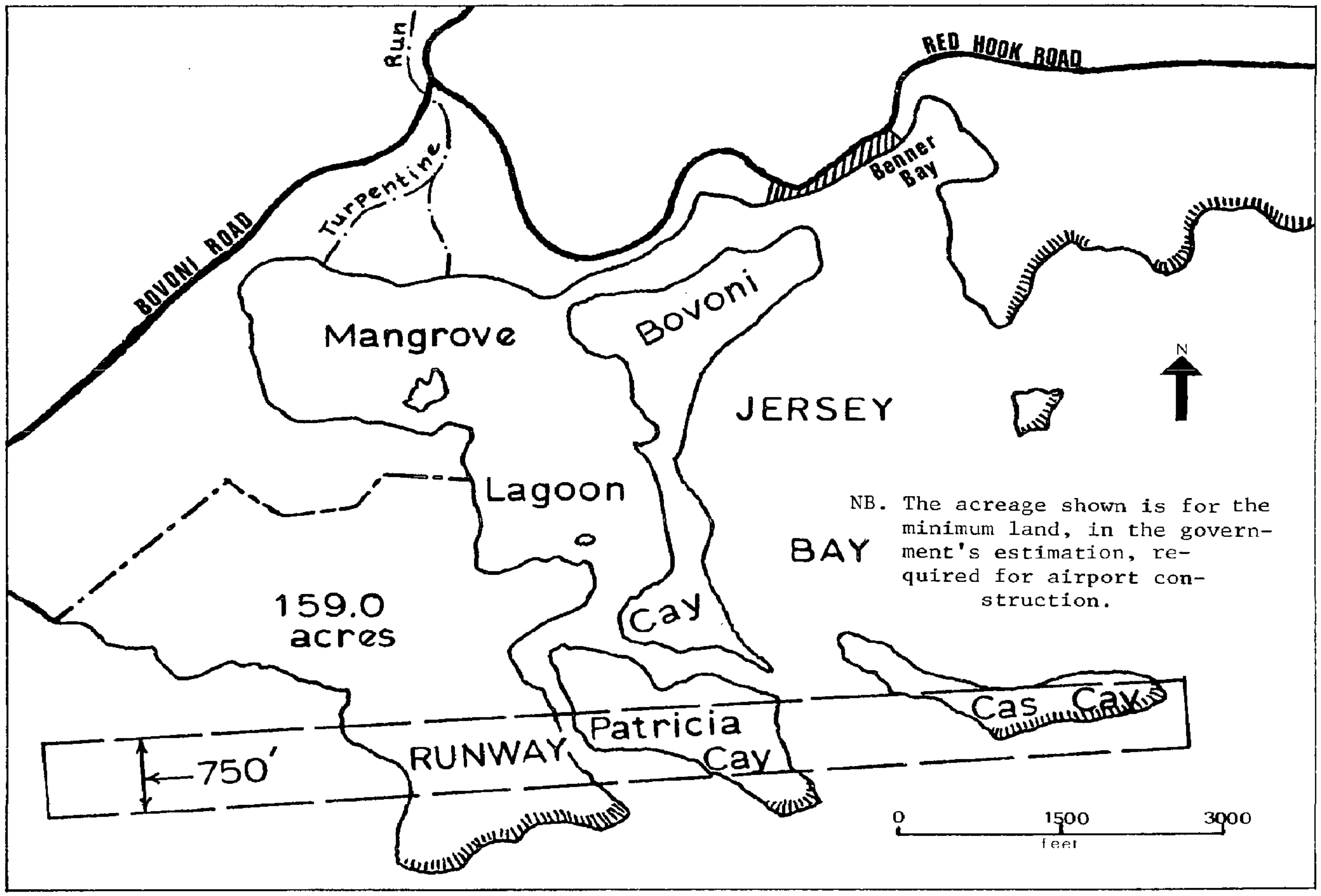


Figure 8. Mangrove Lagoon runway orientation for proposed St. Thomas jet airport, 1968. (Source: Tabb and Michel, 1968.)

a contract by the Governor's Office to the University of Miami in February of 1968 for a preliminary environmental assessment which resulted in a survey of the floral, faunal and hydrographic features of the Mangrove Lagoon. The consultants' report (Tabb and Michel, 1968) can be summarized as follows.

1) Turbidity from the silty clay component in the hill masses scheduled to be excavated and used for runway site fill would affect the entire bay area and, if prolonged, could have serious ecological consequences.

2) The construction of the airport would require paving over massive portions of the adjacent hillside areas, resulting in accelerated freshwater runoff in times of heavy rainfall, which would further aggravate pollution problems and result in nutrient enrichment (including sewage).

3) High water clarity and the natural seawater circulation were absolutely vital to the continued biological well-being of the Bay.

4) To conclude that conditions within the Bays might be improved by the addition of nutrient materials such as sewage was an unwise assumption.

5) The circulation pattern of the Mangrove Lagoon and the western part of Jersey Bay was dominated by the water transport induced by breakers on the shoals between the mainland and Patricia Cay and Patricia and Cas Cays. Transport from these breakers flows into Jersey Bay and the Mangrove Lagoon, overcoming the normal tidal flows and owing its existence to a rare combination of topography and wave characteristics coupled with a diurnal tide of a very small amplitude.

It is understandable that the Virgin Islands Governor's Office was unhappy with this report. An effort was made to seek a technological solution to the problem posed by the closure of circulation along Patricia and Cas Cays by the proposed airport project. An engineering consultant suggested the possibility of establishing an artificial wave run-up ramp and empondment on the seaward side of the projected runway, with a tunnel or sluiceway to be constructed under the airport runway itself. Such a scheme would <u>theoretically</u> maintain the pattern of water flow into the Lagoon and thereby maintain the normal circulation regime within the Lagoon itself (Michel, 1970).

At the same time, as the public debate continued, a worried voice was heard from a new direction, namely, from the island of St. John which lies immediately to the east of St. Thomas and directly under the path of the projected take-off patterns for the larger jets which would use any new airport at the Mangrove Lagoon. The U.S. National Park on St. John and a luxury resort hotel at Caneel Bay, St. John, were uneasy and quietly requested a U.S. Department of Interior, Fish and Wildlife Service study team to visit the Lagoon to provide further documentation on its ecological value.

The study team reported that "the Mangrove Lagoon is easily the most significant [mangrove] area remaining and is, in fact, very near the only stand of appreciable size that remains in the American Virgin Islands." They also found that "the Mangrove Lagoon is in fact the major remaining habitat in the northern U.S. Virgin Islands for about twenty species of herons, egrets, and other waterbirds and an equal number of wintering and migratory species." The U.S. Fish and Wildlife Survey experts expressed concern for the loss of habitat for waterbirds that live on Cas Cay and the adjoining waters of the Mangrove Lagoon, noting that encroachment on their habitat had already brought the population of many of these birds to extremely low levels (McNulty et al., 1968).

The administration was sufficiently confident with its position on building an airport in the Mangrove Lagoon that it purchased the land at Long Point, the focal point of the proposed facility. It also established a Port Authority so that it would be in a position to build and manage the new airport. However, the Governor was to discover that it was easier to decide to build a new airport than to find the money to construct it. During the ensuing, rather extended, delay yet another study of the Mangrove Lagoon, involving nine months of field work, was carried out by the research arm of the local college, the Caribbean Research Institute. The final report from this survey (Grigg et al., 1971) more or less coincided with a year long down-turn in tourist air arrivals and with acknowledgment by the administration that it had not been able to identify the necessary funds for airport construction.

The environmentalists and most residents of the Lagoon area were elated, assuming the Mangrove Lagoon was now out of "danger" since no new airport would be located there. But the government purchase of a key parcel of land at the Lagoon was a harbinger of other things to come --other incremental kinds of change and new pressures to "use" the now government-owned land in the Lagoon, if not for an airport then for whatever was convenient. Further, the territory-wide accelerated growth pattern, especially for the island of St. Thomas, was rapidly subsuming the Mangrove Lagoon and its watershed. Local planning, resource management, and environmental protection agencies were simply overwhelmed by the process of change. They were unable to deal with the pace and magnitude of growth, landscape alteration, and resultant environmental impacts generated by outside, off-island factors and funding.

Between 1970 and 1971 the number of boats in the Lagoon had doubled, and a new full service marina (Antilles Yachting Services) and three new bare-boat chartering operations had started up in the Benner Bay area, with construction just beginning at another marina at Compass Point. At the northern end of the Lagoon, a fair-sized residential community was developing, serviced by a 70,000 gallon-per-day sewage treatment plant operated by the Virgin Islands Public Works Department, with its allegedly treated effluent draining into "polishing" ponds near the Lagoon's edge. At the other end of the watershed, in the Tutu Valley area, a massive residential and commercial building boom was under way. The population of the drainage basin, which had been about 4,000 in 1960, had doubled by 1971. No one foresaw that it would almost double again by 1980, reaching 15,000 persons (nearly one-third the population of St. Thomas). This substantial growth would also eventually spur demand for several new sewage treatment plants (funded largely by the U.S. government) and thousands of septic tank installations in both the coastal and more remote watershed housing units and smaller commercial establishments.

Local environmental agencies had been concerned for some time about the problem of how to handle domestic and commercial sewage and waste water from burgeoning new "point sources" in the Lagoon watershed area.

Signals from the Washington-based federal agency concerned with territorial "sewage problems" favored a "treatment" instead of a "disposal" strategy. Unfortunately, the former strategy was inappropriate for island systems. Therefore, instead of opting for a low-cost ocean outfall disposal strategy (appropriate for offshore islands) for raw macerated sewage, local government authorities were forced to accept the federally "approved," standard continentally based approach of a fairly sophisticated system of complex aerobic/ mechanical sewage treatment plants, which are costly and energy intensive. Unfortunately, isolated, upland units require polishing ponds which use up limited land area, and larger "downstream" coastal treatment facilities still require short ocean outfalls for final disposal of the partially treated effluent.

Most of the subsequently built sewage treatment plant systems were not designed for tropical environments, rarely performing to design specifications and with a fairly high rate of breakdown. Furthermore, they require a high degree of operator skill if they are to be maintained and remain functional. As a consequence of periodic, often extended electrical power outages, a not uncommon phenomenon in island areas, raw untreated sewage often passes directly into associated polishing ponds or the coastal littoral environment.

Many of these problems were anticipated locally, but because the external funding sources pressed for use of standard continental criteria and preferred technology, the island got what it did not need --a high cost, high technology, breakdown prone, decentralized management nightmare of a system. The Virgin Islands could and probably should have opted for the World Health Organization (WHO) strategy which encourages island areas to avoid elaborate treatment systems and use well designed, long ocean outfalls for disposing of macerated and chlorinated raw sewage, preferably below the coastal thermocline (as, for example, in the case of the Cook Islands [Raratonga], Western Samoa [Apia], and Papua New Guinea [Lae]).

The Virgin Islands did not, however, choose to reject the "inappropriate" sewage treatment strategies imposed from outside (to do so would have reduced funding levels), and the Mangrove Lagoon watershed was to eventually have a total of five government operated systems--all disaster prone and difficult, if not impossible, to run efficiently.

In the meanwhile, within the Mangrove Lagoon itself (more than half of which was bounded by privately owned land), development activities were expanding, stimulated by various U.S. (off-island) tax policies favoring "charter boat" operations. By 1975, Antilles Yachting Services, a large marina operation based in the Lagoon at Benner Bay, applied for a permit for expanded facilities. The environmental assessment report accompanying the permit application emphasized that because there were so many other large-scale pollutants entering the Lagoon area from the watershed runoff and from the malfunctional, government-operated sewage treatment plant at Bovoni and from the government's solid waste disposal facility at Long Point, the pollution contribution from their own modest proposal of a few docks and a little bulkheading was very small by comparison and would not make a substantial difference (Insular Environments, 1975b). They were in fact saying, "Why single us out?" The implication was that the larger pollution sources in the area, resulting from ongoing government activity, should be dealt with first in coping with the general deterioration of the ecosystem.

But even as these events were occurring, there seemed to be new hope for the Lagoon from a different direction. Stimulated by the passage of the federal Coastal Zone Management Act of 1972, the local territorial government elected in 1974 to apply for the necessary planning grants to implement a Virgin Islands Coastal Zone Management Program. Under the aegis of the local Planning Office, a team was assembled and contracts let for specialized planning studies. The first of these, completed in 1975 (Towle, Grigg, Rainey et al., 1976), suggested that the "Mangrove Lagoon" be considered as an "area of particular concern" (APC).

By June of 1977 the Virgin Islands had completed its preliminary Coastal Zone Management Program Plan (VI Government Planning Office, 1977) which, after extensive public hearings and extended legislative debate, was approved in October 1978. The program consolidated and centralized the local permitting process for development projects, officially identified so-called "areas of particular concern" (including the Mangrove Lagoon), laid out the requirements for more elaborate environmental impact review documents to accompany permit applications for development activities, and provided criteria for restricting development in the coastal zone to water-dependent uses. Once the planning phase was completed, the administration of the program was turned over to the Virgin Islands' environmental agency, the Department of Conservation and Cultural Affairs (DCCA).

Many observers believed that with the advent of the Coastal Zone Management (CZM) Program, piecemeal development and mismanagement of the Lagoon watershed would be a thing of the past. The future of the ecosystem, however, remained at risk without remedial action to reduce pollution loading.

The U.S. Environmental Protection Agency (EPA) (through the Virgin Islands Department of Conservation and Cultural Affairs) funded two studies to address the problem of pollution loading (Nichols et al., 1979a and 1979b), but neither had any observable effect on either the expanding operation of the solid waste disposal facility or on the increasing volume of sewage and nutrients discharged into the watershed by the government-operated sewage treatment plants. These plants continued to be hydraulically overloaded and to malfunction and, in some cases, to not function at all for extended periods.

Finally, the Department of Public Works, which was officially charged with responsibility for managing both the solid waste disposal site at the Lagoon head and the five sewage treatment plants in the watershed (at that time), continued to have problems. The Department was hard pressed to find man-power, funds, and facilities to address the dramatic increase in solid waste generated on St. Thomas. Volumes rose from 100 tons per day in 1971 to over 150 tons per day in 1981 and up to 200 tons per day by 1984. The burdens imposed by the continual operation of sewage plants running at 120 to 150 percent capacity and by the frequent power outages due to mechanical failures at the power plant also proved difficult. Furthermore, because local hotels were required under the Virgin Islands Environmental Protection Act to install package sewage treatment plants, the Public Works Department was continually training sewage plant operators, only to lose them to the private sector.

Lastly, it must be remembered that the Mangrove Lagoon was only one of many stressed areas in the Virgin Islands through this entire rapid growth period, causing the agencies involved to divide their interests, forces, and finances between the three major islands of St. Thomas, St. Croix, and St. John.

The foregoing discussion presents the context for the next series of impacts on the Lagoon which brings the current case study to what we call the remedial phase. In the early 1980's, the territorial government obtained funding for a new hospital to be located on the outskirts of the capital city of Charlotte Amalie, St. Thomas. The site was then occupied by the island's only horse racetrack, a very popular, heavily used facility for local racing enthusiasts. Because time was of the essence in commencing construction of the hospital, a quick decision was made by government to move the racetrack to the Lagoon. The reasons appeared sound: the government owned the land (which made it convenient) and, further, there was a partially completed racetrack there already. It had been started by the Department of Public Works in 1968 in the mangrove wetlands at the lower end of Turpentine Run, but terminated because the local government had failed to secure necessary federal permits.

The government's hastily assembled environmental assessment report, accompanying its coastal zone permit application in late 1980 for siting the racetrack in the Lagoon area, argued that it was Public Works Department's sewage treatment plant, immediately to the west of the racetrack site, that was causing all the problems in the Lagoon. The only irreversible environmental effect of the racetrack would be to diminish the area available for nesting birds. The Coastal Zone Commission granted the permit in early 1981. Public confidence in the efficacy of the Virgin Islands CZM permitting process was not enhanced.

It is ironic that just two months after the Coastal Zone Commission permit was issued for the racetrack, the senior planner of the Division of Coastal Zone Management completed and circulated for review his very detailed "management plan for the St. Thomas Mangrove Lagoon area of particular concern" (Teytaud, 1981). The plan was too late to have any effect, too complex for efficient application, and too removed from prevailing uses and management requirements to enjoy acceptance as a workable plan of action or for controls.

As water quality continued to decline and shoaling accelerated, DCCA came under increasing pressure from a newly formed, private sector Benner Bay/Lagoon Marine Industry Association and others to take more direct action to reduce Lagoon pollution loading and also to permit a deepening of the access channel by dredging. DCCA turned to the U.S. Army Corps of Engineers District in Jacksonville, Florida, with a request to study the feasibility of improving the flushing of the Lagoon. Proposed modifications included widening and deepening the Lagoon channel to Benner Bay and dredging a turning basin at the end of the Bay. The Corps responded favorably and promptly launched a preliminary reconnaissance survey. Their September 1982 report (U.S. Army Corps of Engineers, 1982) documented approximately 400 boats docked in the Bay, the majority of them in excess of 28 feet in length. To quote the report:

> Benner Bay is one of the three major harbors in St. Thomas. It provides docking and anchorage for a large portion of the charter sailboats in the islands and, in times of severe weather, serves as a vital harbor of refuge for many additional boats. The bay also houses five commercial marinas and one of the few boat-hauling and complete service repair facilities in the Virgin Islands. Since a large percent of the boats in the islands have drafts in excess of five feet, shoaling in the bay has greatly curtailed its usefulness as an anchorage both in emergencies and on a long-term basis. In addition, economic growth of the existing marine-related businesses in the area has suffered from the inability of deeper draft vessels to enter the bay.... Shoaling in the bay is also suspected to have contributed to the environmental degradation of the area by decreasing the flushing rate of the bay and the adjacent mangrove lagoon.

The Corps estimated that 45,000 cubic yards of material would need to be excavated, costing $160,000 for final planning and engineering studies plus an additional $495,000 for dredging and construction costs, plus incidentals, for a total of $655,000. It would take two years, however, just to complete the detailed project plan. The "remedial action" phase of Lagoon management was fast approaching.

The local marina operators found two years to be somewhat long for simply a planning phase and opted to do it themselves. The idea was, however, expanded to include an additional dredged area for ninety new boat slips, but the permit application to the Government was rejected, in part because of rising concern within DCCA about the number of moored and docked live-aboard boats used as residences. The agency believed that live-aboard boats were contributing significantly to the growing pollution problem in the Lagoon. Concern was laid to rest, however, in 1983, when an EPA funded study of vessel wastes in the territory demonstrated that while the Lagoon's boat population had risen in one year from 400 to 481 vessels, only 81 were live-aboards. Furthermore, the aggregate Biological Oxygen Demand (BOD) loading from all boats was only 8.6 lb/day, while at the Lagoon head, the combined loading of the sewage treatment plant and Turpentine Run effluents was 455 lb/day, or 98 percent of the problem (Wernicke and Towle, 1983).

With few options left open, and with public pressure mounting concerning both the public "dump" and sewage pollution at the Lagoon head, the government was forced to take action. It elected (with U.S. federal funding) to "eliminate" the dump by building a "high-tech" 350 tons per day solid waste incinerator/energy recovery plant (to make fresh water by seawater desalination) and elected to eliminate the "sewage" problem by building yet another high technology, centralized sewage treatment system (replacing all existing smaller plants which would be abandoned). The total estimated cost is 25 million dollars. The two proposed facilities are to be located at the Lagoon head shoreline (the old "dump site"), on the land previously purchased by the government for the aborted jet airport (Virgin Islands Planning Office, 1983).

As for the Mangrove Lagoon, its days are clearly numbered, and in one--perhaps two--decades it will have more facilities than fish, more boats than birds, and more modifications than mangroves, requiring ever more costly pollution control and continuing remedial measures (like dredging) to do what nature once did for free.

4.2.4 Retrospective Conclusions

In the first place, there was a conceptual failure by almost everyone to perceive the Lagoon and its associated watershed as a system of connected and related parts (some more critical than others). This resulted in a sequence of structural design failures in virtually every management sector or agency concerned with the Lagoon "sink" at the lower end of the watershed.

For example, the natural scientists who produced the approximately 20 research reports, monitoring documents, and development impact assessment studies between 1968 and 1983, with only two partial exceptions, failed to address the totality of the ecosystem, focusing only on the "effects" manifested in the Lagoon. The Mangrove Lagoon without its watershed may have been a useful and convenient study framework but it was not a satisfactory resource management model.

As a consequence, there was a tendency to measure and count the wrong things and not to quantify others. In studies of the Mangrove Lagoon there were elaborate scientific measurements and quantification of waves, currents and fisheries, of fecal coliform and other water quality parameters, and of the distribution of benthic and pelagic organisms, sea grasses, algae, and mangroves. But it might have been more useful to count fewer fish and algae, and to allocate more time and effort to count the number of site development permits, septic tanks, and housing units, and to measure periodically the devegetated areas in the uplands, as well as look at things like commercial effluents, stream flow and sediment loads in Turpentine Run. An assessment of the driving variables and trends in the whole system would have been more useful than just measuring their impacts on the aquatic system at the lower end of the watershed.

Even with this expanded focus, the task of data analysis leading to a determination of significance and to implications for management would have remained at risk because natural scientists are not accustomed to, skilled at, or comfortable interpreting these kinds of data. A team effort involving planners, resource management technicans, and natural and social scientists was required, but the terms of reference for most studies rarely encouraged or even permitted such an approach.

Both the planning and management systems failed to conceptualize the ecosystem as a "watershed unit" and therefore proceeded over the years to look at the phenomenon of growth in the area through an artificial framework of "census enumeration districts" and zoning districts and codes designed in 1970 but never modified in the face of emerging concentration and density factors in the "Turpentine Run/Mangrove Lagoon ecosystem."

In any event, just the existence of a central, physical or town planning unit (whatever it is called) can give all concerned a false sense of security. This problem is especially awkward when dealing with coastal and marine matters in developing island areas, largely because planning units seldom have staff competent to adddress the complex question of coastal resource planning. This situation is especially bothersome for insular areas undertaking more intensive strategies to develop coastal and marine resources.

As in the case of Rodney Bay in St. Lucia (see Section 4.1), there were also systemic failures in the transition of the Virgin Islands Mangrove Lagoon and its watershed from a low-cost viable natural system to a pollution prone area requiring high-cost engineering interventions to maintain its "utility" to residents and users. Units of the local resource management system (planning, zoning, environmental control, waste disposal, land use, and coastal zone management) were completely overwhelmed by the magnitude of the tasks required in the face of externally generated and accelerated development activity. They never seemed to "catch up" as their functions required more lead time and expertise than were available locally, even though external funding support was ostensibly provided for some elements of their resource management functions.

For example, the establishment of a Virgin Islands environmental management agency, the Department of Conservation and Cultural Affairs (DCCA) in 1968 tended to encourage a false sense of environmental security. It was simply too new and too complex an undertaking to be effective in its early years. The institutionalization of any new, broadly focused and "technically" based government department (or its ministerial equivalent) takes time, is fraught with organizational, funding and staffing problems and is destined for a difficult first decade of trial and error learning, with some successes and many failures. The Mangrove Lagoon was, unfortunately, one of the latter.

DCCA's agenda from 1970 onward was too full to allow the agency to pay much attention to the Mangrove Lagoon (although it did, with off-island funds, support several studies focused on the Lagoon but not properly aimed at the right issues). Therefore, when the new, externally funded Virgin Islands Coastal Zone Management Program was approved in 1978 by the local legislature (based on a three-year planning effort) and assigned to DCCA to administer, those within the agency and those outside concerned with coastal resources somewhat naively assumed that a balance could be struck between developmental pressure and environmental imperatives in coastal areas. Hope may spring eternal, but unfortunately reality creeps in, and in the case of the Mangrove Lagoon, the Virgin Islands' CZM program was fundamentally flawed. Using an external (federal U.S.) model, it split out a relatively narrow "coastal zone" along the land/sea interface into a two-tier demarcation, a) ignoring the fact that, in small islands, the <u>entire</u> island is a coastal zone and b) excluding from the CZM program's purview and permitting jurisdiction the entire inner core of the island and thus most upland "watershed" areas (for example, the most heavily populated segments of the Turpentine Run-Mangrove Lagoon drainage basin).

There was also a technical failure of researchers, planners, and managers to address the full spectrum of driving variables within the system. The numerous studies of the natural system and its changing characteristics produced mostly negative management recommendations of the "don't do this anymore" character, with little concern for how to effect needed changes in user behavior, management structures and policy. At no time was there a systematic investigation of the social system and its characteristics, limits, changes, and driving variables--which were continually interacting with the natural parameters of the Mangrove

Lagoon and its watershed.

Between 1960 and 1984, the Mangrove Lagoon watershed experienced the emergence of a variety of new social units of direct and indirect users of the Lagoon. In 1960 there were only farmers, fishermen and a sprinkling of residents and small commercial establishments (served by septic tanks). By 1984 there were nearly 500 vessel owners, an active marine industry, thousands of low-income public housing residents, thousands of middle-income single family dwellings, thousands of apartment dwellers and owners, and hundreds of commercial businesses. To some, this was progress. But there were numerous deferred or hidden costs, not the least of which was the degradation of the Mangrove Lagoon.

Finally, the Virgin Islands Mangrove Lagoon example illustrates several additional technical problems worthy of mention.

- There was a general failure to recognize the fact that the aggregate effect of degradation in an ecosystem like the Mangrove Lagoon can be worse than the sum. Initially, incremental changes are minimized and considered acceptable because the natural ecosytem is "working" and can handle the changes. But in later stages, larger incremental changes are justified as inconsequential (in the presence of the aggregate pollution effect). The argument is made that by concentrating polluting activities in one location, the use of other still pristine areas for those same activities will be avoided.
- There was a failure of government to abide by its own established rules and to apply the same environmental standards to itself as it requires of the private sector. Permit systems involving subjective judgments by the permitting agency only work well when everyone assumes the procedure is "fair" and "reasonable." When, for example, government agencies subvert this system by manipulating the process through subterfuge, or by applying higher "anti-pollution" or environmental quality standards to others than they are willing to

honor, then the permit system will break down--not in form but in function.

- There was a tendency on the part of all off-island, external development funding agencies involved in Lagoon watershed development to ignore the environmental impact of their lending or grant input. It is almost as if there were a separate set of less stringent rules for "offshore" areas, but, as O'Riordan (1981) and others have noted, it is unrealistic to assume that external (off-island) funding sources and institutions will voluntarily seek to establish the full spectrum of environmental costs or be willing to internalize them, within discrete project budgets. However, until such costs (representing a draw-down on the natural and social systems' capital stock) are identified and quantified, development planning and growth management will continue to generate unanticipated environmental crises, disbenefits and ecosystem losses, leaving islands at risk.
- The Virgin Islands' experience demonstrates that the impact of inappropriate capital-intensive technologies on fragile insular ecosystems will tend to reduce long-term resource flexibility because of the virtually irreversible alterations to specialized and highly complex land/sea ecosystems caused by such intrusions. This dysfunctionality results from the incompatibility of grafting high-volume technologies onto small closed environments with a very limited capacity to absorb the residuals (McElroy, 1978b). As McElroy has noted, "The result is the substitution of man-made inputs for irreplaceable natural ones, and in the long run development options are restricted and perverse feedbacks reduce the viability of environmentally sensitive industries like tourism. Such technological dependence chronically limits future local options" (McElroy, 1978b).

4.3 ECNAMP: A Regional NGO/PVO Participatory Planning Approach

Over the past eight years, the Eastern Caribbean Natural Area Management Program (ECNAMP) has developed as an effective regional approach to island resource assessment, environmental management, and ecodevelopment. It is a private sector initiative supported by the Rockefeller Brothers Fund, World Wildlife Fund, International Union for the Conservation of Nature, UNEP, and others.

ECNAMP was based on an hypothesis (derived from prior experimental activity in Latin America) that, given the pace of Caribbean tourism development and landscape change, a systematic national park and wildlands program was needed in island countries. Such an approach would serve a dual purpose of analysis and action: the process of identification, justification, selection, planning and protecting "critical natural areas" also provided a mechanism for introducing multiple-use resource assessment, strategic planning, and management techniques. Each would be addressed through a non-formal, hands-on, learning-by-doing process. By linking conservationists, local users and institutions, development planners, and unique ecosystem features in a kind of "non-Faustian bargain," both the development and conservation ethics could be honorably addressed in a well choreographed framework of human and natural ecosystem interactions. The whole, it was assumed, would be greater than the sum of its parts.

Essential to ECNAMP's development was acceptance of a long-term approach: a small "force for change" over an extended period of time (three to ten years) would be more effective than a larger force over a short span of time (one to three years). Further, ECNAMP has been structured so that, except in rare cases, a less "qualified" indigenous expert, consultant, or participant was preferable to a more qualified "continental" expert from the outside. Additionally, a locally designed and produced plan (perhaps using external counsel), however simple or imprecise, was preferable to an externally produced, more sophisticated plan or scheme. The entire concept was, in the language of educators, an experiential learning strategy for <u>both</u> the teacher and the learner. Best of all, it has worked!

ECNAMP was originally launched in 1976 by a grant from the Rockefeller Brothers Fund (under the auspices of the Caribbean Conservation Association and the University of Michigan's School of Natural Resources) as the Eastern Caribbean Wildlands Program. It took as its thematic approach the need to define strategic planning programs for natural areas in the Eastern Caribbean. The initial effort embraced a strong conservation theme, with an emphasis on the region's needs and best options for insular park, preserve, and natural area protection and preservation.

By the end of 1980, through the gradual evolution of a rather low-key, "bottom-up" strategy emphasizing participatory components, ECNAMP had emerged more as a process than as a discrete program. It was less of a natural-area protagonist and more an attempt "to stimulate ... creative development ... through the definition and use of socially prudent approaches designed to match the environment's potential" (Putney, 1981). The resultant emphasis has been on the human and social components of the natural resource ecosystem, on the interaction of the human resource base and the natural resource base, and on the development of a sustainable "ecodevelopment" process. In effect, the "island experience" of the early years generated a quasi-reversal of emphasis from wildland protection to ecodevelopment and sustained resource utilization strategies. Even more significant was the shift in focus from terrestrial to marine environments and resources.

ECNAMP's long-term potential as an agent of insular change is based on the premise that strengthening local institutional capabilities will enhance the capacity of an island area to effectively manage its natural resource base. As a catalytic, skills-building effort, the program has developed an integrated series of mutually reinforcing activities. Major program components include research, training, education, mapping, planning and field projects, each designed to strengthen the capabilities of island resource managers (such as fisheries officers and planners) in the Eastern Caribbean. The goal is to foster management strategies sensitive to human needs and economic imperatives which do not exceed ecological constraints.

One of its earliest program components was an inventory and mapping effort, combining locally collected and collated natural resource systems data (for each of 25 island areas in the Eastern Caribbean) with data on established resource users and the human resource base. The resulting output of this survey and mapping project was a series of island data atlases (18 maps per island). Atlases were designed to provide a broad spectrum of information for local and regional policy makers, planners, and resource managers (especially those who had collated and analyzed the data as a training process). The information compiled illustrates the inter-relatedness of both the biological and socio-economic aspects of development activity and encourages a systematic approach to decision making and resource utilization (Putney, 1982).

More recently, ECNAMP program efforts have included non-formal, community-based coastal zone management and environmental education in St. Lucia; assistance to a forestry products crafts industry in Dominica; and a marine parks program for the British Virgin Islands which emphasizes traditional use, economic activities, recreation, education, and research as well as protection of the natural environment. Other projects are an integrated, multi-island, intra-governmental strategy for resource planning and development for Anguilla, St. Barthelemy, and St. Martin/St. Maarten, and a multiple-use development planning effort for the Cabrits Peninsula in Dominica. This last project incorporates an ecodevelopment approach for utilizing the resources of a local fishing community and developing a nearby historic site located within the Dominica National Park.

ECNAMP activities are structured to support a process which is holistic rather than segmented into smaller parts. Its integrated approach to natural resource management emphasizes coordination, with a series of linked program elements carried out within a highly flexible, decentralized management framework to encourage integrated learning and transferability. Dispersed offices and personnel located on several islands in the Eastern Caribbean (Barbados, St. Croix, St. Lucia, Antigua, British Virgin Islands) participate in the program, and affiliated associates can be found in most of the other larger islands of the Eastern Caribbean. Since its inception in 1978, the ECNAMP operation has evolved as a network of collaborating individuals and institutions from the region who cooperate in the ECNAMP framework when appropriate. It uses a talent pool of individuals already in place in the islands of the Lesser Antilles, thus enhancing ECNAMP's ability to be responsive to changing local requirements and to adjust requirements in response to ongoing community-based assessments.

The importance of participatory strategies to all facets of program planning and implementation has been consistently stressed by ECNAMP personnel. ECNAMP strategists recognize that communities, together with government planners, must be an integral part of the decision making process for natural resource utilization. Emphasis has been placed on the use of local community expertise, assessments, and solutions to meet local problems and define local needs. The linking mechanism is a regional networking of indigenous institutions and consultants, responding to community-level needs in designing and implementing program activities in the small decentralized islands of the Eastern Caribbean (Putney, 1981; Towle, J., 1982).

The change process fundamental to development can perhaps best be accomplished within an organizational framework which acknowledges the uncertainty associated with the task of development. An appropriate response to such a risk-bearing environment is a process of ongoing creative adaptation. This is the working model of ECNAMP. Its funding and executing agencies have permitted core personnel to work within an environment relatively free of institutional constraints or plan-specific approaches to resource management. Rather, an experiential, action-based, capacity-building program style has been encouraged. The ensuing climate of innovation and flexibility has permitted ECNAMP to adapt the process en route which has been, in effect, goal enhancing.

ECNAMP is a catalytic development process for natural resource management with increasing emphasis on coastal areas. It is not an organization in and of itself, but it manifests a capacity building framework which is being "institutionalized" as a learning model by a network of collaborating program participants in island areas throughout the Eastern

Caribbean. It is as much a learning process as a doing process and, as such, is a unique program, with replication possibilities, for developing island areas (Towle, J., 1982).

Its most recent publication, "Guidelines for Integrated Marine Resource Management in the Eastern Caribbean," provides a useful model demonstrating what can be done at the local and regional level by employing a "participatory" strategy, limited funds, unlimited patience, and a willingness to listen to the non-professional resource managers--i.e., the traditional users of the resource. It is recommended reading and a working handbook for anyone addressing island coastal zones and marine resource development and management (Geoghegan, 1983).

5. THE PACIFIC ISLAND REALM: EXAMPLES AND LESSONS

5.1 Regional Overview

Embracing some 64 million square miles and covering nearly one-third of the earth's surface, the Pacific Ocean is the largest, most prominent feature of the globe. It also contains the world's largest collection of islands--some "continental," most "oceanic." It includes the world's second and third largest islands (New Guinea and Borneo), the world's two largest independent archipelagic states (Indonesia and the Philippines) and perhaps twenty or so island groups encompassing more than a hundred thousand islands, atolls and islets. There are twenty separate smaller political entities of which ten are independent "developing" island countries.

If the reader can conceive of a line drawn along the great circle route (the shortest distance) from Japan, eastward across the Pacific Ocean to central Chile and then back to Australia's south coast, the wedge-shaped enclosed area or "triangle" contains nearly all of the island groups of the Pacific, encompassing the islands of Melanesia, Micronesia and Polynesia, and some five million people (three-fifths in New Guinea). This wedge-shaped Pacific Ocean "island" subregion, even though only about one-fourth of the larger Pacific Basin, covers a vast oceanic area nearly 9,600 km (6,000 miles) long measured on the east-west axis and averaging about 4,800 km (3,000 miles) on the northsouth axis. For every 500 square miles of ocean there is an average of about one square mile of island "land." Under the framework of the emerging "Exclusive Economic Zone" concept (200-mile-wide extensions to the territorial sea boundary), land-to-sea area ratios vary widely, with New Guinea at 1:10, Fiji at 1:60, the Cook Islands at 1:3,000 and Kiribati at 1:6,000 (all figures rounded).

Some island groups, like Fiji, are true "clusters," while most are spread out in curvilinear arcs over great distances like the Solomons, the Cook Islands, Tonga and especially Kiribati (the former Gilberts) which extends over 4,000 km (2,400 miles) of ocean space but has only 567 km^2 (215 square miles) of land area.

In 1979 the Pacific island area received about three percent of the world-wide total of overseas development assistance (concessionary grants) mainly from Australia, New Zealand, the United Kingdom, France and the UN. By way of comparison, the Caribbean region received about five percent and the five island states in the Indian Ocean area received two and one-half percent. Donor/recipient funding relationships in the Pacific vary widely, some highly dependent on a few bilateral sources and others with a broader, more multilateral external funding base.

5.2 Fiji: The Regional Center

Fiji is made up of about 322 islands which are strategically located in the center of the South Pacific island area. The total land area of Fiji is 18,272 km^2 (7,000 square miles). There are two rather large islands, Viti Levu with 10,429 km^2 and Vanua Levu with 5,556 km^2, and ninety-five other inhabitated islands like Taveuni (470 km^2). Approximately 95 percent of the population of Fiji lives on the two main islands of Viti Levu and Vanua Levu. Population is concentrated in Suva, Latoka, and Nadi areas of Viti Levu (Figure 9).

The economy of Fiji is primarily agrarian. Sugar is the primary export. Tourism in Fiji is second to sugar as a foreign exchange-earning sector. Other major exports are gold, copra, fish and coconut oil. The population of Fiji is approximately 635,000, of which forty percent work in the agriculture sector. Bilateral overseas development assistance to Fiji in 1980 was 31 million dollars (total overseas development assistance was 33 million dollars), less than ten percent of total Fijian goverment expenditures which in 1980 were US$360 million. According to Hamnett et al. (1981), "Just after independence in 1970, Fiji relied on the United Kingdom, Australia, and New Zealand for a majority of its aid. Since that time, Fiji has successfully captured aid funds...[but] has also built up its own ability to generate development funds internally." Fiji is therefore less vulnerable to major changes in foreign aid allocations." Food imports per capita in 1978 were only US$114, and the government has a fairly elaborate diversification strategy designed to reduce even this relatively low level of dependency on external food supplies. The government of Fiji, unlike most Caribbean countries, has

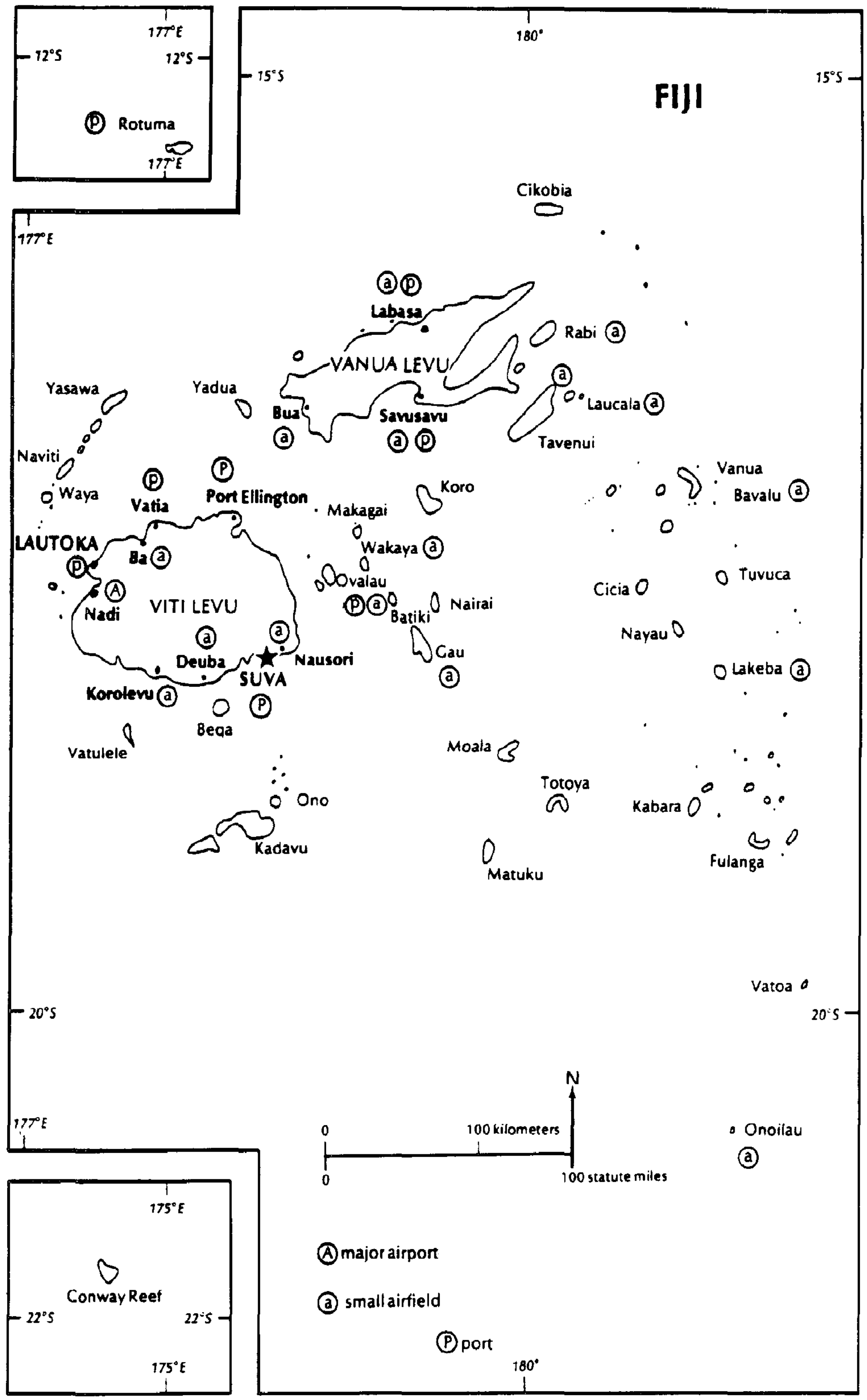


Figure 9. Fiji Islands. (Adapted from East-West Center, 1982.)

a well developed structure of divisional and local government units.

Fiji is also the site of the regionally supported University of the South Pacific and various other regional programs and projects supported by international agencies. This centralization of research stands in contrast to the Caribbean where regional agency and service headquarters are based in a variety of places (like Barbados, Trinidad, Jamaica, St. Lucia and Guyana).

Fiji has a very professional planning division, which has produced top quality national development planning documents (Fiji, 1980). In the fourteen years since independence, it has made significant progress in addressing both growth strategies and environmental management issues, though the format differs from island counterparts outside the Pacific area. Overall long-range planning objectives are designed to promote self-sufficiency, in part through rural sector and peripheral island development programs with the aim of encouraging Fijian citizens to expand primary production and to own and manage domestic and international business ventures serving domestic needs in order to make Fiji less dependent on external help. Fiji's expanding interest in using coastal and marine resources to accelerate this process is reviewed in the following sections.

5.3 Fiji and the Coastal Zone

For many oceanic islands there appears to be a class of marine resources that are in excess of local subsistence requirements. In most smaller island countries, it is not clear to what extent it is practical to exploit these resources in a more extensive, intensive, or commercial way for local use, for supplying urban areas or for export, without jeopardizing subsistence use levels and encouraging food imports at high costs.

We have taken for our case study in this instance certain prototypic examples from the island group of Fiji. There the indigenous population's perception of man and his natural resource base takes the form of an all-embracing, unifying concept of interdependence between humans, land, and sea. The concept is implicit in the Fijian word "vanua" (whereby it is impossible to separate out any single component) and forms the basis of traditional Fijian resource rights (Baines, 1979). For Fijians who use and draw subsistence from coastal areas, the land itself as well as adjacent lagoons, coastal reefs and other marine components are seen as part of an integrated whole, inseparable from other portions of village land regardless of boundaries that might artificially separate marine and terrestrial ecosystems or divide or designate them by such distinctions as "high-water mark" or "the beach" or even the "coastline." As Baines (1982) has noted, "In Fiji this enlightened perception of resources persists even in the externally influenced Fijian culture of today."

This perception is, of course, at odds with British Admiralty Law and land title law, imposed upon and common to Fiji for more than a hundred years. It is possible for private individuals and corporations to own some land above the high-water mark. It is also possible, in the case of traditional or native land above the high-water mark, for it to be owned on a kind of village-rooted communal basis. However, anything below the mean high-water mark and extending seaward to the island's outer-reef edge is legally defined as the property of the nation but is also subject to a traditionally derived, now codified (under a national Native Lands Trust Commission) set of practices based on "communal use rights," all of which, in turn, constitutes a rather remarkable, integrated, grass-roots coastal resource management strategy.

It is, in effect, a bottom-up coastal zone management program, to the extent that it is an internalized equilibrating process for adjusting to the carrying capacity of the system. Change is absorbed or resisted and risk is spread, by limiting use of the marine "commons" (which is important to island peoples in the face of seasonal changes, natural disasters and unpredictable outside influences). It is solidly based on locally derived, traditional technology and on an awareness of the limits of the system (Hardin, 1968).

In both the Caribbean and the Pacific, larger as opposed to smaller islands and especially island groups display significant differences in both the perception and the use of coastal resources. For example, smaller islands or islands with very small shelf areas in the Caribbean and also atoll communities in the Pacific have developed fairly diverse technologies and not inconsiderable skill for going "offshore" to exploit fish on adjacent or even distant deep-water outer-reef slope areas. Larger islands or islands with larger coastal shelves, as in the case of islands on the Virgin Islands platform or as in the Fijian case, have tended to venture not quite so far offshore for fishing purposes. Barbados, in the Lesser Antilles, is an interesting case in point here because the Barbadian fisherman, lacking both an extensive shelf and protecting satellite islets and therefore working in more exposed open sea area, especially when loaded after fishing, cannot easily exploit the shelf areas of the more westerly islands to leeward, just over the horizon. He has, therefore, evolved a very special kind of boat, quite different from other Lesser Antillean watercraft, enabling him to fish in the more exposed waters on the deep shelf off Barbados.

A different situation has emerged in Fiji. Baines (1982) has noted that in the case of traditional Fijian communities, which have access to an extensive shelf area, there are "no Fijian names for the high-quality snapper now being fished in Fiji from the deep-water outer-reef slope." Fijians simply did not venture into or attempt to harvest fish from the outer deep-water reef slopes, for such coastal villagers had access to inshore marine resources.

Additionally, traditional "territorial" limitations have also defined the particular areas which community or village groups were to exploit. Such traditionally defined "fishing rights" areas continue to be important in Fiji today and are delimited by boundaries which generally are seaward extensions of the land boundaries to which a particular group has legal rights (Baines, 1982). This approach is, in modern terms, a "limited entry system" serving as an internal mechanism to maintain a sustainable-yield strategy for use of marine resources.

Any given fishing village might have exclusive rights to use an area immediately offshore. Its dimensions were determined customarily by historical shifts of power and influence and, to a degree, reflected the local sequence of village establishment. A given village would also customarily possess shared use rights with some limited number of additional villages in other demarcated areas (with seasonal limitations or for an occasional "harvest"). Thus, there tended to exist a kind of equilibration process whereby each village defined a basic subsistence area plus several kinds of fall-back, emergency use or seasonal use areas shared with others that combined the coastal, lagoonal, and offshore reef system in a fairly complex pattern of demarcated use rights. In more recent times these traditional use rights (in part because they have been nationally codified) have been seen by some as a constraint upon more modern kinds of development activity, such as marinas, hotels, or other tourist operations, because to use such traditionally demarcated fisheries areas the developer is required to negotiate for any new "use" of the area. Since use rights are not customarily sold but only leased, the end result is an informal permitting system whereby the new user pays a recurring annual fee which, in turn, becomes a limiting device on the use of the resource.

For example, the author learned on a recent site visit to Fiji (1983) of a large tourist operation on the western coast of Viti Levu which was desirous of using various nearshore, uninhabited islets for a "deserted island beach experience" for its clients (who would be delivered to the areas by boat). The operation had to "negotiate" with the "controlling" village for such access. In addition, the tour operators had to specify intended use patterns and sites, establish nonconflicting schedules, and also pay a "use" fee. They could not, therefore, treat the islets as "commons" and knew full well that their activities (and any negative environmental impacts) would be monitored by the traditional users. Similar examples have surfaced relative to marine sand mining/ dredging projects which have been required to negotiate a fee-payment with traditional use-rights holders, not for the sand (which belongs to the "crown") but for "diminished fishing opportunities", i.e., presumed temporary environmental impacts. Even coastal mangroves have come under these arrangements, for during disputes over shoreline reclamation efforts, traditional users (who seasonally harvest crabs, etc., for food from the mangroves) have brought complaints to the Native Fisheries Commission, asserting that they had been deprived of a traditional harvesting option and sought to recover the value of that loss. In such cases, the local litigants have been awarded between $258/acre/year and $384/acre/year for lost use rights (Baines, 1979).

Such a system of checks and balances reduces the indiscriminate, irrevocable allocation or destructive use of any coastal resource in favor of a sustained, non-destructive use. It has a "free," built-in monitoring system (because the users jointly share the resource), establishes a cost for utilization of the "commons," and represents an internalized and informal, multiple-use, participatory, sustainable-yield coastal resource management strategy which favors the maintenance of local subsistence use and national self-reliance, with cost figures attached to commercial exploitation schemes (Hardin, 1968; Gilles and Jamtgaard, 1982-1983). Any attempt to install a highly formalized top-down "coastal zone management system" in place of or casually superimposed upon this preexisting and traditional island system would undoubtedly be a mistake. While not every island has quite such an effective, codified, and workable coastal resource "management" mechanism already in place as does Fiji, most islands have locally evolved, village-based, uncodified counterparts (see the Rodney Bay example in Section 4.1).

Since Fiji emerged as an independent nation in 1970, increasing attention has been paid to coastal resource development potential. One result is an expanding and profitable offshore fisheries focus on the skipjack tuna. Exploitation of this fishery has, in turn, involved international development of commercial joint venture and licensing arrangements with the Japanese as well as various domestic horizontal and vertical integration arrangements for new local businesses. Elements of the new economic strategy include the successful development of local can manufacturing, fish processing, vegetable oil supply, marketing companies, and ship building enterprises. Other experiments, focusing on the commercial expansion of nearshore artisanal (traditional, small boat, low-technology, mostly subsistence) fishery resources have not been quite so successful.

It is useful to review two prototypic examples of well-meaning attempts to "develop" traditionally used coastal fishery resources on a commercial basis while still maintaining an artisanal base. They have each been analyzed in some detail by Baines. Both projects were planned on the premise that artisanal fishermen and their respective villages had some understanding of the concept of surplus production and of marketing for cash. It was assumed that there was a link between the sale of fish for cash and the possibility of exchanging services and cash for a variety of other goods that would benefit the individual or the village.

A simple two-phase model for commercial development of a coastal fisheries resource (based on a single offshore insular village unit but assuming some cooperation between neighboring villages) was designed by the local Fisheries Division to exploit local reef and lagoon resources. The effort was to require only shallow draft, small traditional boats and nylon seine nets. It had been assumed that after the village repaid initial capital loans, surplus income would be invested in a later phase for larger boats and better gear to enable trolling and possibly pole-and-line fishing activity outside the reef. The overall scheme required the government to provide some additional shipping service for ice transport to be used in outer island fish storage facilities and for the return trip by sea to the main urban center of Suva (Figure 9). The only uncertainty in the model was the renewable-yield potential of the area to be fished. At the time there were no simple guidelines to assess the fisheries potential of coral reef and adjacent shallow-water environments, although this shortcoming has since been remedied (Baines, 1982).

Shortly after the project was launched, technical and climatic circumstances introduced additional uncertainties in the logistical support side of the endeavor. Engine breakdowns and bad weather prevented some scheduled ice deliveries and fish collection trips by the government's boat, resulting in a general decline of enthusiasm on the part of the participating fishermen. But the most significant problem was not technical but social. The ice delivery and fish pick-up by the inter-island service boat, when it worked, involved a fixed schedule. The fourteen-day cycle of catching fish, preparing and icing the catch and then loading it for shipment to market imposed a regular concentrated pattern of activity which conflicted with other village activities. These behavior patterns had been more traditionally based on seasonal changes and on planting and harvesting cycles for both terrestrial food crops and for the optimal time required for achieving the best harvest of marine species. Most fishermen, accustomed to the normal "feast or famine" cycles of fishing, limited by both biological and climatological considerations, had spread the risk of economic survival over a variety of additional pursuits. Maintenance of small-scale farming plots was an important secondary occupation. Villagers found it very difficult, under these circumstances, to adapt to the fourteen-day project cycle which seemed so reasonable from the perspective of the project planner in Suva (Baines, 1982).

Fortunately, the project was not abandoned. By shifting to more appropriate fish processing techniques, ice supply and shipment problems were essentially eliminated. Fish was dried and smoked and dried sea cucumber (beche-de-mer) was added as an exploitable resource, all of which could be safely stored until transport. The solution represented an adjustment of the project design to the more traditional, local activity pattern which had long combined both agriculture and fisheries. Adaptation to this strategy essentially guaranteed the project's success (Baines, 1982).

A second project in Fiji involved an enterprising effort to encourage coastal villagers to exploit beche-de-mer (dried sea cucumber). In this case the fisheries' project planners determined, in advance, "customary" or traditional fishing areas of target villages, the availability of adequate beche-de-mer stocks, the basis of community support for the project, and the presence of the required labor supply. A sincere and effective effort was undertaken to train selected persons from the various target villages as both harvesters and processors to guarantee a supply. This strategy also ensured the application of techniques necessary to produce a high-quality dried product that could be stored for shipment and be acceptable for the export market. The initial effort produced a good product which was processed with enthusiasm and brought a good price in Suva. Villagers were more or less satisfied, although they expressed some unhappiness about the long interval between the collection and processing work and the cash proceeds which ultimately resulted from sales. In time, this unhappiness resulted in a gradual waning of community enthusiasm, and the only alternative that seemed acceptable was for the villagers to harvest but not process beche-de-mer, even though they would be paid a much lower price for the unprocessed animals. They clearly were more interested in the immediacy of cash return, and thus the beche-de-mer industry developed through an intermediary (not a villager) who purchased the raw material and then processed it for shipment to Suva and ultimate export (Baines, 1982).

However, as harvesting continued and stocks declined, fishermen began looking to the stocks in areas controlled by other villages not involved in the scheme. The search for additional stocks resulted in an unfortunate confrontation over fishing rights,and in failure of the project because the carrying capacity of the target area had been exceeded. This outcome suggests that fishing rights for domestic consumption are not easily merged with commercial exploitation of the resource for export. As Baines concludes, "...successful coastal resource development projects require that the chosen technology be consistent with the social organization of the communities involved in its application" (Baines, 1982).

Promising and effective new strategies for small island coastal resource development are possible, but only if environmental perceptions of coastal communities are better identified and appreciated, and local understanding of the ecosystem and its management requirements can somehow be tapped. Central planners, and external development change agents need to be responsive to this information source and imaginative enough to incorporate such data into economic and development models for small island areas. Anything less than this will, if the island experience is any guide to the future, diminish the resource base, encourage island "openness" and demands which exceed ecosystem capacity, create internal user conflicts and new dependencies for the island, and subvert future attempts to develop more self-reliant, national coastal resource use, management plans and practices.

If small coastal resource development projects require midstream re-design (based on feedback from the participants), then larger schemes are even more at risk if they are not sufficiently flexible to make such adjustments. Current international and bilateral development project design formats--at least for island areas--are more often inappropriately structured and rarely permit truly flexible readjustment of program elements, and objectives in response to changing circumstances. As a result, in the larger search for effective, workable "leverage" points to provide for basic needs, many projects brought to islands from the outside fail to establish and put in place an institutionalized living mechanism (people, structures, and technology) for growth that enhances national or insular self-sufficiency, reduces dependency, minimizes vulnerability, and is economically viable. This problem is endemic to islands; the view from inside (looking out) bears little resemblance to the view from outside looking in. Bridging this conceptual gap has nothing to do with funding levels or more foreign aid--it is solely a question of how to address technical assistance for and to island areas in a more constructive, creative, and appropriate way, one that is sensitive to unexpected events and to the island's requirements for self-reliance and survival, not as a microstate but as an island system. There is a difference.

5.4 Center-Periphery Questions (The UNESCO/MAB Fiji Project)

Between 1972 and 1980 Fiji and small satellite islands to the east of Viti Levu and Vanua Levu, particularly the Lau group, became a kind of test site for what may be the most significant, detailed and instructive study carried forward in the last several decades on man/environment relationships in island areas. The study comes to grips with island carrying capacity, small island dependency, productivity, and vulnerability, and related development options for insular areas.

In 1972, the UNESCO Program on Man and the Biosphere (MAB) launched a special study project on "the ecology and the rational use of island ecosystems." Humans were the focal point of the study, with an emphasis on the problems of island populations within their environmental context. The island ecosystem project was to offer exceptional opportunity to study, under relatively controlled conditions, the entire spectrum of ecological, economic and social factors influencing man's relationship with the biosphere. Its objectives were to pursue three themes: (1) management of environmental resources by island populations, (2) impact of external forces on islands and (3) impact of alien plants and animals on island ecosytems.

The study assumed that island ecosystems, because of their small size and isolation, were intrinsically susceptible to environmental degradation resulting from external influences, and that islands would also "provide unusually favorable conditions for scientists to study ecological, social and cultural models of human carrying capacity." Additionally, although among islands there is tremendous variability (which offers opportunity for comparative studies), the program designers also assumed that "islands constitute discrete units of manageable size in which scientific measurement might be facilitated" (UNESCO/MAB, 1973).

As a working hypothesis, the project sought to explore the concept of carrying capacity of various types of islands along a continuum of subsistence-based, self-sufficient island systems and more developed islands which had lost their internal capacity to prevent or control environmental degradation.

It was also presumed that research work on the less developed islands would (in a kind of preservationist mode) look to strategies for maintaining traditional forms of stability. In the case of islands already substantially integrated into wider economic and technical systems, research emphasis would be placed on remedial strategies for emergent environmental problems caused by over-population, unbalanced land use, misuse of resources and the negative impacts of tourism (UNESCO/MAB, 1974).

As part of its overall world-wide strategy, the UNESCO/MAB planning group began to search for an island test site in which to examine man/environment equilibria. Outlying islands in the Pacific area were considered to be good examples of a situation common to many tropical islands: mono-cultural use of land for export crops, subsistence food production, and inter-island exchange of produce (taking advantage of ecological diversity) between primary and secondary island areas, in combination with the use of coastal marine and reef resources. It was assumed at the time that many island areas and particularly the peripheral islands of larger island groups were experiencing a process of disintegration of the normal network or flow of materials, goods and people. At the same time they also remained marginal to national growth centers. As a result, peripheral islands were increasingly under-utilized and under-populated, while the "core" island areas were experiencing urbanization and losing their former self-sufficiency in food production. As urban core islands were growing and in a sense becoming more centralized and marginal to external systems (because of their openness), the outer islands or peripheral areas were increasingly more vulnerable, dependent and less diversified. Outlying areas were, therefore, less able to contribute to any national strategy for self-reliance and internally based economic development.

With the financial assistance of the United Nations Fund for Population Activities, the UNESCO/MAB program in 1973 designed and mounted a pilot research project with field studies to be undertaken principally in the small eastern island group of Fiji, concentrating on the systems relationships among (a) human population dynamics, (b) the use of natural resources from a set of previously interlinked ecosystems (marine, coastal and terrestrial) and (c) the function of the outer islands in relation to national and global economic development structures. This multidisciplinary project was headed by Dr. Harold Brookfield, a geographer affiliated with the University of Melbourne in Australia and later the University of West Indies in Barbados. Topical areas covered in the subsequent research effort were reef systems, soil and vegetation, land use and land holding, nutrition, work input, demographic considerations, migration and the larger question of center-periphery relationships. More complex questions of island carrying capacity, vulnerability, dependency, and development planning were also considered. During the course of the project the interdisciplinary study team also become very much enmeshed in Fijian efforts to design improved long-range development strategies for Fiji and in a search for development guidelines appropriate to the Fijian insular system (diCastri and Glaser, 1979).

The MAB Fiji project was far too complex and its products too extensive to adequately summarize or even review here. The seven volumes of documentation constitute perhaps the best available analysis of what makes islands systems "tick" (MAB, 1977, and Brookfield, 1977, 1978a, 1978b, 1979, 1980). It is instructive to note what happened in Fiji for it is a microcosm of what happens generally to oceanic island systems.

Until the twentieth century, ecological variety in the outer islands of Fiji gave rise to specialized, localized production which supported an active, although informal, system of direct inter-island trade. Some exchange of goods extended to nearby islands in Tonga outside of the boundaries of Fiji. With development in the core or center (essentially Suva on Viti Levu), there was a change in the terms of the relationship between the center of Fiji and the very productive and diverse satellite island areas. As the center of the Fiji island system enlarged, the smaller outer island systems were absorbed into the structure and framework determined by the center. As a result, the outer island group tended to lose its own diversity, productivity and independence of judgment as to what and when to produce in order to survive.

Adjustments to the needs of the larger system diminished the capacity of the outer island group to serve the larger task of national self-reliance and self-sufficiency. In Fiji's case, the outer or easternmost islands are increasingly marginal to and dependent upon the centralized decision making and resource use systems, which continue to be mono-cultural and export oriented and over which they have little control.

Brookfield's own retrospective overview of the Fiji project is instructive (1980). He was perhaps the first to suggest, based on field work in Fiji, that despite the good intentions of the UNESCO/MAB program the research study had suggested "the need for a new integrating paradigm, in which the relative roles of the social and natural science contributions might be clarified within a unified framework."

Brookfield was concerned as early as 1972 with the MAB program notion that the "rational use of island ecosystems" could be defined because this involved a behavioral assumption regarding the existence of "rational ecological man." Who was to define what was "rational"? It ignored the fact that an islander's own perception and set of values did not necessarily seem to find any clear place within the framework (i.e., that there were differing versions of rationality). Furthermore, even at the outset of the project, Brookfield expressed some concern about the conception of islands as "laboratories" for the study of population/environment relations and about the assumption that a high degree of closure existed in island/environment systems which made them useful objects of study. "This assumption," according to Brookfield, "is not tenable for the majority of the world's island communities and is not tenable for any island in which externally generated development efforts are being made." Colonial and mercantile expansion had subsumed previously independent systems within larger hierarchical systems of spatial integration, to the detriment of both (Brookfield, 1980).

The Fiji carrying capacity project began when the entire MAB program philosophy was shifting. By 1974 a major stumbling block was removed by introduction of the concept of "the human use system" as defined in a UNESCO/MAB (1974) document. The perspective of MAB shifted in less than a year to incorporate a new kind of social science dimension into its approach, one which defined the human use system as "organizations through and by which resources are managed. They vary in size and composition from the household or village to the nation state or multinational corporation. In their spatial expression they are rarely, if ever, congruent with ecosystems" (UNESCO/MAB, 1974).

In Brookfield's opinion, the importance of the concept of "human use systems" lay in freeing the Man and the Biosphere Program from its original insistence on the concept of man <u>within</u> the ecosystem. He notes somewhat plaintively, however, that as the MAB program regarding islands has evolved, human use systems (although acknowledged after 1974) have generally been examined <u>separately</u> from the natural ecosystems which they manage and exploit, and the problem of integration has not yet been resolved. His project in Fiji is one of the few MAB initiatives that has avoided this problem.

A few of Brookfield's conclusions drawn from the empirical field work of interdisciplinary research teams in Eastern Fiji deserve a brief summary here. They bear directly on the design of effective and appropriate development intervention for island coastal ecosystems and resources. When the project was conceived by the UNESCO/MAB task force in 1974, the basic concern in man/environment interactions focused on growth implications and the impacts of the increasing scale and volume of human activity. Enlargements in the structure of human use and resource management systems were presumed to result in the incorporation of smaller systems as effective working sub-systems of the new enlarged structures. Life would go on as before with the addition of a few new rules. For example, an island government could quite logically design a "rational" coastal zone management framework, using a scaled-down external model, which would simply incorporate more traditional, smaller human use systems and structures without injurious change. At the same time, the central hierarchy of human use systems would expand its sphere of influence. The planning and decision making processes for those more universal (centrally perceived), more critical resource management issues would provide the controls to improve or guarantee the quality of life. This would protect the environment and optimize coastal resource allocation and use. The evidence from the Fiji field work, however, suggested that this assumption simply was not true.

The historical process of change for Fiji's peripheral islands was not transactional, but rather transformational. Smaller human use systems on the periphery were not simply subsumed or affected in a benign fashion; they were structurally transformed by the transition process into something else. A lessening of resource use differentiation and a loss of an internal capacity to manage those environmental and other variables it had traditionally managed successfully were the results. This loss of management capacity and diminished differentiation of use appeared to be a greater problem on the peripheral/marginal areas than it was in the populated core areas which were presumably more stressed. For these reasons, among others, Brookfield concluded (1980) that one had to reject any notion that small islands, as man/environment systems, were microcosms of conditions in the world or continents as a whole. They were, however, representative of those parts of the world that have been rendered peripheral by spatial structuring forces within the larger world system.

In other words, islands are representative of peripheral regions of Third World countries that are themselves peripheral within the international system. Brookfield is positing the outline of a peripheral or marginal systems paradigm to supplement or replace the island ecosystem paradigm (see Section 7).

In the Fiji case, as local peripheral human use systems were absorbed and transformed by larger systems in the process of development, local decision making structures were "transformed" into a kind of "client" status within larger decision making structures. The division of labor ended up being reallocated from the center, viewed in terms of the demands of the larger absorbing system. The interdependence of the smaller, diverse "satellite" islands' collectively self-reliant economies were essentially destroyed and replaced by dependence on the center and the world system which lies beyond it. The consequence was that the fine mesh of "rational" resource allocation that had evolved out of the man/environment relationship in the peripheral islands was, in effect, removed.

The result is not, as noted earlier, a simple transactional process of "change by consensus," but involves a "transformation" process for the social, economic, and resource management systems in the out-island areas. Therefore, any a priori presumption that the center is more "rational" than the periphery in its resource allocation strategies and priorities is, at best, risky. All too often, technical assistance strategies do exactly this.

5.5 The CCOP/SOPAC Regional Coastal Zone Strategy for Islands

The Committee for Coordination of Joint Prospecting for Mineral Resources in South Pacific Offshore Areas (CCOP/SOPAC) is an intergovernmental body established under the sponsorship of the United Nations Economic and Social Commission for Asia and the Pacific (ESCAP). Its mission is to develop and promote investigation of the mineral potential (including petroleum) of shelves, platforms and the ocean floor in the South Pacific Ocean. The present Committee, comprising ten island members, had its origins in various planning sessions carried forward by ESCAP's predecessor and others in late 1970 and early 1971. Considerable interest had been expressed in the petroleum potential of the submerged shelf areas of South Pacific islands after the 1968 discovery of seepages of crude oil in the Kingdom of Tonga. Increasing attention was paid to the possibility of finding economic deposits of both petroleum and detrital heavy minerals (placers) in the beach and nearshore areas of several island countries. This coincided with rising interest in prospects of mining manganese nodules from the Pacific Ocean floor for their metallic content. The inaugural session of CCOP/SOPAC was held in Suva, Fiji, in 1972, and annual meetings have been held in various member countries since that date.

In 1974, the United Nations Development Program (UNDP) commenced support of various planning and operational phases of the CCOP/SOPAC regional program. In 1979 the terms of reference for the overall project were expanded to include additional inshore "coastal" activities and marine studies. Since that date, CCOP/SOPAC has responded to increased requests from member countries for "inshore" baseline studies and technical assistance dealing with seabed sand dredging, sewage outfall siting, beach erosion and other coastal marine problems (Table 4). The primary objective of the ancillary "inshore" program was to obtain and make available to planners and engineers the environmental baseline data needed to determine design criteria for ongoing or proposed development activities in the coastal areas of member countries. A secondary objective was to encourage the development of a small group of trained nationals capable of carrying out investigations, baseline measurements

Table 4. Examples of South Pacific Island Coastal and Inshore Marine Resource Development Program Requests (1981). (Source: Towle, E., 1981.)

Categories	Ocean Outfalls	Ports and Harbors	Sand Supply, Dredging	Lagoons and Estuaries	Fisheries Support	Shoreline Erosion	Impact Assessment	Misc.
Tasks/ Needs	Siting, Impact, Design	Siting, Impact, Design	Supply, Impact, Risks	Resource Management Criteria	Baseline Data, FAD Siting	Dimensions Methods, Mitigation	Baseline, Methods, Training	Training, Mapping, Education
Country								
Cook Islands	X		X	X		X	X	
Fiji	X	X	X		X	X	X	X
Kiribati		X	X	X		X	X	
Papua New Guinea	X	X						X
Solomon Islands	X	X			X		X	X
Tonga		X	X	X	X	X	X	X
Vanuatu		X		X	X		X	X
Western Samoa	X	X	X	X	X	X	X	X
TOTALS	5	7	5	5	5	5	7	6

and similar activities in the inshore marine environment with minimal outside assistance. The overall inshore program has been designed to address these two priorities and to be responsive to the marine resource development initiatives of the member countries.

Carried forward since 1979 within the larger framework of the ESCAP/UNDP offshore mineral prospecting project, CCOP/SOPAC's inshore program has been extremely successful. Implementation has proceeded on a modest scale amid the press of previously scheduled, larger scale offshore and nearshore geophysical and geological program elements. The expansion of the project's original terms of reference in 1979 to include nearshore studies, training, and technical assistance was motivated by growing awareness of the need to provide South Pacific island governments with access to the technical expertise and data base. This information was required by their planners and decision makers who were, on the one hand, involved in the development of coastal resources, but, on the other, sought to avoid adverse environmental impacts resulting from their decisions and actions. It was a well conceived strategy to reduce local risks and costs by improving project and facilities design and siting, while utilizing local raw materials extracted from the coastal zone and incorporating at the same time a local skills training and data base building program component.

The CCOP/SOPAC inshore coastal resource program to date encompasses major efforts in Fiji, Western Samoa, Tonga, the Cook Islands, New Guinea, the Solomons, Vanuatu and Kiribati. Additionally, a series of prototypic inshore/nearshore training workshops have been held in cooperation with the University of the South Pacific (Institute of Marine Resources), the United Nations University and the University of Hawaii (International Sea Grant Program).

The inshore program is compatible with CCOP/SOPAC's basic mission of supporting marine geophysical and geological surveys and data analyses and marine mineral prospecting. It responds in a timely and relevant fashion to member country requests for practical, short-term technical assistance for inshore marine resource development projects, for baseline data, and for site surveys. Further, it makes cost-effective use of complex scientific equipment acquired by the project for esoteric, long term, less visible offshore seabed hydrographic, oceanographic, and geophysical investigations.

It also incorporates a reinforcing combination of (a) practical short-term training on site; (b) extended, paraprofessional attachment training at Suva project headquarters and on various survey vessels; (c) problem-focused, short-term workshop training; and (d) formal, thematically focused, earth science courses offered by the University of the South Pacific.

Taken together, these four training elements of the CCOP/SOPAC inshore program constitute an effective "marine literacy" strategy for younger technicians from member island countries confronted with an unfamiliar nearshore and deep-water environment. The CCOP/SOPAC inshore initiative is a practical and regional marine resource development and coastal zone management program in embryo. As such it adjusts its participatory strategy to reflect country differences, local priorities, available skills and institutions. It is problem-oriented and seeks to use and improve existing human and institutional resources currently engaged, although often inexpertly, in the marine resource development process. The program has developed and maintains an effective network of active in-country participants and advisors which provides informational feedback loops and enhances a two-way flow of operational and technical data and counsel critical to the success of the overall program (the CCOP/SOPAC telex network linking the participants is an important technical element, but the "network" process is only facilitated by, not dependent upon, the telex system).

There are some lessons to be learned from the CCOP/SOPAC experience. Without a cadre of bottom and mid-level technicians in each island country who are reasonably skilled in and conversant with the sampling, numeration and mapping processes used in marine inshore areas, national or regional environmental management programs for islands are at risk, if not scheduled to fail. A cadre of skilled para-scientists is a sine qua non of effective inshore project design, impact mitigation, monitoring, and evaluation. The ECNAMP project (Section 4.3) in the

Caribbean addresses this problem to a degree. The CCOP/SOPAC training program in the Pacific, as designed and implemented, is even more responsive to this requirement. The existing technical skills training curriculum for island country nationals is on target. Training is offerred in bathymetry, cartography, field measurements, position fixing, seabed and sub-seabed seismic profiling, side scan sonar mapping, precious coral stock surveys, current measurements (by dye, drogue and meter methods), water quality indicators, sediments, and data recording, reduction and reporting techniques.

The CCOP/SOPAC approach, like that of ECNAMP in the Caribbean, has been successful and cost-effective for a variety of reasons. It is flexible, open-ended, not too highly structured, relies principally on existing in-country persons and institutions, and maintains a closely coupled network (horizontal and vertical) of users and cooperating local agencies and institutions. It also has developed a management information system, along with good communication linkages. Islands participate in establishing priorities, levels of effort, and, to a degree, levels of precision. These islands are partners, not targets.

Both ECNAMP and CCOP/SOPAC make use of regional university-based persons with expertise (but not so much the institutions themselves which have a different agenda and more rigid calendars). Both emphasize function rather than form, service rather than structure, building skills rather than academic credits, and the long as opposed to the short term. Mr. Cruz Matos, head of CCOP/SOPAC, and Mr. Allen Putney, principal investigator of ECNAMP, have been successful because they, quite simply, understand islands better than most and have therefore been able to develop workable programs (which are both pragmatic and non-formal) for expanding local capacities to utilize and manage coastal resources.

6. TECHNICAL CONSIDERATIONS

6.1 Island Vulnerability: The Search for a Model

6.1.1 An Overview

Both natural and social scientists tend to agree on one important characteristic of islands: their vulnerability to interference from outside. Ironically, oceanic islands are increasingly vulnerable due to their very isolation. In the past, this characteristic inhibited development; now, however, remoteness is largely immaterial because of the revolution in transportation and communications. The barrier of remoteness has been overcome by factors far removed from the shores of the islands themselves -- factors that set up wholly unanticipated technological encounters. Remoteness no longer guarantees freedom from pollution, offshore oil spills, inappropriate coastal architecture, tourism, ocean dumping of chemical wastes, or the destruction of habitats and indigenous species (some endemic) by introduced exotic species. All have affected oceanic islands in recent years.

The anomaly of the island situation is twofold. On the one hand, increasing numbers of continentals regard islands as both idyllic sites for vacation experiences and as superior sites for offshore banking centers, free ports, and specialized industries (some seeking to escape formal environmental controls). On the other hand, they often expect islanders to develop their resources to service these demands indefinitely, yet with no loss of the unique character of the insular situation.

Additionally, isolation, circumscribed space, and other environmental factors affecting islands have resulted in specialized biotic and human communities. The indigenous life forms of an oceanic island tend to be less tolerant of changes in environmental conditions than those on the margins of continents (Wood and Johannes, 1975). Man's intrusion on some oceanic islands has been permanently devastating to fragile, long-term, evolutionary interdependencies (Carlquist, 1965, 1972; Wace, 1978; Gorman, 1979; Mueller-Dombois, 1973). Obviously, intensive and sophisticated scientific research is indispensible for understanding the dimensions of the problem. But as Fosberg noted twenty years ago:

> It is clear enough that the arrival of man has invariably increased, to some extent, the degree of instability in these systems. With the advent of modern man this increase has frequently assumed catastrophic proportions. The losses in organic diversity, soil development, water retention capacity, and biotic community organization all amount to an increase in entropy; and in cases of extreme degradation this increase has brought about a high entropy level. It is suggested that this is bad from any conceivable viewpoint.

One objective of the UNESCO Man and the Biosphere Program, launched in 1973, was to assess the vulnerability of islands to exotic species introduction. Another objective was to explore cultural, social, and technological introductions as well, for these raise dependency levels. It was hypothesized that most inhabited islands lie somewhere on a continuum between two extremes. At one end, the least vulnerable are those islands where external agents have had little impact on formerly closed, self-equilibrating, self-sufficient systems. At the other end of the continuum are islands with institutionalized openness, so heavily affected by the impact of the outside world that the island system has lost its internal capacity to manage the environment, prevent decay and satisfy requirements for food, water, shelter, and other basic needs. As a result, such islands have a high degree of vulnerability and dependency.

It was assumed at the time that the island microcosm could model both man's destruction of his own habitat and his success or failure in achieving a steady-state adaptation to modified habitats. The microcosm model would reflect his learning to live with the problems he had created, thereby reducing his vulnerability over time. But the positive (reinforcing) feedback loop from initial vulnerability to openness to new dependencies back to increased vulnerability is difficult to control in the face of new kinds of unanticipated external and internal driving variables or factors. For example, in some cases, islands have been catapulted, figuratively speaking, into the technological world of the twentieth century within a decade or two. The environmental, cultural, and economic impacts of these changes have been severe. The experiences of these islands (with "high-tech" sewage treatment systems, desalinization plants, agro-business enterprises, mining technologies, high-rise hotel structures, jet airports, and pesticides) serve as harbingers of what other developing islands may expect in the future.

The seriousness of the "technological encounter" is reflected in widespread changes in uses of coastal land and in concomitant environmental stresses and incompatibilities that the new activities create. Exploring and drilling for oil and natural gas, tourism, and offshore dredging are especially noteworthy in this regard because of their potentially pervasive impacts on coastal areas, their presumed economic benefits to traditional island economies, and the intensity with which they are being pursued at present.

St. Thomas in the U.S. Virgin Islands, with 50,000 persons on 28 square miles (1,786 persons/square mile) serves as a useful case. It is an oceanic island that has relied on technology and accepted dependency status to overcome traditional barriers to development due to resource scarcity. Because of its mountainous terrain, poor soil and unreliable rainfall, more and more food for its burgeoning resident population must be imported. Furthermore, fresh water, also scarce, must either be imported by tanker or manufactured in costly desalinization plants. Owing to the scarcity of construction aggregate, sand must be imported and dredged from inshore areas, often with adverse effects. Finally, because flat, developable land itself is in short supply, it is "created" by dredge-and-fill operations along the coast, disrupting fisheries, damaging reefs, and degrading the quality of inshore water (Frankenhoff, 1974; McElroy and Albuquerque, 1983).

An insidious aspect of the exogenous off-island influence factor is the global-development phenomenon itself. Decisions that can affect an island and its coastal zone may be made thousands of miles away, for example, in the boardrooms of multinational corporations. The tourism industry provides a good example: corporate hotel interests, international airlines, cruise ship lines, travel agents, the publishing industry, banks, metropolitan newspapers and television advertisements, and even direct mail outlets have immense power to create tourism "booms" for islands. In many cases, the insular areas which experience the full impact of this development may not themselves be the chosen target islands. Rather, they may be swept along in a development thrust aimed at a sister island, a neighboring archipelago, or even a broad oceanic region. Without advance notice and in the absence of contingency planning, the vulnerability of adjacent islands is exacerbated. In many cases, the pace of change is incomprehensible and overwhelming.

This secondary transfer or "wake-effect" is most easily demonstrated by the impact that the growth frenzy of the 1960's and 1970's in the U.S. Virgin Islands had on the neighboring British Virgin Islands and on even more distant islands in the Eastern Caribbean (Jackson, 1981; Howell and Towle, 1976; Towle, Howell, and Rainey, 1976). The advent of regular international jet air service between the United States, Australia and New Zealand has had significant repercussions on South Pacific island stop-over/refueling points such as Raratonga in the Cook Islands, Viti Levu in Fiji, and even Pago Pago in American Samoa.

6.1.2 Indexing Insular Vulnerability

It has been suggested that a ranking system for vulnerability, reflecting an island's position on a undeveloped/degradation/dependency continuum, would provide a useful reference point. Such a ranking system could benefit both development assistance planning by "outsiders" and design of national self-sufficiency strategies from "inside." However, there are different sources, kinds, and levels of "vulnerability." For convenience, these are approached here within three artifically separated categories or groups: the environmental system, the human system, and the economic system. Each will be summarized separately.

First, the basic island ecosystem and its intrinsic environmental characteristics and associated ecological vulnerabilities must be considered. Despite numerous prior attempts to classify these environmental characteristics (see Section 3 above), no vulnerability ranking index has been attempted as a component of other classification efforts by scientists (Douglas, 1969; Pierre Gourou in Fosberg, 1963; UNCTAD, 1974).

However, the recent, subregional ecosystem assessment efforts of Putney (1982) in the Caribbean and Dahl (1980) in the Pacific are useful prototypes. In concert with UNEP's country environmental profiles, IUCN/WWF's World Conservation Strategy, and the rather extensive literature base on insular flora and fauna, the subregional assessments are sufficient to permit formulation of a vulnerability ranking system for island ecosystems.

Secondly, there is an insular "human system" (societal) vulnerability factor which may be unique to island microcosms. With few exceptions, societal vulnerability has only recently been the subject of preliminary investigations (Rappaport in Fosberg, 1963; Brookfield, 1977-1980; UNESCO/MAB, 1974; MAB, 1977; and Stinner et al., 1982). An indexing/ranking system for this aspect of island system vulnerability is a long way off as the social scientists have lagged behind their natural science counterparts in building a generic island system data base.

Thirdly, there is the matter of insular economic vulnerability, by far the most dynamic and least subtle of the three. This more quantifiable factor is quite possibly the most important in the short run because it is the most amenable to modification from inside through domestic national development planning and policy reorientation.

6.1.3 The "Unbalanced Books" Model: Islands At Risk

One clue to economic vulnerability is the level of island dependency induced by external driving variables such as multinational initiatives, bilateral and multilateral foreign aid, satellite communications and international energy and commodity pricing programs. Numerous studies have been completed on the economic dependency characteristics of smaller island systems. Some focus on commodity trade and exports (UNCTAD, 1974 and Dommen, 1980a and 1983), some on production, diversity, and environmental limits (for internal or external trade) (Brookfield, 1977-1980), and still others on the openness of island economies (McElroy, 1978b and 1983). In 1981, Michael Hamnett and three colleagues of the East-West Center's Pacific Island Development Program in Hawaii put together an effective ranking strategy to establish an index of island economic vulnerability. Based on a sample of fourteen Pacific island countries and territories, the model provides a framework and simple formula to assess six separate indicators of economic vulnerability (or per contra, resiliency). In short, the model provides a format for establishing a composite island vulnerability index and ranking number. A summary of the results was recently published by the East-West Center (Hamnett et al., 1981).

Hamnett and his colleagues observed that, although numerous oceanic island areas had achieved political independence in the past twenty years (nine in the Pacific and eight in the Caribbean), all remained economically dependent on external capital, commodity export markets, and outside sources of costly energy and development assistance. This dependency persisted despite efforts to achieve a respectable measure of economic self-reliance. Some appeared more successful than others, and strategies varied. For example, the head of Papua New Guinea's National Emergency Service declined a million dollars in foreign aid disaster relief funds in 1981, offered by the United Nations. This decision was based on the grounds that such outside aid might make the recipients, and the Melanesian nation itself, too dependent on outsiders in the future.

By way of contrast, in 1979 only about four percent of the revenues of the Trust Territory of the Pacific Islands were generated by economic activity within the territory. The 100 million dollars (U.S.) being provided to Micronesia suggests an index of emerging, irreversible dependency. Western Samoa, which obtained nearly half of its foreign assistance from various multilateral sources, may be slightly better off and less vulnerable to the vicissitudes of outside policy changes. Surely there was a way to assemble a useful "picture" of dependency levels and types, based on this kind of information.

It was assumed by the Hamnett team (1981) that six major constraints contributed to the economic dependence and vulnerability of island nations and territories in the Pacific basin:

- the need for some states, still not fully independent, to gear their economies to the needs of a colonial power rather than their own needs

- the strain of trying to internally finance extensive government programs
- the high cost of energy coupled with the region's almost complete dependence on imported fuels
- an overreliance on imported food supplies
- a lack of diversity in exports
- an overdependence on foreign aid.

Using only readily available, standard statistical data and information for 14 selected Pacific island areas, Hamnett and his associates then converted these six constraints into the six sub-components of an economic vulnerability index, namely, (1) foreign aid dependency, (2) diversity of exports, (3) food substitutability (could the island feed itself if it had to), (4) dependency upon imported fuel, (5) fiscal integrity (cost of government operations compared to Gross Domestic Product), and (6) political constraints (types of external ties affecting internal decision making). Very simple, hand-calculation formulas were employed to generate the six indices. The indices were then combined into a composite index of economic vulnerability, shown in Table 5.

The last three entries in the table suggest that standard U.S. domestic policies for its island territories may have produced some adverse effects. They further suggest that current U.S. technical assistance strategies for non-domestic developing islands may need readjustment to ensure that increased local self-reliance is a targeted objective, rather than an assumed by-product. The mere transfer of funds to offshore island areas to address development problems is not a final solution as it may unintentionally generate increased dependency and, therefore, vulnerability. By skewing the allocation and development of local resources in favor of imports and external control factors, such practices too often leave the island with even fewer options and more dependent than before. It also appears that the planning and design phases of island technical assistance projects should incorporate "an assessment of vulnerability," perhaps as a new component of the standard impact assessment.

Table 5. Composite index of economic vulnerability (Source: Hamnett et al., 1981).

	Ranking (least to most vulnerable)
Tonga	(1)
Solomons	(2)
Papua New Guinea	(3)
Fiji	(4)
Western Samoa	(4)
Vanuatu	(5)
Kiribati	(6)
Cooks	(7)
Tuvalu	(8)
New Caledonia	(9)
Niue	(10)
French Polynesia	(11)
Trust Terr. of the Pacific Is. (U.S.)	(12)
Guam (U.S.)	(13)
American Samoa (U.S.)	(14)

For this to succeed, however, Hamnett's prototype "island economic vulnerability model" needs both refinement and regular updates. Additionally, a similar composite economic vulnerability index would be an instructive development planning tool for the Caribbean and Indian Ocean island areas. What is ultimately needed, however, is an island economic vulnerability index for all developing islands regardless of their location or political status. Similar vulnerability indices could also be developed for specific island ecosystems (as natural but modified or stressed systems) and possibly of insular coastal zones.

But for development planning, the numbers are not as important as the interrelationships among the six constraints. Even island systems are complex, and the trade-offs between various constraints and options need to be recognized, ranked, evaluated, and employed as inputs to the strategic planning process for development, if insular vulnerability is to be kept within lower risk ranges and manageable bounds.

One Pacific islander summed it all up rather nicely when he said, "For independent small island states the real issue is the nature and degree of dependence because they really only have independence of limited choice within a dependent system" (Kavaliku, 1980).

The implications of all of the above for island coastal zones, for Exclusive Economic Zones (EEZ's) and for marine resource development strategies lie far beyond the scope of this study and are a task for yet another day. But foreign aid and technical assistance programs are an ongoing present day phenomena. Therefore, the following section explores the linkage between island coastal and marine resource development, on the one hand, and island vulnerability mitigation on the other.

6.2 Coastal and Marine Resources: An Island Dilemma

6.2.1 The Risks of Development

Developing island countries, especially the smaller systems, are particularly dependent upon their surrounding marine environments and coastal zone. Populations, ports, marinas, mangrove lagoons, major cities, artisanal fisheries critical to local food supplies, occasionally a commercial pelagic fisheries industry, some agriculture, all watershed drainage, and most industrial, commercial, and energy supply activity are clustered in this highly complex, circumferential area where the island meets the sea.

The greater the pace of island development, the greater the stress placed upon this high-energy, pollution prone interface of interacting terrestrial and marine ecosystems. These pressures create a need to devise workable and appropriate management strategies and practices for the resource base to achieve sustainable development goals. But this is not easy to accomplish because most proven continental and temperate zone approaches, procedures and models are inappropriate for tropical and subtropical seas, where the majority of developing islands are situated. The greater the degree of island openness (and therefore vulnerability), the greater the risk of imported, irreversible, potentially destructive schemes, technologies, and capital investments.

Fortunately, the miniscule size of oceanic island areas tends to rule out most of the spectacular strategies and technological options for achieving a new kind of power over nature because the resources are simply not generally available to carry out this conquest. Nevertheless, islands should not allow themselves to be inveigled or importuned by multinational corporations and aid programs "peddling" high technologies to accept a kind of Faustian bargain to conquer nature in their own island ecosystem. This is one of the few cases where the "economy of scale" principle benefits islands. Some things are just too big to fit!

For example, most islands are too small to provide a sufficient market for the alleged minimum bottom-end/break-even point for "super-tech" energy systems--like nuclear power generation (500 to 1,000 megawatts) or ocean thermal energy conversion (OTEC) strategies (200 to 500 megawatts) (Cohen and Dunning, 1978). But their isolation and strategic locations, not their market potential, open them up to other coastal dependent high-technology uses such as oil refinery sites, super tanker deep-water transshipment terminals, rented military bases (US$200 million/year to the Phillipines) and test sites, and ever larger destination sites for tourists.

On a less dramatic, but more extensive, scale, island coastal areas have been and continue to be victimized by carelessly planned marine sand mining schemes; mariculture ventures; municipal and industrial wastewater discharge outfalls; port terminal, breakwater and causeway construction; coral harvesting; solid waste disposal activity (with associated leachates); and the discharge of cannery wastes.

Once again, it is a case of good intentions gone astray because of systemic deficiencies on the part of both island leadership (tending to look outward for assistance) and development institutions (which often assume existing program and project planning, review, and evaluation mechanisms will weed out the unworkable or non-productive, environmentally objectionable development schemes). Most of these activities are carried forward with externally provided bilateral and multilateral development assistance funding. In theory, negative impacts can be anticipated and eliminated, or reduced to acceptable levels, by the funding agency's requirement of an environmental impact assessment (EIA) and by applying standard "island specific" criteria, conformance tests and project post-audits. However, the last three are rarely completed.

These steps plus programs to train islanders and provide assistance in building island institutions to address "environmental issues" help to insure that environmental constraints in the development process are locally defined and applied. The emphasis here, however, is not about applying constraints on development. Rather, the concern is to understand generic constraints on island strategies for development and undesireable constraints on future options caused inadvertedly by ill-conceived development schemes. There are several very specific constraints or problems which affect the design quality, effectiveness and the implicit element of risk in most island development projects.

Tropical marine and coastal ecosystems pose an especially difficult environmental management problem. Their chemical and physical characteristics, their community structure, and their biological functions differ or behave differently from their better known temperate zone counterparts. Tropical island systems tend to have lower tolerances to various kinds of abnormal stress resulting from excessive and recurring concentrations of waste discharges in any particular location, principally but not entirely because of their smaller size and reduced ecological diversity. A detailed tabular summary of how tropical systems differ from temperate continental coastal systems is provided by Johannes and Betzer (1975), a very useful document for coastal resource development planners. The dispersal, breakdown, uptake and impact of water pollutants (including sediment discharge) also differ quantitatively in the tropics. An appreciation and understanding of how they differ are essential for proper marine resource planning, structural design, environmental monitoring, and impact mitigation strategies in tropical waters.

In the meanwhile, tropical island coastal "zones" remain at risk because of their contemporary uses, because they are more sensitive to stress (than continental, temperate systems), and because we are slow in applying what we already know about pollution loading limits, thresholds, standards, and appropriate practices under insular circumstances.

6.2.2 The Promise of Development

While island coastal zones and marine resources are ecologically vulnerable and are the target of not inconsiderable contemporary development activity, they also constitute the best hope for islands to recover a degree of self-reliance, thereby reducing some types of less desireable dependencies. The logic of our emphasis on coastal and marine resource development within the smaller island context is straightforward. The practice of exchanging traditional, precarious, export-based, plantation-type mono-culture (sugar, copra, bananas, nutmeg) for new export-based industries such as more diversified agriculture and mini-agro-business, enclave tourism, and manufacturing has not really worked well. It has worked only when supported by massive foreign aid which props up the economy to compensate for export revenue failures and provide funds for expanding social programs (McElroy, 1978a). One style of dependency has simply been traded for another, leaving the local economy with essentially undeveloped, internal linkages (especially in clustered, multi-island systems) and a weak economic base for self-sustaining growth both essentially unchanged (Brookfield, 1977, 1980). And still the question remains of how an island breaks out of this expanding framework of constraints, dependencies, and vulnerability, especially when "land resources" are still heavily influenced by surviving remnants of the "plantation system," even in newly independent islands.

Our purpose in focusing on the development potential of coastal resources is to address the matter of historical dependencies and recurring cyclic instability, induced principally by external forces. Devising an island coastal resource development management strategy then can be seen as essentially an "... orderly attempt to gain a degree of internal control over one area of the domestic domain that is still amenable to public intervention, namely the vital resources of the coastal zone" (emphasis added) (McElroy, 1978a).

Given the recent addition of the 200-mile "exclusive economic zone" (EEZ) concept to the traditional coastal zone, Dolman (1982) is probably correct in observing that "ocean space and marine resources may be the comparative advantage of island states which can be exploited to the benefit of both people and as a source of foreign exchange." He is certainly correct in deploring the fact, again specifically referring to island systems, that "the seas and their resources have been forgotten in development thinking and planning, in part as a consequence of colonialism and preoccupation of colonial managers with cash crops and the exploitation of land based resources."

Dolman fails, however, to convey a feeling for both the magnitude of the "coastal/marine space/EEZ" resource assessment task and the dimensions of coastal and offshore resource management responsibilities for smaller island areas with underdeveloped institutional and technical capabilities for such tasks (see Section 6.3).

Villamil (1974) may have been ahead of his time when, in discussing open-system planning, he noted that "...the survival of small island systems depends on the adoption of development paths which are responsive to their characteristics and aspirations." The surrounding, encompassing, ever present sea-context of an insular system may force just such a reorientation in resource development perspectives. Islands, by definition, have far more "coastal zone" per unit of land area or population than continental systems. It is one of their unique characteristics, and it holds a relatively undeveloped set of resources, especially if one considers the EEZ as a part of the coastal zone.

Obviously, in each island country, a long-range coastal zone-marine space management strategy is needed to serve locally defined objectives. At a minimum, such a strategic planning effort should assure orderly development of more familiar, more accessible inshore and coastal resources, and to protect (conserve) the offshore EEZ resources until such time as the island has the technical capacity to design and implement appropriate resource development activities. In sum, if island coastal zones are as important to island futures as we argue (on the basis of the literature, our examples, and our experience), then it behooves bilateral and multilateral technical assistance agencies aiding in the process of island development to pay more attention to expanding the capacity of island systems to optimize the uses of their coastal resources and to conceptualize new uses for their newly demarcated EEZ marine space.

6.2.3 Developing Marine and Coastal Resources: Early Initiatives

For most continental countries, concern with the ocean, marine resources and even coastal matters is a rather small part of their larger national interest. This is also true for many newly independent island states struggling with basic problems of nationhood, divestiture of colonial ties, encouraging a sense of national identity and creating a viable economic system out of traditional plantation-based agriculture and other land-based enterprises within a volatile world economy. Therefore, an appreciation for the development potential of insular marine and coastal resources is a relatively new phenomena and experimental attempts to inventory and evaluate the components, assess their economic potential and devise an integrated framework or model for their development and management are even now just beginning to surface in a serious and productive way.

Exactly ten years ago a United Nations' study on the special characteristics and problems of "Developing Island Countries" devoted only two paragraphs (out of 44 pages) to the exploitation and control of marine resources (UNCTAD, 1974). The following year another arm of the United Nations also devoted only two paragraphs in a 26-page brief on coastal area management and development to the special coastal problems of developing island countries (UN/ECOSOC, 1975a), while a second 60-page UN paper on "Marine Questions: Uses of the Sea" does not discuss islands at all (UN/ECOSOC, 1975b). During the 1970's the UN Ocean Economics and Technology Office and UNESCO's separate Marine Science Division and its Man and the Biosphere program did a little better by islands and developed special initiatives to adapt emerging continental coastal zone management, environmental education, marine science training, and man-environment research perspectives to islands and island groups in the Caribbean, the South Pacific and elsewhere (UNESCO, 1973, 1974, 1981; Valencia, 1981).

Since about 1978, other regionally focused, internationally sponsored attempts to develop island-specific "coastal resource" initiatives have emerged under the aegis of CCOP/SOPAC (see Section 5.5), the United Nations Development Advisory Team (Baines, 1981), UNEP's

Caribbean and South Pacific regional environmental planning strategies (UNEP, 1980; Dahl, 1980), the University of the South Pacific in Fiji (which established an Institute of Marine Resources under the directorship of Dr. Uday Raj), and the East-West Center at the University of Hawaii (Hamnett et al., 1981 and Valencia, 1981). Each of these represents continuing program efforts.

In the non-government sector (which has greater freedom to experiment) parallel but different approaches to island coastal and marine resource development and management problems have emerged since the mid-1970's. Useful initiatives have been undertaken by the following:

- Dalhhousie University of Nova Scotia (Caribbean - see Mitchell and Gold, 1982 and Gold et al., 1982)
- The RIO Foundation (Caribbean, Pacific, and Indian Ocean - see Dolman et al., 1982)
- The German Foundation for International Development (Caribbean and Pacific - see Szekielda and Breuer, 1976)
- The Eastern Caribbean Natural Area Management Program (ECNAMP) (under the aegis of the University of Michigan and the Caribbean Conservation Association, with primary funding from Rockfeller Brothers Fund, International Union for Conservation of Nature [IUCN] and World Wildlife Fund [WWF] - see Geoghegan, 1983; Putney, 1981 and 1982)
- Environmental Research Projects (Caribbean - see Goodwin and Taylor, 1981; Goodwin and Cambers, 1983)
- Island Resources Foundation (Caribbean and Pacific - see Towle, 1978, 1979a, 1979b, 1981).

Some of these experimental private sector strategies by non-profit organizations have potential as model components of larger more comprehensive governmental coastal resource management schemes. Others offer alternative approaches altogether.

Each of these "experiments," involving island governments but initiated by non-government organizations, has been a learning experience for the sponsoring institution and for island governments, planners and managers. Some approaches (ECNAMP, CCOP/SOPAC, and Dalhousie) have had longer time frames and been more effective than others; all remain functional, and none should be overlooked in the near future as "how-to-do-it" models by those designing and planning, within larger frameworks, bilateral or multilateral technical assistance strategies addressing island coastal zones and marine resource management. The nucleus of a new "integrated" approach is beginning to take shape, but there is no one preferred model as yet.

6.2.4 The "Resource Management Community"

One recent private approach to marine resource management in the Eastern Caribbean (see Section 4.3) has demonstrated the value of emphasizing local participation, communication, and consensus-building strategies through carefully established networks of resource users, technicians, scientists, planners and managers. Taken together, in the smaller island context, this heterogeneous grouping can be conceived of as a "resource management community"--a concept which lends itself to using a consensus strategy for both planning and management. This can be illustrated as follows.

In continental societies, as even in some larger islands, a marine or coastal resource manager is generally assumed to be a professional-level government official charged with the guidance and control of resource usage operating within an established framework of plans, policies, rules, regulations, buttressed by legislation. One should not assume, however, that the absence of professionals in any given island means that no resource management takes place. In most traditional island societies, especially those with extensive subsistence-level coastal villages, an alternative resource management system has evolved over time among the resource users. By custom they apply management techniques learned through experience to sustain the resources upon which they depend. Sometimes a whole village or groups of users in a cooperative format develop strategies to protect the resource base which they understand and identify as vital to their future. As in the case of the fishing village of Gros Islet in St. Lucia (Section 4.1) or the coastal villages in Fiji (Section 5.3), collectively learned "wisdom" about the nature and limits of the resource base resulted in different but similar "limited entry" strategies. As Geoghagen (1983) has recently reported, there are many other instances of island fishing communities "... voluntarily closing off certain fishing areas where overfishing has reduced yield, until the stock is replenished...." These actions select the "option that will be of greatest benefit to them in the long run. This kind of self-regulation allows the resource users to retain control of their own lives and of the resources upon which they depend."

Furthermore, the use of consensus-building networks as a management tool should not be underestimated. By improving communication channels between user groups, planners and government managers, various existing traditional, community-based management mechanisms, not normally recognized or used by government, can be identified and utilized effectively in a more holistic coastal resource management strategy.

6.3 The Economic Significance of Island Coastal/Marine Resources

Insular countries have two things in common with continental countries. First, both have a "national interest" in oceans (Alexander, 1973), as evidenced by the bitter debates over EEZ boundaries at UN Law of the Sea III and continuing bilateral negotiations to define shared boundaries. Second, neither insular or continental states have made significant progress in quantifying the economic significance or contribution of coastal and marine resources to the national economy as a whole or in establishing the dimensions of forward and backward linkages and multipliers for ocean-related industry. National accounts simply are not kept in a way that makes it easy to separate ocean-related economic activity. The principal problem is that national income accounts are maintained on a production, industry or activity sector basis (e.g., forestry, manufacturing, etc.) with no spatial breakdown. For example, there are gross tourism industry figures but no separation of land-dependent from sea-dependent tourism.

A way to solve this problem, however, has been recently developed by four enterprising economists from Columbia University's Graduate School of Business, who designed a conceptual and statistical methodology for extracting the needed ocean-related economic figures from available census data and the national income accounting system. In 1980, they published their findings in a significant article entitled "Contribution of the Ocean Sector to the United States Economy" (Pontecorvo et al., 1980). Based on their model, the aggregate value of the U.S. ocean sector for 1972, the most recent year at the time for which data was available, was $30.6 billion, comparable to agriculture at $35.4 and communications at $29.4, but significantly larger than mining, oil, and gas at $18.9. Note, however, that since the total U.S. GNP for 1972 was $1,171.1 billion, the ocean sector contributed only 2.6 percent of this--not a terribly impressive figure.

In islands, however, as we will demonstrate in a moment, the situation is markedly different. The Pontecorvo model had been circulated in 1979 as a research working paper and caught the attention of an equally enterprising group of researchers at the Dalhousie University Ocean Studies Program (DOSP) in Canada interested in the EEZ question as it relates to insular systems. The DOSP group had previously been investigating certain marine law and policy questions in the Eastern Caribbean where island countries are close together and conflicts over use of the sea were emerging. When the Foundation for Reshaping the International Order (RIO) of the Hague, Netherlands, cast about looking for an institution to carry out two case studies (Grenada and St. Lucia) dealing with the capability of smaller island states to deal with EEZ's, marine space and economic development, the Dalhousie group was selected and supplementary funding support obtained from the Canadian International Development Agency (CIDA). Under the direction of Dr. Edgar Gold, the project research team of ten persons (including three West Indians) commenced work in 1980 and by 1982 had completed two significant reports, one dealing with development and ocean management in the Eastern Caribbean (Gold et al., 1982) and the other entitled "The Integration of Marine Space in National Development Strategies of Small Island States" (Mitchell and Gold, 1982). Taken together, they represent a truly new approach, in part because they adapted the Pontecorvo methodology to island situations (St. Lucia and Grenada).

The approach used was simple and straightforward enough to apply to any island state, using available data without computers or sophisticated economic procedures. While the procedure needs refinement, it does offer the opportunity of establishing an economic rationale for placing greater emphasis on developing improved island coastal and marine resource assessment, planning, development, and management efforts.

Ocean- and coastal-related industries and uses are first identified and sorted into two categories, depending on whether they directly utilize an "ocean/coastal" resource in a harvesting or productive process (supply side, as in the case of fisheries or a marina or resort hotel) or exist because the demand for the establishment's "product or service" is due in part to some attribute of the ocean or coastal zone (demand side, as a contractor who builds a dock for a marina, a store that sells boat engines, or a wholesaler or farmer providing provisions to coastal hotels). The next step involved attempts to measure linkage effects between various industries involved on both "sides" and then effects on the island economy as a whole. Linkages were split out as follows:

- backward, where growth and development in ocean/coastal industries induce investment and development in other sectors, providing inputs to ocean/coastal industries such as boat and ship building, port facilities, engine repair and other service activity
- forward, where ocean/coastal industries exert an influence on industries using "products" from the coastal/marine zone as an input such as coral sand and block for construction use, fish processing
- demand, where incomes generated by marine/coastal related industries stimulate increased demands for consumer goods and services.

Using this approach, the DOSP team then developed an ecodevelopment framework for applying a simple model for an integrated marine system to enhance island development and economic self-sufficiency. Despite implicit weaknesses (for example, it leaves out local village-based subsistence marine protein production values), the DSOP project established one very important fact--islands' coastal and marine resources are far more significant than previously realized by most development planners.

The reader will recall that only 2.6 percent of the 1972 GNP for the United States was attributed to "ocean-related activity." By way of contrast, that figure based on DSOP findings for St. Lucia (1978) was 33 percent of GNP, for Antigua-Barbuda 32 percent of GNP (1981), and for Grenada (1978) over 30 percent (Mitchell and Gold, 1982). <u>These islands were at least ten times more dependent on coastal and marine resources than the United States</u>--a rather compelling argument for paying more attention to devising appropriate management strategies for island coastal zones and associated marine resources and for carrying out a similar coastal/marine economic assessment for other developing islands.

One barrier to getting on with these tasks is the "land" orientation of most island planners and the absence of marine resource professionals in most island planning units--a matter addressed in the next section.

6.4 <u>Island Coastal Resource Planning</u>

6.4.1 Conceptual Problems

Over the past two decades, developing island countries in the Caribbean, the Pacific and the Indian Ocean area have consistently acknowledged the need, embraced the principles, and, largely with the technical assistance of the United Nations Development Programme (UNDP), established the basic framework for physical and economic planning (UNDP, 1977). All island countries have planning units, some more centralized and comprehensive than others, some still partially staffed by expatriate professionals, but most staffed by islanders trained in universities abroad or regionally by continental instructors with continental perspectives and a fundamental preoccupation with land-based physical planning. Geoghegan is partially correct when she observes that "... smaller islands have often tried importing the planning techniques of industrialized nations, even though limited size and financial resources make those techniques unworkable" (1983). The central problem is the ignorance of most planners about marine ecosystems, resources, industries, uses, and such things as ships, ports, fisheries, and how to map corresponding data.

Why is this the case, even though islands have a larger stake in the proper planning of coastal and marine resource use than their continental counterparts? The root of the difficulty, in the author's opinion, lies in the land-focused planning models transplanted by the UNDP and others into the island context. As a result, the existing central planning offices, natural resource ministries and statistical agencies of the smaller island states involved in the CCOP/SOPAC inshore program do not, at the present time, collect, store, analyze or report most of the kinds of marine and coastal baseline environmental data needed for coastal resource development planning and for the optimal engineering design of marine structures and facilities. The same is true for the independent island states in the Eastern Caribbean.

Out of the 16 island government planning units visited by the author over the past five years, not one could provide a "sea-use map" comparable to readily available detailed and continually updated land use maps. Soil but not sea "capability" maps were available. Not one had a detailed map of coastal erosion sites, of former dredging sites, of pollution prone/stressed coastal environments, of vessel traffic, or of anchorage/mooring patterns for boats comparable to their detailed vehicular traffic and parking plans. Not one had thought about sea area "zoning" controls comparable to land zoning. In all sixteen cases, data were available on land but not sea mining sites, on hotel but not charter yacht bed nights, on agricultural input but not marine sector input to GNP, on taxi drivers but not boat operators, on potential geothermal or hydro-power generation sites on land but not on nearshore cold water upwelling zones with thermal energy conversion potential.

6.4.2 Information Problems

Not only is site-specific coastal resource user data (quantitative, spatial, or qualitative) generally unavailable, but routine environmental data is also hard to obtain. At a UN/ESCAP (Economic and Social Commission for Asia and the Pacific)-sponsored workshop on environmental statistics held at the East-West Center in Hawaii (October 1980), it was concluded that "a major handicap for the inclusion of ... environmental considerations in development planning is the lack of environmental data on which environmental agencies may base their judgments within the context of planning efforts" (UN/ESCAP, 1980). Additionally, it was also found that "... environmental statistics per se are not collected" by government statistical offices.

Even in U.S. offshore island areas like the Virgin Islands, Puerto Rico, Guam and Samoa, which already have developed coastal zone management plans and programs as part of a larger national strategy, the problem persists because of a structural failure in the design concept. The basic framework was designed for coastal states of the United States, many of which already had elaborate information collection, storage, and retrieval systems, extensive baseline data, numerous cooperating institutions, overlapping agency jurisdictions and, to a degree, a tradition of data sharing, exchange and transfer. But when the concept was transplanted to offshore insular systems, with only some minor modifications, the absence of a data base, storage, retrieval and management information system (as a program component) became a serious limiting factor.

These planning and information "failures" are not, however, so much the island's fault as the result of inappropriate approaches imposed from outside--models derived from continental areas with less at stake in the "coastal zone." Further, on the basis of three quite different experiments, two in the Caribbean (ECNAMP and Dalhousie) and one in the South Pacific (CCOP/SOPAC/Inshore Program), reviewed elsewhere in this document, it is clear that there are ways to temporarily circumvent these problems and get on with effective insular coastal resource development and management efforts.

In the ECNAMP (Caribbean) case, the ongoing resource data inventory, mapping and analysis effort has emphasized local participation in the collection of existing, best available data, downplays research/field work, while emphasizing training and use of mid-level prototypic resource managers (both government and non-government) supplemented by in-region generalists, all within a closely coupled network of participants exchanging, reviewing, storing, and using data on both a single island and a regional level. Formats are kept simple, data distribution is wide, and feedback loops are carefully cultivated for updating the data base. The ECNAMP program has been strong on qualitative resource and user assessment and weak on quantitative resource and user data.

By way of contrast, the CCOP/SOPAC/Coastal Resource Program has tended to emphasize mid to lower level technicians (in geology, oceanography, marine science, fisheries, etc.); training in more precise cartographic, oceanographic, resource assessment skills; technical agency and university networking; and on-site applied quantitative research and measurement, with less emphasis on generating qualitative coastal resource and user information, more on improving local quasi-professional skills and performance capabilities, and on island specific problem solving (e.g., where and how to site an outfall or a sand mining effort).

The Dalhousie approach (Section 6.3), while less participatory, nonetheless addresses both the planning and informational lacunae, with an emphasis on the latter. All three approaches offer guidelines for a more effective comprehensive approach.

The nucleus of a conceptual management-information framework for combining these three different but promising efforts is provided by Wilimovsky (1979) in his paper on minimal data requirements for aquatic resource management in developing countries. Wilimovsky notes that decision making is generally based on readily "available data," appropriately processed, interpreted and communicated; and "the manner in which such information is conveyed to the user essentially and effectively controls the degree to which one receives, understands, and accepts the information as knowledge" upon which to base decisions. There is considerable evidence to support Wilimovsky's charge that many resource data collection programs overemphasize precision, even though at the management/decision level the very precise data is combined with imprecise guesses. Although the data base for coastal resource managers in small islands is marginal, it is still accessible, useable, and improveable if a management information system sensitive to local conditions, practices, sources and users is designed, put in place and made to work.

Lastly, a word about non-formal information sources is important. Data collection and marine resource management efforts should not only incorporate but reflect "local lore" drawn from traditional island fishermen, ship captains, divers, and other long-standing local subsistence and small-scale commercial users of the marine and coastal environment. Such persons need to be encouraged to participate in the information network (Baines, 1982; Johannes, 1978; Putney, 1981; Geoghegan, 1983). Regular consultation with such individuals for data collection purposes becomes the entry point for their direct participation in the planning and implementation of the management strategy itself.

7. SYNTHESIS: FROM THEORY TO PRACTICE

7.1 The Island Puzzle

Luigi Pirandello's famous play "Six Characters In Search of An Author" provides the inspiration for this summary section wherein we explore the progress being made toward developing a new framework or paradigm for perceiving and understanding the "genius" or nature of small island places and the driving forces which both sustain and change them. The search for a new island paradigm has been years in the making, and we--islanders and continentals alike--are still in a transition period regarding the theory of the island circumstance. For those practical persons seeking to identify leverage points and appropriate mechanisms to assist in the complex process of aiding "sustainable" island development (or ecodevelopment), the insular coastal zone management and environmental planning strategies currently being refined offer some hope of defining more holistic perspectives on "rational resource use" and more effective intervention strategies appropriate to island systems.

But there are problems. The very diversity, ubiquity, heterogeneity, and remoteness of islands induces enormous variations in how they are perceived--conceptually, metaphorically, analytically, descriptively. At one and the same time they are closed, self-sufficient, idyllic, isolated and, alternatively, open, dependent, parasitic, linked. They are both prisons of the mind and places of renewal of the human spirit. While they are living laboratories, metaphorical models and museums of evolution, they are also spatially unique microcosms of some external human ecosystems <u>and</u> a viable home to islanders who have traditionally faced and adjusted to the insular condition with all its vicissitudes and variations.

Perhaps islands and islanders, in all their global diversity, demonstrate an anthropomorphic version of Werner von Heisenberg's principle of uncertainty--even the act of observing (or using) them induces change in the thing being examined. Hence, the result is a kaleidoscope of images reflecting the insular condition.

In any event, attempts to classify, categorize, enumerate, and label islands have, to date, been far from successful. There is still no really useful taxonomy (or classification framework) of island systems. Neither is there a comprehensive or even partial assessment of the "global resource" (as we have, for example, in the case of mangrove systems, coral reefs, forests, marine mammals, or endangered species). What we do have is a vast spectrum of diverse islands and an evolving set of "island tested" or island specific models or methodologies which sequentially and cumulatively are effecting a shift in the way "islands" and insularity are perceived.

7.2 The Island Ecosystem Paradigm

There has been a long tradition of systematic investigation of islands by natural scientists. For all of the natural science disciplines, islands have provided a kind of living microcosmic laboratory of great value. Within the past half century, the flexible concept of the "ecosystem" has become the dominant "framework" for island research to define study area boundaries and sets of factors (variables) to be included or excluded. Best articulated by Fosberg (1963) but replicated by dozens of other theoreticians and employed by thousands of scientific practitioners, the island ecosystem and its varying assemblages of lesser sub-unit ecosystems became the standardized and accepted way of looking at islands. And, in the absence of any appropriate paradigm except for the Darwinian evolution theory and the MacArthur and Wilson "spatial isolation" theory of island biogeography (which were both derived from island observations), the "ecosystem" model became in effect a surrogate paradigm.

Under the post-World War II impacts of internationalized decolonization and development assistance initiatives, in combination with dramatic shifts in air transport and electronic communication technologies, islands everywhere began to experience new kinds of pressure on their environments. These threats to the insular environment (ecosystems to some) carried implications beyond irreversible changes in physical and biological assets. The environment is an integral part of the total island matrix that defines the quality of life for island peoples and visitors alike. The somewhat vague concept of "quality of life" has slowly gained favor as the framework for merging economic, social, and environmental development objectives. It expanded the narrow measure of progress by standard economic indices such as GNP and per capita income, incorporating other social-welfare indicators, environmental factors, traditional resource uses, and amenities which constitute a vital part of any island's life-support system.

The decade of the 1970's, however, saw a more fundamental redefinition of the island ecosystem model with an increasing emphasis placed on island people, socio-economic vulnerability, system complexity, and the importance of traditional resource management approaches, all reflecting the uncertainties of island life due to natural hazards, historical dependency factors, isolation, independence (for some) and expanding social, economic, and technological pressures from outside.

Beginning in 1973, the UNESCO Man and the Biosphere Program launched a rather significant long-term research project focusing on "Islands and the Rational Use of Island Ecosystems," which is still ongoing although its approaches are very different from those of 1973. The island-man-island ecosystem transactional model is slowly being modified by the addition of both center-periphery considerations in multi-island systems and human system transformation theory for "outer islands" (Brookfield, 1977, 1978a,b, 1979, 1980), and more recently by the addition of the "vulnerability" model of Hamnett et al. (1981) and the experimental island marine economy model of the Dalhousie University research team in the Eastern Caribbean (Gold et al., 1982, and Mitchell and Gold, 1982).

7.3 Towards A New Paradigm

Environmental problems generated by island development are neither incidental or ephemeral, especially because they add new limits to already naturally constrained future options. As island habitats are reshaped, the environmental transformation induced by development is resulting in significant cultural reorientations and changes in the institutional structure whereby humans address the environment. Systematic investigations into these processes is called human ecology. It represents an approach which seeks to bridge the gap between the natural and social sciences and is based on the premise that human social systems and natural ecosystems each influence the other and changes in one system are quite likely to generate compensatory changes in the other.

But for human ecology to be useful in optimizing development choices and minimizing man/environment conflict, the natural and social sciences need to work together as equal partners, a circumstance which rarely occurs. Social scientists seldom participate in resource management and environmental planning activities, and such programs are customarily developed largely by the natural and physical scientists. When social scientists do become involved, it is usually to provide some incidental, peripheral commentary on an already defined program; they are brought in long after the design phase to provide a "token" social science input. In one recent coastal zone planning format prepared specifically for Third World country use, "legal, political, financial, and cultural factors" are not scheduled "inputs" until two-thirds of the way through the process and then only to help evaluate previously determined alternatives (Neuman in Valencia, 1981).

The lack of social science participation in the design phases of resource assessment and coastal zone management endeavors means that the definition of problem areas for study falls entirely within the hands of the natural scientists who tend to assume that the physical and biological aspects are empirically primary. They tend to use natural ecosystems (or sub-units thereof) to define the boundaries of the study, whether it is a tropical river basin, mangrove lagoon, endemic species habitat, a beach, or a coastal zone. Only after the natural scientists have defined the "proper" unit of study are the social scientists invited in to provide counsel on how human systems affect the operation of the natural system.

Unfortunately, this approach generally does not work because as Rambo (1981) has noted, "... social scientists work in terms of their own special unit of analysis. This unit is not people as such but an altogether different conceptual unit which is seldom fully isomorphic with the ecosystems defined by the natural scientists." Social scientists each focus on a slightly different aspect of human use systems (for example, the anthropologist addresses cultural systems, the sociologist looks at systems of social organization, the economist explores the market system, the administrative analyst and the planner or manager deal with information systems). These components make up the totality of the social system which interacts with the equally complex natural system.

Although the social scientists, seeking to understand the structure and dynamics of social systems, have made significant progress in recent decades, the availability of socio-economic management strategies for application in island environmental and coastal resource management efforts remains outside the purview of most natural scientists and resource managers with science-oriented backgrounds. As a result, natural scientists often fail to appreciate the value of human social system paradigms for addressing man/environment interactions. Natural scientists continue to be presumptive about the primacy of the physical and biological sciences, while social scientists continue to be diffident about coming forward with viable alternative approaches to an analysis of human interaction with the environment. Both groups would benefit from more frequent, more direct (even forced) kinds of interaction.

However, while social scientists may contribute new ways of "perceiving" the problem and may be especially useful in projecting social impacts and looking at patterns, institutions, options and constraints at various hierarchical levels, a local "participation" strategy (especially at the village level) is essential to document how the existing human use system functions and to establish and evaluate objectives (potential futures). Adding the social scientist to the coastal resource management planning process is, to a degree, only a means to an end, improving and accelerating the data gathering and analysis activity. To a degree, using a participatory strategy compensates for the absence of more rigorous or more elaborate social science input and also functions as a "ground truth" or corroborating mechanism when more formal kinds of social science inputs are available.

The implications of all of this for islands are quite clear and relevant to those whose work involves island conservation and development, especially coastal and marine resource management. There is no one simple paradigm for islands or island microcosms yet--only a series of models (which have served as surrogate paradigms), such as the ecosystem model, the man-biosphere interaction transactional model, and variations on these (like the microcosm model), all moving in the same general direction, namely, an integration of natural and social science knowledge about island processes (derived from different disciplines and interdisciplinary models) within a new framework or paradigm.

In any event, the island ecosystem model or "surrogate paradigm" has served its purpose (and is still relevant to some disciplines). Over past decades it has been pushed and massaged and modified by alternative ways of looking at the insular condition. The feedback loop has not yet been closed and will not be until insular marine environments and marine resources, not just ecosystems, are addressed more systematically as a key element for a more holistic framework for analysis, management, and development of island systems. Some preliminary experimental models and methodologies have proven very promising--opening up new ways to address insular vulnerability (Hamnett et al., 1981), marginality (Brookfield, 1980, and Geoghegan, 1983), dependency (McElroy, 1978b) coastal resource opportunity (Gold et al., 1982), and planning, education and management considerations (Putney, 1982).

No one is, of course, simply waiting for a new paradigm to emerge before proceeding with action strategies. To a degree, only the island "scientist" or specialist is concerned with the paradigm question of "how do island systems work?" Most island resource development practitioners are far more concerned with (1) technology (management, concepts, and strategies as a kind of existing paradigm "software") and (2) institutions (delivery systems for management in a particular insular setting), and are not generally concerned with the theory of why this or that does or does not work in the island context.

Even this case study, despite occasional lapses into more paradigm related theoretical discussions, has sought to focus principally on the technologies of island resource management and on workable island specific institutional arrangements. However, the evolution of a new paradigm, island resource management technologies, and institutional delivery systems are not disconnected entities. All "experimental" or experientially derived perspectives are relevant to the task of improving island system management and the way "managers" perceive and establish a consensus about what they are doing and where they are going.

At the present time, the best hope for combining various experimental approaches to coastal resources in island areas and in accelerating the formulation of a new paradigm for (and general theory of) islands lies in focusing on a conceptual integration of islands and their habitat--"the sea and all that is therein." Insular coastal zones (or marine environments), therefore, offer the prospect of being not just a vehicle for economic revitalization (see Section 6), but also, as the process of management and development proceeds, could provide the missing elements needed for shaping a new conceptual paradigm for island systems.

Therefore, island planners and leaders and the designers of bilateral and multilateral technical assistance strategies for island "coastal zones" will over the next decade or so--whether willingly, consciously, inadvertantly, or perhaps reluctantly--be participants in this process. The island world (within the world island) is close to a paradigm shift. In the meanwhile, useful tentative models, conceptual tools and technical components are available. What is done with them to ensure the survival of island systems is the question.

8. LESSONS LEARNED

8.1 Islands As Unique

Oceanic island states are different in kind, not just in matters of scale, from continental systems and states, a circumstance which suggests the need for caution in extrapolating from continental marine resource development planning strategies and coastal zone management models.

All oceanic islands by definition are surrounded by the sea and have circumferential (not linear) coastal and exclusive economic zones which are always larger than total associated land areas. Island cluster states have no other option except to use costly sea and air transport modes to link-up separate parts of the country which often are dispersed over expansive ocean areas. Most island states (unlike continental countries) have no land frontiers or central terrestrial core distant from the sea, and, therefore, coastal resource planning and management is largely synonymous with national resource planning and management. There is an implied risk, however, in this approach because to a degree it is more holistic and comprehensive than traditional land-oriented physical and economic planning as currently practiced in island states.

All islands are microstates, but not all microstates are islands. Despite its widespread use by the United Nations and some academicians, the term "microstate" is not therefore very appropriate to island systems as it overemphasizes the common constraint of smallness at the expense of the more fundamental constraints of true insularity (isolation, circumferential sea boundaries, dependence on coastal and marine resources, storm risks, limited species diversity, ecological fragility and high levels of biotic endemism).

8.2 Limitations to the Island Microcosm Concept

Islands are not intrinsically microcosms of continents, but smaller oceanic islands (or groups) tend to be microcosms of other larger islands (or groups) or of islands considered generically. Larger oceanic archipelagic or cluster islands may be "microcosms" of marginal, peripheral coastal areas or systems on the edges of continents, to the extent that they help define or demonstrate generic center-periphery or core-margin relationships. The island microcosm concept appears, therefore, to have more academic metaphorical value than applied methodological utility. To the degree that it implies (or the reader infers) that island microcosms are dwarf-like miniatures of continents, it is misleading, falling somewhere between the perception of islands as "satellites" and islands as laboratories.

8.3 Limitations to the Insular Coastal Zone Concept

Island coastal zones are analogous to a topological Moebius strip with no real inside and outside--the sea and the island are truly one identity and in this study are called the "island system." Most islanders innately sense this fusion which goes beyond linear interrelationships or interdependencies of man-land-sea. Perhaps because it is part of the insular mystique, the concept is easily given up by islanders confronting allegedly more acceptable, more rational, but narrower planning, management, and development models when they travel "off-island" for technical and professional training at continental institutions.

In any event, most ongoing island resource planning activity is essentially land-oriented (i.e., inside looking out) which neglects coastal and marine factors, the reasons for which have been previously addressed. But to effect the needed conceptual and structural shift to a more holistic "island system," or island-man-sea framework for resource assessment, development and management planning, one has to first address the implicit land vs. sea asymmetry of the data base, available technical and professional skills, environmental and development control legislation, and institutional capabilities. Secondly, there is a need to develop a more integrated island-man-sea resource management framework by combining the perspective (and respective expertise) of the islander (institutionalized or interpreted by the island core or political center), the out-islander (the margin or periphery), the sister islander (neighboring/regional considerations), and the non-islander (continental/international). Both approaches can be pursued simultaneously. There are two options.

On the one hand, the "coastal zone management concept" (essentially a continental notion) could, with the "insular" adaptations previously suggested, serve as the land-sea linking device and the vehicle for upgrading insular utilization of coastal and marine resources, reducing vulnerability and external dependency, and achieving a greater degree of self-reliance as an insular system.

On the other hand, the standard "coastal zone concept" when applied to islands presents three basic difficulties: (1) when looking inward, because of the "smallness" of the land area, it becomes not a "zone" but an entire matrix of all island watersheds (technically subsuming all planning); (2) when looking outward, because of the vast expanse of the EEZ in comparison to the island itself, the coastal zone concept and label become inappropriate; and (3) when single country island clusters or multiple island systems with closely coupled core and satellite "islands" (as in the case of Fiji, Tonga, Grenada, and St. Vincent) try to use the "coastal zone" format, how do they handle the spatial and jurisdictional problem of what is and what is not "coastal zone." In these cases, the "coastal zone" is not a very useful term, as least for management purposes.

It is suggested, therefore, that for smaller oceanic island systems, the "coastal zone concept" (as a vehicle for change and management) be incorporated within an integrated "marine resource management" concept or its equivalent. In effect, "coastal zones" mean more to continents than to islands; marine resources (which subsume insular coastal zones) mean more to islands than to continents.

8.4 Technical Limits and Options

The reader might assume from this study that extremely isolated, traditionally self-sufficient, more marginal, and less developed islands and peripheral systems represent the ideal, to be encouraged because of their inherently greater stability and sustainability. Their impact on unique, exotic or endangered island habitats and species is seemingly less destructive than larger scale, more intrusive, externally generated activity. This is not the intended lesson.

These "out" island areas (whether undeveloped smaller satellite islands--however ecologically unique--or less developed peripheral outlying coastal areas) are far more important to the core or center than has been previously recognized (not in a preservation mode but as efficient production units that happen to create fewer negative enviromental impacts). One task is to incorporate these peripheral areas and their proven "potential" within the larger island national development planning process without detracting from their character as self-sufficient island system sub-units. This requirement and the larger task of devising appropriate coastal resource management strategies for island systems can best be accomplished by paying attention to the following operational considerations.

- Even a simple development project, if its ecological, sociological, and economic consequences have not been carefully thought through, may have strong adverse impacts on the resource in question, on community relations and on the success of other, apparently unrelated development projects.
- A cultural orientation is necessary not only in the choice of a coastal resource development technology but in the case of all research, planning and management activities maintaining active linkages with established practices in the communities involved.
- Technical assistance planning efforts based on continental models by off-island entities dealing with insular coastal resources will be more effective if they are focused on local development opportunities, are integrated with existing human use systems, are less regulatory and constraining than presently available continental models, and place greater emphasis on consensus-building strategies which combine users and managers.
- In small islands rapid, incremental growth or large-scale projects often overwhelm local institutional resource management capabilities. Compensatory training, education and institution building strategies have tended to

lag behind, suggesting the need for more emphasis on strengthening local institutions and their capacities to anticipate and assess the potential environmental impacts of development activities. This can best be accomplished through participatory, interdisciplinary planning and management initiatives (both governmental and nongovernmental) at the local level, rather than through more formal, off-island approaches.

9. GUIDELINES

(1) Continental models and practices for pre-project environmental impact assessment, while useful, need substantial re-design to serve a practical purpose when applied to island systems.

In project planning, design and development for islands, the absence of an antecedent or parallel comprehensive resource assessment can, as in the Rodney Bay, St. Lucia, example (Section 4.1), lead to unanticipated, adverse environmental and social effects. However, the presence of environmental profiles and environmental impact assessment documentation is no guarantee of success and can induce a false sense of security (as in the Mangrove Lagoon, Virgin Islands, example in Section 4.2) unless the framework for the impact assessment is broadened to reflect insular human use conditions (such as descriptions of man-land-sea, non-cash subsistence economic factors), constraints (such as national vulnerability/dependency indices), and the bias or skew factor resulting from a marginal marine data base and historically land-oriented planning practices.

For island areas, environmental impact assessment procedures should be further expanded to incorporate the design of a follow-up project monitoring and evaluation strategy (with clear delineation of assigned responsibilities, schedules, reporting and funding options). Some attention should also be paid to scheduling a post-audit activity. In other words, the impact assessment approach, if used, should be a less static vignette and more concerned with process, feedback and verification of both external and domestic assumptions. A three-stage effort is required --before, during and after--the latter two preferably by an independent entity.

Additionally, the natural ecosystem concept, as employed by many scientists carrying out environmental impact and resource assessment efforts, results in an incomplete definition of project boundaries. The concept must be expanded to include human use systems and related linkages, with appropriate "boundaries" for analyzing project impacts on human ecology.

(2) Guidelines for coastal resources management should be enforceable and equitably applied. Unenforceable environmental management legislation for coastal and marine resources and/or regulations and permitting procedures which the government itself is not willing to honor are worse than no rules at all because they compromise government credibility among resource users.

Encouraging the hasty drafting of coastal zone or marine resource management legislation should be avoided. Legislation should be drafted when based on solid (not necessarily precise) scientific and socioeconomic information--including information about how traditional uses, users, and resource management practices will be affected, or what industries need incentives or restrictions to enhance development and increase local self-reliance.

Enabling legislation for coastal zone management programs that require massive off-island hiring of expatriate professionals does not meet these standards and should be avoided as premature.

(3) Training and education strategies should be integral components of resource assessment, impact assessment, or marine/coastal resource management planning efforts.

Training and education strategies in marine and coastal resource assessment and management for and in island areas should focus primarily on mid-level technician skills-building and on upgrading the marine literacy of local economic and physical planners and marine resource users, primarily using sequential, participatory, problem focussed workshops and in situ informal short courses designed to cut across disciplinary or ministerial (sectoral) boundaries.

The relative smallness of the population base in most small islands makes it very difficult to identify and provide manpower requirements in addressing technical areas like marine resource development. Unfortunately, as the Minister of Education for Tonga (former Chancellor of the University of the South Pacific in Fiji) has noted, "... training provided overseas is expensive and disrupting" (Kavaliku, 1980).

Prospective skills-training workshops or programs might focus separately or collectively on establishing management objectives and guidelines on coastal zone or marine resource assessment, on community participation, non-formal data collection, resource mapping (by type and by "objective"), impact assessment methodologies, ecodevelopment principles, and alternative management devices such as marine parks or artificial reefs for fisheries enhancement. As appropriate to the island or island group a workshop format could address preparation of resource planning guidelines for specific issues such as docks and piers, harbors and boat channels, causeways and jetties, baseline data gathering, small boat harbor development, beach and shoreline erosion control, beach nourishment/enhancement, lagoonal systems, waves, swells, tides and currents, and risk analysis. Such topics should be approached as simply and in as practical a fashion as possible. In each case the workshop should emphasize what could be done using locally available skills and materials, equipment and instruments. As a second concern, workshops should address what other management goals could be addressed given a modest additional increment of expanded skills training, a few basic research tools, instruments and measuring devices, along with standard data recording forms and "how-to-do-it" handbooks. The reinforcing incentive of being part of both a national and regional network and baseline data/information management system could enhance the strategy further.

(4) Large-scale development projects in smaller islands should be spread over the longest possible time frame and should be designed to be carried forward in stages, to reduce temporally concentrated impacts and encourage mid-project re-design if necessary.

Major coastal/marine resource development projects on smaller islands affecting complex inter-related ecosystems, whenever possible, should be designed for phased implementation, thus allowing time "breaks" between phases to assess impacts and to make appropriate compensatory adjustments. This is especially crucial when the natural resource base provides input to a local and traditional subsistence economy.

The irreversible "transformational" effects of major development schemes on traditional human use systems and the equally irreversible environmental effects of major projects suggest the need for both careful monitoring and retention of the option for mid-project re-design if required.

(5) At a minimum, continentally derived coastal zone management models require major reformulation if they are to be employed in small island circumstances, and in some cases continentally derived models will be inappropriate.

Scaling down existing continental approaches to coastal and marine resource management is not enough. The focus, boundaries, structure, planning, staffing, and funding elements of a coastal zone management approach all require re-thinking and re-design within an island context to incorporate the following:

- an emphasis on local development opportunities integrated with existing human use systems
- fewer top-down regulatory constraints than in continental models
- targeted emphasis on marine literacy and locally required management information systems (formal and informal)
- reformulation of the concept of "public participation" to place more emphasis on concensus and less on formalized ex post facto responses
- provisions to enhance insular self-sufficiency (which means appropriate, locally sustainable technological transfer and ecodevelopment approaches)
- an emphasis on "production" diversity, decentralization (the peripheral system), and the expansion of internalized markets, even at the expense of (a) exports, (b) alleged economies of scale, and (c) foregone outside investment or foreign aid funds for high-tech schemes
- greater incorporation of existing institutions
- emphasis on inter-island regional linkages and opportunities for shared training, management and enforcement.

(6) The existing informal network of island coastal and marine resource planning and development practitioners (institutional, governmental, individual), who have developed the new approaches and models reviewed herein, collectively constitute a unique "insular resource"

which should be tapped for island coastal and marine resources management.

Numerous innovative and experimental approaches to island coastal resource management have already been developed and are accessible. Their diversity reflects both the complexity of the problem and the universe of island types. Current initiatives to structure more formalized coastal zone management programs need to find ways to utilize these proven island specific strategies. The primary task at hand, therefore, is not fundamentally a basic research problem so much as it is a technical application problem. It is, therefore, appropriate to devise mechanisms to apply what has been learned. This is seldom done by development agencies working within an island context, however, being left primarily as a task for an academician's post-audit, years after the fact.

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