Biological Services Program

FWS/OBS-80/59
FEBRUARY 1981

PROCEEDINGS
U.S. FISH AND
WILDLIFE SERVICE
WORKSHOP

COASTAL ECOSYSTEMS OF THE SOUTHEASTERN UNITED STATES

Fish and Wildlife Service

U.S. Department of the Interior

The Biological Services Program was established within the U.S. Fish and Wildlife Service to supply scientific information and methodologies on key environmental issues that impact fish and wildlife resources and their supporting ecosystems. The mission of the program is as follows:

- to strengthen the Fish and Wildlife Service in its role as a primary source of information on national fish and wildlife resources, particularly in respect to environmental impact assessment
- to gather, analyze, and present information that will aid decisionmakers in the identification and resolution of problems associated with major changes in land and water use
- to provide better ecological information and evaluation for Department of the Interior development programs, such as those relating to energy development.

Information developed by the Biological Services Program is intended for use in the planning and decisionmaking process to prevent or minimize the impact of development on fish and wildlife. Research activities and technical assistance services are based on anaysis of the issues, a determination of the decisionmakers involved and their information needs, and an evaluation of the state of the art to identify information gaps and determine priorities. This is a strategy that will ensure that the products produced and disseminated are timely and useful.

Projects have been initiated in the following areas: coal extraction and power plants; geothermal, mineral, and oil-shale development; water resource analysis, including stream alterations and western water allocation; coastal ecosystems and Outer Continental Shelf development; and system inventory, including National Wetland Inventory habitat classification and analysis, and information transfer.

The Biological Services Program consists of the Office of Biological Services in Washington, D.C., which is responsible for overall planning and management; National Teams, which provide the Program's central scientific and technical expertise and arrange for contracting biological services studies with states, universities, consulting firms, and others; Regional Staff, who provide a link to problems at the operating level; and staff at certain Fish and Wildlife Service research facilities, who conduct in-house research studies.

FWS/OBS-80/59
February 1981

PROCEEDINGS

U. S. FISH AND WILDLIFE SERVICE WORKSHOP

ON

COASTAL ECOSYSTEMS OF THE SOUTHEASTERN UNITED STATES

A Compilation of Seminars, Discussions, Papers and Biological Summaries Presented At Big Pine Key, Florida
18-22 February 1980

Prepared & Edited by

Dr. Robert C. Carey, Project Manager
Dr. Paul S. Markovits, Editor
Bureau of Educational Research & Field Services
Montana State University
Bozeman, Montana 59717

Dr. James B. Kirkwood, Project Officer
U.S. Fish and Wildlife Service
75 Spring Street, S.W.
Atlanta, Georgia 30303

Contract 4-16-0004-80-010

Prepared for
The Coastal Ecosystems Project
Office of Biological Services
Fish and Wildlife Service
U. S. Department of Interior
Washington, D. C. 20240

DISCLAIMER

The opinions, findings, conclusions or recommendations in this report are those of the authors and do not necessarily reflect the views of the Office of Biological Services, Fish and Wildlife Service, U.S. Department of the Interior, nor does mention of trade names or commercial products constitute endorsement or recommendation for use by the Federal Government.

This report should be cited:

Carey, R. C., P. S. Markovits, and J. B. Kirkwood, eds. 1981. Proceedings U.S. Fish and Wildlife Service Workshop on Coastal Ecosystems of the Southeastern United States. U.S. Fish and Wildlife Service, Office of Biological Services, Washington, D.C. FWS/OBS-80/59. 257 pp.

TABLE OF CONTENTS
including
AGENDA

ACKNOWLEDGMENTS

There were a few individuals who made the workshop and the Proceedings particularly successful. Drs. Robert Carey and Paul Markovits, Montana State University, were extremely cooperative and hard working when carrying out their contractual responsibilities. Ms. Irene Hooper, assisted by several members of her staff, provided critical decisions involving problems that arose during the workshop. Ms. Ruth Slette, Support Services, Region 4, FWS, performed the duties of Contract Officer. Mr. Richard Huber, Assistant Regional Director for Environment, provided guidance and advice on all phases of the workshop.

U.S. Fish and Wildlife Service editorial reviews were provided by Dr.James Lewis, Ft. Collins, CO, and by Dr. Carolyn French, Elaine Bunce and Gaye Farris of the National Coastal Ecosystems Team.

PREFACE

The Coastal Ecosystems of the Southeastern United States Workshop was conducted 18-22 February 1980, at Seacamp on Big Pine Key, Florida. The workshop was co-sponsored by the United States Fish and Wildlife Service's Office of Biological Services, Coastal Ecosystems Project, Washington, D.C., and the Office of Environment, Atlanta, Georgia. Two contractors were used. The Bureau of Educational Research and Field Services, Montana State University, provided administrative assistance including working with speakers when acquiring and editing reports and preparing a camera-ready copy of the Proceedings. Newfound Harbor Marine Institute provided the meeting rooms, facilities for field trips, transportation, living quarters, and meals. Seventy-five people, in addition to the 28 speakers listed in the "Contents" section of the Proceedings, attended the workshop.

The purpose of the workshop was to provide training on recent developments in understanding coastal ecosystems in the Southeastern United States for Fish and Wildlife Service (FWS) field personnel and other natural resource managers in the Region. Because of the high interest of the Ecological Services field staff in specific ecosystems and the large number of technical experts who were willing to participate, it was decided to devote major emphasis to three types of systems: marshes, mangroves, and sea grasses. Other systems such as coral reefs, mud flats, bottomland hardwoods, and estuaries were discussed in less detail.

Twenty-three papers were presented during the workshop. There also were slide show presentations given by Mr. Becker, Newfound Harbor Marine Institute, and Mr. Kosin, Key West National Wildlife Refuge, as well as eight field trips.

Questions regarding this publication, or requests for copies, should be directed to:

Information Transfer Specialist
Biological Services
U.S. Fish and Wildlife Service
75 Spring Street, S.W.
Atlanta, Georgia 30303

or

Information Transfer Specialist
National Coastal Ecosystems Team
U.S. Fish and Wildlife Service
NASA - Slidell Computer Complex
1010 Gause Blvd.
Slidell, Louisiana 70458

OVERVIEW OF THE NATURAL COMMUNITIES OF BIG PINE KEY, FLORIDA

Bill Becker
Newfound Harbor Marine Institute
Big Pine Key, Florida 33043

ABSTRACT

The natural communities of Big Pine Key, Florida, represent a high diversity of marine and terrestrial habitats within a tropical ecosystem. The site of this "Coastal Ecosystems Workshop" is the Newfound Harbor Marine Institute of Big Pine Key which offers resident education and research programs in marine studies with a predominant emphasis on field activities.

BIG PINE KEY

Big Pine Key with its surrounding waters in the Lower Florida Keys is considered to be one of the most biologically diverse areas in Florida. Lying just north of the Tropic of Cancer, with a climate moderated by the Florida Current offshore, this second-largest of the Florida Keys supports a flora and fauna that are essentially tropical.

Large areas of Big Pine Key lie within the National Key Deer Wildlife Refuge and the National Great White Heron Wildlife Refuge. There are many acres of pinewoods dominated by the Caribbean slash pine, Pinus elliotii var. densa., and buttonwood sloughs and hardwood hammocks are scattered throughout the area. Of particular interest are Watson's Hammock and the Cactus Hammock -- both containing rare tropical flora, including several U.S. champion trees. Big Pine Key is the population center of the endangered Key deer (Odocoileus virginianus clavium), a diminutive subspecies of the northern white-tailed deer.

Geologically, Big Pine Key sits astride the surface interface of the two carbonate rock types which make up the Florida Keys: Key Largo limestone and Miami oolite. The cross-bedding of the oolite over the Key Largo formation, combined with the sizeable land mass of Big Pine Key, causes the retention of a large freshwater lens up to 12 m in depth.

Shorelines of the Island are dominated by the red mangroves, Rhizophora mangle. Sand beach areas are sparse, primarily located along the Southeast Point, and interspersed with rocky intertidal platforms up to 50 m wide.

Coupon Bight State Aquatic Preserve is a large, shallow-water embayment surrounded by the southern extremities of Big Pine Key. Mixed sponge and algae assemblages intermingle with wide expanses of turtle grass, Thalassia testudinum.

South of the Island 6.4 km is Looe Key coral reef, generally accepted as one of the most diverse and beautiful reefs of the Florida tract. The reef is being considered for designation as a Federal Marine Sanctuary. Other nearby coral areas include a deep reef slope in 24-37 m of water and an extensive patch reef system landward of the outer reef tract.

NEWFOUND HARBOR MARINE INSTITUTE AT SEACAMP

Newfound Harbor Marine Institute (NHMI) at Seacamp is on the southwest tip of Big Pine Key. NHMI/Seacamp programs have been introducing people to the tropical environments of the Lower Florida Keys since 1966. As a private, non-profit, scientific and educational organization, the Institute is the only full-service marine education center in the Florida Keys, providing professional instruction, boat trips, conference facilities, laboratories, library, meals, and lodging.

WELCOME

James B. Kirkwood
Regional Activity Leader
Coastal Ecosystems
Biological Services
U. S. Fish and Wildlife Service
75 Spring Street, S.W.
Atlanta, Georgia 30303

On behalf of Biological Services' Coastal Ecosystems Project and the Fish and Wildlife Service, I welcome you to the first Coastal Ecosystems Workshop in Region 4. This workshop may act as a model for future training workshops in Region 4. We hope that you will suggest improvements that we can incorporate in future workshops of this kind.

A special note of thanks is given to Mr. Joe Carroll. He has increased the success potential of the workshop by helping to coordinate and develop field trips.

The contracted co-coordinator for the workshop is Dr. Paul Markovits, from Montana State University. He and the other Coastal Ecosystems Activity staff, whom I will introduce later, are eager to provide help and assistance.

I wish to introduce the following people:

1. Mr. Richard T. Huber is the Assistant Regional Director for Environment in Region 4. He is responsible to the Regional Director for the Biological Services, Ecological Services, and Environmental Contaminants Evaluation Programs.
2. Mr. Donald J. Hankla is the Area Manager for Florida, Georgia, Puerto Rico and Virgin Islands - our FWS host for this workshop.
3. Dr. Richard Wade is the Regional Team Leader of Biological Services. A project of Biological Services is responsible for this workshop.
4. Mr. James Barkuloo and Dr. Lee Barclay are Assistant Regional Activity Leaders for the Coastal Ecosystems project in Region 4.
5. Dr. Robert Stewart is the Team Leader of Biological Services' National Coastal Ecosystems Team at Slidell, Louisiana. The National Coastal Ecosystems Team will assist with the editing and will publish the Proceedings of this workshop.
6. Dr. John Van Derwalker is the Team Leader for Biological Services' National Western Energy and Land Use Team in Ft. Collins, Colorado.

Welcome to you who are not affiliated with the Fish and Wildlife Service. Your participation will add much to the success of this workshop. Please make a special effort to get acquainted with those people you do not know and feel free to actively participate in the discussion sessions and field trips. Your participation is not only welcome but a vital component of a successful workshop.

We plan to include the most relevant parts of discussions in the Workshop Proceedings. The discussions will be recorded for that purpose.

I am looking forward to a very productive and stimulating workshop with you.

A FUNCTIONAL CLASSIFICATION OF WETLANDS

Eugene P. Odum
Institute of Ecology
University of Georgia
Athens, Georgia 30602

ABSTRACT

The U.S. Fish and Wildlife Service has commissioned a national wetland inventory which includes a proposed classification of wetlands and aquatic habitats of the United States. The classification section of this landmark effort is published (Cowardin et al. 1979). When fully completed, the wetlands inventory and classification will provide a means of locating wetlands in the United States. The inventory will hopefully provide a basis for determining the relative value and need for preservation of different kinds of wetlands in different states and regions. My paper goes beyond the classification and evolution of habitats and stresses the importance of determining the inflows and outflows of a wetland ecosystem when using a holistic approach to assessment and management.

INTRODUCTION

The FWS classification scheme recognizes five basic habitats, namely, marine, estuarine, riverine, lacustrine, and palustrine. Within these broad headings, wetland types are classified according to a highly visible and stable characteristic which can be quickly and easily recognized, as for example, a physical feature such as the type of substrate (e.g., rocky shore, mud flat,) or a biological feature such as the perennial vegetation (e.g., Spartina salt marsh, eel grass flats, cypress-gum swamp forests). Each structural type is subdivided according to controlling forces or "modifiers" that relate to water regime (e.g., tidal, seasonally flooded) and salinity (e.g., fresh, brackish, hypersaline).

To be useful over large regional areas, conspicuous structural features which can be recognized from aerial photos obviously provide the best basis for a classification. Unfortunately, some of the most important characteristics of wetlands involve ecosystem-level functional processes which are not so readily visible, but are nevertheless especially important when it comes to management. Accordingly, there is some justification for seeking a classification based on functional attributes as the primary rather than secondary criteria.

FUNCTIONAL CLASSIFICATION

One approach to a functional classification is to consider the nature of the input and output environment. Very frequently it is the inflows from an adjacent environment which act as the all important "forcing function" that determines how and at what level the wetland system functions. In such a situation, disturbance or modification of the adjacent environment may have a much greater effect than similar perturbations within the wetland system itself. These relationships are shown in Figure 1. In all ecosystems it is the input of energy which determines the functional nature of a system and also very frequently its structure. In the wetlands there are two input energy flows that

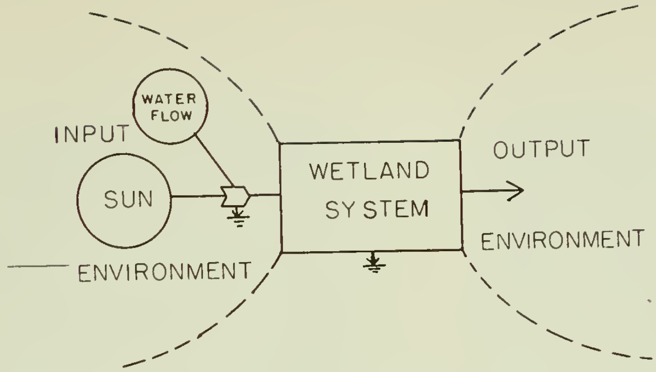


Figure 1. The input and output environments are an integral part of a functional ecosystem. For wetlands the water flow input is especially important in shaping both productivity and vegetative structure.

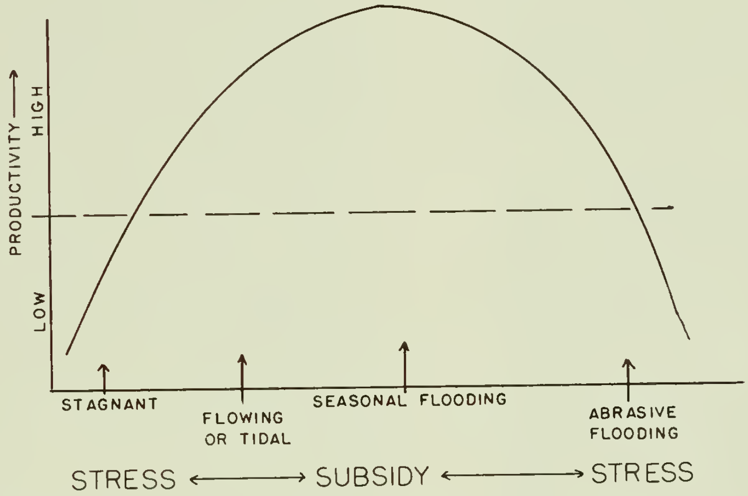


Figure 2. The effect of a subsidy-stress gradient of water flow regimes on the productivity of wetlands. After Odum, 1978, based partly on data of Conner and Day, 1976.

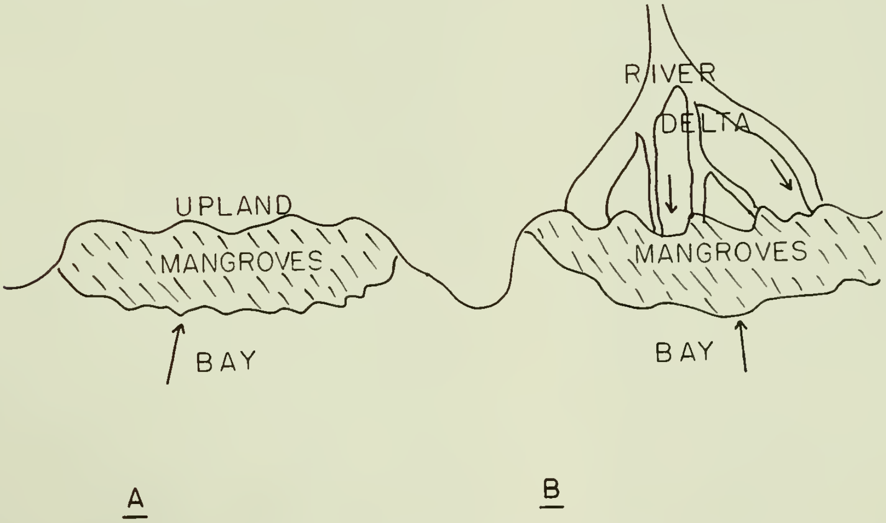


Figure 3. Two bay-side mangrove communities with different input environments. Arrows indicate water flow inputs. See text for explanation.

need to be considered. One is the sun, of course, because the wetland systems are largely solar-powered ecosystems, and the other is the embodied energy of water flow. Solar energy is pretty much a common denominator in all wetlands, although it may vary regionally and with latitude. Therefore, we do not need to consider solar energy in a classification system, but instead can concentrate on the water flow factor. The water flow regime, as is now generally recognized, not only determines the nature of the substrate and the type of vegetation, but also is a major factor determining the level of productivity.

Water flow acts in many situations as an energy subsidy which enhances the performance of the system. In other circumstances where the water flow is abrasive or extremely irregular or contains toxic substances or excess salts, the input becomes a stress which reduces the potential productivity of the system. Moderate water flow and especially regular up-and-down movements (Figure 2), such as tidal action or seasonal flooding on a river floodplain, generally enhances the productivity of the system so that vegetative growth is more vigorous and the wetland more valuable. Where water level changes are extremely irregular or where flood waters remain for a long period of time, stagnant (anaerobic) conditions are produced. Often, salt accumulation results. A less productive ecosystem occurs which frequently has a characteristic structural appearance, e.g., a high salt marsh where the grass is very short or the surface is covered only with thin vegetation of Salicornia.

Keeping in mind a subsidy-stress gradient (Figure 2, and Odum et al. 1979) we can devise a classification based upon the input environment (Table 1) (see p. 9). To the natural water regime categories are added classifications for eutrophicated (nutrient-enriched) and chemically stressful inflows in each of the habitat types. This classification covers the all too common situation where organic matter, nutrients, toxic chemicals, and similar materials are flowing into the wetland, from an adjacent area, as a result of human activities.

Wetlands do have some capacity for assimilating some kinds of wastes and nutrients. Therefore, it is very important to determine whether these materials are acting as subsidies or stresses. If the former, then the wetland could be placed in the high production category. If their materials are acting as stresses, the wetland could be placed in the low production category. A suitable dividing line could be the average regional productivity, as shown by the dashed line in Figure 2. Anything above this line would rate high and anything below would generally fall in the low production category. It is important to note that the input environment is not necessarily always "upstream"; the input forcing function may come from more than one direction or even "downstream" depending on the layout of the landscape.

Identification of the input environment in relation to the wetlands system is extremely important in terms of estimating the impact of a manmade disturbance. Two coastal mangrove communities, one in which the water flow subsidy comes entirely from the bay side (tidal action) while in the other community there is also a flow of water coming down from a river delta on the land side of the system, are shown in Figure 3. Thus, in one situation (A), the input environment is largely on the bay side, whereas in the second example

(B), the input environment also includes very important flows from the land side.

If a landbased development was proposed for situation A, then we could say that it would have comparatively little effect on the mangroves, assuming that the development is designed not to introduce sediment or sewage into the mangrove belt. For example, in situation A, a recreational community might be built on the land side without very much disturbance of the mangrove community. In contrast, any kind of development would threaten the pattern of water flow from the land side in situation B, and thus have a great impact on the mangrove community. For example, canals, dikes or other devices which would change or reduce the water flow would then have a major impact. If one wishes to preserve the mangrove community in its natural condition in this situation, then development on the land side would be inadvisable. Or if development such as a highway or housing tract is to be carried out, the engineering challenge is to design it to maintain the water circulation. The primary consideration or guideline, then, is not to interfere with the water flow input subsidy wherever it exists.

It often is advisable to consider the output environment (Figure 1). One could devise an output-based classification although in general this probably would not be as useful as the input-based classification already discussed. The output feature of major importance concerns the nature and extent of net export of energy and materials from the wetland system. Exports of organic matter, nutrients, or toxic chemicals not only affect the downstream adjacent system, but also the wetland itself. Disturbances in the downstream environment may block export flows which then would, so to speak, back up into the wetlands community and perhaps have a major effect on it.

A preliminary classification might include several situations in regard to exports as follows:

1. Detritus systems (net primary production--little consumed within the system) with a net export of organic matter.
2. Grazing systems (net production--largely consumed) with little or no export of organic matter but an export of nutrients.
3. Grazing systems without a net export of organic matter or nutrients.
4. Eutrophicated systems with a pass-through export of organic matter or nutrients, or both.
5. Stressed systems with a pass-through export of toxic materials.

Many tidal salt marshes are good examples of detrital systems which export large amounts of organic matter to surrounding estuaries which support microbial populations, detritivorous animals, and ultimately fisheries. Where the production is pretty much consumed within the ecosystem, e.g., where a marsh might be heavily grazed or the grass cut for hay, then there could be little or no export from the system, or export could be mostly in the form of nutrients which are released by the grazing activities. In these latter two examples the output environment differs in significant ways which are important to recognize not only from the standpoint of the value of the system itself, but also because of its impact on the adjacent systems which are receiving the exported material.

Again, if man-made pollution coming into the wetland system is not completely assimilated by the system, there may be a significant export from the system of these materials either in a modified or in an unmodified form. Or, dissolved oxygen in the water may be severely reduced making the export environment anoxic. This subject of output environment is one of the areas of our greatest ignorance because little is known about the fate of wastes introduced into the wetlands in terms of the capacity for the wetlands to assimilate them, the effect on export water quality, and the capacity of the wetland to change the nature of these materials and thereby export something that differs from that which is imported. Presumably, toxicity would be generally reduced by passing through a wetlands system, but it is always possible that some changes could occur which might increase the toxicity of particular substances that are then exported.

SUMMARY

A holistic approach to impact assessment and management of a wetland ecosystem must include consideration of the input and output environments. As shown in Figure 1, it is not just the "black box" (which we can define as any recognizable unit whose function can be evaluated without specifying the internal contents) that is important, but also the nature of the inflows and outflows which in most circumstances determine the functional nature of the system. Patten (1978) has introduced a concept of "environ" to designate a particular component, e.g., a species population which would include the component plus the input and output environment. According to this concept, an ecosystem consists of the sum of all of the environs. No matter whether one is trying to deal with the wetland as a whole, or with one or more of its major populations or other components, the nature of inputs, and often the outputs, must be considered. A striking example can be demonstrated by the situation that exists within the Everglades National Park. The fate of the wetlands in the Park and the wading birds, alligators, and all the other inhabitants depends almost entirely on the large input environment north of, and outside the jurisdiction of, the Park because the water flow that nourishes the unique "river-of-grass" communities comes largely from the input environment.

LITERATURE CITED

Conner, W. H., and J. W. Day. 1976. Productivity and composition of a bald cypress-water tupelo site and a bottomland hardwood site in a Louisiana swamp. Amer. J. Bot. 63: 1135-1364.

Cowardin, L. M., V. Carter, F. C. Golet and E. T. LaRoe. 1979. Classification of wetlands and deepwater habitats of the United States. Biol. Serv. Prog., U.S. Fish and Wildlife Service. FWS-OBS-79/31, Washington, D.C. 103 pp.

Odum, E. P. 1978. Ecological importance of the riparian zone, pp. 2-4. In R. R. Johnson and J. F. McCormick (eds.) Strategies for Protection and Management of the Floodplain Wetlands and Other Riparian Ecosystems. Gen. Tech. Rep. WO-12, Forest Service, USDA, Washington, D. C.

Odum, E. P., J. T. Finn and E. H. Franz. 1979. Perturbation theory and the subsidy-stress gradient. Bioscience 29: 349-352.

Patten, B. C. 1978. Systems approach to the concept of environment. Ohio J. Sci. 78: 206-222.

Table 1. Input-based classification of wetlands.

I. Lacustrine Habitats

A. Subsidized (generally high production) Systems

1. Stable water levels with mixing currents (wind, temperature driven)
2. Irregular fluctuating water levels
3. Regular seasonal drawdown

B. Stressed Systems

1. Stagnant, anoxic (low production)
2. Eutrophicated (net import nutrients)
3. Stressed by toxic substances or excess organic matter

II. Riverine Habitats

A. Subsidized (high production) Systems

1. Flowing water
2. Freshwater tidal
3. Seasonally flooded
4. Impounded, but with seasonal drawdown or turnover (oxbows, man-made impoundments with gates)

B. Stressed Systems

1. Stagnant or completely impounded
2. Eutrophicated
3. Toxic input

III. Estuarine Habitats

A. Subsidized (high production) Systems

1. Moderate energy tidal (at least flooded in spring tides)
2. High energy tidal (daily flooded)
3. Brackish tidal

B. Stressed Systems

1. High salinity stagnant
2. Low energy tidal (infrequently flooded)
3. Eutrophicated
4. Toxic input

DIFFERENCES BETWEEN SOUTH ATLANTIC AND GULF COAST MARSHES

Armando A. de la Cruz
Department of Biological Sciences
Mississippi State University
Mississippi State,
Mississippi 39762

ABSTRACT

The one factor that determines the biological (plant communities), ecological (primary productivity, food web, energy flow), and chemical (salinity, nutrients) differences between the South Atlantic and Gulf Coast marshes is water - the hydrological processes and hydrodynamic regimes that characterize each region. Gulf Coast marshes are developed primarily on deltaic formations constructed on alluvial deposits created by several major river systems, while the South Atlantic marshes are basically formed on estuarine and lagoonal soft silt deposits bridging the barrier islands and the mainland shorelines. Tides in the South Atlantic (a tidal dominated coast) are normally semidiurnal with fluctuations of more than 2.0 m; meteorological phenomena are more stable with fewer events of major storm surges. In the Gulf, tides are generally diurnal with maximum fluctuation of 0.3 m; but during periods of lowest fluctuations, tides can change over to very weak semidiurnal occurrences. Prevailing local weather conditions, the occurrence of seasonally changing major wind directions, high energy summer tropical storms, and gulf basin natural oscillations complicate the hydrodynamics of the Gulf marsh system. The peculiar hydrology of the Gulf Coast (a wave dominated coast coupled with the great freshwater input dominated by the Mississippi River) influences salinity producing a more diverse vegetation structure and seasonal fluxes of materials into the Gulf Coast marsh-estuary.

INTRODUCTION

Chapman (1961) recognized the South Atlantic and Gulf Coast marshes as belonging to the same geographic region characterized by a common general physiography. Both groups of marshes generally occur on gently sloping coastal plains with a broad continental shelf under conditions of a sea which is slowly rising relative to the land (Cooper 1974). These salt marshes are built primarily in estuaries where major rivers, draining large expanses of upland watershed, deposit heavy silt burdens on relatively flat substratum of soft and greyish silt (Linton 1968). Marshes are found behind beach ridges and barrier islands; also along shallow shorelines of estuaries, coves, and bays; and in up-river tributaries reached by saltwater intrusions.

The Atlantic and Gulf Coast marshes exhibit certain vegetational structures that are characterized by particular plant dominance and association, and only in isolated cases, by specific community types or plant species (Figure 1). For examples, (a) the southern part of Texas and the lower east and west coasts of Florida are dominated by a mangrove-marsh association; (b) Juncus gerardi is characteristic only of the higher latitudes north of the Chesapeake Bay marshes. Cooper (1974) observed that these plant associations actually grade into one another so that the marsh is in reality a series of communities which grade gradually from the shorelines or banks of

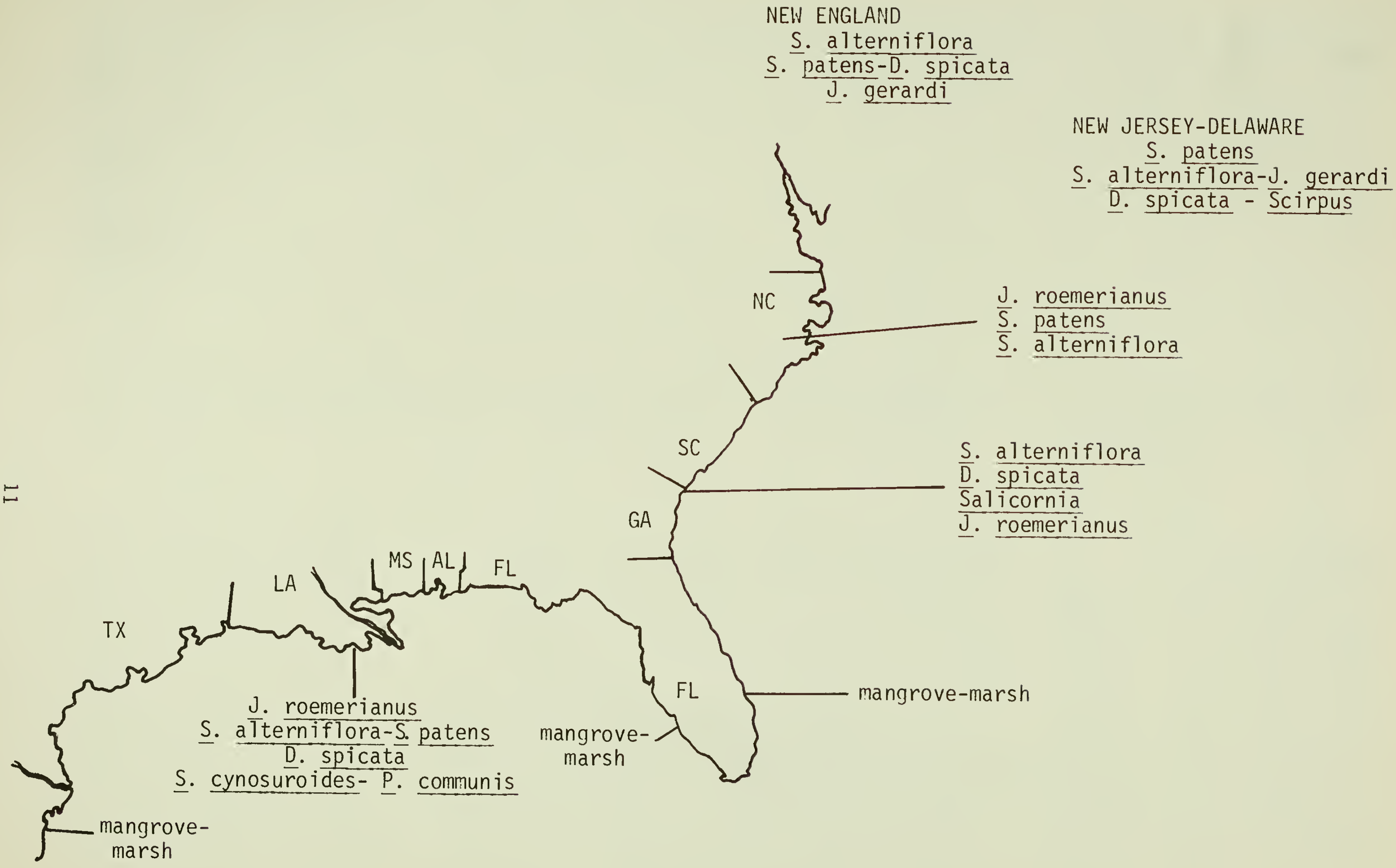


Figure 1. Plant associations of the Atlantic and Gulf Coast marshes.

tidal rivers and creeks to higher ground. However, regionally distinct community types can be recognized as a result of local physiographic and hydrologic differences. A comparison between the South Atlantic and Gulf Coast marshes will illustrate some of these differences.

COMPARISON OF SOUTH ATLANTIC AND GULF COAST MARSH-ESTUARIES

Studies of marsh estuaries from various geographic regions have shown differences in primary productivity (Turner 1976, Linthurst and Reimold 1978), decomposition of plant detritus (de la Cruz 1980), and transport of carbon (de la Cruz 1979). It is apparent that no two marshes or bay estuaries are exactly alike, even if they occur in the same geographic region, mainly because of hydrologic properties and hydrodynamic processes peculiar to a particular marsh-estuary. For this reason, the South Atlantic and Gulf Coast marshes will be compared primarily but not exclusively on the basis of differences of some of the ecological characteristics (Table 1) between representative marshes, namely: (1) South Carolina-Georgia marshes and (2) Mississippi-Alabama marshes.

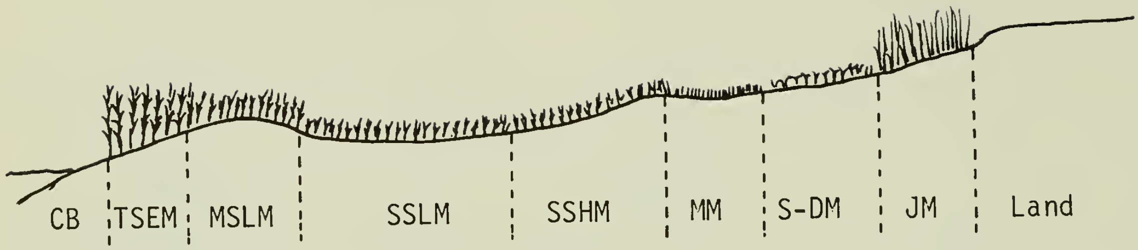
FLORA AND FAUNA

The South Carolina-Georgia marshes probably represent the most developed of salt marshes in the United States. These are regularly flooded low marshes dominated by smooth cordgrass (Spartina alterniflora) which forms vast, continuous pure stands between the barrier islands and mainland shores. These broad, nearly level expanses of grass and soft sediment develop under the influence of high tidal amplitudes, numerous dendritic creeks, and deep tidal channels, all giving the marsh a characteristic dissection pattern when viewed from the air (Cooper 1974). These marshes lie between mean sea level and about mean high water. The S. alterniflora marsh characteristic of this South Atlantic coastal region exhibits ecophenic zonations which grade into the high marsh Salicornia-Distichlis-Juncus association (Figure 2).

The marshes characteristic of the Gulf Coast, exemplified by the north central Gulf region, are primarily irregularly flooded marshes dominated by the black needlerush (Juncus roemerianus) on deltaic plain sediments deposited by a number of fairly large coalescing river systems. The Gulf Coast marshes generally lack relief features and most areas are only slightly above mean Gulf level (Chabreck 1972). Distinct zonation of marsh communities is generally lacking, although ecophenic forms of J. roemerianus occur in certain areas. For examples, at Bay St. Louis, Mississippi, tall Juncus (2 m) occurs in fairly extensive stands immediately behind natural levee ridges of tidal bayous and creeks, and short Juncus (0.5-1.0 m) can be seen forming unevenly distributed prairies on the high marsh. Kruczynski et al. (1978) observed tall Juncus near water edges and short Juncus near salt barrens in northern Florida. The Mississippi-Alabama marshes, and other marshes of the Gulf Coast region, are more characterized by patchy distribution of several mixed species due to localized variations in soil or water regime, or both. Banks of tidal bayous and creeks are usually vegetated with another association of plants (e.g., S. alterniflora) rather than an ecophene of the dominant species (i.e., J. roemerianus). Figure 3 is a composite profile diagram of a

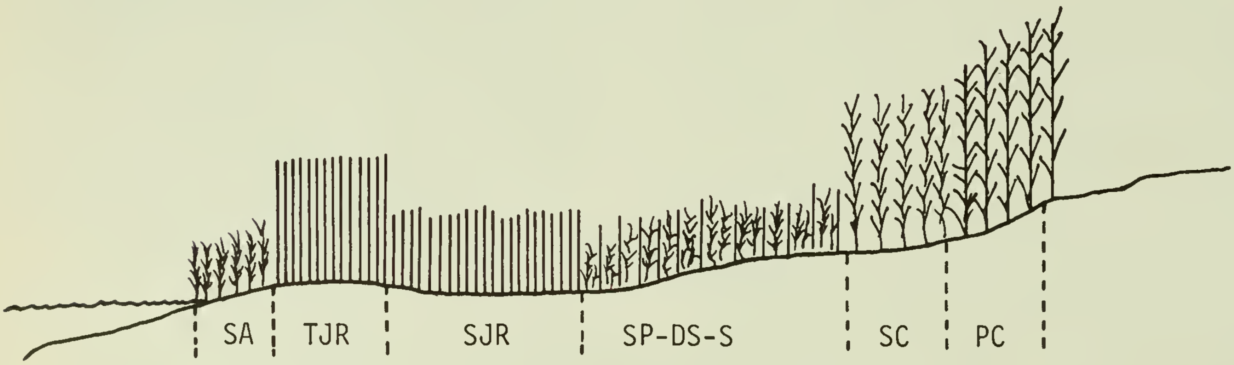
Table 1. Comparison of South Atlantic and Gulf Coast Marshes.

Item	South Atlantic	Gulf Coast
Plant Angiosperms		
Dominant plant	*Spartina alterniflora*	*Juncus roemerianus*
High Marsh plant association	*Salicornia-Distichlis-Juncus*	*S. patens-Distichlis-Scirpus*
Inland Marsh plant association	*S. cynosuroides-Typha*	*S. cynosuroides-P. communis-Cladium*
Fauna		
Dominant insect	*Orchelimum fidicinium*	*Orchelimum concinnum*
	Prokelisia marginata	*Conocephalus* spp.
Benthic bivalves	*Midiolus demissus*	*Polymesoda caroliana* *Modiolus demissus*
Snails	*Littorina irrorata*	*Melampus bidentatus* *Littorina irrorata*
Crabs	*Uca* spp. and *Sesarma*	*Uca* spp. and *Sesarma*
Mammals	*Procyon lotor*	*Ondatra zibethica* *Myocastor coypus*
Salinity Range	10-30^{o}/oo	2-15^{o}/oo
Tide Cycle (Amplitude)	Semi-diurnal (2.0 m)	Diurnal (0.3 m)
Freshwater Input		
Major River System	Savannah River	Mississippi River
Annual Precipitation	120 cm	140 cm
Primary Productivity	1000-2000 g/m^2/yr	1500-3000 g/m^2/yr
Secondary Productivity		
Penaeid Shrimp yield	5,964 tonnes (13.2 kg/ha)	55,193 tonnes (33.9 kg/ha)
Total fish yield	144,245 tonnes (320.2 kg/ha)	790,625 tonnes (485.4 kg/ha)
Size of intertidal areas	450,500 ha	1,628,900 ha



CB = Creek Bank
TSEM = Tall Spartina edge marsh
MSLM = Medium Spartina levee marsh
SSLM = Short Spartina low marsh
SSHM = Short Spartina high marsh
MM = Minax marsh
S-DM = Salicornia-Distichlis marsh
JM = Juncus marsh

Figure 2. Characteristic Spartina alterniflora ecophene zonations in the South Atlantic marshes. From J. M. Teal (1962).



SA = Spartina alterniflora
TJR = Tall Juncus roemerianus
SJR = Short Juncus roemerianus
SP-DS-S = Spartina patens-Distichlis spicata-Scirpus spp. Assoc.
SC = Spartina cynosuroides
PC = Phragmites communis

Figure 3. Composite profile diagram of a Mississippi salt marsh.

Juncus dominated marsh in Mississippi.

The fauna of S. alterniflora marsh characteristic of the South Atlantic has been summarized by Cooper (1974) from a trophic standpoint based on the original report of Teal (1962) as follows: The salt marsh grasshopper (Orchelimum fidicinium) and the salt marsh plant hopper (Prokelisia marginata) are the two major herbivores, Orchelimum, eating smooth cordgrass tissues, and Prokelisia, sucking the juices. These and other less numerous insects support spiders, wrens, and sparrows. A low proportion of the total energy flow of the marsh moves through the grazing, herbivore-based food chain. A much larger group of organisms lives at or near the mud surface feeding on organic detritus, formed by bacterial decomposition of S. alterniflora, and on algae. S. alterniflora stems are broken down by bacteria. These bacteria reduce the total amount of organic matter present but increase its food value (de la Cruz 1965).

The most conspicuous algae-detritus feeders are fiddler crabs (genera Uca and Sesarma), horse mussels (Modiolus demissus), and the salt marsh periwinkle (Littorina irrorata), in addition to the variety of annelid worms, oligochaetes, and insect larvae. These algae-detritus feeders, in turn, may be eaten by mud crabs (Eurytium limosum), clapper rails (Rallus longisrotris), and raccoons (Procyon lotor). These relationships hold for the smooth cordgrass-dominated areas.

The fauna of the Gulf Coast marshes has been the subject of recent and ongoing studies in Florida (Livingston et al. 1975, Subrahmanyam et al. 1976), Louisiana (Day et al. 1973), and Mississippi (Doubinis 1978, Parsons 1978, Humphrey 1979, Wilder 1979). In our studies of a Juncus marsh at Bay St. Louis, Mississippi, we found three species of conocephaline grasshoppers which are the primary insect grazers on Juncus: Orchelimum conicinnum, Conocephalus hygrophilus, and Conocephalus sp. (Parsons and de la Cruz, in press). The most common macrobenthic fauna are the fiddler crabs (Uca longisignalis and Sesarma reticulatum), horse mussel (Modiolus demissus), marsh clam (Polymesoda caroliniana), marsh snails (Littorina irrorata and Melampus bidentatus), and a variety of meiobenthos (nematodes, polychaetes, foraminiferans, copepods, and amphipods). The muskrat (Ondata zibethica) and nutria (Myocastor coypus) are mammals in the Louisiana-Mississippi marshes which are important commercially for their pelts.

TIDE, FRESHWATER INFLOW AND SALINITY

The periodic changes in, and distribution of, salt concentrations are primarily influenced by tidal amplitudes and freshwater influx. In the South Atlantic estuary, tides are characteristically semidiurnal with high fluctuations ranging from 2.0-2.5 m. Average annual precipitation in the South Carolina-Georgia coastal region is about 120 cm. Although the area has several rivers delivering fresh water into the estuary (e.g., Altamaha River in Georgia and Santee River in South Carolina), only the Savannah River has a major influence on the salinity conditions in the marsh-estuary. The South Atlantic marshlands exemplified by the South Carolina and Georgia marshes are truly salt marshes for they are inundated by water of 10-30^{o}/oo salinity.

The Gulf Coast marshes are more of a low salinity marsh with extensive inland extensions consisting of freshwater wetlands. The tidal cycle in the Gulf is normally diurnal with a 0.3-0.5 m amplitude but it changes over to semidiurnal during periods of lowest fluctuation. Average precipitation in the region is 140 cm per year. Freshwater input to the Gulf Coast is dominated by the Mississippi River. Other major river systems such as those found in Mississippi, Alabama, Florida (Pearl and Pascagoula Rivers; Biloxi, Bay St. Louis, Mobile, and Apalachicola Bay systems) contribute to the brackish conditions of the large bodies of water behind the barrier islands (e.g., Mississippi Sound). Salinity of surface waters in the bayous, tidal creeks, bay and sound range from 2-15 $^{o}/oo$.

PRODUCTIVITY

Primary productivity of angiosperms in the South Atlantic marshes based on the works at Sapelo Island was 1000-2000 $g/m^2/yr$ for the tall form of S. alterniflora and 354-643 $g/m^2/yr$ for the short high marsh form (Turner 1976). On the Gulf Coast, primary production estimates for various marsh communities range from 1500-3000 $g/m^2/yr$ (Turner 1976, Hopkinson et al. 1978, White et al. 1978). Numerous primary production studies of marsh communities have been done in both geographic regions using and comparing different techniques (de la Cruz 1980) on aerial, and recently, underground tissues. The results vary, and in some cases inconsistently. Nevertheless, Gulf Coast marshes seem to have higher primary production values than Atlantic marshes.

Secondary production can be expressed in terms of marsh-dependent fisheries and shellfisheries. In the South Atlantic (North Carolina, South Carolina, Georgia and East Florida), annual penaeid shrimp yields averaged 5,964 tonnes (heads-off) or 13.2 kg/ha of marsh area (Turner 1977). The combined penaeid shrimp yield of West Florida, Alabama, Mississippi, Louisiana, and Texas was 55,193 tonnes or 33.9 kg/ha of supporting intertidal marsh. Total fishery landing according to the NOAA-NMFS Current Fisheries Statistics Nos. 7703 and 7704 for the entire South Atlantic region was 144 million kg in 1976 (fish = 118 million kg; shellfish = 26 million kg), while the entire Gulf Coast region had 791 million kg in the same year (fish = 664 million kg; shellfish = 127 million kg). The Gulf region has the largest fishery landings in the U.S. and among the highest in the world. It will be noted that the proportion of total shellfish to fish yields is about the same on the Gulf and South Atlantic coasts, but the Gulf Coast has a higher production per area of supporting marsh.

HYDRODYNAMICS AND MARSH FUNCTIONS

The functions of the salt marsh as producer and reservoir of energy and nutrients, and as nursery grounds for fish and shellfish, have been the basis for strong support of scientific studies of marshlands, for earnest public concern about wetland preservation, and for the urgent move to legally protect the Nation's coastal zones. These functions of the marsh can be seen at its optimum level in the South Atlantic and Gulf Coast estuaries. Both coastal regions are characterized by marsh communities with high primary production capacities and an estuary with substantial fishery yields. Turner

(1977) has shown that there is a statistically significant positive relationship between size of supporting marsh areas and yields of dependent fisheries.

The bigger intertidal areas and larger combined water surface area of intertidal estuaries, bayous, creeks, channels, and ponds in the Gulf Coast provide greater nursery habitats than the South Atlantic. More important, as far as the general fertility of the marine area is concerned, is the movement of excess organic matter produced on the marsh to the neighboring estuarine and marine environments. This movement pattern is where the South Atlantic and Gulf Coast marshes differ. In the South Carolina-Georgia Coast, the regular, twice-a-day cycle of high amplitude tides flushes the marshes of their litter and detritus production. Meteorological events in the southeast region are stable and more predictable. Between 1954-77, only six weather disturbances of hurricane force hit the South Atlantic Coast. The last of these hurricanes (Ginger) that hit the coast directly from the Atlantic Ocean occurred in 1971. Two hurricanes (named Dora 1964 and Alma 1966) came from inland after they had devastated the Gulf Coast and veered eastward.

The hydrodynamics of the Gulf Coast is quite complex. Freshwater enters the Gulf from a number of large river systems exhibiting areal, seasonal, and annual variations. The periodic rise and fall of the tide is subject to the effects of changing weather conditions. Changing meteorological conditions may change the level of the water from which the tides rise and fall, altering both the time and occurrence and the levels of high and low tides. With strong southerly winds, Gulf waters will pile up along the coast and move inland through the many bays, bayous, and canals. Periods with prolonged winds frequently result in inundation of the marshes. The depth of flooding is determined by the duration and velocity of the winds, the elevation of the marsh, and its distance from the Gulf. Extremely high tides are associated with tropical storms and hurricanes, and tide water may be pushed inland for considerable distances (Chabreck 1972).

Tropical storms and hurricanes approaching the coast are preceded by storm surges characterized by gale force winds that stir bottom sediments, causing widespread turbidity, shore and bank erosion, and marsh inundation at higher energy regimes. The ratio between the detritus that gets stranded on higher grounds and of the amount that gets washed into the Gulf is not known although these phenomena clean the marshes of organic debris. A survey conducted by Hackney and Bishop (pers. comm.)* after a low level hurricane (named Bob) on 11 July 1979, showed that approximately 226 tonnes of dead plant materials were removed from a 96 ha marsh in Bay St. Louis, Mississippi; 7.7 tonnes were redeposited as wrack, thus, about 218 tonnes were transported out of the marsh system. From 1954 to 1977, the National Hurricane Center of the NOAA National Weather Service at Coral Gables, Florida, recorded some 12 major hurricanes hitting the U.S. Gulf Coast.

During winter, strong northerly winds depress tidal level to as low as 0.5 m below normal. The marshes are thoroughly drained, sometimes for long periods of time. During the rainy season, Nichols (1959) observed that periods of high winds in adjacent upland areas may curtail tidal effects in the marsh streams until the freshwater level is lowered to that of the current high tide level. A study by Chabreck and Hoffpauir (1962) revealed considerable monthly differences in mean tides.

This already dynamic situation in the Gulf is further complicated by the physical nature of the Gulf. Its irregularly shaped basin and connections with the Atlantic Ocean and Caribbean Sea cause co-oscillations (seiche) with the tidal movements in the entire Gulf (Marmer 1954). Smith (1978a, 1978b) has recently shown that this oscillating tidal motion caused meteorologically forced fluctuations in local water levels and salinity distribution.

Set against this complex hydrodynamic background in the Gulf of Mexico is the characteristic pattern of natural transport of organic matter from marsh to estuary and to the Gulf. Gulf Coast marshes normally accumulate greater amounts of dead material relative to South Atlantic marshes. The low energy regime of tidal force probably has less influence on the lateral movement and physical fragmentation of dead material on a day-to-day basis. The flushing of the marsh occurs in pulses over long periods of time with the summer southerly winds and storm tides providing the driving force in the export of organic material.

In contrast, the low energy of Gulf Coast tides which fluctuate once daily provide longer periods and calmer inundations of marsh areas, thus permitting optimum deposition of nutrients of oceanic and terrestrial origin (Hackney and de la Cruz 1979). The peculiar hydrodynamics along the Gulf Coast results in outwelling of organic matter, from the marsh system to the Gulf waters, which is temporally and spatially quite different from that of the South Atlantic.

LITERATURE CITED

Chabreck, R. H. 1972. Vegetation, water, and soil characteristics of the Louisiana coastal region. La. State Univ. Agric. Exp. Stn. Bull. 664. 72 pp.

Chabreck, R. H., and C. M. Hoffpauir. 1962. The use of weirs in coastal marsh management in Louisiana. Proc. Annu. Conf. Southeast. Assoc. Game Fish Comm. 16: 103-112.

Chapman, V. J. 1961. Salt Marshes and Salt Deserts of the World. Interscience, New York. 392 pp.

Cooper, A. W. 1974. Salt marshes, pp. 55-97. In H. T. Odum, B. J. Copeland, and E. A. McMahan (eds.), Coastal Ecological Systems of the United States. The Conservation Foundation Publ. Dept., Washington, D. C.

Day, J. W., Jr., W. G. Smith, P. R. Wagner, and W. C. Stowe. 1973. Community Structure and Carbon Budget of a Salt Marsh and Shallow Bay Estuarine System in Louisiana. Louisiana State Univ. Center for Wetland Resources Publ. LSU-SG-72-04. Baton Rouge. 79 pp.

de la Cruz, A. A. 1965. A Study of Particulate Organic Detritus in a Georgia Salt Marsh-estuarine Ecosystem. Ph.D. Dissertation. Univ. Georgia, Athens. 110 pp.

de la Cruz, A. A. 1979. Production and transport of detritus in wetlands. In Wetland Functions and Values: The State of

Our Understanding. Amer. Water Resour. Assoc., Minneapolis, Minnesota.

de la Cruz, A. A. 1980. Recent advances in our understanding of salt marsh ecology, pp. 51-65. In P. L. Fore and R. D. Peterson (eds.), Proceedings of the Gulf of Mexico Coastal Ecosystems Workshop. U. S. Fish and Wildlife Service, Albuquerque, New Mexico, FWS/OBS-80/30. 214 pp.

Doubinis, E. M. 1978. Seasonal and Spatial Distribution of the Carolina Marsh Clam Polymesoda caroliniana (Bosc) in a Mississippi Marsh with Some Notes on its Dessication Resistance and General Ecology. M.S. Thesis, Mississippi State Univ., Mississippi State. 49 pp.

Hackney, C. T., and A. A. de la Cruz. 1979. Patterns of suspended particle transport in a Mississippi tidal marsh system. Gulf Res. Rep. 6(3):217-224.

Hopkinson, C. S., J. G. Gosselink, and R. T. Parrondo. 1978. Aboveground production of seven marsh plant species in coastal Louisiana. Ecology 59(4): 760-769.

Humphrey, W. D. 1979. Diversity, Distribution and Relative Abundance of Benthic Fauna in a Mississippi Tidal Marsh. Ph.D. Dissertation, Mississippi State Univ., Mississippi State. 93 pp.

Kruczynski, W. L., C. B. Subrahmanyam, and S. H. Drake. 1978. Studies on the plant community of a North Florida salt marsh. Part I. Primary production. Bull. Mar. Sci. 28(2): 316-334.

Linthurst, R. A., and R. J. Reimold. 1978. Estimated net aerial primary productivity for selected estuarine angiosperms in Maine, Delaware, and Georgia. Ecology 59(5): 945-955.

Linton, T. L. 1968. A description of the South Atlantic and Gulf Coast marshes and estuaries, pp. 1-25. In J. D. Newsom (ed.), Proceedings of Marsh and Estuary Management Symposium. Louisiana State Univ., Baton Rouge.

Livingston, R. J., G. J. Kobylinski, F. G. Lewis, III, and P. F. Sheridan. 1975. Long-term fluctuations in epibenthic fish and invertebrate populations in Apalachicola Bay, Florida. Fishery Bull., 74(2): 311-321.

Marmer, H. A. 1954. Tides and sea level in the Gulf of Mexico, pp. 101-118. In Gulf of Mexico, Its Origin, Waters and Marine life. U.S. Fish and Wildlife Serv. Fishery Bull. 89.

Nichols, L. G. 1959. Geology of Rockefeller Wildlife Refuge and Game Reserve. Louisiana Wildlife and Fisheries Comm., New Orleans. 28 pp.

Parsons, K. A. 1978. Insect Population Diversity and the Effects of Grasshopper (Orthoptera: Tetigoniidae) Grazing on the Energy Flow of a Mississippi Juncus roemerianus Marsh. M. S. Thesis, Mississippi State Univ., Mississippi State. 37 pp.

Parsons, K. A., and A. A. de la Cruz. In press. Energy flow and grazing behavior of conocephaline grasshoppers in a Juncus roemerianus marsh. Ecology.

Smith, N. P. 1978a. Long-period, estuarine-shelf exchanges in response to meteorological forcing, pp. 147-159. In J. C. J. Nihoul (ed.), Hydrodynamics of Estuaries and Fjords. Elsevier Scientific Publ. Co., Amsterdam.

Smith, N. P. 1978b. Tidal and long-period exchanges between upper Laguna Madre and Corpus Christi Bay, Texas. Taius 11(1): 37-51.

Subrahmanyam, C. B., W. L. Kruczynski, and S. H. Drake. 1976. Studies on the animal communities in two North Florida salt marshes. Part II. Macroinvertebrate communities. Bull. Mar. Sci. 26(2): 172-195.

Teal, J. M. 1962. Energy flow in a salt marsh ecosystem. Ecology 43(4): 614-624.

Turner, R. E. 1976. Geographic variations in salt marsh macrophytic production: a review. Contrib. Mar. Sci. 20(1): 47-68.

Turner, R. E. 1977. Intertidal vegetation and commercial yields of penaeid shrimp. Trans. Amer. Fish. Soc. 106(5): 411-416.

White, D. A., F. E. Weiss, J. M. Trapani, and L. B. Thien. 1978. Productivity and decomposition of the dominant salt marsh plants in Louisiana. Ecology 59(4): 751-759.

Wilder, B. J. 1979. Distribution Ecology of the Salt Marsh Snail, Melampus bidentatus Say in a Mississippi Tidal Marsh, with a Brief Study of Salinity Preference. M. S. Thesis. Mississippi State Univ., Mississippi State. 42 pp.

ACKNOWLEDGMENT

I thank Dr. Thomas W. Lins of the Department of Geology and Geography, Mississippi State University for his critical review of the manuscript.

Supported by a grant from NOAA Office of Sea Grant, U.S. Department of Commerce under grant No. NA 79AA-D-000-49. Mississippi-Alabama Sea Grant Consortium Publication No. M-ASGP-79-013.

*C. T. Hackney and T. D. Bishop (in press). Note on the relocation on marsh debris during a storm surge. J. Estuarine Coast. Mar. Sci.

EFFECTS OF IMPOUNDMENTS IN MARSHES ON WILDLIFE AND FISHERIES

Robert H. Chabreck
School of Forestry and Wildlife Management
Louisiana State University
Baton Rouge, Louisiana 70803

ABSTRACT

Marsh impoundments of coastal areas control water levels and salinities for the purpose of wildlife habitat improvement, aquaculture, water storage for irrigation and industrial uses, mosquito control, and navigation. Impoundments categorized by water level and salinity regimes include four types: permanently flooded with freshwater, manipulated freshwater, permanently flooded with brackish water, and manipulated brackish water. Each type of impoundment is evaluated in regard to major groups of sport and commercial wildlife and fish species including waterfowl, coots, gallinules, rails, wading birds, fur bearers, alligators, freshwater fishes, estuarine fishes, and crawfish.

INTRODUCTION

Canal dredging and linkage of canals with natural tidal channels have accelerated drainage of marsh in many areas, resulting in salt water intrusion into many marshes historically free of salt water, and greatly increased environmental stress on plant and animal populations. Marsh impoundments, which are constructed for wildlife habitat improvement, restore traditional salinity regimes and prohibit excessive drainage, thereby creating a stable environment for fish and wildlife. Therefore, in evaluating the effects of marsh impoundments on fish and wildlife resources, it is wise to consider the historical fish and wildlife usage of a particular area and the present usage.

IMPOUNDMENTS AND WILDLIFE AND FISHERIES RESOURCES

The vegetational and hydrological characteristics of coastal wetlands are primary factors regulating their value to wildlife and fisheries resources. Vegetation produced on wetlands serves as the primary food source and often determines the number and species of animals that an area will support. Hydrological factors such as water salinity and tidal action may affect species tolerance to a particular habitat or regulate the means by which access is gained to the area.

The following is a discussion of the vegetational and hydrological characteristics of four types of impoundments. The conditions described apply primarily to coastal areas of the South Atlantic and Gulf Coastal regions of the United States.

PERMANENTLY FLOODED FRESHWATER IMPOUNDMENTS

Marsh impoundments of this type are usually located inland from the normal influence of tides. In nonimpounded fresh marsh, drainage is usually slow and, as a result, water depths are greater than in tidal marsh. Marshes permanently flooded by impounding usually have even greater water depths. During periods with unusually heavy rainfall, water may be as much as 1 m deep.

Marsh soils typically have high organic matter content due to slow decomposition rate in flooded soils. In permanently flooded freshwater impoundments, organic matter accumulates at an even greater rate and marsh elevations increase above that of natural marsh. Also, scattered floating mats of organic material often develop on the water surface.

Typical vegetation consists of perennial plants adapted to growth in deep water. Plants commonly found are spikerushes (Eleocharis spp.), softstem bulrush (Scirpus validus), bulltongue (Sagittaria falcata), and many other species of aquatic plants. Floating mats of organic matter are held together by emergent species such as pennywort (Hydrocotyle spp.) and maidencane (Panicum hemitomon).

Waterfowl

This type of impoundment receives substantial use by dabbling ducks, particularly gadwalls (Anas strepera) and American wigeons (Mareca americana) (Palmisano 1972), which feed on leafy plant materials. Water depths are often too great for bottom feeding by seed-eating dabblers; but, where shallow water is present, dabblers find adequate food and often occur in large numbers. Diving ducks, such as ring-necked ducks (Aythya collaris), prefer this deepwater habitat and concentrate there in large numbers. Permanently flooded impoundments are particularly valuable to ducks during prolonged drought, when most marshes dry. By maintaining a surplus of water, this habitat is more able to withstand drought. During fall of 1968, a severe drought was in progress along the southwestern Louisiana coast when wintering ducks began arriving. Most marshes were dry, but the birds were able to use the permanently flooded freshwater impoundments where conditions were ideal.

Snow goose (Chen hyperborea) use of this type of impoundment is very low; however, white-fronted geese (Anser albifrons) are often found in great numbers on such habitat on the Lacassine National Wildlife Refuge. The white-fronted geese will feed in nearby harvested rice fields and use the impoundments as rest areas.

Coots, Gallinules, and Rails

Coot use of this impoundment type is very high and birds will remain there throughout the winter. Highest quality habitat is provided for gallinules during the breeding and wintering seasons when floating mats of vegetation are available. Rails also use the impoundments, but to a lesser degree.

Wading Birds

Shallow water must be available to attract wading birds to impoundments. Nesting rookeries are often established where groups of trees are present on small islands. However, the birds may have to travel several kilometers from the rookeries to feeding areas.

Furbearer

Muskrat use is usually limited by excessive water depths that restrict lodge building. Nutrias, however, build small resting platforms with emergent vegetation and do very well in this habitat. Plant communities consist largely of species used by nutrias as food. Minks and river otters also utilize this habitat when dense vegetative cover is available for denning. River otters may use the habitat and travel great distances to cover. Raccoons prefer areas with shorelines available for feeding; consequently, this impoundment type is usually less desirable for raccoons.

Alligators

Excellent feeding conditions and abundant prey species for alligators occur in habitat provided by this impoundment-type. However, alligator nest sites are usually limited unless islands or spoil deposits are available.

Freshwater Fishes

Permanently flooded freshwater impoundments in coastal marshes provide ideal habitat for freshwater fishes when water depths are adequate. Turner (1966) sampled a 16,000-acre impoundment on Lacassine National Wildlife Refuge and found that the standing crop ranged from 37.8 to 40.95 kg per acre. Largemouth bass (*Micropterus salmoides*), redear sunfish (*Lepomis microlophus*), and warmouth (*Chaenobryttus gulosus*) (all favorites of sport fishermen) were the predominant species. Deep canals adjacent to levees and boat trails in the marsh were considered important as fish travel lanes during drought.

Estuarine Fisheries

Freshwater marshes, whether impounded or not, are usually unfavorable habitat for estuarine fisheries.

Crawfish

This habitat will support populations of crawfish, but breeding habitat may be limited to areas adjacent to levees or islands. Numerous aquatic predators also reduce crawfish numbers.

MANIPULATED FRESHWATER IMPOUNDMENTS

Marsh impoundments of this type are usually located inland from the normal influence of tides. Water manipulation in impoundments managed for ducks encourages germination and growth of annual plants. The major species produced by drying an impoundment are grasses and sedges such as wild millet (*Echinochloa walteri*), fall panicum (*Panicum dichotomiflorum*) and fragrant flatsedge (*Cyperus odoratus*) (Chabreck 1960, Baldwin 1967, Carney and Chabreck 1977). Other plants often found in this type of impoundment are bulltongue, California bulrush (*Scirpus californicus*), and spikerushes. Water depths are usually held at low levels (5 to 46 cm deep) to make the areas attractive to dabbling ducks. Crawfish are produced in abundance by this management system and provide a food source to many forms of wildlife.

Waterfowl

This type of impoundment is usually managed for dabbling ducks; consequently, it is only normal to expect high usage by this group. A study by Chabreck et al. (1974) disclosed that use by dabbling ducks of a freshwater impoundment was more than four times that of an adjacent nonimpounded freshwater marsh. Major use was by seed eating dabblers. Diving ducks, mainly lesser scaup (*Aythya affinis*), increased as water depths increased in the area, and dabbling duck populations declined under the same conditions. Snow geese often concentrate in this impoundment-type.

Coots, Gallinules, and Rails

Coots and rails use these impoundments quite heavily, but gallinules do not show any particular preference for the type. Rails prefer areas with shallow water and remain abundant in the impoundments as long as water depths are favorable and escape cover is adequate. Coot use increases in late winter when annual plants lodge and large open bodies of water form.

Wading Birds

Wading birds are attracted to the impoundments by shallow water conditions and the abundance of invertebrates, mainly crawfish, that are available as food. Also, as water is gradually removed during the growing season, shallow isolated pools are created and wading birds flock to the area to feed on stranded aquatic organisms.

Furbearers

Habitat available in this impoundment-type is highly preferred by most fur animals, particularly minks, raccoons, and river otter, which feed on crawfish. The type is also favorable for nutria, but muskrats only occur in small numbers. As available cover diminishes in late winter, fur animals move out of the impoundment.

Alligators

Alligator use of the impoundment-type is comparatively high, and like most other carnivores, alligators are attracted by the abundance of crawfish. The impoundments also provide good nesting habitat for alligators; however, removal of water too early in the spring (before June) may simulate drought conditions and reduce nesting efforts (Joanen 1969).

Freshwater Fishes

Although a freshwater environment is provided, freshwater fish production is curtailed by the drying process. Freshwater fish habitat is only provided in canals or deep channels not subject to drying.

Estuarine Fisheries

Impoundments of this type are normally constructed in freshwater marsh and such marsh is usually considered unfavorable habitat for estuarine fisheries.

Crawfish

Manipulated freshwater impoundments are used in aquaculture for growing crawfish (Perry et al. 1970). Water is removed in early summer to enhance crawfish reproduction and remove predators of crawfish (mainly fishes). Marshes managed by this process often produce in excess of 562.5 kg of harvestable crawfish per hectare.

PERMANENTLY FLOODED BRACKISH WATER IMPOUNDMENTS

Impoundments of this type are usually managed to produce widgeongrass (*Ruppia maritima*) for the purpose of attracting ducks (Chabreck 1960). Permanently flooded brackish water impoundments have been used most often in South Carolina (Morgan et al. 1975). Although the impoundments are described as permanently flooded, drainage at 2- to 3-year intervals is necessary for best widgeongrass growth.

Waterfowl

The impoundments are used heavily by gadwall, American widgeon, and lesser scaup, which are attracted by dense stands of widgeongrass. The permanently flooded brackish water impoundments are used to a much lesser extent by other dabbling ducks and use is regulated by water depths. The impoundments are not normally used by snow geese.

Coots, Gallinules and Rails

The impoundments receive high use by coots, and the birds will congregate in dense flocks shortly after fall migration. Concentrations of coots and ducks often become so great that widgeongrass food supplies may be depleted early in the wintering season. Gallinules do not frequent this habitat and rails are often excluded by water depth or lack of protective cover.

Wading Birds

Wading bird use is usually curtailed by excessive water depths. Very often, only impoundment edges are used by the birds. However, Provost (1967) reported that overall bird usage of salt marshes was increased by permanent flooding as part of a mosquito control program in Florida.

Furbearers

Fur animal populations are usually low because of inadequate protective cover and food supplies. Plants preferred by muskrats or nutrias and prey species used by carnivores are absent or in very limited supplies.

Alligators

Habitat conditions provided by this impoundment-type are not favorable to alligators. Water salinities are often above the tolerance levels of small alligators and summer food supplies are usually inadequate for attracting large animals. Brackish marshes, whether impounded or natural, are not preferred habitat for alligators.

Freshwater Fishes

Marshes with high water salinities, whether impounded or not, are unfavorable habitat for freshwater fishes.

Estuarine Fisheries

Brackish marshes and associated water bodies serve as a vital nursery area for estuarine fisheries (Gunter 1967), and levee systems used for impoundments block the ingress and egress of fish and shellfish from tidal channels. Also, organic detritus from marsh plants serves as a primary food source for estuarine fisheries, and levee systems block the movement of this material into estuarine waters. However, when brackish water impoundments are drained, detrital material is flushed out and becomes available as a component of the aquatic food chain.

Crawfish

Brackish marshes, whether impounded or not, are unfavorable habitat for crawfish.

MANIPULATED BRACKISH WATER IMPOUNDMENTS

Impoundments are often constructed in tidal marsh and alternately flooded with brackish water and drained to encourage growth of duck food plants. Brackish water impoundments used for mariculture are also included in this category; however, marsh impoundments have been used only to a very limited extent for mariculture. Impoundments of this type comprised approximately 10 percent of the total area in marsh impoundments in South Carolina (Morgan et al. 1975).

Waterfowl

Neely (1960) described a procedure for growing saltmarsh bulrush (*Scirpus robustus*) in brackish water impoundments in South Carolina that involved flooding and draining the area monthly during the growing season. Water was kept at a depth less than 30 cm and dabbling ducks such as mallards (Anas platyrhynchos), pintails (Anas acuta), and black ducks (Anas rubripes) could easily reach the bottom for feeding. Such impoundments provide excellent dabbling duck habitat and are also used by diving ducks and snow geese. Dwarf spikerush (Eleocharis parvula) and widgeongrass grow along the shoreline of ponds or in openings among stands of saltmarsh bulrush and also provide food for waterfowl.

A similar management system is used in Louisiana and involves prolonged drying during the spring and early summer to produce saltmarsh purslane (Sesuvium maritimum) and dwarf spikerush. Dabbling duck usage of the impoundments is very high.

Coots, Gallinules, and Rails

Coots are attracted to habitat as provided by this impoundment type. Also, clapper rails use the shorelines of ponds. Gallinules generally avoid brackish marshes regardless of management practices (Lowery 1974).

Wading Birds

The cycle of flooding and draining attracts wading birds and conditions for feeding are ideal until mid-summer when vegetation growth becomes very dense. However, water is maintained at shallow depths and shoreline areas remain attractive.

Furbearers

This impoundment-type provides ideal habitat for fur animals. Abundant cover, food, and feeding conditions are available for both herbivores and carnivores. Impoundments containing bulltongue provide better fur animal habitat than those with saltmarsh purslane.

Three-cornered grass (Scirpus olneyi), a highly preferred food of muskrats, nutrias, and snow geese, is also grown in brackish water impoundments under a system of manipulated water levels. A marsh manager in Louisiana has harvested over 63 muskrats per hectare on a 400-hectare impoundment containing three-cornered grass.

Alligators

Alligators mostly occupy habitats with lower water salinity.

Freshwater Fishes

Brackish marshes, whether impounded or not, are unfavorable habitat for freshwater fishes.

Estuarine Fisheries

Water bodies in brackish marshes are important nursery areas for estuarine fisheries, and levee systems associated with impoundments block normal ingress and egress of species. The movement of organic detritus from impounded brackish marsh to estuarine waters is altered by this system of management; however, the system of flooding and draining provides a means by which detritus can be discharged. In fact, plant growth is enhanced by the management procedure and detritus production may actually be increased.

Lunz (1967) described procedures for mariculture in brackish and salt-marsh impoundments. The procedure would likely reduce production in natural waters, but the overall production of selected estuarine species can be increased by using controlled environments.

Crawfish

Brackish marshes, whether impounded or not, are usually unfavorable habitat for crawfish.

SUMMARY AND CONCLUSIONS

Impoundments permanently flooded with freshwater, manipulated freshwater, permanently flooded with brackish water, and manipulated brackish water have various effects on fish and wildlife resources.

WATERFOWL

Natural marshes, both fresh and brackish, are used by waterfowl; however, habitat conditions often deteriorate because of canal dredging and subsidence. This has resulted in widely fluctuating water levels and salinities that curtail growth of desirable food plants. Marsh impoundments are constructed as a management practice to improve growth of food plants and insure proper feeding conditions, particularly for dabbling ducks (Chabreck et al. 1974, Morgan et al. 1975, Carney and Chabreck 1977). Diving ducks use marsh impoundments with deeper water (0.6 to 1.3 m). Geese show little response to impoundments managed for ducks; however, marshes which are dewatered and grazed by cattle are very attractive to geese (Chabreck 1968).

COOTS, GALLINULES, AND RAILS

Impounding marshes improves habitat conditions for coots because of increased food production. Greatest populations of gallinules are found in permanently flooded freshwater impoundments. Permanent flooding reduces rail use of a marsh, but manipulating water levels increases vegetation density and improves rail habitat.

WADING BIRDS

Wading birds prefer a shallow water environment, and impoundments with manipulated water levels improve habitats for these birds. Freshwater impoundments which produce crawfish are particularly attractive. Usage of impoundments with deeper water is similar to that of nonimpounded marsh.

FURBEARERS

Fur animals are greatly affected by cover and food availability. Freshwater impoundments usually contain larger populations of nutria, mink, and river otter regardless of water levels. Raccoons favor fluctuating water levels and largest populations occur where food, such as crawfish, is abundant. Muskrats generally do poorly in marsh impoundments managed for ducks; however, impoundments can be managed to increase muskrat populations.

ALLIGATORS

Alligators prefer a freshwater environment and marsh impoundments can be managed to maximize alligator production. Freshwater marsh impoundments can be managed for ducks, and still benefit alligators, by properly timing the dewatering cycle to correspond with alligator nesting. Food production and feeding conditions are improved by impounding.

FRESHWATER FISHES

Production of freshwater fishes is increased in marshes in permanently flooded freshwater impoundments. In nonimpounded marshes, freshwater fishes are limited to deeper channels.

ESTUARINE FISHERIES

Tidal channels and ponds in brackish marshes are a vital nursery area for estuarine fisheries. Levee systems, used for impounding brackish marshes, block normal ingress and egress of aquatic organisms and reduce the size of nursery areas. A system used on Rockefeller Wildlife Refuge in southwestern Louisiana permits entrance of estuarine fisheries (mainly shrimp) by opening water control structures on high tide when post-larval forms are present. Post-larval shrimp grow very rapidly and are harvested by sport fishermen with cast nets several months later as the shrimp concentrate at the structures to exit. Other procedures for mariculture in brackish water impoundments were described by Lunz (1967) as a method for increasing production of selected species.

Organic detritus from marsh plants is a basic component of aquatic food chains, and levee systems of impoundments will alter the flow of detritus to tidal waters. However, brackish water impoundments are drained periodically and detritus is discharged into tidal channels.

CRAWFISH

Crawfish require a freshwater environment, and marsh impoundments that are drained during the summer and reflooded in fall produce abundant crops of the crustaceans. Crawfish are a major food item of many other species of fish and wildlife and provide a commercial and recreational resource for man. Natural freshwater marshes produce crawfish, but production is maximized in manipulated freshwater impoundments (Perry et al. 1970).

LITERATURE CITED

Baldwin, W. P. 1967. Impoundments for waterfowl on South Atlantic and Gulf coastal marshes, pp. 127-133. In J. D. Newsom (ed.), Proceedings of the Marsh and Estuary Management Symposium, Louisiana State Univ., Baton Rouge.

Carney, D. F., and R. H. Chabreck. 1977. An evaluation of spring drawdown as a waterfowl management practice in floating fresh marsh. Proc. Southeast. Assoc. Fish Wildl. Agencies 31:266-271.

Chabreck, R. H. 1960. Coastal marsh impoundments for ducks in Louisiana. Proc. Southeast. Assoc. Game Fish Comm. 14:24-29.

Chabreck, R. H. 1968. The relation of cattle grazing to marsh wildlife and plants in Louisiana. Proc. Southeast. Assoc. Game Fish Comm. 24:55-58.

Chabreck, R. H., R. K. Yancey, and L. McNease. 1974. Duck usage of management units in the Louisiana coastal marshes. Proc. Southeast. Assoc. Game Fish Comm. 28:507-516.

Gunter, G. 1967. Some relationships of estuaries to the fisheries of the Gulf of Mexico, pp. 621-638. In G. H. Lauff (ed.), Estuaries. Publ. No. 83. Am. Assoc. Adv. Sci., Washington D.C.

Joanen, T. 1969. Nesting ecology of alligators in Louisiana. Proc. Southeast. Assoc. Game Fish Comm. 23:141-151.

Lowery, G. H., Jr. 1974. Louisiana Birds. Louisiana State Univ. Press, Baton Rouge. 651 pp.

Lunz, G. R. 1967. Farming the salt marshes, pp. 172-177. In J. D. Newsom (ed.), Proceedings of the Marsh and Estuary Management Symposium, Louisiana State Univ., Baton Rouge.

Morgan, P. H., A. S. Johnson, W. P. Baldwin, and J. L. Landers. 1975. Characteristics and management of tidal impoundments for wildlife in a South Carolina estuary. Proc. Southeast. Assoc. Game Fish Comm. 29:526-539.

Neely, W. W. 1960. Managing *Scirpus robustus* for ducks. Proc. Southeast. Assoc. Game Fish Comm. 14:30-34.

Palmisano, A. W. 1972. Habitat preferences of waterfowl and fur animals in the Northern Gulf Coast marshes, pp. 163-190. In R. H. Chabreck (ed.), Proceeding Second Symposium Coastal Marsh and Estuary Management. Louisiana State Univ., Baton Rouge.

Perry, W. G., Jr., T. Joanen, and L. McNease. 1970. Crawfish-waterfowl a multiple use concept for impounded marshes. Proc. Southeast. Assoc. Game Fish Comm. 24:506-513.

Provost, M. W. 1967. Managing impounded salt marshes for mosquito control and estuarine resource conservation, pp. 163-171. In J. D. Newsom (ed.), Proceedings of the Marsh and Estuary Management Symposium. Louisiana State Univ., Baton Rouge.

Turner, D. D. 1966. Distribution and Abundance of Fishes in Impoundments of Lacassine and Sabine National Wildlife Refuges. M.S. Thesis, Louisiana State Univ., Baton Rouge. 52 pp.

HABITAT VALUE OF COASTAL WETLANDS

William E. Odum
Thomas J. Smith
Department of Environmental Sciences
University of Virginia
Charlottesville, Virginia 22903

ABSTRACT

The value of coastal wetlands of the Gulf of Mexico and Southeastern U.S. coasts to fishes, waterfowl, and furbearers is briefly reviewed. The relative importance of reproduction, "nursery" usage, and feeding are compared for the three groups of animals. Three subsystems of coastal marshes, (1) the high marsh, (2) the intertidal marsh, and (3) tidal channels, are compared for their value to the three animal groups. The importance of interspersion or "networks" of tidal channels and wetlands is emphasized. Finally, the general lack of knowledge of the connection between wetlands destruction and changes in fish and wildlife populations is discussed.

INTRODUCTION

Although the general value of coastal marshes to fish and wildlife is widely recognized, many of the specific details remain obscure. This is not surprising because much of the necessary research has not been done.

The purpose of this short paper is to summarize briefly some of the information which exists concerning the use of coastal marshes by fishes, waterfowl, and furbearing mammals. Coastal marshes are defined as wetland areas subject to some tidal action and salinity.

Table 1. The relative importance of coastal marshes for three life history functions of the three principal animal groups as estimated by the authors.

	Reproduction	"Nursery"	Feeding
Fishes			
Finfish	LOW	HIGH	HIGH
Shellfish	HIGH	HIGH	HIGH
Waterfowl	LOW-MOD.	LOW-MOD.	HIGH
Furbearers	HIGH	HIGH	HIGH

Table 2. A partial list of some of the estuarine-dependent species from the Gulf and S. E. Atlantic coasts. (S = spawning dependence, N = nursery dependence, and F = feeding by juveniles and adults).

Common Name	Scientific Name	Use
Menhaden	*Brevoortia* spp.	N,F
Mullet	*Mugil* spp.	N,F
Spotted seatrout	*Cynoscion nebulosus*	N,F
Grey seatrout	*C. regalis*	N,F
Sand seatrout	*C. arenarius*	N,F
Red drum	*Sciaenops ocellata*	N,F
Tarpon	*Megalops atlantica*	N,F
Silver perch	*Bairdiella chrysura*	N,F
Croaker	*Micropogon undulatus*	N,F
Spot	*Leiostomus xanthurus*	N,F
Jacks	*Caranx* spp.	N,F
Summer flounder	*Paralichthys dentatus*	N,F
Striped bass	*Morone saxatilis*	S,N,F
Blue fish	*Pomatomus saltatrix*	F
Shrimp	*Penaeus* spp.	N,F
Blue crab	*Callinectes spaidus*	N,F
Oyster	*Crassostrea virginica*	S,N,F
Bay scallop	*Argopecten irradians*	S,N,F

COASTAL MARSHES AND LIFE HISTORY STRATEGIES

Thayer and Ustach (1980) have pointed out that coastal marshes function in three important ways in fish and wildlife life history cycles. They provide (1) sites for reproduction, (2) a conducive environment for early life stages (i.e., play a "nursery" role), and (3) an area for feeding on concentrated high quality food. The relative roles of coastal wetlands for these three functions for the three animal groups are shown in Table 1 and discussed in the following sections.

HABITAT VALUE FOR FISHES AND SHELLFISH

Coastal marsh ecosystems provide all of the important ingredients for successful fish and shellfish populations: (1) adequate protection from predators, (2) substrates for attachment of sessile stages, and (3) a varied and concentrated food source. It is not surprising, therefore, to find a very high percentage of species of commercial and recreational fishes which are dependent upon estuaries and their associated coastal marshes at some stage in their life histories. On the coast of the Gulf of Mexico, for example, 90-97% of the biomass of commercial landings and 80% of the recreational biomass are species which are estuarine-dependent at some stage in their life (McHugh 1967). A list of some of the most important estuarine dependent species of the Gulf and S.E. Atlantic coasts are shown in Table 2.

Probably the most important fish-related role of coastal marsh-estuarine systems is as a nursery area. The combination of intermediate salinities, shallow water,

Table 3. The authors' estimate of the relative value of the three subsystems of the coastal marsh ecosystem to the various animal groups.

	High marsh	Intertidal marsh	Tidal channels
Fishes	LOW-MOD.	HIGH	HIGH
Waterfowl	HIGH	MOD-HIGH	MOD-HIGH
Furbearers	HIGH	HIGH	MOD.

This ignores any indirect value of the high marsh to fishes, e.g., the export of dissolved organic carbon.

plentiful submerged and emergent vegetation, lack of strong wave action, and high primary production provides an ideal environment for postlarvae and juveniles.

Contrary to popular belief, coastal marshes are not of overwhelming importance as spawning sites for most fish species. Although some sessile species of shellfish (e.g., clams, oysters, and mussels) utilize the marsh system for reproduction, most fishes of commercial and recreational importance, and even some shellfish (e.g., penaeid shrimp and blue crabs), move to the mouth of the estuary, off the beaches, or even offshore to spawn. Most of these species move inshore as postlarvae and spend their early life history in close association with coastal marshes. There are other species which spawn offshore and move into the estuary as juveniles or adults for the primary purpose of feeding (e.g., bluefish and spanish mackerel). Cronin and Mansueti (1971) summarized the various fish life history strategies and how they relate to the estuary-coastal marsh system.

WATERFOWL

Waterfowl utilize Gulf and S.E. Atlantic coastal wetlands primarily as autumn, winter, and early spring feeding areas and not as nesting and nursery areas. These latter activities take place in inland freshwater areas, particularly north of latitude 40°.

There are, of course, exceptions to the preceding general statement about coastal wetlands of the southeastern U.S. The fulvous whistling duck may utilize marsh and mangrove areas of the Southeastern United States for nesting (T. J. Smith, personal observation). Other species known to breed in or near coastal wetlands include black duck (Anas rubripes) (Gneis et al. 1971, Palmisano 1972), the blue-winged teal (Anas discors) (McCormick et al. 1970), the mallard (Anas platyrhynchos) (Bellrose 1976), and wood duck (Aix sponsa) (Johnsgard 1975).

Nevertheless, the greatest use of coastal wetlands by waterfowl is for autumn, winter, and early spring habitat and feeding. The combination of plentiful, high quality food and protection from most predators results in high densities of many waterfowl. Stewart (1962) surveyed the coastal wetlands of the upper Chesapeake Bay and found an average density of dabbling ducks, diving ducks, coots and whistling swans of $900/km^2$.

Many waterfowl appear to utilize the lower salinity end of the estuary preferentially, presumably due to the greater preponderance of edible vegetation. In Louisiana, Palmisano (1972) found that the dabbling ducks (Anas spp.) utilize freshwater and slightly brackish wetlands in preference to those of high salinity. However, certain species definitely prefer higher salinity wetlands. Smith and Odum (in press) report that snow geese (Anser caerulescens atlantica) in North Carolina feed primarily upon the roots and rhizomes of smooth cordgrass (Spartina alterniflora).

FURBEARERS

Coastal marshes have a uniformly high value for all life stages of furbearers (Table 1). Unlike waterfowl and fishes, furbearing mammals are relatively nonmigratory. Muskrats (Ondatra zibethica) and nutrias (Myocastor coypu), for example, may spend their entire lives in a 100 ha marsh. Although racoons, minks and otters may range a little more widely, it is not unusual to find populations which are almost totally tied to a single coastal marsh ecosystem.

THE RELATIVE HABITAT VALUE OF COASTAL MARSH SUBSYSTEMS

Coastal marsh ecosystems can be conveniently divided into three major subsystems: (1) the high marsh, (2) the intertidal marsh and associated mudflats, and (3) tidal channels which intersect the high and intertidal marsh. Table 3 contrasts the relative values of the three subsystems to fishes, waterfowl, and furbearers.

Fishes utilize the intertidal marsh and tidal channels for both feeding and refuge. The high marsh is of value only (1) on extremely high tides for short-term feeding and (2) as a site for scattered pools which may provide nursery habitat for small fishes. It may be possible that certain materials (plant detritus, insects) are transported in significant quantities from the high marsh to subtidal locations where they can be utilized by fish. This hypothesis, however, is speculative and has not been satisfactorily quantified.

A further consideration for fishes is the relative positions of the three subsystems. Although unproven, it seems that elaborate networks formed by tidal channels' penetrating marshes are of more utility to fishes than marshes without channel network. Elaborate channel networks allow easy access and facilitate the exchange of marsh and aquatic products such as particulate organic matter. Furthermore, a highly developed network has a greater ecological "edge" consisting of the transition from open water to vegetated wetland and hence provides better protection as well as all of the other advantages of edges or ecotones.

Furbearing mammals appear to utilize all areas of the marsh extensively for feeding and "cover." Subtidal channels provide convenient transportation routes and escape cover from certain predators. Intricate networks of marsh and channels appear to be favored over extensive areas of undissected marshes.

Waterfowl generally make greatest use of the high marsh, particularly for feeding. The intertidal marsh is important for a few species (e.g., the snow goose). Subtidal channels provide sites for resting and protection from terrestrial predators. When submerged vegetation is present, then the subtidal channel may be of great importance for waterfowl feeding.

CONCLUSIONS

Several examples of the state of knowledge of habitat value of coastal wetlands have been presented and it should be evident that our knowledge is very limited. Accurate, quantifiable measures of habitat value are almost totally lacking. Indices utilized in other habitats such as foliage height diversity and dimension analysis have been generally ignored in analyzing coastal wetlands.

Although it is suspected that geomorphology (e.g., stream networks) is important, proof is lacking. Little is known of the relative values of different marsh vegetation, except as direct food value for waterfowl and furbearers.

Probably the greatest lack of understanding concerns the relationship between wetland destruction and subsequent changes in fish and wildlife harvests. Papers such as Mock's (1967) study of brown shrimp dependence upon vegetated shorelines are too few. Although Turner (1977) has established a statistical relationship between shrimp harvests and wetland acreage, the detailed explanation of this relationship remains unknown. Ten years ago Odum (1970) reviewed the scant literature linking wetland destruction to changes in estuarine fish populations. Very little has been added to our understanding since then.

LITERATURE CITED

Bellrose, F. C. 1976. Ducks, Geese, and Swans of North America. Stackpole Books, New York. 487 pp.

Cronin, L. E., and A. J. Mansueti. 1971. The biology of the estuary, pp. 14-39. In P. A. Douglas and R. H. Stroud (eds.), A Symposium on the Biological Significance of Estuaries. Sport Fishing Institute, Washington, D.C.

Gneis, A. D., R. I. Smith, and J. P. Rodgers. 1971. Black Duck Distribution, Harvest Characteristics, and Survival. U.S.D.I., Fish and Wildlife Serv. Spec. Sci. Rept. Wildlife No. 139. 241 pp.

Johnsgard, P. A. 1975. Waterfowl in North America. Indiana Press. Bloomington, Indiana. 567 pp.

McCormick, J., R. R. Grant, Jr., and R. Patrick. 1970. Two Studies of Tinicum Marsh, Delaware and Philadelphia Counties, Pennsylvania. The Conservation Foundation. Washington, D.C. 104 pp.

McHugh, J. L. 1967. Estuarine nekton, pp. 581-671. In G. Lauff (ed.), Estuaries. Publ. No. 83, Amer. Assoc. Adv. Sci., Washington, D.C.

Mock, C. R. 1967. Natural and altered estuarine habitats of Penaeid shrimp. Gulf and Caribbean Fisheries Inst. Proc. 19: 86-98.

Odum, W. E. 1970. Insidious alteration of the estuarine environment. Trans. Amer. Fish. Soc. 99(4): 836-847.

Palmisano, A. W. 1972. Habitat preference of waterfowl and fur animals in the northern Gulf coast marshes, pp. 163-192. In R. H. Chabreck (ed.), Proceedings of Marsh and Estuarine Management Symposium, Louisiana State Univ., Baton Rouge.

Smith, T. J., and W. E. Odum. In press. The effects of grazing by snow geese on coastal salt marshes. Ecology.

Stewart, R. E. 1962. Waterfowl Populations in the Upper Chesapeake Bay Region. U.S.D.I., Fish and Wildlife Serv. Spec. Sci. Rept. Wildlife No. 65. 208 pp.

Thayer, G. W., and J. F. Ustach. 1980. Gulf of Mexico wetlands: value, state of knowledge and research needs. In Proceedings Gulf Coast Workshop. NOAA/ Office of Marine Pollution Assessment.

Turner, R. E. 1977. Intertidal vegetation and commercial yields of penaeid shrimp. Trans. Amer. Fish. Soc. 106: 411-416.

ECOLOGY OF TIDAL,

LOW SALINITY ECOSYSTEMS

William E. Odum
Thomas G. Smith
Department of
Environmental Sciences
University of Virginia
Charlottesville, Virginia 22903

ABSTRACT

Tidal, low salinity ecosystems are defined as coastal areas composed of wetlands and open water which have a measurable ocean-derived tide, very low salinities and ecological communities composed primarily of freshwater species. They occur along both the Atlantic and Gulf coasts but reach their greatest development along the mid-Atlantic coast between the Hudson River, New York, and Norfolk, Virginia. Although not well studied, these ecosystems appear to differ significantly from higher salinity estuarine ecosystems. These differences include greater species diversity of plants, higher primary productivity, and increased production of many waterfowl, furbearer, and fish species.

INTRODUCTION

This paper is concerned with the area at the low salinity end of the estuarine gradient (Figure 1), subjected daily to ocean-induced tides, but which has nearly fresh water. Typically, the animal and plant communities are dominated by freshwater species, although marine fishes may make seasonal visits.

This region has been classified by a number of names including (1) "oligohaline" meaning "few salts," (2) tidal freshwater, and (3) freshwater tidal. For convenience, this paper will use the term tidal freshwater ecosystems.

DISTRIBUTION

Although tidal freshwater ecosystems occur all along the Gulf and south Atlantic coasts, they vary considerably from location to location. In many areas of Louisiana and Texas they exist far inland and are affected only by irregular, wind generated tides from the ocean. In the latter situations they are dominated by freshwater flow from inland.

Along the Atlantic coast they are found primarily in the upstream tidal portions of rivers such as the Savannah, Santee, Pamlico, James, Potomac, Delaware, and Mullica along with a host of smaller rivers and tidal creeks. The best developed and most extensive areas generally occur between the Hudson River, New York, and Norfolk, Virginia. It is this region of tidal freshwater ecosystems that is emphasized in the present paper.

The area covered by tidal freshwater is considerable. Odum et al. (1980) estimate that tidal freshwater wetlands in the U.S. (excluding associated open water) probably range between 0.5 - 1.0 million hectares. It is important to remember that individual ecosystems may differ considerably and they will not all have the same general characteristics as discussed in this paper.

EXISTING LITERATURE

Few scientists have distinguished between tidal freshwater and the better studied estuarine ecosystems. As a result the literature is both scattered and brief. One of the earliest studies was a survey of Tinicum marsh adjacent to

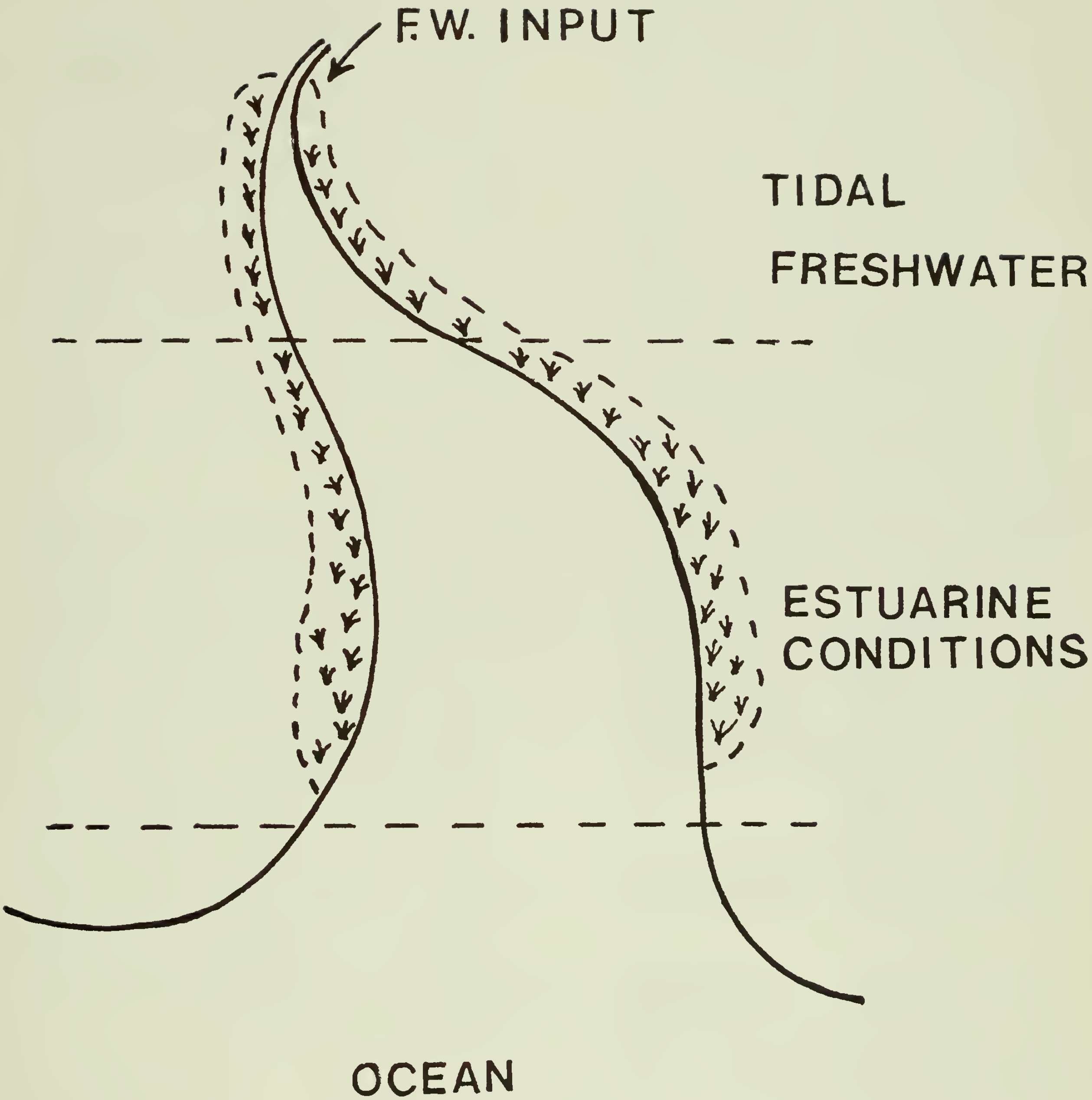


Figure 1. This schematic diagram shows the estuarine gradients from oceanic conditions to freshwater. The zone discussed in the paper is at the top of the diagram.

the Delaware River (McCormick et al. 1970). Odum (1978) presented a review of literature dealing with tidal freshwater ecosystems along with comments for coastal zone management. Whigham et al. (1978) summarized the literature on primary production while Simpson et al. (1978) did the same for nutrient cycling. Odum and Heywood (1978) reported decomposition rates for intertidal vegetation in this environment. A general review paper by Copeland et al. (1974) summarized information on oligohaline ecosystems and includes certain aspects of tidal freshwater ecosystems. Finally, Odum et al. (1980) discussed the habitat value of this type of ecosystem compared to higher salinity systems. Included in this review are papers by Palmisano (1972) and McHugh (1967).

Because of this sparsity of information, it is necessary to make a number of hypothetical statements about tidal freshwater ecosystems. Years from now it may become apparent that many of these hypotheses are either slightly incorrect or simply dead wrong!

A COMPARISON OF TIDAL FRESHWATER AND ESTUARINE ECOSYSTEMS

One of the easiest ways to present what little we know about tidal freshwater ecosystems is to contrast them with the better studied estuarine ecosystems. Odum (1978) compared these two types of ecosystems; a slightly modified version of this comparison is shown in Table 1. It is important to remember that comparisons of these types are gross oversimplifications because estuaries are gradients from freshwater to marine conditions and the characteristics at any given location may fluctuate daily, seasonally, or from year to year.

LOCATION

Not surprisingly, tidal freshwater ecosystems are usually located at the head of estuaries while the estuarine and marine wetland ecosystems are in the mid and lower portion of the estuary nearer marine conditions. Exceptions may occur wherever significant freshwater input enters from the sides of estuarine basins. In all cases, there must be sufficient freshwater flow to maintain very low salinities, but not so great as to completely dampen the upstream moving tidal wave.

TIDAL RANGE

In many locations the tidal range is greater within the freshwater environment than further downstream in the estuary proper. For example, the estuarine marshes at the mouth of the Potomac River experience a tidal range of about 0.5 m, but 30 km upstream the tidal freshwater marshes have a tide in excess of 1 m. This phenomenon can be attributed to several factors including (1) constriction of the tidal wave as it moves upstream into a narrowing river bed; and (2) creation of a standing wave by reflection of a portion of the tidal wave off resistant geomorphological materials at the head of the tidal portion of the river.

SEDIMENTS

Although local variations may exist due to current and wave patterns, there is always a pronounced difference between the sediments of the two environments. Tidal freshwater sediments are principally silts and clays of a very fine texture and typically have a high organic carbon content. Estuarine sediments, by comparison, generally

Table 1. A comparison of tidal freshwater and estuarine ecosystems.

System characteristic	Tidal freshwater ecosystems	Estuarine ecosystems
Location	head of estuary	mid & lower estuary
Sediments	silt-clay, high organic content	more sand, low organic
Dissolved oxygen	very low (summer)	low (summer)
Vegetation	freshwater species	marine & estuarine species
Plant diversity	high	low
Plant zonation	present, but not always distinct	pronounced
Seasonal sequence of plant species	pronounced	absent or minor
Aboveground primary production	very high (?)	high
Ratio of decomposition of intertidal plants	extremely rapid	moderate
Food quality of plant detritus	very nutritious	moderately nutritious
Primary consumers	larval insects, annelids, & amphipods	mollusks crustaceans, & polychaetes
Fish community	freshwater & oligohaline species + anadromous larvae and juveniles	estuarine & marine species
Waterfowl	high usage	medium to low usage
Furbearers	high population densities	medium to low population densities
Nutrient cycles	high "leakage" in autumn & winter	slower releases

have a higher sand content, a larger particle size, and may have a lower organic carbon content. Peat deposits exist in both types of wetlands in response to local variations in types of vegetation.

DISSOLVED OXYGEN

As a result of its finer, high organic sediments, the tidal freshwater environment often has lower dissolved oxygen values than the estuarine environment. This becomes particularly pronounced in small, restricted tidal creeks in the late summer. These low oxygen concentrations appear to be a severe limiting factor in certain areas of the tidal freshwater environment and greatly reduce the diversity of benthic organisms.

VEGETATION

The dominant plant species of the tidal freshwater marshes are freshwater species such as arrow arum (*Peltandra virginica*), spatterdock (*Nuphar luteum*), wild rice (*Zizania aquatica*), pickerel weed (*Pontedaria cordata*), arrowhead (*Sagittaria* spp.), and bur marigold (*Bidens laevis*). Estuarine and marine species such as *Spartina alterniflora* and *Juncus roemerianus* are occasionally present but do not appear to compete successfully with the freshwater species.

A zonation pattern is usually present in the freshwater marsh, but is not as distinct as in estuarine marshes. An intertidal or "low marsh" often exists and is dominated by broadleafed plants such as *Peltandra* and *Nuphar*. The "high marsh" includes more grasses and shrubs capable of tolerating waterlogged soils.

PLANT DIVERSITY

Plant species diversity is much higher in the tidal freshwater marsh ecosystem. Whereas estuarine and marine wetlands typically have less than 12 species of plants present, it is not uncommon to find 50 to 60 species of plants in the tidal freshwater marsh. As a result, rarely do one or two species dominate the freshwater tidal marsh as occurs in the coastal *Spartina alterniflora* and *S. patens* marshes.

SEASONAL SEQUENCE OF PLANT SPECIES

Whigham et al. (1978) have recorded an annual sequence of species within the tidal freshwater plant community in New Jersey and Delaware. A similar pattern was observed in Virginia. The species progression begins with a spring domination by the perrenial broadleafed plants such as *Peltandra*. The standing crop of these plants reaches a maximum in early summer after which it is overtopped and exceeded in biomass by annual grasses such as *Zizania*. These, in turn, may be largely replaced by broadleafed plants in early autumn. Clearly, there is a complex progression of dominant species. Detailed understanding will require further research.

ABOVEGROUND PRIMARY PRODUCTION

The previously mentioned seasonal sequence of species makes estimates of annual primary production exceedingly difficult to obtain. Estimates based on standing crop measurements throughout the growing season by Whigham et al. (1978) indicate that aboveground primary production in the tidal freshwater marsh may be even higher than the estimates from estuarine marshes. Through using a tagging technique in which each stem is marked at intervals of 2 weeks, values of 3,000-4,000 g of organic matter per m^2 per year in typical Virginia tidal, freshwater marshes were found. Once again these estimates are preliminary and further research is needed.

RATES OF DECOMPOSITION

Decomposition rates of intertidal freshwater marsh plants are relatively well documented (Odum and Heywood 1978). These plants generally decay much more rapidly than their counterparts in estuarine marshes. For example, Nuphar luteum may decompose completely in 25 days while most of the other intertidal freshwater species are broken down within 50-150 days. This is in contrast to the estuarine and marine macrophytes which take a year or more to decompose completely (Odum et al. 1972). Decomposition of the high marsh species from the tidal freshwater marsh, such as Typha and Phragmites, is a slower process and similar to the high marsh plants from the estuarine marshes. The rapid rate of decay of the intertidal freshwater species appears to be related to their relatively high nitrogen content and apparent low crude fiber content.

NUTRIENT CYCLING

Available information on nutrient dynamics in freshwater tidal marshes was summarized by Simpson et al. (1978). Two phenomena have emerged from this preliminary work. First, these wetlands appear to have a great assimilative capacity for dissolved nutrients introduced either from natural or artificial sources (McCormick et al. 1970). This capacity appears to be most pronounced during the growing season and somewhat reduced during the winter months. Second, because of the rapid decomposition rates of the dead vegetation, tidal freshwater marshes appear to release or "dump" copious quantities of dissolved and fine particulate nutrients during the autumn and early winter. It is not clear whether this nutrient load is flushed downstream or simply absorbed into nearby sediments.

PRIMARY CONSUMERS

Virtually no research has been done on secondary production in tidal freshwater ecosystems. Initial impressions based on limited sampling are that insect larvae, annelid worms, and amphipods are the most important groups of primary consumers of plant materials and plant detritus, at least from a numerical standpoint. This contrasts with the trophic structure in estuarine environments which is commonly based on crustaceans, molluscs, and polychaete worms (Odum and Heald 1975).

FISH COMMUNITY

The fish community found in the freshwater tidal environment appears to be dominated by three ecological groups: (1) freshwater species such as the yellow perch (Perca flavescens), and the sunfishes (Lepomis spp.); (2) oligohaline species such as the white perch (Morone americana), and the tidewater silverside (Menidia berylina); and (3) anadromous species such as the striped bass (Morone saxatilis), and the alewife (Alosa pseudoharengus), which are represented by spawning adults, larvae, and juveniles. This fish community contrasts markedly with the estuarine community dominated by estuarine and marine species.

WATERFOWL

The critical importance of the tidal freshwater environment to ducks and geese has been well documented (Bellrose 1976). The fact that this type of ecosystem is much more valuable as waterfowl habitat than most estuarine areas can be attributed to the diversity and nutritional quality of the vegetation in the tidal freshwater marsh. There are, of course, exceptions. The snow goose (*Chen caerulescens atlantica*) shows a clear preference for estuarine wetlands where it feeds on the roots and rhizomes of *Spartina alterniflora* (Smith and Odum, in press).

FURBEARERS

Muskrats (*Ondatra zibethica*) thrive in both freshwater and estuarine marshes, although salinities above 20-25 ppt appear to be less suitable. Palmisano (1972) points out that muskrats in Louisiana reach their highest densities in brackish marshes dominated by *Scirpus olneyi* and *Spartina patens*. In terms of average production of muskrats, he found tidal freshwater and brackish water areas about the same. Nutria (*Myocastor coypu*), however, demonstrated a clear preference for freshwater marshes as did raccoons (*Procyon lotor*), although both are found in low to moderate salinity marshes. Mink (*Mustela visor*) and otter (*Lutra canadensis*) appear to be able to utilize all coastal marshes with equal success. Stone et al. (1978) noted that the number of mammal species doubled in Louisiana marshes in the transition from saline to freshwater coastal locations.

NUTRITIONAL QUALITY OF PLANT DETRITUS

A recent finding by Dunn (1978) concerns the nutritional quality of tidal freshwater marsh plants as compared to plants from estuarine locations. He found a clear preference by amphipods for decaying *Nuphar* and *Peltandra* compared to *Spartina* and *Juncus*. This preference appears to be related to the higher nitrogen content and lower crude fiber content of plants that grow in tidal freshwater as opposed to those that grow in more saline waters.

CONCLUSIONS

The initial conclusion which can be drawn is that the tidal freshwater environment differs significantly from the estuarine environment. This is particularly noticeable for processes such as primary production, decomposition, nutrient cycling, and aspects of secondary production.

The tidal freshwater environment including wetlands appears to be at least as productive from an ecological standpoint as the estuarine and marine wetlands; thus, it is logical that they should be at least as well protected by State and Federal wetland legislation. Unfortunately, in many States this is not the case. Much revision of local and Federal laws needs to be aimed at tidal freshwater zones. The high primary productivity and use by waterfowl and anadromous fishes alone are enough to justify stringent protective measures.

LITERATURE CITED

Bellrose, F. C. 1976. Ducks, Geese and Swans of North America. Stackpole Books, New York. 487 pp.

Copeland, B. J., K. R. Tenore, and D. B. Horton. 1974. Oligohaline regime, pp. 315-338. In H. T. Odum, B. J. Copeland, and E. A. McMahan (eds.), Coastal Ecological Systems of the United States. The Conservation Foundation. Washington, D. C.

Dunn, M. L. 1978. Studies on the Breakdown of Freshwater Tidal Marsh Plants. M.S. Thesis, Univ. Virginia, Charlottesville. 87 pp.

McCormick, J., R. R. Grant, Jr., and R. Patrick. 1970. Two Studies of Tinicum Marsh, Delaware and Philadelphia Counties, Pennsylvania. The Conservation Foundation. Washington, D.C. 104 pp.

McHugh, J. L. 1967. Estuarine nekton, pp. 581-621. In G. Lauff (ed.), Estuaries. Publ. No. 83, Amer. Assoc. Adv. Sci., Washington, D.C.

Odum, W. E. 1978. The importance of tidal freshwater wetlands in coastal zone management, pp. 1196-1204. In Proceedings Symposium Technical, Environmental, Socioeconomic, and Regulatory Aspects of Coastal Zone Management. Amer. Soc. Civil Engin. San Francisco, California.

Odum, W. E., and E. J. Heald. 1975. The detritus-based food web of an estuarine mangrove community. Estuarine Res. 1: 265-286.

Odum, W. E., and M. A. Heywood. 1978. Decomposition of intertidal freshwater marsh plants, pp. 89-97. In R. E. Good, D. F. Whigham and R. L. Simpson, (eds.), Freshwater Wetlands: Ecological Processes and Management Potential. Academic Press, New York.

Odum, W. E., M. L. Dunn, and T. G. Smith. 1980. Habitat value of tidal freshwater wetlands. In Wetland Functions and Values: The State of Our Understanding. Am. Water Resour. Assoc.

Odum, W. E., J. C. Zieman, and E. J. Heald. 1972. The importance of vascular plant detritus to estuaries, pp. 91-114. In R. H. Chabreck (ed.), Proceedings of the Marsh and Estuarine Management Symposium. Louisiana State Univ., Baton Rouge.

Palmisano, A. W. 1972. Habitat preference of waterfowl and fur animals in the northern Gulf coast marshes, pp. 163-192. In R. H. Chabreck (ed.), Proceedings of the Marsh and Estuarine Management Symposium. Louisiana State Univ., Baton Route.

Simpson, R. L., D. F. Whigham, and R. Walker. 1978. Seasonal patterns of nutrient movement in a freshwater tidal marsh, pp. 89-97. In R. E. Good, D. F. Whigham and R. L. Simpson (eds.), Freshwater Wetlands: Ecological Processes and Management Potential. Academic Press, New York.

Smith, T. G., and W. E. Odum. In press. The effects of grazing by snow geese on coastal salt marshes. Ecology.

Stone, J. H., L. M. Bahr, Jr., and J. Day. 1978. Effects of canals on freshwater marshes in coastal Louisiana and implications for management, pp. 299-320. In R. E. Good, D. F. Whigham, and R. L. Simpson (eds.), Freshwater Wetlands: Ecological Processes and Management Potential. Academic Press, New York.

Whigham, D. F., J. McCormick, R. E. Good, and R. L. Simpson. 1978. Biomass and primary production in freshwater tidal wetlands of the middle Atlantic coast, pp. 3-20. In R. E. Good, D. F. Whigham, and R. L. Simpson (eds.), Freshwater Wetlands: Ecological Processes and Management Potential. Academic Press, New York.

Discussion I - Ecology of Coastal Marshes (E. Odum, A. de la Cruz, R. Chabreck, and W. Odum)

Q. A. Thorhaug: The system of values that Odum has described for marshes seems to have utility. How would you begin to try to use this system in areas, for example, where human developments in marshes posed a problem?

A. W. Odum: The value system placed on marshes is a rough estimate used to generate discussion. Weighting values and transferring them directly to management decisions can be very dangerous. A Rhode Island study of marshes showed that quantifying these data may be very misleading. In many situations local expertise is more valuable than anything else. I approve of assigning high, medium, and low values but beyond that it is very dangerous. I think there is a real danger in having a value system, whether it is based on dollars or some arbitrary scale of points which may be totally wrong. I am sure someone here would like to argue otherwise.

Q. E. Odum: Is there any such thing as a permanent impoundment of a marsh? If water levels are not fluctuated, does not the ordinary process of succession occur eventually, causing the marsh to no longer exist?

A. R. Chabreck: That is correct. In the Lacassine Refuge pool, I mentioned, the marsh floor has built up over the past 20 years and it is approximately 0.6 m thicker than the outside marsh. This depth change would normally favor another plant community. However, the water level is continually raised and therefore the marsh condition remains.

Q. A. Banner: Considering a permanently impounded marsh, do you believe there is any significant export of dissolved organic material to the estuary?

A. R. Chabreck: There is a significant amount of material which is exported depending upon the rate of discharge of water from the impoundment. There was concern that construction of weirs across tidal channels would block the movement of the detrital material, dissolved organic materials, or suspended organic materials. We found by analyzing data collected over 20 years that organic material was exported and did not accumulate in the water body behind the weir as it would normally accumulate in a lake. Upstream from the weir it was noted that there was no accumulation of organic material. In regard to your question, there is or can be a significant amount of dissolved organic material exported to the estuary in this manner.

Q. A. Mueller: What is the relative value of detritus versus phytoplankton in relation to estuarine fisheries production and energy sources?

A. A. de la Cruz: Many phytoplankton workers contend that production of phytoplankton is quite high and therefore very important in estuarine systems. My feeling is that the detrital system also feeds the phytoplankton system because a lot of nutrients are being released in a very gradual process. There is storage of nutrient energy in the detrital system. Naturally, microbes and phytoplankton are also going to fit in.

Stomach analyses of fish and shellfish indicate that phytoplankton and detritus are extremely important in their diets. A fish may go through a stage in its life history when it is most dependent on phytoplankton and algae and then in a later stage it may switch to detritus. This might be dependent upon on the life history of the organism or the availability of food.

A. E. Odum: Carbon 13 trace ratios have been used to indicate plant use. Rooted plants, like Spartina, have a different ratio of carbon isotopes than algae. This C-13 method has shown that there is a great deal of algae going into an organism which may not necessarily be phytoplankton. I tried to show that a great many benthic algae are associated with detritus. Therefore, when detritus particles are eaten by an organism, a great deal of algae are also eaten, in shallow waters in particular. However, a great deal depends on the turbidity of the water and the light penetration.

It is very difficult to determine the origin of phytoplankton, whether it comes from shallow water, or whether it comes from the open ocean. Bacteria also are important sources of food for many organisms. Any source of detritus is going to increase the amount of bacteria and algae. Therefore, it is going to increase the amount of food in the energy cycle.

A. W. Odum: A rule of thumb to tell the relative importance of detritus and phytoplankton (I might be wrong; however, no one has proven it) is to look at the ratio of the amount of wetlands versus the amount of open water. In a situation where there is a small amount of wetlands and a large amount of open water, the odds are that the phytoplankton food chain will be more important than in an environment where the reverse is true.

We used to think in terms of export of particulate matter away from the marsh, off shore into an embayment. Now, I think more in terms of export from the marsh into a nearby creek, or bayou, where small animals gather and there are primary detritus food chains. The farther away from the wetlands, the less important the detritus chain becomes and more important the seagrasses become.

The C-13 work presently being done is extremely difficult to interpret because things are a lot more complicated than were originally thought.

A. A. Thorhaug: In the tropics when the water is clearer, there is a less abundant phytoplankton system. The marshes and the sublittoral attached benthics also become much more important as you move into the Caribbean. Disturbances of the sediments reverts the system back to a more turbid and less abundant benthic system. If disturbances involve either the plankton or fixed benthic marsh system, more harm is done to the slower growing long life system. Plankton may recolonize in a matter of weeks, whereas mangrove systems or seagrass systems may take 25-40 years or more to recolonize.

Q. L. Barkley: In the South Atlantic we are being faced with requests for additional impoundments of high marshes for waterfowl use. One of the arguments used by those who are opposed to impoundments is that there is an unknown but relatively high value of high marshes to coastal fisheries. Would you please comment on any information you have regarding value of marshes.

A. E. Odum: One other value of the high marsh is that it acts as an overflow in storms, a place for water to release its energy during times of high energy storm tides. Also, hurricanes and storm tides might be one reason why Gulf Coast marshes exceed in nutrients as compared with high marshes on the Atlantic Coast.

A. A. de la Cruz: The high marsh can also be used as a buffer and a retainer of water. For example, in tropical areas where there are monsoon rains, the high marshes buffer the water flow into the bay and coral reef, and act as a reservoir for fresh water. Overland flow is very important as far as high marshes are concerned, especially because it transports nutrients from the high marsh area. Channeling, diking, and excavating fresh water marsh may interfere with the natural freshwater reservoir or buffer which the high marsh presently affords.

Q. R. Huber: I have noticed that in many areas, where there are holes just knee deep, heavy concentrations of fingerling fish are just waiting for the next high tide. Would not a dike ruin this kind of system?

A. W. Odum: Studies in Cape Cod have shown that nitrogen, in particular, coming into marshes comes from ground water. If a dike is put in, the water table would be altered and it would be very hard to predict exactly what would happen to the nutrient balance. The low and high marshes are so closely linked that if you alter one, you alter the other.

MANGROVE ISSUE DEBATES

IN COURTROOMS

Ariel E. Lugo
Institute of Tropical Forestry
P.O. Box AQ
Rio Piedras, Puerto Rico 00928

ABSTRACT

Thirteen issues of mangrove ecology that have been debated in court rooms are reviewed by comparing the testimony of witnesses with the state of knowledge as reflected in the literature. The issues are: effects of heated effluents on mangroves; whether freshwater mangroves exist; flooding of mangroves; wildlife in mangroves; senescent mangroves; impounded mangroves; killing of mangroves by oil and salinity; regeneration of mangroves in an oil contaminated soil; "other" types of mangroves; the value of mangroves; is one mangrove acre the same as any other ; are all mangroves needed ; and, are black mangroves useless? It is concluded that the average work associated with impact statements is of poor quality, reductionist in approach, and normally incomplete. Ethical questions associated with ecological work are also discussed.

INTRODUCTION

In 1970, Bill Odum showed that red mangroves were of direct value to estuarine food chains. It was hoped that his work would dispel ideas such as those voiced in a 1969 letter from Harold Humm to John J. McCue, recommending the destruction of mangroves because, based on his 35 years of experience, a bulkhead was more beneficial to fish than a mangrove forest which he considered "a form of wasteland."

Since 1970, there has been a plethora of ordinances, laws, executive orders, directives, and plans all designed to protect mangroves. Yet, mangroves are far from being a "secured" ecosystem. Developers continue to find ways of circumventing scientific knowledge even when this knowledge suggests that the destruction of mangroves is not good for the welfare of society.

A number of ecological issues raised in legal controversies will be reviewed in this paper. Those issues considered most significant in legal controversies which directly involve the author are discussed below. Trial testimony is presented as written in official transcripts. Names are deleted whenever possible, and "company" is used to mean the proponent of the project.

ISSUES

MANGROVE STRESSORS MAY CAUSE SUBTLE VISUAL EFFECTS

Heated effluent from a power plant was believed to be stressing a red mangrove forest in Guayanilla Bay. The consultant for the company argued that this was not the case because trees were green, growing and reproducing. A closer look at the trees revealed that, compared to controls, the size of mangrove leaves was significantly reduced although the length/width ratio remained constant in those trees in the area receiving heated effluent (Lugo and Snedaker 1974). Also prop roots per unit area increased, seedlings decreased in size and abundance (Banus and Kolehmainen 1976), and epiphytic communities on roots lost species diversity (Kolehmainen et al. 1974). This case illustrates that some mangrove stressors cause subtle visual effects that require careful study if they are to be detected early. Physiologically however, the effects could be more significant (Lugo 1978, Lugo et al. 1980a).

FRESHWATER MANGROVES

Many company consultants argue that there are "freshwater mangroves" which are nontidal and not connected to the sea, therefore not important for marine life. A sample of court testimony illustrates this position:

The court: And it is your position with respect to the Vacia Talega mangrove swamp, it is not part of the marine ecosystem?

The witness: That is my opinion. It is not a part of the marine ecosystem.

The court: It might just as well be located in the El Yunque mountains?

The witness: Yes. (p. 502 of PFZ Properties Inc. v. Russell Train et al. 1974.)

The same witness referring to his sworn statement said:

A. I prepared it and signed it.

Q. What does it provide?

A. It provides reference to the fact that mangrove existence need not be related to tidal fluctuations. (p. 447 in PFZ Properties Inc. v. Russell Train et al. 1974.)

The following documents and Environmental Impact Statements (EIS) contain references to "freshwater mangroves":

Palmer Developments Inc. (1974); PFZ Inc. (1974); trial transcript of PFZ Properties Inc. v. Russell Train et al. (1974); and U. S. Army Engineer District, Jacksonville (1979). However, none of them contains data to substantiate this designation. In the case of the Marco Island "freshwater mangroves" (U. S. Army Engineer District, Jacksonville 1979) data scattered in the EIS contradicts the designation of mangroves as a freshwater ecosystem.

Freshwater mangroves are a myth (Lugo 1974). Studies have shown that soil salinities in "freshwater mangroves" normally exceed the maximum that freshwater plants tolerate (about $0.5^{o}/_{oo}$) and they are usually twice as high as surface water salinity (Brinson et al. 1974, Lugo and Cintron 1975, Cintron et al. 1978).

DETERMINATION OF NORMAL FLOODING IN MANGROVES

In PFZ Properties Inc. v. Russell Train et al. (1974), consultants argued that the water level in the mangrove forest was abnormally high due to recent rains. The water level, however, was not abnormal because black mangrove pneumatophores were all above water. These and other adventitious structures in wetlands are excellent water level indicators (Lugo and Cintron 1975, Lugo et al. 1980b). Continuous overtopping usually results in mortality. Development projects on or away from the mangrove areas, if not designed properly, may cause excessive inundations of wetlands.

THE WILDLIFE VALUE OF MANGROVES

Many consultants argue that if wildlife or fish are not observed during their short visits to mangroves, the forest is of little value for fish or wildlife. Others argue that fish from the sea never visit the mangroves because these may not be connected to the sea. For example: (p. 400 in PFZ Properties Inc. v. Russell Train et al. 1974).

Q. To broaden the question a little bit, what is the relationship in your opinion between the food chains in Vacia Talega and food chains in Pinones?
A. None whatsoever.
Q. In your opinion, are these food chains complementary in any way?
A. No.
Q. Are the fish in Pinones obligated to the biota in the food supply?
A. No. We should remember we are talking in terms of distance between the site, 170 acres, or 178 cuerdas, which is approximately 5 kilometers away from the lagoon.

This witness used a seine inside the mangrove forest and only caught *Gambusia* and other small fish. Government witnesses caught tarpon in the same area and found their stomachs full of *Gambusia*. The lawyer for the developer argued that the tarpon ate the *Gambusia* by mistake while it was being caught and that the small fish decomposed in the stomach of the tarpon because the Government biologist failed to put alcohol inside the stomach cavity.

In another case a consultant said:

"The only birds seen in this zone were a few upland species, the bluejay and grackle. No periwinkles or mangrove tree crabs were observed in this area. For these reasons I would classify this zone at this site as of very limited biological value and of relatively minor importance to the continued productivity of the surrounding waters. This is not a generalization about all high-marsh mangroves, but of this particular zone at this site." (pp. 40-41 in U.S. Department of the Army 1976.)

This consultant went on to quote a Fish and Wildlife Service report that had reached similar conclusions based on an equally incomplete survey of the region and an equally narrow view of the role of mangroves. These reports ignore what is known about periodic migrations, export of food to other ecosystems, the complex food webs that are so typical of coastal ecosystems, and the many rhythms of animal activity that exist in any ecosystem. Physical presence of fish and wildlife or lack of it is not the sole criteria for determining the wildlife value of an ecosystem.

SENESCENT MANGROVES

The same consultant said that the riverine mangroves in the Jentgen property in Everglades City were senescent and evidenced impeded exchange with the sea (U.S. Department of the Army 1976). When the author (Lugo) visited, a vigorous riverine forest typical of this mangrove forest type was found. The Environmental Monitoring and Support Laboratory (1978) produced aerial photos that clearly showed a healthy forest with an ample number of channels that allowed exchange of water and materials with the sea. What the consultant failed to realize was that mangroves are ecosystems under constant successional turmoil. Tides, waves, humans, hurricanes, and even frost constantly stress them. The site had vigorous black mangroves replacing red mangroves which were dying. The consultant opted to call the place senescent rather than healthy. Obviously a narrow view of ecosystem processes can lead inexperienced observers to mislead the public.

IMPOUNDED MANGROVES

Dikes, roads, and poorly designed constructions cut circulation to mangroves, causing impoundment and eventual mortality and replacement of the ecosystem (Patterson Zucca 1978, Lugo et al. 1980a). The Fish and Wildlife Service specializes in this type of management, particularly in its refuge management system. The Ding Darling Refuge in Sanibel Island, Florida and the Boqueron Refuge in Puerto Rico are examples. Healthy mangroves and impoundments do not mix. Yet, some consultants have argued strongly about the existence of impounded mangroves in such places as the Estuary's property, Ft. Myers; Vacia Talega, Puerto Rico; Marco Island, Florida; and the Jentgen property at Everglades City, Florida.

In PFZ Properties Inc. v. Russell Train et al. (1974) and in Estuaries Properties Inc. v. Board of County Commissioners of Lee County, Florida (1976), simple calculations were made of the organic matter, salt, and water budgets of mangroves, which show the fallacy of such arguments. If mangroves were indeed completely impounded, in a period of 10 years or less they would accumulate enough water, salts, and organic material to change the habitat substantially. Survival in the new habitat could not be expected to occur. Mangrove ecosystems are open systems and, in fact, most wetlands are. Yet, the idea of impoundment leads to the following point of view: (p. 28 in deposition for Estuaries Properties Inc. v. Board of County Commissioners of Lee County, Florida 1976).

Q. In your opinion is the black mangrove forest a minor contributor community to the Estero Bay system?

A. Yes. In our opinion, it is.

Q. Would you describe to me the basis for your opinion?

A. Well, the most familiar one to most people would be the difference in the amount of leaf material fall from the trees.

As shown below, this position is without foundation. Black mangroves produce as much litter as any other type of mangrove and they can be just as productive (Lugo et al. 1975, Pool et al. 1975).

THE LETHALITY OF OIL TO MANGROVES

This issue was debated in the Zoe Colocotroni oil spill in Bahia Sucia located in the southwestern coast of Puerto Rico (The Commonwealth of Puerto Rico and the Environmental Quality Board of the Commonwealth of Puerto Rico v. the SS Zoe Colocotroni, her engines, appurtenances, etc. et al. 1973). In this case, high soil salinities clouded the issue somewhat even though our studies included before and after photos that showed that the mangrove kill occurred after the spill in oiled areas with low soil salinity (less than 55‰) (Lugo et al. 1980a). There is no question, however, that oil kills mangroves.

In the Peck Slip Spill on the north coast of Puerto Rico, the Department of Natural Resources monitored leaf fall from the day of the spill to the present. A 100% defoliation occurred within 60 days after exposure to only a few tons of oil (Cintron 1979, personal communication). Thirty days after the minor spill, leaf fall in oiled areas was 13-15 $g/m^2/day$ versus .2 $g/m^2/day$ in controls (Cintron 1979, personal communication). Today these trees are dead.

FOREST REGENERATION IN AN OIL-CONTAMINATED SOIL

This is the most controversial oil related question in the mangrove field today because physiological evidence is lacking for definite answers. I testified (in The Commonwealth of Puerto Rico and EQB v. Zoe Colocotroni, 1973) that mangroves could not survive with the same vigor under conditions of chronic oil exposure because at some critical point in their life cycle their dependence on the resources of the site would increase relative to what they were early in the life cycle when they are more dependent on internal storages. At that point, either mortality would occur, or mangrove growth would decelerate and result in a forest with a lower stature than expected under normal conditions. This opinion is based on close observations in Bahia Sucia. There, seedlings grew with vigor only along the edge of water courses where they floated on the tides and where tidal flushing washed oil away. These seedlings grew fast, in dense clumps, and suffered high rates of mortality.

In oiled sediments not exposed to a high frequency of flushing, seedling establishment was nil. This high mortality occurred despite the fact that seedlings are more tolerant to stress than adults (Lugo et al. 1980a). Seven years have elapsed since the oil spill in this locality and this situation has not changed. Surviving seedlings do not exceed 2-3 m which is lower than expected for this site. Yet, to a one-time visitor, without the reference of time, the forest appears to be growing normally and with great vigor.

THE "OTHER" TYPE OF MANGROVES

In the Estuaries and Pelican Bay EIS's, mangroves were classified into tidal and impounded. Tidal mangroves were declared useful to the estuary but the impounded mangroves were not because they lacked connection to the sea. The Marco Island EIS (U.S. Army Engineer District, Jacksonville 1979) mangroves are subdivided into tidal or fringe, freshwater, and "other." Such classifications are "senescent," "freshwater," "isolated," and "other" categories with no ecological basis. All natural mangrove forests are tidal and can be correctly classified according to frequency of inundation, physiognomy, geomorphology of the basin, species dominance, or by the intensity and type of energy flows converging on them. Classifications are confusing, misleading, and are self-serving in the intent of justifying careless destruction of public resources.

THE VALUE OF MANGROVES

The monetary value of ecosystems is a controversial issue which can be roughly divided into three points of view by individuals:

Those who believe mangroves do not have any value and thus color all their statements to minimize value. Harold Humm's letter is a prime example.

Those who look for direct use by humans before they assign any value. As an example, consider this quote from an April 26, 1969 letter to James S. Mattson from M. E. Bender from the Institute of Marine Science, Virginia:

"Damage assessment, in my mind, must be directed toward equitably determining the economic losses resulting from spills. Any scheme must consider the following for natural resources:

a. loss of harvestable natural resources (from either death or contamination) and . . .
b. the length of time to recovery.

It is not reasonable to impose fines for animals and/or plants of no economic value. For those creatures which serve as food for usable species, it would be reasonable to equate their loss as supporting items in the food chain. However, this would automatically be accomplished when one considers the recovery period."

Those who assign value based on ecological criteria assuming that ecosystems have intrinsic values that market approaches cannot even begin to measure (Gosselink et al. 1973, Lugo and Brinson 1980).

It is hoped that we are past the age when arguments like those of Dr. Humm are taken seriously. The narrow view of Dr. Bender's argument, however, now prevails and has led to an interesting controversy between Shabman and Batie (1978) and E. P. Odum (1979). My views are expressed in Lugo and Brinson (1980) and all that can be added here is that much more research is needed in this area if we are to make serious progress in the management of mangroves and the natural resources associated with them.

COMPARISONS OF ONE HECTARE OF MANGROVE WITH ANOTHER

This question was posed to me by the judge in the Jentgen case (James J. Jentgen v. United States 1978). I argued that in terms of litter production, a hectare of riverine mangrove is at least two times more productive than a hectare of basin forest and 10 times as productive as scrub mangroves. Yet, an acre of basin forest may be more productive in terms of dissolved organic matter production and scrub mangroves may prove important as protectors of stressed watersheds. The point is that all mangrove acres are not created equal because each may be performing a specialized role that is of great value to the region.

THE MINIMUM MANGROVE AREA NEEDED TO MAINTAIN ESTUARINE WATERS

In Puerto Rico, a consultant recommended that a 30-m fringe of mangroves was all that was needed to maintain a healthy bay ecosystem. The recommendation was based on the width of the red mangrove fringe, around the bay, and opened thousands of "useless" hectares of black and white mangroves to development. If the respiration (R) of the bay is taken as a measure of organic matter demand, one finds that production in bay waters plus organic input (P) from 30 m of red mangroves are not enough to support the bay's metabolic activity. Only if one adds the organic runoff from black and white mangroves does one balance the P/R of the bay. Obviously, estuarine bay waters depend on allochthonous organic inputs to maintain their metabolism and this can easily be shown with metabolic measurements in bay waters (Brinson 1973, Carter et al. 1973, Twilley 1980).

THE ECOLOGICAL ROLE OF BLACK MANGROVES

The hottest mangrove issue in Florida today deals with the ecological role of black mangrove forests. Common points of view among consultants are:

- "We think that on the basis of all the evidence available to us that this black mangrove has very limited assimilative capacity, and that it cannot be counted on to remove the nutrients from upland run off." (pp. 55-56 in deposition for Estuaries Properties Inc. v. Board of County Commissioners of Lee County, Florida 1976)

- "We see that natural impoundment of black mangroves as having an environment so hostile that the fish cannot enter it, nor can they cross it to go up higher into the system, but they will come to that edge." (p. 47 in deposition for Estuaries Properties Inc. v. Board of County Commissioners of Lee County, Florida 1976)

- In the same document page 1617:

  Q. Right, I understand that. Okay, you discussed the periodic flushing of the mangroves at a time known as "bad water"?

  A. Yes.

  Q. Are there any studies or documents which indicate the amount of dissolved oxygen in the water receiving this bad water, or is this just folklore?

  A. No, no, it is not folklore. The long-term studies were done by us in Everglades Park over a period from 1957 to 1960. And it shows that for practically all of the warmer summer months these areas are deficient in oxygen, usually totally deficient at night, and with a slight oxygen content during the day.

These points of view reflect confused and at times uninformed views about ecosystems. Simple calculations of net primary productivity rates illustrate that black mangroves may assimilate 16 times more nutrients than estuarine waters (based on a gross production of 16 g/m^2/day for mangroves (Lugo et al. 1975) and 1 g/m^2/day for the Bay (Carter et al. 1973). Sell (1977) documented this assimilative capacity in riverine mangroves.

I have been studying black mangroves with students and colleagues since 1971 (e.g., Lugo and Snedaker 1975, Lugo et al. 1975). Our findings so far show that black mangroves may produce up to 7 tonnes of detritus/ha/yr of which approximately 2-3 tonnes/ha/yr are exported to bays as high quality organic matter. Our research for EPA has documented annual patterns of organic exports to estuarine waters, the metabolic response to exports in estuarine waters, and the dynamics of dissolved oxygen inside black mangrove swamps (Twilley 1980). The idea that these ecosystems are unproductive is a myth and nonsense. Yet, this is one of the most dangerous issues now facing mangroves in Florida.

DISCUSSION

There are a number of common denominators that appear throughout all these issues. Perhaps the most obvious is the confusion in ecological concepts that are normally taught at college freshman level. Being expert witness in trials such as the ones reviewed is disappointing and not intellectually stimulating. This is a sad commentary about our system to deal with environmental issues. Still, the three greatest evils in my view, are: reductionism, shoddy work, and lack of ethics.

REDUCTIONISM

I have observed a tendency in many scientists to approach obvious ecosystem problems with a reductionist mind set that defies description. Part of the problem behind this is that everybody wants to be a mangrove expert. I have seen vitae that, although academically sound (and some not even that), show no evidence of ecological training at the ecosystem level or worse yet, no experience with mangroves. Consider the following exchange in a court of law (pp. 464-469 in PFZ Properties Inc. v. Russell Train et al. 1974):

Q. Now, we have reviewed your 24 publications and your curriculum vita. Any of those publications have anything to do with mangroves?

A. No, sir. I told you I have not published any other papers on mangroves.

Q. Have you done any studies on the productivity of mangroves?

A. No, sir.

Q. Have you done any studies on the rates of growth of mangroves?

A. No, sir.

Q. Have you done any studies on factors which affect the productivity or growth of mangroves?

A. No, sir.

Q. Have you done any studies on the detritus production of mangroves?

A. No, sir.

The Court: What do you mean by detritus?

Mr. Varnum: Could you define detritus?

A. Particulate matter that gets to the sediment or to the water.

The Court: That they throw off, you mean?

The Witness: Fallout, yes.

Mr. Varnum: Do you consider yourself an expert in mangrove ecology?

A. I do.

Q. Even though you have had no studies, no professional papers; is that correct?

A. Yes, sir.

Q. You are basically a zoologist, isn't that correct?

Mr. Egar: I would like to raise an objection to: no studies, and no professional papers; of what type?

The Court: I think the Doctor has been pretty clear about it. He hasn't done any special studies on the subject of mangroves. He is basically a zoologist who is a professor of marine sciences, and I suppose it would be fair to say in your own judgement you know as much about mangroves as anybody else.

The Witness: That is fair.

The Court: But the literature on mangroves is somewhat limited.

The Witness: It's limited as far as my own contribution is, yes.

Much of the transcript has been excluded for sake of brevity. This tends to show, however, that people bring points of view to cases that are hard to believe. Consider what a professor from the University of Miami said about the southwest coast of Puerto Rico:

> "Attention is drawn to the vegetational picture because it, to a large extent, also portrays the animal life of the area, highly stressed, depauperate, existing precariously with all the odds against it. And, it is this place of all possible places, that it has been decided to make a court case, not out of the oil spill itself, but of the biological effect of the oil spill on a mangrove community. It thus becomes even more important that the area be seen in its totality and it is unfortunate that no biological studies or surveys had been made in the area prior to the spill. This is, however, understandable because its situation and conditions are such that, as described above and on page 1, it would never have been considered for study by zoologists due to its isolation and obvious depauperate condition" (p. 26 in exhibit T of The Commonwealth of Puerto Rico and EQB v. Zoe Colocotroni et al. 1973).

This is mind boggling because the writer is referring to the subtropical Dry Forest Life Zone, representative of 50% of the world's tropical forests and to the specific area where Golley et al. (1962) did the already classic mangrove productivity study. Yet, his reductionism is such that these areas do not appear to even have scientific interest. Reductionist scientists are not trained nor capable of understanding the large-scale issues of ecosystem ecology.

SHODDY WORK

Poor quality of "research" work appears to be the rule in the world of mangrove ecology done by consultants. Consider the following exchanges:

Q. There is a statement: "We have designated these as a black rush zone, as the mangrove zone, on the basis of dominant plant species, Juncus, rhizosphere. These two zones show clarity in good aerial photos and outlines on the Windsor tract where they are best developed." Now I would like you to explain to me -- I think this is a good quality aerial?

A. Extremely good quality aerial, but we didn't have this one.

Q. Okay, how a mistake of this magnitude characterizing this as a black rush forest*, could have been made, if in fact, aerials were referred to?

A. When we (indicating) were doing the vegetation survey of these - well, I shouldn't say "us." I wasn't involved in it then, ______________** and ______________** were doing it, the register of the black rush here (indicating) and here (indicating) was "ground truthed" from the boat coming up. It was assumed that this register was the same as this (indicating). You follow?

---

*The area was actually black mangrove forest.

**Names deleted.

The aerial register was the same. It was a wrong assumption. These are black rush (indicating), these are not (indicating), ____________** and ______________** assumed that this green register was black rush (indicating) showing through as an understory to the mangrove color.

Q. I can understand that in that portion of the property, but how about over in the other parts of the property (indicating)? These areas certainly do not show the same sort, but nevertheless, they are included as "black rush."

A. Right.

Q. The individual trees are very evident?

A. Right, and ______________** presumed that it was black rush understory.

Q. Okay.

A. I don't know for sure, but it was an error, and it wasn't until we got into the second phase of the study that we got into ground truthing in this area. (pp. 49-50 in deposition for <u>Estuaries Properties Inc</u>. v. <u>Board of County Commissioners of Lee County</u>, <u>Florida</u>, 1976).

Q. I very frankly am confused how a scientist could look at this aerial, which you said that you used, or comparable ones, and conclude that this is a black rush (indicating).

A. We assumed that there would be a black rush mixture extended all the way from the creek where we first saw it over here (indicating). (p. 66 in <u>Estuaries Properties Inc</u>. v. <u>Board of County Commissioners of Lee County</u>, <u>Florida</u> 1976).

**Names deleted.

ETHICS

Ethical questions are now appearing with more frequency in ecology and there are many suggestions to license ecologists. This approach will not solve anything as consultants (the good and bad ones) are members in "good standing" of the scientific community and they can easily afford license fees. In fact, some use the scientific community or past distinguished careers to gain credibility outside of the scientific community while failing to abide by scientific rigor. To me, this is unethical and deserves ample discussion. Obviously, government scientists are in a position to act as selective agents for upgrading the quality of ecological work that reaches them. Yet, as long as we in government use lowest bidders or let companies select the same people repeatedly, regardless of past records, we will get what we pay for or deserve, the lowest quality.

Consider the following exchange (from page 38 in deposition for <u>Estuaries Properties Inc</u>. v. <u>Board of County Commissioners of Lee County</u>, <u>Florida</u> 1976) which summarizes the crux of the matter:

Q. . . . my question is: You had one statement* from strictly an ecological point of view: "With Estero Marine bay in mind, the entire black mangrove forest should be preserved, left intact."
I would like to know whether you still espouse that statement from a strictly ecological point of view.

A. That's correct, if I had the choice.

Q. So the constraint on the black mangrove is, in

*In a report to his contractor.

fact, not imposed upon yourself as an ecological point of view, but is imposed by a matter of pragmatics by your employer, or somebody else?

A. Yes.

BURDEN OF PROOF

Who should be responsible for ecological research that is used to make resource management decisions? Ideally, these decisions should be made by reputable scientists free from the pressures that obviously burden today's consultants. However, reality is not this ideal. Instead, government must spend large sums of monies to verify the results of poor work that costs millions of dollars to private companies. Public resources suffer the consequences of this system. In the few cases that reach the courtroom, government must prove its case, it must show "damage to the environment" regardless of how asinine the development is or how truly damaging its consequences are to society. During this process, reductionism, ill prepared lawyers, misconceptions, a cumbersome judicial system, and so on, all work against the natural ecosystem.

Why is the absolute burden of proof not on the proponent, rather than on the custodian of public resources?

ACKNOWLEDGMENTS

I thank S. Brown, G. Cintrón, B. Cintrón, and B. Liegel for their help during the preparation of this manuscript.

LITERATURE CITED

Banus, M., and S. E. Kolehmainen. 1976. Rooting and growth of red mangrove seedlings from thermally stressed trees, pp. 46-53. In G. W. Esch and R. W. McFarland (eds.), Thermal Ecology II. CONF 750425 Technical Information Center, ERDA. Springfield, Virginia.

Brinson, M. M. 1973. The Carbon Budget and Energy Flow of a Tropical Lowland Aquatic Ecosystem. Ph.D. Dissertation, Department of Botany, Univ. of Florida, Gainesville.

Brinson, M. M., L. G. Binson, and A. E. Lugo. 1974. The gradient of salinity, its seasonal movement, and ecological implications for the Lake Izabal-Rio Dulce ecosystem Guatemala. Bull. Mar. Sci. 24(3): 533-544.

Carter, M. R., L. A. Burns, T. R. Cavinder, K. R. Dugger, P. L. Fore, D. B. Hicks, H. L. Revells, and T. W. Schmidt. 1973. Ecosystems Analysis of the Big Cypress Swamp and Estuaries. U.S. Environmental Protection Agency Region IV, Athens, Georgia.

Cintrón, G., A. E. Lugo, D. J. Pool, and G. Morris. 1978. Mangroves of arid environments in Puerto Rico and adjacent islands. Biotropica 10: 110-121.

Commonwealth of Puerto Rico and the Environmental Quality Board of the Commonwealth of Puerto Rico v. The SS Zoe Colocotroni, her engines, appurtenances, etc., et al. 1973. Civil No. 252-73. United States District Court for the District of Puerto Rico.

Environmental Monitoring and Support Laboratory. 1978. Aerial photographic and cartographic displays. Jentgen Property Everglades City, Florida. October 1, 1978 EMSL-LV Project RSD 7889. Environmental Protection Agency, Las Vegas, Nevada.

Estuaries Properties Inc. v. Board of County Commissioners of Lee County, Florida. 1976. Case No. 76-1560. State of Florida Division of Administrative Hearings.

Golley, F. B., H. T. Odum, and R. F. Wilson. 1962. The structure and metabolism of a Puerto Rican red mangrove forest in May. Ecology 43: 9-19.

Gosselink, J. G., E. P. Odum, and R. M. Pope. 1973. The Value of the Tidal Marsh. Center for Wetland Resources, Louisiana State Univ., Baton Rouge. 30 pp.

James J. Jentgen v. United States. 1978. Miami Court of Claims No. 415-76.

Kolehmainen, S., T. Morgan, and R. Castro. 1974. Mangrove-root communities in thermally altered area in Guayanilla Bay, Puerto Rico, pp. 371-390. In J. W. Gibbons and R. R. Sharitz (eds.), Thermal Ecology I. AEC Symposium Series (CONF 730505) Augusta, Georgia.

Lugo, A. E. 1974. Manglares de agua dulce: ley mito, pp. 1-8. In A. E. Lugo (ed.), Primer Simposio del Departamento de Recursos Naturales. San Juan, Puerto Rico. 116 pp.

Lugo, A. E. 1978. Stress and ecosystems, pp. 62-101. In J. H. Thorp and J. W. Gibbons (eds.), Energy and Environmental Stress in Aquatic Systems. USDOE Symposium Series (CONF-771114), National Technical Information Service, Springfield, Virginia.

Lugo, A. E., and M. M. Brinson. 1980. Calculations of the value of salt water wetlands. In Wetland Functions and Values: the State of Our Understanding. (in press).

Lugo, A. E., and G. Cintrón. 1975. The mangrove forests of Puerto Rico and their management, pp. 825-846. In G. Walsh, S. Snedaker, and H. Teas (eds.), Proceedings of International Symposium on Biology and Management of Mangroves. IFAS, Univ. of Florida, Gainesville.

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

Lugo, A. E., and S. C. Snedaker. 1975. Properties of a mangrove forest in southern Florida, pp. 170-212. In G. Walsh, S. Snedaker, and H. Teas (eds.), Proceedings of International Symposium on Biology and Management of Mangroves. IFAS, Univ. of Florida, Gainesville.

Lugo, A. E., G. Evink, M. M. Brinson, A. Broce, and S. C. Snedaker. 1975. Diurnal rates of photosynthesis, respiration, and transpiration in mangrove forests of south Florida, pp. 335-

350. In F. B. Golley and E. Medina (eds.), Trends in Tropical Ecology. Springer-Verlag, N.Y.

Lugo, A. E., G. Cintrón, and C. Goenaga. 1980a. Mangrove ecosystems under stress. In G. W. Barret and R. Rosenberg (eds.), Stress Effects on Natural Ecosystems. (in press).

Lugo, A. E., J. Nessel, and T. Hann. 1980b. Organic matter and phosphorus storage in roots and the influence of root distribution on plant survival in a north-central Florida Cypress strand. In K. C. Ewel and H. T. Odum (eds.), Cypress Swamps. Univ. of Florida Press (in press).

Odum, E. P. 1979. Rebuttal of "Economic value of natural coastal wetlands: a critique." Coastal Zone Manage. J. (in press).

Odum, W. E. 1970. Pathways of Energy Flow in a South Flordia Estuary. Ph.D. Dissertation, Univ. of Miami.

Palmer Developments, Inc. 1974. Declaración de Impacto Ambiental. Junta de Calidad Ambiental, San Juan, Puerto Rico.

Patterson Zucca, C. 1978. The Effects of Road Construction on a Mangrove Ecosystem. M.S. Thesis, Univ. of Puerto Rico at Rio Piedras. 77 pp.

Pool, D. J., A. E. Lugo, and S. C. Snedaker. 1975. Litter production in mangrove forests of south Florida and Puerto Rico, pp. 213-237. In G. Walsh, S. Snedaker, and H. Teas (eds.), Proceedings of International Symposium on Biology and Management of Mangroves. IFAS, University of Florida, Gainesville.

PFZ Inc. 1974. The Mangroves of Puerto Rico. San Juan, Puerto Rico.

PFZ Properties Inc. v. Russell Train et al. 1974. Civil Action No. 74-1534. United States District Court for the District of Columbia.

Sell, M. G. 1977. Modeling the Response of Mangrove Ecosystems to Herbicide Spraying, Hurricanes, Nutrient Enrichment, and Economic Development. Ph.D. Dissertation. Department of Environmental Engineering Sciences. Univ. of Florida, Gainesville. 389 pp.

Shabman, L. A., and S. S. Batie. 1978. Ecological value of natural coastal wetlands: a critique. Coastal Zone Manage. J. 4(3): 231-247.

Twilley, R. 1980. Organic Exports from Black Mangrove Forests in South Florida. Ph.D. Dissertation, Department of Botany, Univ. of Florida, Gainesville (in preparation).

U.S. Army Engineer District, Jacksonville. 1979. Draft Environmental Impact Statement on Permit Application for Deltona Corporation's Residential Development in Wetlands near Marco Island, Florida. Jacksonville, Florida.

U.S. Department of the Army. 1976. Transcript of Public Hearings. Permit Application No. 73-1124 May 11. Jacksonville District, Corps of Engineers, Everglades City, Florida.

MANGROVE MISCONCEPTIONS AND REGULATORY GUIDELINES

Samuel C. Snedaker
and Melvin S. Brown
Division of Biology
And Living Resources
Rosenstiel School of Marine
and Atmospheric Science
University of Miami
4600 Rickenbacker Causeway
Miami, Florida 33149

ABSTRACT

Within the realm of lay and scientific opinion, a variety of misconceptions about the structure and functioning of the mangrove ecosystem frequently provides distorted bases for making decisions in the public interest. For example, belief is popularly held that: 1) red mangroves have a higher ecological value than do the black and white mangroves; 2) a mangrove fringe forest is the most important component of the mangrove ecosystem; 3) mangroves have minor value to fisheries unless inundated by the majority of high tides which provide a mechanism for exporting detritus and; 4) one needs only to look at a mangrove forest to determine its relative productivity. Decisions made as a result of these beliefs, which have no known scientific basis, may cause unnecessary ecological problems and provoke unnecessary litigation. Regulatory agencies have a responsibility to protect and conserve natural resources for the public weal and to do so on a rational and scientific basis. Now that the constitutional issue of a "taking" is being argued more frequently in the Federal courts, it is becoming increasingly necessary to make decisions on the firmest foundation possible. This paper discusses several misconceptions which can be used to resolve development conflicts.

INTRODUCTION

The purpose of this paper is twofold: to explore certain misconceptions about the structure and functioning of the mangrove ecosystem and to offer some alternatives for executing sound ecological decision and policy making by the regulatory agencies.

Before the enactment of Federal, State and local laws to protect the mangrove environment, it was profitable for landowners to bulkhead, dredge, and fill coastal property to enable human use. Of course this practice destroyed the very essence of ecological value and is now largely abandoned. However, property owners still expect to achieve some fair and equitable use of their holdings in the coastal zone and, for the most part, the regulatory agencies strive to meet the minimum demands.

Spurious scientific arguments are frequently used as the basis for the issuance of permits in order to accommodate landowner requests for development permits. In this regard, there is some merit to the cliche that the best way to kill mangroves is to hire a consultant to generate tenuous arguments for consideration by agency personnel. Generally, these evidentiary arguments seek to show that the specific mangrove area in question is somehow different and thus less valuable than other mangrove areas in its class. This approach is workable to the extent that misconceptions about mangroves are nevertheless proffered and accepted.

In the following sections, some

of the more common misconceptions and the reasons for rejecting their use in regulatory matters are discussed. Some alternative principles which may be applied in the regulatory process are also offered.

MISCONCEPTIONS

Misconceptions about mangroves, relative to the permitting process, are all related to demonstrating that the mangroves in question are different and therefore exempt from total protection. Among the most popular misconceptions are: (1) the mangroves of interest are not very productive, or are significantly less productive than mangroves elsewhere, (2) red mangroves are more valuable than are black and white mangroves, (3) the mangrove fringe forest has a greater ecological value than other mangrove forest types, (4) leaf detritus has an ecological value only if it is continuously exported to nearshore waters, and (5) mangrove ecosystems in a process of observable change have less value than mangroves ecosystems which appear to be stable. As stated, these are either false or lack any logical scientific basis for their justification.

PRODUCTIVITY AND OBSERVATIONS OF COMMUNITY STRUCTURE

The most common misconceptions relate to productivity and the structural appearance of a mangrove forest. It is commonly held that productivity can be established by the observation of structure and that productivity is a direct measure of a mangrove ecosystem's value. Although there are quasi-relationships between productivity and appearance, and productivity of ecological value, their relationships are not precise nor are they quantifiable.

Statements about productivity in relation to appearance generally imply that tall dense forests are more productive than similar forests of shorter stature and lower density. Ignored in these statements is the possibility of successional immaturity (in the latter) as well as an understanding of the relationship among gross primary productivity (GPP), net primary productivity (NPP), respiration (R), and biomass. The fundamental relationship among these parameters can be stated as NPP = GPP - R; two parameters of which have to be known to estimate the third. Thus, it is impossible for one to make any conclusive statement about productivity on the basis of this type of observation. Furthermore, their empirical measurement (i.e., GPP, NPP, R) is difficult even under the best of research conditions (Snedaker and Lugo 1973, Lugo and Snedaker 1974).

The structure or the accumulated biomass of a mangrove forest is positively correlated with NPP, but again it is not possible to determine what fraction of the NPP is represented in the standing stock biomass; that is, what fraction was retained as biomass and what fractions were lost to herbivory and detritus production. These complex relationships involving carbon fluxes simply cannot be estimated reliably from simple observation. Finally, to associate productivity with value of the mangroves frequently means that other important functions are ignored, particularly when low productivities are estimated for a particular forest.

PRODUCTIVITY AND LITTERFALL

Leaf litter production, or detritus production, represents a fraction of the NPP and various attempts have been made to use rates of litter fall as estimates of productivity and ecological value. Unless site specific measurements of carbon flux (i.e., metabolism) and litterfall have been made on a synoptic basis, it is not possible to make accurate statements about this relationship. For example, based on reported measurements (cf. Lugo and Snedaker 1974, Snedaker and Brown 1980) there is a much greater variation in GPP (10x), NPP (10x) and biomass (100x) than there is in litterfall (3x). All known data for these parameters have been summarized (Snedaker and Brown in press) and simply show that mangroves exhibit a variety of carbon metabolism strategies for successful survival, growth, and reproduction, of which no single example can be better or preferable to others.

It is important to recognize that mangrove forests tend to maintain disproportionately high rates of litterfall. For example, the lowest rate of litterfall of 0.8 $g/m^2/day$ reported for the dwarf mangrove forest of southeast Dade County (Snedaker and Brown 1980) is only one-third lower than the maximum reported for the more luxuriant forests in Collier County (Lugo and Snedaker 1974).

LITTERFALL AND DETRITUS EXPORT

Another misconception holds that unless freshly fallen or partially decomposed leaf debris is exported regularly, the mangroves producing the leaf litter have little value to nearshore fisheries. In other words, mangroves situated well inland from the shoreline or tidal creeks have a lower ecological value for fisheries than mangroves exposed to frequent inundation. This may simply not be true. Based on some preliminary research in the mid-70's (Carter et al. 1973, Snedaker and Lugo 1973, Pool et al. 1975) and ongoing research in southern Florida (Lugo pers. comm.), it appears that all mangrove areas, no matter where located, are inundated and flushed periodically during each year.

Export from the less frequently flushed areas also occurs as dissolved organic matter as opposed to whole leaves and large particulates. Dissolved or soluble organic matter is utilized by filter feeders and when flocculated, by benthic feeders such as shrimp, crabs, and mullet. Although the precise relationship has yet to be worked out, there is no valid basis for stating that inland or isolated mangroves have less ecological value for estuarine animals.

RED VERSUS BLACK VERSUS WHITE MANGROVES

Related to observed differences in detrital export is the fact that the red mangroves are considered to have the highest ecological importance of the three species common to Florida. The now-classic works of Heald (1971) and Odum (1971) show that red mangroves drop their leaves continuously throughout the year into the water where they begin decomposition and enter the estuarine foodwebs. However, Heald's and Odum's work on the red mangrove has led many people to believe that it is only the red mangrove which benefits fisheries, resulting with the black mangrove, in specific, not receiving the same degree of protection. This, coupled with the facts that the leaves of the black mangrove decompose *in situ* and export occurs irregularly as dissolved organic matter, causes abundant misunderstanding about the species.

In those areas where the black

mangrove dominates, it exhibits rates of productivity on par with the red mangrove (Snedaker and Lugo 1973, Lugo et al. 1975). The biomass of such forests also is comparable (Lugo and Snedaker 1974) as are the rates of the leaf litter production (Pool et al. 1975). But more important is the fact that the black mangrove is the species best adapted to survive under the environmentally rigorous conditions of the habitat in which it is usually found.

Unlike the red mangrove, the black mangrove also has the ability to readily form a coppice and recover from destructive perturbations such as hurricanes. Thus, simply on the basis of its autecology, there are no valid reasons for giving preference to the protection of red mangroves. With respect to the white mangrove, its autecology is less understood, but the data that are available (references in this paper) suggest that, like the black mangrove, it too is a viable species. To state that one species is better, more important, or has a higher value than another, for whatever reason, is a subjective opinion and at the current level of understanding, not a scientific statement.

MANGROVE FOREST TYPES

Another part of what might be called the myth of the red mangrove is the misconception about the relative importance of the fringe forest where it tends to be the dominant species. In many parts of southern Florida, the fringe forest represents a small fraction of the total mangrove forested area in mangroves. Yet, because of the dominance by the red mangrove and its shoreline position, the fringe forest also receives preferential treatment in agency guidelines. And, nonfringe forest types are considered to be different and unusual expressions of the mangrove ecosystem and therefore of relatively lower ecological value. However, it has been shown that these other forest types, i.e., overwash, riverine, basin, hammock, and dwarf (Snedaker and Pool 1973) have unique characteristics and functional qualities of their own (Lugo and Snedaker 1974, Lugo et al. 1975, Pool et al. 1975, Pool et al. 1977, Carrera and Lugo 1978) as does the fringe forest.

There is no valid scientific reason known to support any statement which claims that one or the other of these mangrove forest types is intrinsically more important than the others. In fact, one could pose the argument that, like the value imposed on species diversity or species richness in a community, similar values are realized when there is a diversity of forested community types in juxtaposition with one another. One important question that remains to be answered is how each of these types with their differing frequencies of tidal inundation contribute to the total detrital export to nearshore waters.

MANGROVES AND CHANGE

The final misconception to be discussed relates to the time at which mangrove ecosystems are observed and the types of ecological changes occurring, such as, dying or recovering from cold stress, expanding in previously unoccupied areas, undergoing a shift in species composition, or disappearing from an area of previous dominance. Frequently, proponents use observations of these types to argue that the area in question is of less value and therefore suitable for conversion to some other use. Although each example would have to be evaluated on its own merit, it can be stated that all of Florida's mangroves exist in a constant state of natural change. The only real difference observed is that the rate of change in some areas is faster than in others.

For the most part these changes in community structure and function are related to range extensions and contractions, local changes in erosion-deposition in a geomorphological context, alteration of freshwater inputs due both to natural conditions and man's influences over surface water resources, and a variety of other causes. Change, per se, is not proof of lesser ecological value.

THE PERSPECTIVE AND THE PROBLEM

To summarize the state of existing knowledge relative to the misconceptions that have been discussed, it is possible to state that:

(1) All mangrove species are probably comparable in their productivities and other measures of functioning when each species is present in specific habitats representing optimum conditions for its survival, growth, and reproduction. It is not possible to observe a mangrove tree or a mangrove forest and visually determine the rates of gross primary productivity, respiration, or net primary productivity. Nor is it possible to infer relative differences in productivity among specific mangrove areas from observations of the structure and standing-stock biomass.

(2) Each species of mangrove and each type of forested mangrove community exhibits comparably high rates of litter (detritus) production indicative of normal functioning. Furthermore, each mangrove forest type is hydrologically coupled to nearby coastal waters, which according to temporal periodicities in inundation, provide a variety of mechanisms for the export of detritus. Simply because an area of mangroves exports a small fraction of its detritus to coastal waters does not mean it is insignificant. One has to take into account the quality of the detritus and the timing of its export during the year.

(3) The ecological value of the mangrove ecosystem is not a function of just the fringe forests and the numbers of red mangroves. Instead, the ecological value is a function of the spatial diversity of species and forest types, their interrelationships with one another, and their collective relationship to surrounding ecosystems. The holistic approach to ecosystems requires that the whole be considered rather than its parts and pieces. No scientific evidence exists, whereupon claims can be made that one part, or one function, is more important than others and therefore should be valued differently.

One could interpret the foregoing discussions in this paper to mean that either all mangroves must be protected, or that no alternatives exist for man's interaction. Whereas the former may be preferable to the latter, it is a fact of life for the regulatory agencies that property owners are going to continue to demand the right to develop and otherwise alter the mangrove environment. To accommodate such initiatives in a sound and rational manner, the following alternatives are offered for guiding what eventually happens. These alternatives are based on two simple rules: do not alter patterns of surface water circulation or the structure of the sediment substrate, and do not work to protect individual species and communities but rather protect the environments that support all species and communities. Translated into practice, we recommend:

(1) Do not create any obstructions to water flow. Roads and access should always be parallel to surface flow patterns, including tides, and never perpendicular. When perpendicular barriers cannot be avoided, they should either follow natural water divides, when present, or contain culverts with a total flow cross-section sufficient to accommodate 50-year flood levels.

(2) Do not force all of the alteration to the environment in one forest type or in an area defined by one particular species. Determine the minimum permissible area and distribute proportionately over all forest types.

(3) Do not fill areas to meet minimum grade requirements. Build houses and facilities on stilts, poles, and pilings to allow for continued surface water circulation and sediment integrity.

(4) Require mitigation in the form of maintaining, expanding, or establishing physical environments suitable for mangrove colonization and regeneration; planting of seedling stock is not necessary when a seed source is available in the vicinity. This is the most reasonable form of mitigation to both offset development impact and maintain the maximum local area in mangroves, and takes advantage of nature's ability to rapidly regenerate mangrove communities.

(5) Use performance standards whenever possible to achieve the goals stated above.

CONCLUSIONS

The interaction among the public, private interests, and the regulatory agencies, and the results of those interactions are based largely on misconceptions about the structure and functioning of the mangrove ecosystem. This has partly been due to a traditional tendency to base decisions on productivity which cannot be casually measured, and on the red mangrove myth insofar as it is believed that this species is more important than all others. By correction of these misconceptions, certain potential ecological and legal problems can be minimized and the activities of the regulatory agencies made consistent with their mission. An improved understanding of the structure and functioning of the mangrove environment offers a variety of alternatives for developers and users, while still retaining an acceptable measure of control regarding the preservation-conservation of this unique Florida ecosystem.

LITERATURE CITED

Carrera, C. J., and A. E. Lugo. 1978. Los sistemas de magles de Puerto Rico. Estado Libre Asociado de Puerto Rico. San Juan. 69 pp.

Carter, M. R., L. A. Burns, T. R. Cavinder, K. R. Dugger, P. L. Fore, D. B. Hicks, H. L. Revells, and T. W. Schmidt. 1973. Ecosystems Analysis of Big Cypress Swamp and Estuaries. EPA 904/9-74-002, U. S. Environmental Protection Agency, Region IV, Atlanta. 478 pp.

Heald, E. J. 1971. The Production of Organic Detritus in a South Florida Estuary. Sea Grant Tech. Bull. No. 6. Univ. Miami. 110 pp.

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

Lugo, A. E., G. Evink, M. M. Brinson, A. Broce, and S. C. Snedaker. 1975. Diurnal rates of photosynthesis, respiration, and transpiration in mangrove forests of south Florida, pp. 335-350. In F. B. Golley and E. Medina (eds.), Tropical Ecological Systems. Springer-Verlag, New York.

Odum, W. E. 1971. Pathways of Energy Flow in a South Florida Estuary. Sea Grant Tech. Bull. No. 7. Univ. Miami. 162. pp.

Pool, D. J., A. E. Lugo, and S. C. Snedaker. 1975. Litter production in mangrove forests of southern Florida and Puerto Rico, pp. 213-237. In G. Walsh, S. Snedaker and H. Teas (eds.), Proceedings International Symposium on Biology and Management of Mangroves, Vol. I & II. 8-11 Oct. 1974 in Honolulu. Inst. Food Agric. Sci., Univ. Florida, Gainesville. 846 pp.

Pool, D. J., S. C. Snedaker, and A. E. Lugo. 1977. Structure of mangrove forests in Florida, Puerto Rico, Mexico, and Costa Rica. Biotropica 9(3): 195-212.

Snedaker, S. C., and M. S. Brown. 1980. Water Quality and Mangrove Ecosystem Dynamics. U. S. Environmental Protection Agency, Ecol. Res. Ser. (in press)

Snedaker, S. C. and M. S. Brown. (in press) Primary productivity of mangroves. In C. C. Black and A. Mitsui (eds.), CRC Handbook Series of Biosolar Resources. Vol. I. Basic Principles. CRC Press, West Palm Beach, Florida.

Snedaker, S. C., and A. E. Lugo. 1973. The Role of Mangrove Ecosystems in the Maintenance of Environmental Quality and a High Productivity of Desirable Fisheries. Report. Bur. Sports Fisheries & Wildlife. Contract No. 14-16-008-606. 381 pp.

Snedaker, S. C., and D. J. Pool. 1973. Mangrove forest types and biomass. In S. C. Snedaker and A. E. Lugo. Report Bur. Sports Fisheries & Wildlife, Contract No. 14-16-008-606.

Discussion II - Ecology of Mangroves (A. Lugo and S. Snedaker)

Q. A. Banner: You seem to consider all mangroves as equal. Yet, if you were to consider the less frequently flooded mangroves further from the receiving water, would the production from those mangroves be more likely to be metabolized *in situ* by bacterial decomposition and the nutrients assimulated there, thus producing less material available for export?

A. S. Snedaker: Consider mangroves growing in Florida which are very much inland, producing litter on the ground. For these, it is only during the fall of the year when there is normally seasonally high water that they are flushed. Are these of more or less importance than the mangroves that export all year round? In situations where the water moves seasonally, we find that the waters (in Little Card Sound, for example) take on a dark stain. This dark stain is due to the tannins in the water. Is it purely coincidence that also at these times there are blooms of phytoplankton? It could be argued that phytoplankton are feeding on this organic matter that is pulsed out once during the year. If this is true, these organic materials are causing a pulsing into the bay thus altering the food chain.

Q. A. Banner: If you had 2 g/m^2 produced in the high marsh and the same amount of productivity in a fringing area, the fringing area materials are exported in the next tide. But, the high marsh material would be consumed there and therefore not available for export. Hectare per hectare, is not the contribution to the bay from the high marsh smaller than from the fringing area?

A. S. Snedaker: In terms of elemental carbon, yes, the mass balance would be less. But, let us look at the quality of it. Fish do not eat leaves. Fish eat broken down particles that have become covered with microorganisms that give the particles higher ratios of carbon and nitrogen. The material that comes out of the black mangrove is in a form that is relatively consumable by the fish. Filter feeders for instance live on this soluble organic material in addition to fine particulates. In one case you provide raw materials that have to be biologically turned into a resource. Whereas in the other, you are already providing that material.

A. A. Lugo: It is also a matter of area. The fringe is a small band around the bay. The density of black mangroves is lower than that of reds; however, the entire area that is covered by black mangroves is far greater than the area covered by the fringe. Therefore, even though there is less material produced per unit area, there is more area to provide the organic compounds.

A. J. Zieman: Dissolved organics may be in higher ratios than particulates; however, the quality has to be taken into account. The first things that come out are high in nitrogen and are utilized rapidly. The tail end that comes out is the particulate material which, to a great extent, is very refractile material that even bacteria have a great deal of difficulty breaking apart. Therefore, there is a qualitative difference in the materials and a differential value in their usefulness.

A. S. Snedaker: The lighter weight compounds are taken up immediately by whatever is around.

The heavier weight compounds stay in the water complex until they are broken down. How, I just do not know. Nothing is escaping. Everything is being utilized in the environment.

Q. Mark Thompson: Do you see a wetlands law in the future, something similar to the Clear Water Act, to protect wetlands specifically?

A. S. Snedaker: I think that if the issue of the taking of wetlands was ever decided in favor of the private interest at the Supreme Court level, it would basically abolish Federal control under existing legislation protecting wetlands. I think what you would find would be chaos or a mad scramble for new legislation to take its place, which might be worse than what we are trying to do now. That is a real cloud on the horizon, for if we lose the laws we have now, what do we do?

Q. E. Odum: The other possibility is that wetlands might be put into the category of navigable waters so that anything with moving water is not ownable. This would be like beaches are now, where you can use them but you cannot own them. What about everything that moves?

A. S. Snedaker: If you define everything that moves as navigable waters you can go all the way to the Continental Divide because there is a hydrological linkage.

A. E. Odum: Exactly.

A. H. Teas: There is one example where a real estate developer, Gables-by-the-Sea, was suing the Corps of Engineers. The U.S. Supreme Court ruled that it was a case of taking. Negotiations between the State of Florida and the developer for a 7-10 million dollar settlement are underway. The ruling had already gone through the State level. This was two years ago and the case has been written up in a number of journals.

Q. A. Banner: What I gather from you is that if all mangroves are valuable, then the concept of mitigation by allowing development in mangroves by enhancing other wetlands areas would not be practical or profitable, or, do you think there is a possibility of enhancing mangroves areas?

A. S. Snedaker: Let me phrase it this way. If you take a mangrove habitat and there is a mangrove environment with a seed source, you will wind up with a mangrove ecosystem. If you develop parallel shore lines what you have done is to alter the environment so that it eliminates mangrove habitats. If you develop along water where you preserve the habitat, you do not have to go back and plant, and you would basically have a mangrove environment that would sustain itself.

Q. E. Odum: Are many of the developments that have tried to preserve mangroves successful?

A. S. Snedaker: In the very early ones, no, because what happened is that a bulkhead was put in and a wall was developed around the area. These were basically disastrous. Then there was a period when people tried to not develop using bulkheads and fill but tried other things. This tended to interfere with the circulation pattern. In order for development to be financially and environmentally productive one has to maintain the environment as much as possible.

Q. M. Thompson: We have very little to say about upland development, do we not?

A. S. Snedaker: Unfortunately, this is true and the hydrology of an area can be disturbed by upland development. I believe that Dr. Teas has done some work where changing the sheet flow and the flow area has actually increased the amount of mangrove area because of increases in salinity and the water table. That is one of the consequences of changing the sheet flow; you change the downstream system.

Q. R. Huber: We've talked a lot about red and black mangroves, what about the white mangroves?

A. S. Snedaker: We have measurements of productivity using litter fall and biomass which show that it is basically no different than the other two. The problem is that you never find the white mangroves growing where you think they should be. Sometimes you find them growing right up on the shore and sometimes they are found in with the black mangroves. There is a concerted effort to find out more about white mangrove ecology.

EFFECTS OF THE ZOE COLOCOTRONI OIL SPILL ON INFAUNAL COMMUNITIES ASSOCIATED WITH MANGROVES

Edward S. Gilfillan
and Ray P. Gerber
Marine Research Laboratory
Bowdoin College
Brunswich, Maine 04011

David S. Page
Chemistry Department
Bowdoin College
Brunswick, Maine 04011

ABSTRACT

During the period of 19-25 November 1978, sediment samples were collected in the mangrove areas on the west side of Bahia Sucia, Puerto Rico, to examine the effects of impacted oil discharged from the tanker Zoe Colocotroni (18 March 1973) on the infaunal community. Samples were taken in seven different types of mangrove habitats and compared to those from a reference, unoiled area. Infaunal organisms larger than 1 mm were included in this study.

The preliminary results indicate that for the black mangrove habitat there were more infaunal organisms larger than 1 mm in the oiled area than there were in to the unoiled area. Biological analysis of the red mangrove fringe areas confirmed that infaunal organisms were present in expected numbers in the unoiled areas, but were much reduced in the oiled areas. Large numbers of organisms were found in the salt lagoons, and even where oil was present there was a greater density than in unoiled areas of this lagoon and a control lagoon. We conclude that only in the red mangrove environment is there remaining damage from the impacted oil on the infaunal organisms.

INTRODUCTION

While there is considerable knowledge concerning the effects of oil spills on temperate marine ecosystems (Nelson-Smith 1973), much less is known of the effects of oil spills on tropical ecosystems. What studies have been carried out (Rutzler and Sterrer 1970, Glynn et al. 1972, Odum and Johannes 1975, Birkland et al. 1976, Chan 1977, Nadeau and Berquest 1977) have not dealt with long-term effects on infaunal animals, nor have these studies been accompanied by competent concurrent characterization of sediment hydrocarbons.

On 18 March 1973 the Liberian tanker Zoe Colocotroni ran aground on Marguerita Reef off LaParguera, Puerto Rico. The vessel was not damaged by the grounding. To free the ship the Captain pumped approximately 4,500 tonnes of oil overboard. About 60 percent of this oil was carried by the wind into Bahia Sucia at the extreme southwestern tip of Puerto Rico, where it impacted a number of different environments.

Impacted environments included seagrass beds, mangrove root communities, red mangrove fringe areas, lagoons, and black mangrove areas. Within 3 to 4 years after the spill the mangrove root communities and the seagrass communities had recovered (Nadeau and Berquest 1977).

In 1977, very highly weathered oil still remained in some areas on the west shore of Bahia Sucia (Page et al. 1979). In November 1978, 5 years after the original spill, a study was initiated to determine the relation between the distribution of oil residues and the distribution of infaunal animals in the oil-affected areas of Bahia Sucia.

STUDY DESIGN

The ecology of the mangrove areas of Bahia Sucia is dominated by soil salinity. The area receives less than 100 cm of rain per year; evaporation is more than 200 cm per year. Soil salinity is influenced by the long-term balance between inputs of freshwater from precipitation and land drainage, and losses of freshwater through evaporation and transpiration. The western shore of Bahia Sucia, where this study was carried out, referred to below as west mangrove area, receives freshwater only from precipitation; consequently the area is extremely arid. The eastern shore of Bahia Sucia receives freshwater not only from precipitation but also from land drainage. As a result the eastern shore is somewhat less arid.

In Bahia Sucia, red mangrove trees are the pioneers. As they grow out into the Bahia Sucia shallow ocean water, debris collects among their prop roots creating a berm which obstructs the flow of water. After circulation is cut off, the salinity begins to rise behind the berm due to the aridity of the environment (Cintron et al. 1977). Mangrove trees vary in their ability to tolerate high soil salinity. Red mangroves are the least tolerant; they cannot tolerate soil salinities much over $60^{o}/oo$ or about twice seawater salinity (Cintron et al. 1977). White mangroves are more tolerant of soil salinity, but are not numerically important in the west mangrove area. Black mangroves are most tolerant of high soil salinities; they can withstand $90\text{-}100^{o}/oo$ soil salinity (Cintron et al. 1977). These differences in soil salinity tolerance give rise to the observed distribution of mangrove trees in the west mangrove area.

Red mangrove trees are found on the seaward side of the berm and on top of it. Behind the berm the red mangrove trees rapidly die off due to increased soil salinity and are replaced by black mangroves. As soil salinities rise still more, the black mangroves die out and a salt lagoon is created. On the land side of the salt lagoon, if there is land drainage or another source of fresh water, a second band of black mangroves may occur. This is a classical example of a physically controlled environment (Sanders 1968).

The oil from the Zoe Colocotroni that reached Bahia Sucia in March 1973 affected a number of environments, each with its own characteristic recovery rate. Only those areas lying within the mangrove fringe are still affected (Nadeau and Berquest 1977). Therefore, the sampling program concentrated on the three habitats: 1. red mangrove fringe; 2. black mangrove areas; 3. salt lagoon. These are all low energy, fine sediment environments in which oil can be expected to have the greatest persistence.

A total of 11 transects were set up in the west mangrove area. Locations of the transects and sampling stations are shown in Figure 1 (descriptions are available from authors). These transects were designed to give coverage to each of the habitats in the impact area.

Transect II revealed a typical distribution of mangroves where no land drainage occurs. There is a very narrow fringe of red mangroves on the seaward side of the berm, a very thin line of black mangroves immediately behind the berm, and a wide salt lagoon backed by a stunted growth of small black mangrove trees. Transect I is similar.

Between Transects II and III a canal bisects the peninsula. On

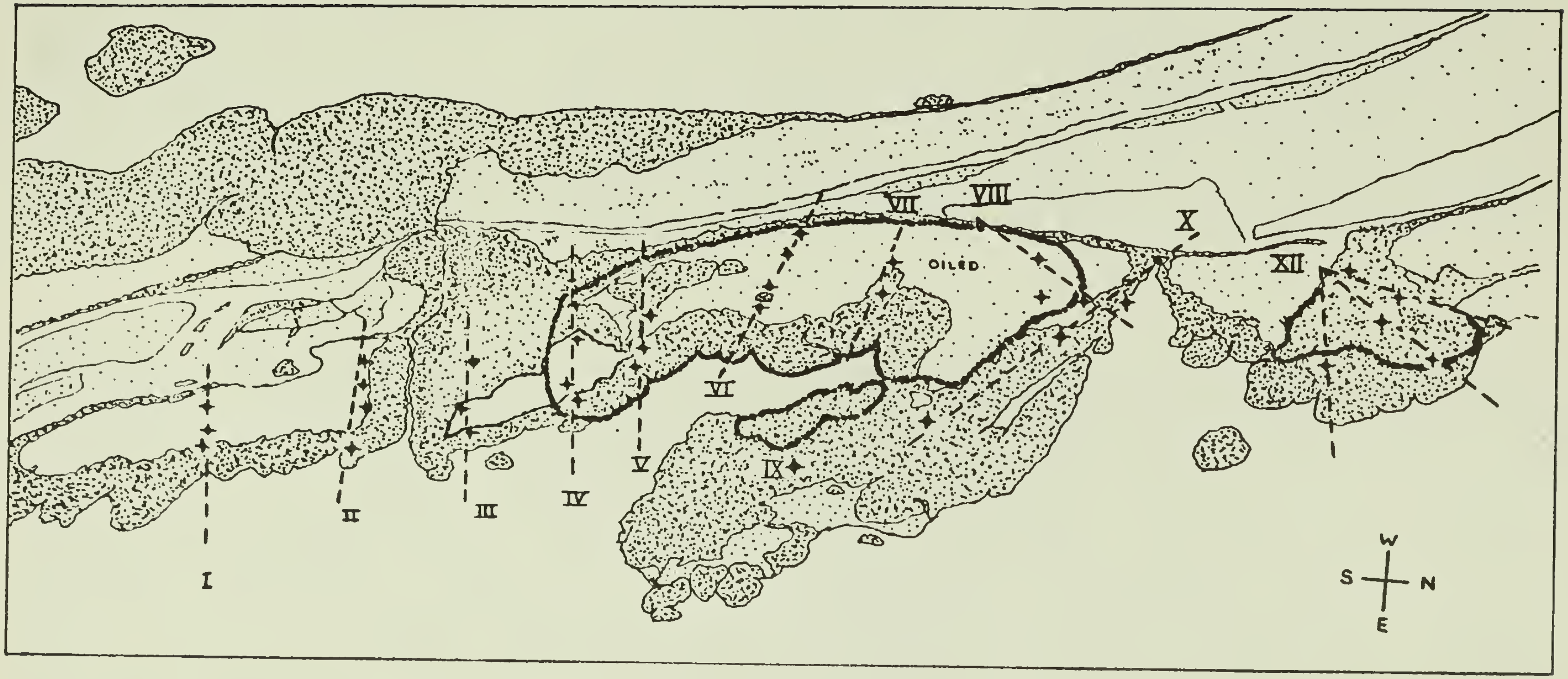


Figure 1. Map showing total oiled area, transects, and sampling locations in the west mangrove areas, November 1978. (See Figure 1 of following paper by Page et al. 1980, Weathering of Petroleum under Tropical Conditions.)

both sides of the canal there is a red mangrove fringe. However, on the south side of the canal the red mangrove fringe is relatively narrow and is backed by areas of dead red mangroves. On the north side of the canal the red mangrove fringe is more extensive particularly on the west side.

There is an extensive growth of black mangroves on the landward side of the salt lagoon on Transects III and IV. Apparently this growth of both red and black mangroves results from water pushed into the area north of the canal by the prevailing winds.

One way to assess what damage the oil from the Zoe Colocotroni may have caused in the impact area is to compare the infaunal community there now with what would have been there had no oil been released into the environment. It was necessary to make comparisons between each of the habitats in the impact area and comparable habitats nearby because no information was available on the composition of the infaunal community in the impact area before the oil spill. We recognize that no area is exactly like another; thus, the validity of such comparisons lies solely on the degree of similarity between the two areas being compared. The greater the differences between the two areas the less valid the comparison between them.

Reference areas for the present study were chosen to be as similar as possible to the habitats in north mangroves with which comparisons were to be made. More than one reference area was chosen for each habitat because conditions within any one habitat are not completely uniform. Four sites were chosen in the Bahia Sucia area. Two of them, site 5-78 and salina control, were chosen to be comparable with conditions in the salt lagoons in the north mangrove area.

Site 5-78 is in a large lagoon among the roots of salinity-killed red mangroves. The salina control site is in a smaller salt pond across the road which is surrounded by black mangroves. The black mangrove control site was on the shore of this small lagoon among the roots of black mangrove trees. The red mangrove control site was among the roots of a stand of red mangroves on the west side of the Cobo Rojo peninsula. Each of these control sites is believed to be typical of the environment of the north mangrove area.

To obtain further reference data an additional set of samples was taken at Guanica about 50 km east of the impact area where conditions exist that are believed to be very similar to those in the north mangroves area. Station G-1 is in a salt lagoon behind a red mangrove berm which is similar to the north mangrove area. Station G-2 is among the roots of black mangrove trees which are growing among dead red mangrove trees. Station G-3 is among the roots of a healthy red mangrove fringe. These sites were chosen to be as similar as possible to habitats in the impact area. At each sampling location a sample of sediment was collected for hydrocarbon analysis.

METHODS

At each sampling location a 100-mm diameter core, 140 mm long, was taken. The core was rough-sieved in the field through a 1-mm screen. The samples were then preserved with formaldehyde for return to the laboratory. In the laboratory the samples were stained with Rose Bengal and rough-sorted using illuminated magnifiers. Animals were then identified and enumerated using a dissecting microscope. Soil salinities were measured during March 1979 at selected stations in each of the habitats on a subsequent visit.

RESULTS

The preliminary results of the sampling program are summarized in Table 1 where the mean population density and number of species are shown for each of the three environments sampled. These data are further broken down into oiled, unoiled, and reference areas. The distinction between oiled and unoiled environments was made on the basis of results of hydrocarbon analysis. Results of the hydrocarbon analysis are being reported separately.

DISCUSSION

When a habitat is oiled there is a fairly well-defined sequence of events, some or all of which may occur depending on the amount and types of oil released into the environment. In the event of severe oiling all pre-existing animals and plants may be killed. Following this initial kill, the oil will begin to dissipate through solution, evaporation, and bacterial degradation.

As the oil concentration is reduced, the first species which are likely to appear are those species of animals and plants which are very resistant to environmental stresses, but which are normally unable to compete well with other species of animals and plants. These are called opportunistic species. Frequently these opportunistic species will become very abundant immediately after an oil spill.

As the oil continues to disappear, more and more of the originally present species will begin to reappear; as they do, the originally present species will begin to outcompete the opportunistic species. Finally, all the originally present species will return, the opportunistic species will disappear, and the area will have recovered.

The above scenario is what one typically expects in a so-called biologically accommodated environment where the occurrence and abundance of a species is more dependent on its relations with other species of animals, i.e., its competitive ability, than on its ability to resist environmental stresses. The seagrass community of Bahia Sucia, and to a much lesser extent the mangrove root communities, are biologically accommodated communities.

However, in the area landward of the berm, in the red mangrove fringe, the dominant factor in the distribution of animals and plants is the soil salinity; this is a very stressful environment. Such environments, where the occurrence and abundance of species are determined by the distribution of some physical factor, are known as physically controlled environments (Sanders 1968). Typically they are inhabited by one or a few species of resistant, opportunistic animals.

Based on previous knowledge of the soil salinity values, we would expect that the red mangrove community would be the least stressed by salinity (42-60%), the black mangrove community would be more stressed (70-100%), and the salt lagoon community would be the most stressed (80-100%). Results of the biological sampling bear this out. When the samples from the unoiled habitats in the impact area are combined with those from the same reference habitats, red mangrove areas are found to be the most diverse. Eight species are found there. Only two species are found

Table 1. Number of species and population density for animals larger than 1mm found in various environments.

Bahia Sucia Environments with oil in sediments in 1978			
	Red Mangrove Environment	Lagoon Environment	Black Mangrove Environment
number samples	5	15	3
number species	2	3	4
mean density no/m^2	64	373	635
Bahia Sucia Environments without oil in sediments in 1978			
	Red Mangrove Environment	Lagoon Environment	Black Mangrove Environment
number samples	9	6	2
number species	7	1	1
mean density no/m^2	919	21	64
Unoiled Environment Reference Areas			
	Red Mangrove Environment	Lagoon Environment	Black Mangrove Environment
number samples	2	2	2
number species	2	2	1
mean density no/m^2	297	291	600

in the black mangrove area; the same two species are found, but in lower numbers, in the salt lagoon habitat.

When the numbers of species and individuals found in samples from oiled habitats are compared with the numbers of species and individuals from the reference and unoiled habitats, an interesting pattern emerges. In unoiled and reference red mangrove areas, a total of eight species of animals was found; 763 animals were found per square meter. In the oiled red mangrove habitat only two species were found and only 64 animals were found per square meter. It is clear that the oiled red mangrove areas have not yet recovered.

In unoiled and reference black mangrove habitat a total of only two species was found; the mean population density was $176/m^2$. In the oiled black mangrove habitat four species of animals were found; the population density was 635 animals/m^2. The black mangrove habitat is normally a very stressful environment. It appears that those species which normally occur there are capable of withstanding the additional stress from the highly weathered oil which is in the impact area.

In unoiled and reference salt lagoon areas, the same two species occur as were found in the black mangrove habitat; the population density was $291/m^2$. In the oiled salt pond area, three species of animals were found; the population density was $373/m^2$. As in the case of the black mangrove habitat, it seems clear that those animals which normally occur in the salt lagoon environment are able to withstand the added stress imparted to them by the very highly weathered oil which remains in their environment.

If the impression has been given that the black mangrove and salt lagoon areas are biological deserts, this is true with respect to animals which are larger than 1 mm. These areas are teeming with life, but predominantly very small animals which are largely epifaunal, i.e., they live on, not in, the sediments. There are also many larger animals such as crabs. There had been a great deal of rain just previous to sampling (November 1978) so the salinity of the overlying waters had been greatly reduced. If one were to visit the area during the dry season, as was the case in March 1979, most of the epifaunal animals would have perished as the salinity of the overlying waters increased.

All three environments sampled in Bahia Sucia are to some degree physically controlled. Animals must be very resistant to stress to live there. This is shown by the low numbers of species found in the reference areas.

A species of the worm Capitella was found in oiled, unoiled, and reference habitats. The appearance of this species is an indication that the environment in which it appears is stressed. All three environments sampled are stressed to some degree by high soil salinity. Capitella sp. did not occur in much higher numbers in the oiled environment than in the unoiled environment as one would expect if the oil in the oiled environments gave Capitella sp. an advantage. As a result it appears that the presence of Capitella sp. in each of the environments arises from the fact that each of these environments is stressed due to high soil salinity.

In summary, each of the environments in Bahia Sucia where oil remains is physically controlled by soil salinity. The preliminary findings suggest that the normal number and kind of animals appear to be present in the salt lagoon environment and the black mangrove environment. Only in the red mangrove environment are the normal number and kind of animals not found, but there are encouraging signs of recovery.

ACKNOWLEDGMENTS

The authors were supported by a grant from the Mobil Foundation during a major portion of this work.

LITERATURE CITED

Birkeland, C., A. A. Reimer and J. R. Young. 1976. Survey of marine communities in Panama and experiments with oil. Report EPA 60013-76-028. Environmental Protection Agency, Washington, D. C.

Chan, E. I. 1977. Oil pollution and tropical littoral communities: biological effects of the 1975 Florida Keys oil spill, pp. 539-542. In Proceedings of the 1977 Oil Spill Conference. American Petroleum Institute, Washington, D.C.

Cintron, G., A. E. Lugo, D. J. Pool, and G. Morris. 1977. Mangroves of Arid Environments in Puerto Rico and Adjacent Islands. Department Natural Resources, San Juan, Puerto Rico. 21 pp.

Glynn, P. W., C. Birkeland, A. Reimen, and J. R. Young. 1972. Fundamental Analysis for Determining the Effects of Oil Pollution on the Ecology of a Tropical Shore. Progress Rept. to Federal Water Quality Administration, Washington, D. C.

Nadeau, R. J., and E. T. Berquest. 1977. Effects of the March 18, 1973 oil spill near Cabo Rojo, Puerto Rico on tropical marine communities, pp. 535-538. In Proceedings of the 1977 Oil Spill Conference. American Petroleum Institute. Washington, D.C.

Nelson-Smith, A. 1973. Oil Pollution and Marine Ecology. Elek Science, London.

Odum, W. E., and R. E. Johannes. 1975. The response of mangroves to man induced environmental stress. In E. J. F. Wood, and R. E. Johannes (eds.), Tropical Marine Pollution. Elsevier Scientific Publ. Co., New York.

Page, D. S., D. W. Mayo, J. F. Cooley, E. Sorenson, E. S. Gilfillan, and S. A. Hanson. 1979. Hydrocarbon distribution and weathering characteristics at a tropical oil spill site, pp. 709-712. In Proceedings of the 1979 Oil Spill Conference. American Petroleum Institute, Washington, D.C.

Rutzler, K., and W. Sterrer. 1970. Oil pollution damage observed in tropical communities along the Atlantic seaboard of Panama. Bioscience 20:222-224.

Sanders, H. L. 1968. Marine benthic diversity: a comparative study. Amer. Nat. 102:243-282.

WEATHERING OF PETROLEUM
UNDER TROPICAL CONDITIONS

David S. Page, J. F. Cooley
and J. R. Hotham
Chemistry Department
Bowdoin College
Brunswick, Maine 04011

Edward S. Gilfillan
Marine Research Laboratory
Bowdoin College
Brunswick, Maine 04011

ABSTRACT

A three-year study was performed on the hydrocarbon residues in the sediments of an oil spill site on the southwestern coast of Puerto Rico. The study area was Bahia Sucia, the location of the Zoe Colocotroni oil spill of 17 March 1973. In comparison to oil spills in temperate sediments, a very rapid rate of degradation of petroleum was observed in the tropical, highly organic mangrove swamp sediments at the spill site. The study also showed that tropical mangrove sediments normally contain significant concentrations of fats, oils, waxes, and hydrocarbons from plant, animal and microbial sources. The biogenic hydrocarbon material, in the normal detritus pool of the mangrove ecosystem, supports an indigenous microbial population. This microbial population was responsible for the observed rapid biodegradation of petroleum hydrocarbons in the mangrove sediments of Bahia Sucia. In determining the state of any petroleum remaining at an oil spill site, analytical methods must be used that can distinguish the relative importance of the various possible sources of hydrocarbons: petroleum, pelagic tar, and biogenic hydrocarbons.

INTRODUCTION

Although there is a considerable body of knowledge concerning the fate and effects of petroleum in temperate areas (Karrick 1977), few chemical studies of the fate of petroleum spills in tropical areas have been reported (Page et al. 1979). An important question after any oil spill is the long-term effects which relate directly to the persistence of petroleum in the impact zone. A concurrent study of changes in the petroleum residues must also be done to understand fully any long-term biological changes observed at an oil spill site. The purpose of this paper is to discuss observed changes in petroleum residues under tropical field conditions and to show how chemical studies at tropical oil spill sites can be complicated by other inputs of hydrocarbons.

In order to study the fate and effects of oil in a tropical mangrove ecosystem, a long-term field study was initiated in 1977. This study concerned an oil spill that occurred 18 March 1973, when the tanker Zoe Colocotroni grounded on a shoal off Guanica on the south shore of Puerto Rico. In an attempt to free the vessel, 5,920 m^3 of Tiajuana medium crude oil was pumped over the side of the vessel. The oil was carried in a westerly direction by the prevailing winds and currents. Approximately 40 percent of the oil rounded the southwest corner of Puerto Rico and entered the Mona Passage. The remainder stranded along the beach and mangrove forest shoreline of Bahia Sucia. The postspill effects on the flora and fauna have been reported elsewhere (Nadeau and Berquist 1977).

SAMPLING AREA AND METHODS

Sites in the Bahia Sucia area were sampled in November 1977, November 1978, April 1979, and September 1979. The sampling methods and analytical methods have been described in detail by Page et al. (1979). An important feature of the analytical methods used to extract and analyze hydrocarbon residues in sediment samples is that they permitted the distinction between petroleum and natural (biogenic) sources of hydrocarbons. To do this, the samples were solvent extracted, fractionated by liquid chromatography into an aliphatic (nonpolar) and aromatic (polar) fraction of hydrocarbons. Each fraction was then analyzed by high resolution glass capillary gas chromatography. We determined the nature of the hydrocarbons present (petroleum or biogenic or both) using the gas chromatograms thus obtained and gained an understanding of the extent to which petroleum residues in the sample were weathered (degraded) by environmental factors. This approach to hydrocarbon chemistry effectively eliminates much of the saponifiable fats, oils, and waxes from the final fractions. This distinction is important because many environmental samples are rich in natural lipid material and would appear to be oil-contaminated if analyzed by a technique such as infrared spectrophotometry that did not discriminate between natural lipid material and hydrocarbons.

Figure 1 shows the impact area of the Zoe Colocotroni spill. This bay comprises the southwest corner of Puerto Rico and is a natural collecting place for waterborne debris carried westward along the southwest coast of the island. Many locations were studied in this area, but for the sake of simplicity only those stations discussed in this paper are marked on Figure 1.

RESULTS AND DISCUSSION

To understand the extent of weathering of spilled oil in a tropical mangrove sediment, one must know the types of biogenic hydrocarbons that are naturally present. Figure 2 shows a gas chromatogram of the aliphatic hydrocarbons from an unoiled sediment at the site marked II-4 in Figure 1. Even though this sediment sample contained over 1,100 ppm of hydrocarbons, it is not an oil-contaminated sediment, except perhaps for some minor input from tarballs that are common features of the flotsam and jetsam of this area.

The gas chromatogram is like a hydrocarbon fingerprint for a given sample. The sources of hydrocarbon peaks noted in Figure 2 correspond to known natural sources of hydrocarbons (Yen 1975). Most unoiled mangrove sediments will produce a pattern of peaks such as that shown in Figure 2. It is important to note that biochemical processes produce only a specific compound, such as the hydrocarbon peak noted as pristane in Figure 2, or at most a limited family of closely related hydrocarbons, such as those in Figure 2 which are derived from leaf detritus in the sediments. The extent to which an oiled sediment gas chromatogram resembles Figure 2 yields information on the extent to which the oil in the sediment has degraded.

The tropical mangrove sediments are hydrocarbon rich as the 1,100 ppm value for the amount of hydrocarbons in the sediment at site II-4 implies. Mangrove leaves contain a considerable amount of lipid material. The leaf surfaces are very waxy in order to promote moisture retention. The hydrocarbon

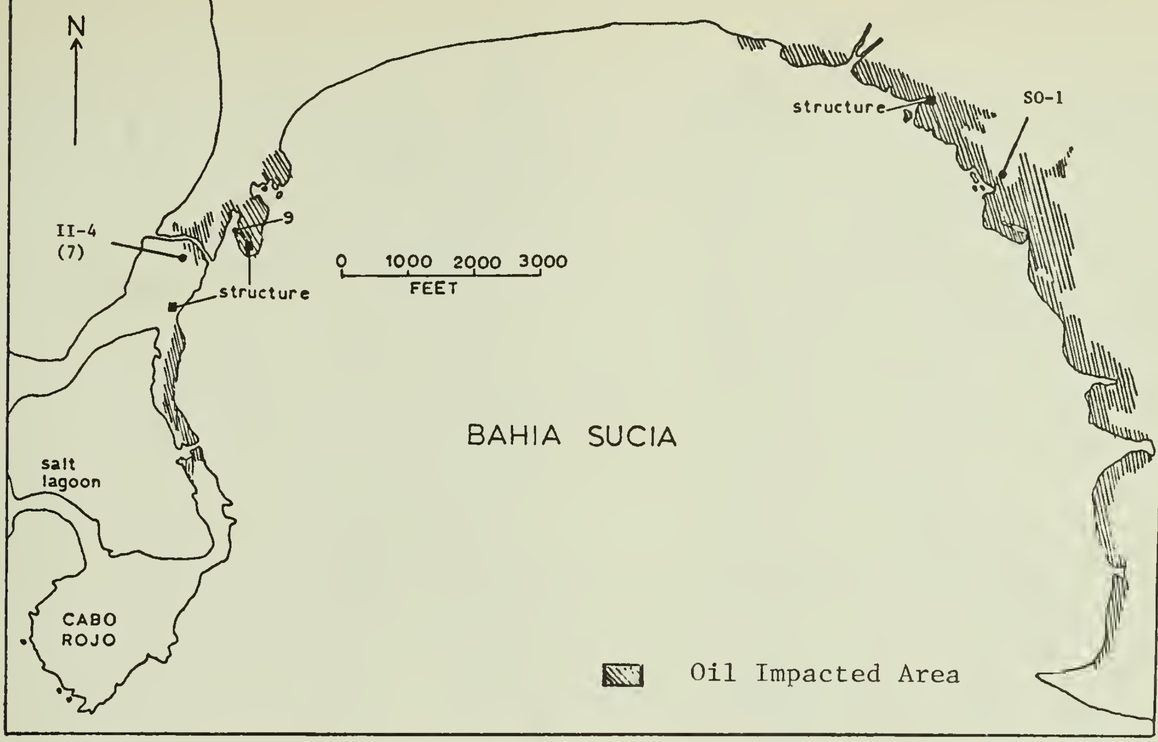


Figure 1. Impact area of the Zoe Colocotroni oil spill.

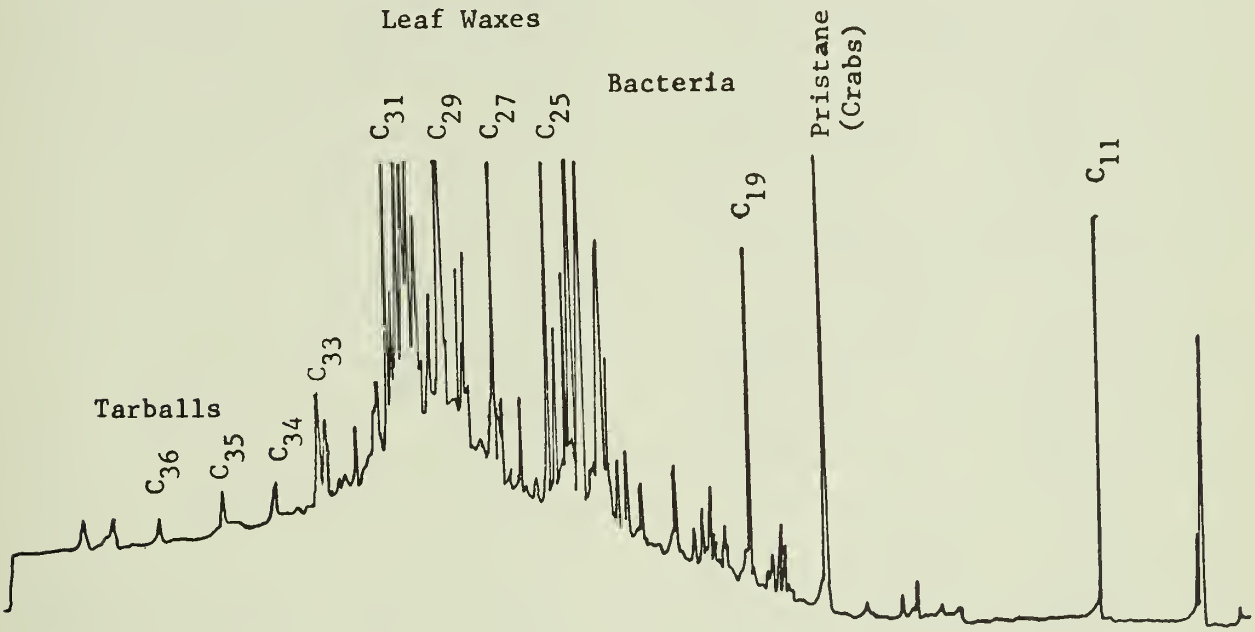


Figure 2. Gas chromatogram of the aliphatic hydrocarbon fraction from site II-4. Each peak in the chromatogram corresponds to a unique substance in the mixture of hydrocarbons isolated from the sample. This is representative of the types of hydrocarbons found in the Bahia Sucia area and is probably representative of mangrove sediments in general. The distribution of peaks in this figure is typical of a site having no input from petroleum other than tarballs.

fraction of the surface lipids of red mangrove leaves constitute 1,500 ppm of the dry weight of the leaf (Page et al. 1979). This is a major source of biogenic hydrocarbons in mangrove sediments.

Figure 3 shows how mangrove leaf aliphatic hydrocarbons and their breakdown products occur in two unoiled sediments, one from a control site in Guanica and the other from site seven on Cabo Rojo. Also evident in the gas chromatograms in Figure 3 is a cluster of peaks around C_{23} corresponding to hydrocarbons produced as a result of bacterial metabolism. These highly organic sediments are rich in microbial life.

In many places, particularly in the areas behind the mangrove fringe, the odor of hydrogen sulfide is unmistakable when one disturbs the soft sediments. This odorous gas is a result of the metabolism of sulfate-reducing bacteria that are abundant in these anaerobic sediments. In the arid environment of Bahia Sucia, fiddler crabs are abundant. The isoprenoid hydrocarbon marked as pristane in Figure 3 is produced by the lipid metabolism of these crabs as well as by other crustaceans.

Oil in the sediments of a heavily impacted, fringing red mangrove area (Figure 4), has degraded in the environment over time. These data are from site nine in a location known as "Hermit One" because of the presence of a hermit's shack nearby. In November 1977, this site was documented photographically and subsequent samples were taken from the same location ± one foot. The sediment was from shallow subtidal mud just adjacent to a fringe of oil-killed red mangroves. Young red mangroves less than 1 m tall were recolonizing the dead area when the first sampling was done in 1977. On subsequent visits, progressive growth of these trees was noted. When one disturbed the sediments at this location, visible globules of oil would rise up and slowly spread out to form a sheen. From 1977-1979, oil dislodged from this soft sediment to became progressively thicker as it degraded to a heavier asphaltic tarry-type material.

Figure 4 is a gas chromatogram of the aliphatic hydrocarbons from a Tiajuana medium crude of the same type as the original spill. From 1977-1979, the hydrocarbons in this location progressed from a mixture of predominantly petroleum-derived hydrocarbons to a mixture of hydrocarbons exhibiting a significant input from biogenic sources. The discrete peaks that can be seen to increase above the unresolved material in Figure 4, ongoing from 1977-79, correspond to the same type of biogenic peaks shown in Figures 2 and 3. The increase in the relative amounts of bacteria-derived biogenic hydrocarbons in the hydrocarbon mixture at this site is a good indication of both biodegradative processes and a decreasing relative amount of petroleum hydrocarbons at this location.

Figure 5 shows the results of a weathering study performed on a minor mystery oil spill observed in April 1979 at the location marked SO-1 on Figure 1. During a field investigation of sites visited on earlier trips on the eastern side of Bahia Sucia, an oily patch was observed in a small area of mud among red mangroves and a sample was taken for hydrocarbon analysis. In September 1979, this same location was sampled again. The gas chromatogram of the April sample shown in Figure 5 shows that there was relatively unweathered petroleum at this site. The regular progression of equally spaced peaks over a broad "hump" or unresolved envelope in the gas chromatogram is indicative of the presence of petroleum.

The boiling range distribution

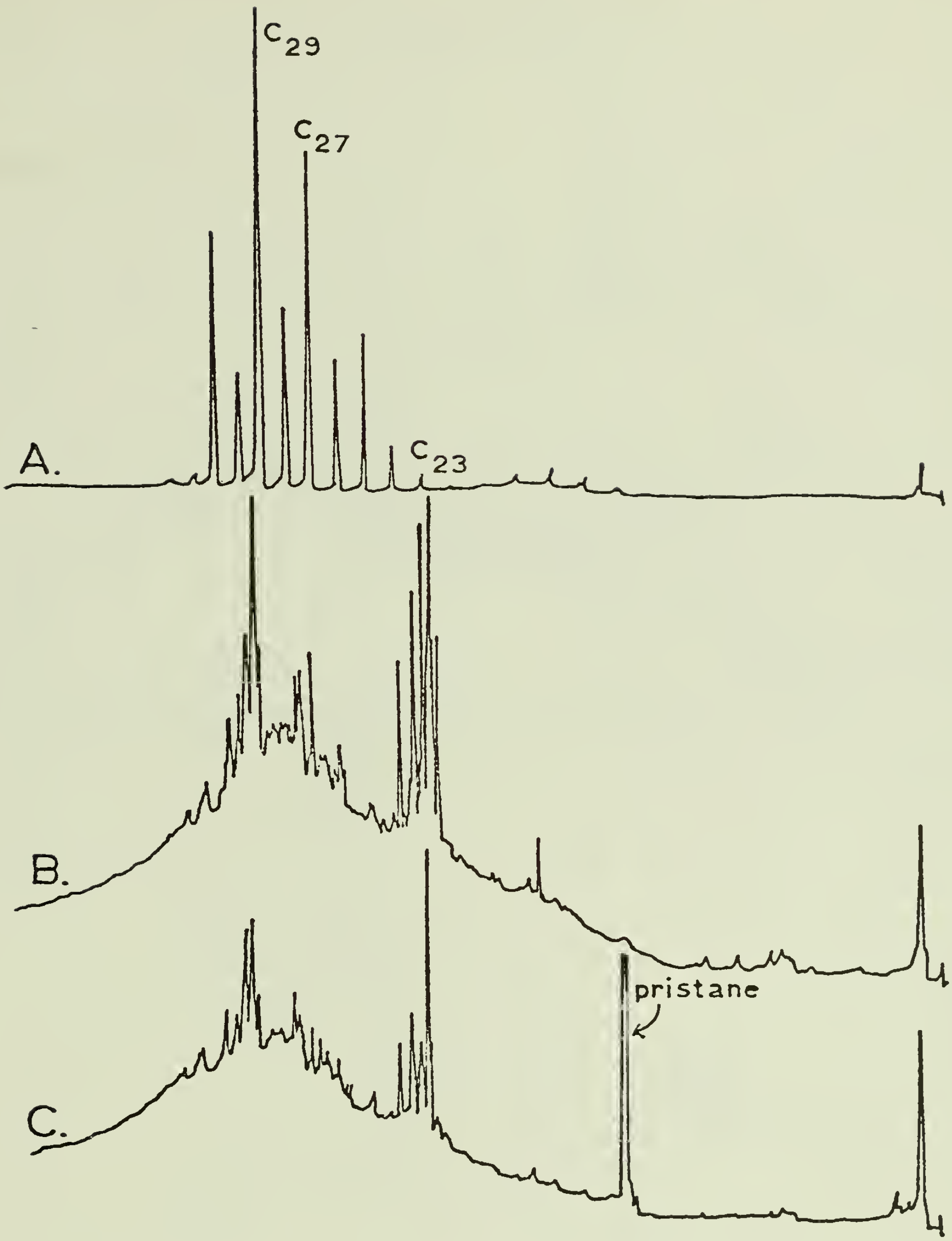


Figure 3. Gas chromatograms of the aliphatic hydrocarbon fractions of red mangrove leaf surface lipids (A) Guanica (control) site sediment sample (B) and Bahia Sucia site 7 sediment sample (C). All three gas chromatograms are lined up vertically so that relationships between the gas chromatograms can be noted. The linear normal alkanes from the leaf lipids (A) also appear in the sediment samples (B) and (C) from the normal leaf drop and detritus turnover.

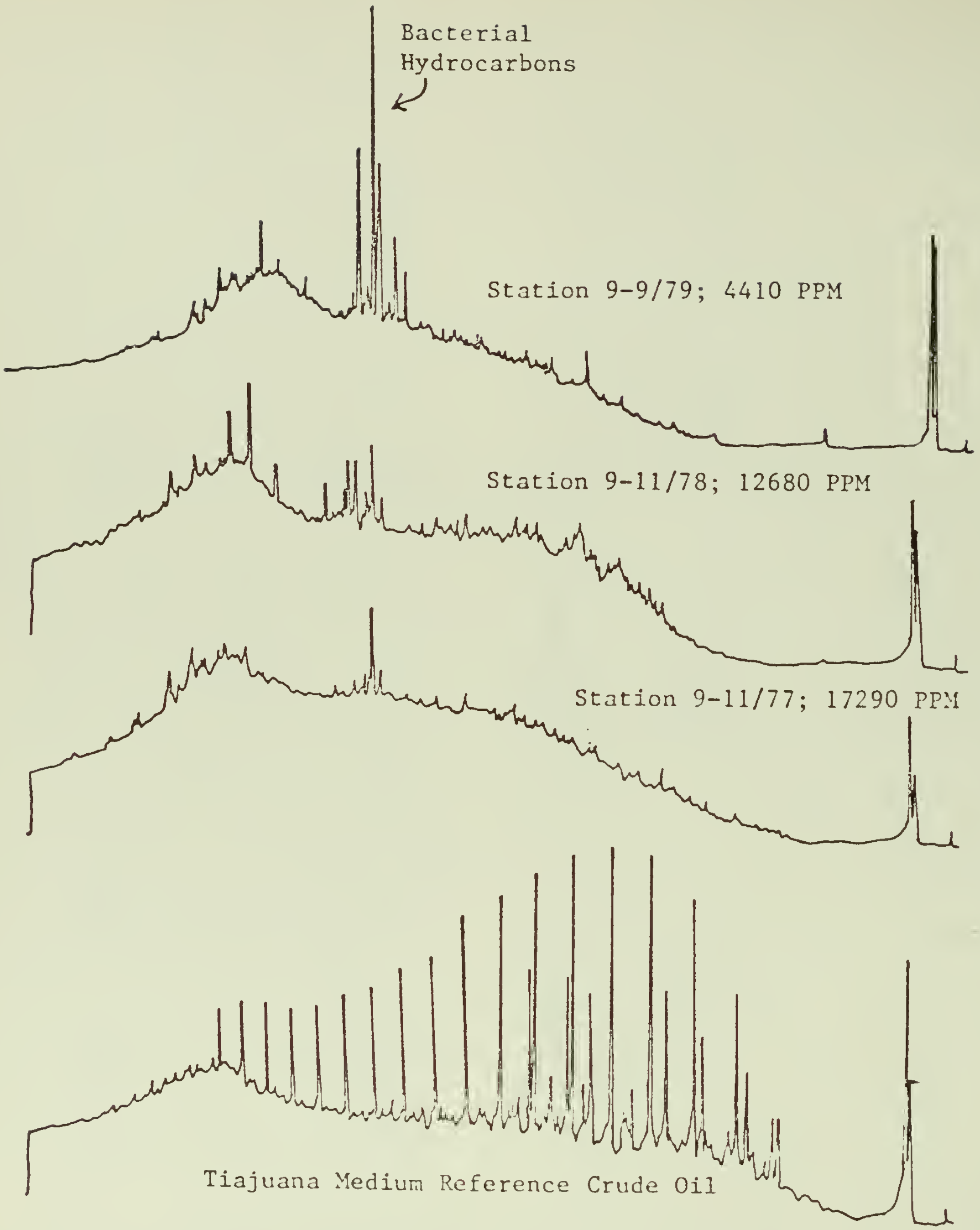


Figure 4. The gas chromatograms of aliphatic hydrocarbon fractions from Bahia Sucia "Hermit One" site 9 over the course of two years. For the sake of reference, a gas chromatogram of the aliphatics of a Tiajuana medium crude oil is also given.

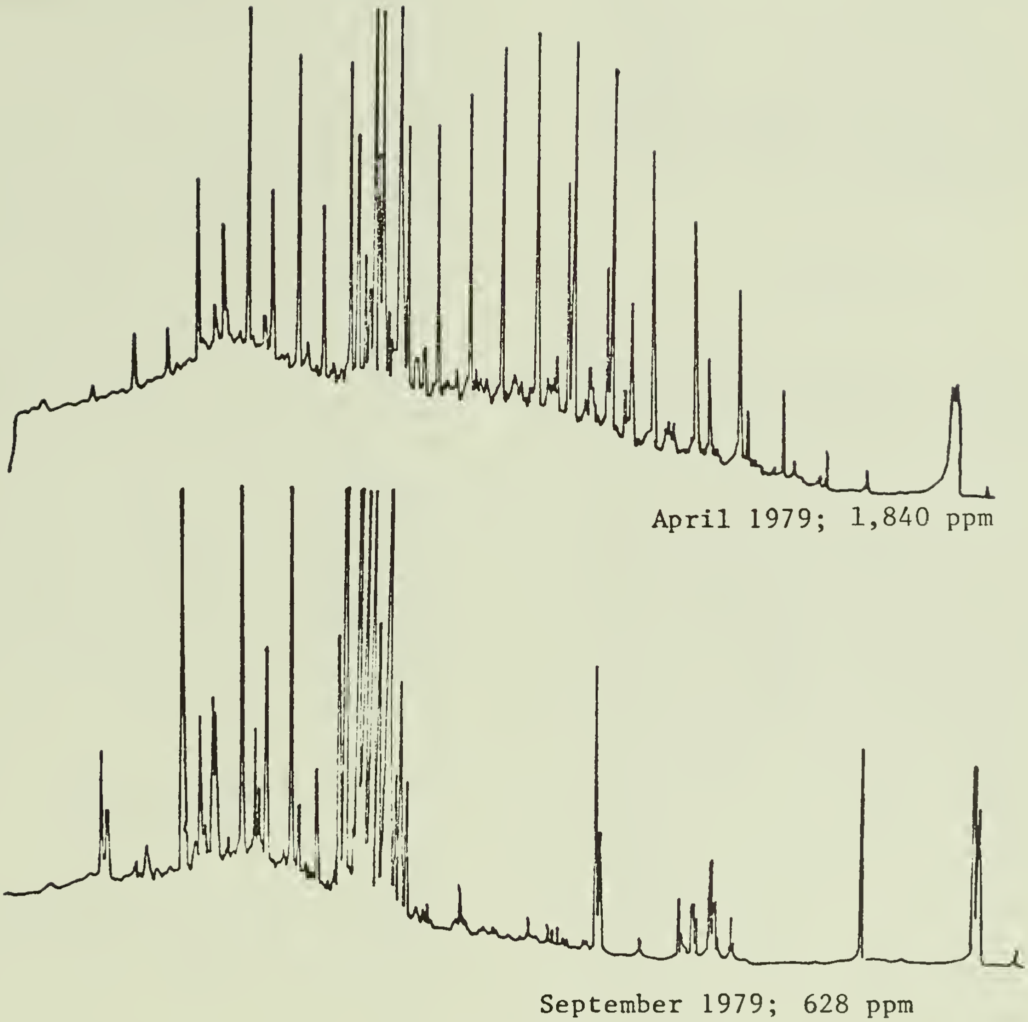


Figure 5. The gas chromatograms of the aliphatic fractions of a minor but recent input of oil at Bahia Sucia site SO-1. The data shows that at the concentration levels observed, the oil had undergone virtually complete degradation within seven months.

of this petroleum product suggests that the original spill product could have been a heavy marine diesel oil. It is noteworthy that seven months later there was not a trace of this petroleum product in the sediments from this location. What was present was an almost identical distribution of hydrocarbon peaks to that shown in Figure 2. Compared to a temperate location oiled to a similar extent, the loss of petroleum here is extremely rapid.

CONCLUSIONS

The work on the Zoe Colocotroni oil spill has yielded information that supports the following conclusions:

1. The tropical mangrove ecosystem is naturally a hydrocarbon-rich environment. For example, the total concentration of hydrocarbons present at site II-4 (Figure 2) is 1,130 ppm, of which there is only a minor amount of tarball-derived petroleum hydrocarbons. The April 1979 sample contained 1,840 ppm of total hydrocarbons at the site marked SO-1 (Figure 5); petroleum comprised a major part. One might think both locations were contaminated with oil if only the ppm values were relied on. The gas chromatograms show that this conclusion is not correct. Studies in which analytical methods are used, that do not distinguish petroleum-derived hydrocarbons from biogenic hydrocarbons, can lead to incorrect conclusions.

2. The recovery potential (from an oil spill) for a coastal mangrove ecosystem is high compared with temperate locations. Because of the large input of biogenic hydrocarbons into the sediment detritus pool from such sources as leaf surface lipids, a microbiotic community already exists that is capable of using hydrocarbons as a carbon source.

There is a considerable need for more information on the behavior and effects of spilled oil on tropical mangrove forests. Information is needed on the exchange of oxygen and nutrients in the soft sediments. Detailed studies of actual oil spills in mangrove forests should be made in which sampling is initiated immediately after the spill and continued for at least 4 years. Little is known about the breakdown products of petroleum in these mangrove sediments. Sublethal effects of petroleum on mangroves should also be investigated because of their crucial importance to the coastal ecosystem. One must be very careful to avoid making extrapolations from studies of temperate zone oil spills because of the unique features of tropical spill sites. What is needed is the development of a body of knowledge, pertaining to the tropics, comparable to that being developed for temperate spill sites.

ACKNOWLEDGMENTS

The major part of the work reported in this paper was supported by a grant from the Mobil Foundation.

LITERATURE CITED

Karrick, N. L. 1977. Alterations in petroleum resulting from physico-chemical and microbiological factors, pp. 225-300. In D. C. Malins (ed.), Effects of Petroleum on Arctic and Subarctic Marine Environments and Organisms. Volume I, Academic Press Inc., New York.

Nadeau, R. J. and E. T. Berquist. 1977. Effects of the March 18, 1973 oil spill near Cabo Rojo, Puerto Rico on tropical marine communities, pp. 535-538. In Proceedings of the 1977 Oil Spill Conference. American Petroleum Institute, Washington, D.C.

Page, D. S., D. W. Mayo, J. F. Cooley, E. Sorenson, E. S. Gilfillan, and S. A. Hanson. 1979. Hydrocarbon distribution and weathering characteristics at a tropical oil spill site, pp. 709-712. In Proceedings of the 1979 Oil Spill Conference. American Petroleum Institute, Washington, D.C.

Yen, T. F. 1975. Genesis and degradation of petroleum hydrocarbons in marine environments, pp. 231-267. In T. M. Church (ed.), Marine Chemistry in the Coastal Environment. ACS Symposium Series 18. American Chemical Society, Washington, D.C.

ECONOMICS AND FEASIBILITY OF MANGROVE RESTORATION

Roy R. Lewis, III
Mangrove Systems, Inc.
504 S. Brevard Ave.
Tampa, Florida 33606

ABSTRACT

Mangrove communities are forested systems that have, in the past, been subjected to large scale destructive activities of man. Recent legislation in the United States requires protection of this resource.

Restoration and creation of mangrove forests are feasible from an engineering and plant materials viewpoint. Key questions still remain as to the functional abilities of a restored created system versus a natural forest.

Economically, forests can be planted with seeds at a cost of $1,500 to $5,000/ha. A large time gap exists, however, until the forest is mature (30-50 years). Reforestation by natural means may negate any need for active seeding. Reforestation using more mature plant materials increases the cost of planting to as high as $216,000/ha. Factors to be considered in determining the feasibility and economics of mangrove restoration and creation are discussed.

INTRODUCTION

The restoration of mangrove forests has recently received considerable study. (See Teas 1977 or Goforth and Thomas 1979 for up-to-date reviews.) The reason for the increased interest is threefold. The first is that the long-ignored value of mangrove forests has been realized and scientifically documented (Odum 1971, Odum and Heald 1972). The second is that large-scale losses of mangroves have occurred (Lugo and Cintron 1975, Chardon 1976, Lewis 1977). The third is that regulatory agencies now have legal authority to control development in mangrove forests and to require fines, replanting of damaged forests, or mitigation through other means.

The two largest examples of regulatory agency requirements for planting mangroves are at Grassy Point, Charlotte County, Florida (Teas et al. 1975) and at Alucroix Ship Channel, St. Croix, U.S. Virgin Islands (Lewis 1979, Mangrove Systems, Inc. 1979). In the former, 2.23 ha were planted with 60,000 red mangrove (*Rhizophora mangle* L.) seedlings and in the latter, 6.15 ha were planted with 86,000 red mangrove seedlings and 32,000 black mangrove (*Avicennia germinans*) seeds.

Much larger mangrove reforestation efforts have occurred in the past in relation to silviculture in the Pacific. Natural secondary succession has been the primary means of reforestation, but active planting is mentioned by Watson (1928) for Malaysia, Noakes (1955) for Malaysia, Banijbatana (1958) for Thailand where 15,200 ha of planted *R. mucronata* are noted, and by Teas (pers. comm.) where 38,000 ha of mainly *R. apiculata* were planted in South Vietnam in 1934.

FEASIBILITY OF PLANTING MANGROVES

Based upon the aforementioned projects, it has been possible to plant mangrove seeds or seedlings throughout the world. Several key questions that need to be asked, however, are: (1) Is there any advantage to actively planting versus natural revegetation (secondary succession)? (2) What is the time frame for planted materials to reach maturity? (3) How rapidly does a planted system take on the biotic community aspects of a natural mangrove forest? Presently, there seems to be no work being done on the last question.

Secondary succession in mangrove forests has been studied by Holdridge (1940) and Wadsworth (1959) in Puerto Rico, Durant (1941) and Noakes (1955) in Malaya, Banijbatana (1958) in Thailand, Detweiler et al. (1975) in Florida, and MacNae (1968) in the Indo-Western Pacific.

In nearly all situations, the species that first colonize and dominate a recently cleared forest are not the dominant species of the mature forest. This is the classic case of several seres leading to a climax community. Detweiler et al. (1975) compared an undisturbed mangrove forest with an adjacent forest that had been cleared in Tampa Bay, Florida. They found that Salicornia virginica L. and Spartina alterniflora Loisel were the dominant plants in the sere present 3 years after disturbance. Red mangroves, in particular, were not recolonizing the site. As a result, the developer who originally cleared the site was required to plant approximately 25,000 red mangrove seedlings. Part of the reason this species may not have been recolonizing was the presence of dead trees and slash from the original clearing. MacNae (1968) mentions this same problem.

MacNae (1968) also mentions the "nurse" effect of one species on another, specifically involving Avicennia marina in Natal and Bruguiera parviflora in Australia and Burma. The nurse effect is described as:

> "Once established the Avicennias and the species of Sonneratia cause accretion by impeding water movement, the soil level rises, and other species of Rhizophora, Bruguiera and Xylocarpus, germinate from stranded seeds and become established. All these trees tend to grow taller than the pioneers, overtop them and these then die off. Hence one rarely finds a well-grown tree of Avicennia marina in a Rhizophora or Bruguiera forest." (MacNae:149).

Facilitation of establishment of a species by another species has not received as much study as exclusion phenomena. An example is the invasion of broom-sedge (Andropogon spp.) into old fields facilitated by shading of its seeds by tall weed flora (Solidago spp., Aster spp.) (Crafton and Wells 1934). Lewis and Dunstan (1975) have described such facilitation by Spartina alterniflora, which creates a physical trap to hold seedlings of red, black, and white mangroves. Pioneer S. alterniflora marshes on dredged material islands in Tampa Bay, Florida, are thus gradually replaced by mangrove forests. These forests are dominated by black and white mangroves, possibly as a result of selective exclusion of larger red mangrove seedlings (Lewis and Lewis 1978).

Exclusion of one species by the establishment of another is widely noted. For example, Niering and Egler (1955) describe the exclusion of trees by a community dominated by a shrub (Viburnum lentago). Similarly, Holdridge (1940) mentions the physical exclusion of mangrove seeds in marsh fern (Acrostichum aureuon) areas in cutover mangrove areas in Puerto Rico. MacNae (1968) mentions similar exclusion by slash, Acrostichum spp. or beach thistle (Acanthus). Lewis (1979) attributed the very slow recovery of an oil damaged mangrove forest on St. Croix, at least partially, to physical exclusion of red mangrove seedlings by dead prop roots and fallen limbs.

The importance of understanding the natural succession in mangrove forests and the nurse and exclusion phenomena is that each forest system has its own unique characteristics that may indicate: (1) natural recovery will be sufficient to provide revegetation and that manual planting is unnecessary, (2) a "nurse" species may be the best species to use in revegetation, or (3) problems of exclusion by other plant species or slash may require large-scale clearing of the site before planting.

Mangroves are very difficult to establish along shorelines with a large fetch (3 km). Also, the elevation of planting is very critical. These two characteristics are particularly important in trying to create mangrove habitat on eroding shorelines (natural and man-made) (Savage 1972, Hannan 1975, Teas 1977, Savage 1978) or dredged material islands (Lewis and Dunstan 1975, Lewis and Lewis 1978). There is no question that along some shorelines large mangrove forests shelter the shore from storm attack including hurricanes (Craighead and Gilbert 1962); however, large areas of mangroves can be defoliated, uprooted, buried, and killed. Mangroves have been considered for years as landbuilders, but there exists an equally large group of individuals who believe mangroves <u>follow</u> the accretion of land and do not initiate it (see review of both ideas by Carlton 1974).

The extensive root network of mangroves has led to the suggestion that they may be used to stabilize eroding shorelines (Savage 1972, Carlton 1974). In real life experiments, however, (Autry et al. 1973, Hannan 1975) success with all three species was very low and artificial protection (stakes, tires) did not appear to help. As noted by Hannan (1975) "only trees planted in an enclosed lagoon have thrived." Similar experiments on a dredged material island in Tampa Bay also had 100 percent failure of planted red and black mangrove seedlings except in a protected lagoon. Teas (1977) also lost all of his transplanted mangroves within 24 months of planting at a high wave-energy site. The only reported success at establishing mangroves on an eroding shoreline is that of Goforth and Thomas (1979). At their highest wave energy site, fresh seedlings (propagules) and 12- to 18-month-old seedlings of the red mangrove showed very poor survival. Two- to 3-year-old small trees (0.4-0.8 m tall) however showed excellent (100 percent) survival after 23 months. The use of a power auger to provide a hole for planting was, no doubt, a deciding factor for this high success.

ECONOMICS OF PLANTING MANGROVES

Teas (1977) has summarized the estimated costs of planting mangroves of various sizes. Table 1 includes his data plus that of Goforth and Thomas (1979), Lewis (1979), Mangroves Systems, Inc. (personal quotation), and Hoffman and Rodgers (1980) and correspondence from C. E. Pennock (1977).* The costs range from $1,140/ha for collected seedlings to $216,130/ha for three-year-old nursery grown trees ($35.00 each). It is important to note that only 1 of the 25 values in Table 1 is that of an actual commercial project that has been completed. The others are estimates based on costs incurred during small-scale experimental projects, or costs excluding profit and overhead. The need for surveys, meetings with regulatory agencies, and travel also can add

Table 1. Estimated cost ($/ha) for planting mangroves by using various techniques.

Species and technique	Spacing (m) 0.30	0.61	0.91	Source
Red mangrove				
Propagules (collected)	10,175	2,470	1,140	Teas (1977)
			12,500[a]	Lewis (1979)
			6,250	Lewis (1979)
	15,000	3,200	1,500	Mangrove Systems, Inc. (1980)
Propagules (purchased)	11,251	2,742	1,261	Teas (1977)
	16,000	3,500	1,600	Mangrove Systems, Inc. (1980)
Red, black and white mangroves				
6-month-old seedlings (purchased)	22,400	5,400	2,510	Teas (1977)
	107,593	27,232	12,103	Mangrove Systems, Inc. (1980)
Red, black and white mangroves				
3-year-old trees (purchased)			216,130	Teas (1977)
			40,755	Correspondence from C. E. Pennock, 1977
			70,000	Mangrove Systems, Inc. (1980)
Red mangroves				
3-year-old trees (transplanted)			45,386	Goforth and Thomas (1979)
Black and white mangroves (transplanted)			10,959	Hoffman and Rogers (1980)

[a]Actual cost of commercial project.

considerably to planting costs as reflected when all factors were included (Lewis 1979).

PLANT MATERIAL AVAILABILITY

Along with the references listed in the Literature Cited section, additional information on plant material availability, prices, and planting guidelines is available from the following:

1. Horticultural Systems, Inc.
   P.O. Box 70
   Parrish, Florida 33564
   813-776-1605

2. Mangrove Systems, Inc.
   504 S. Brevard Avenue
   Tampa, Florida 33606
   813-257-3231

3. Howard J. Teas Nursery
   6700 S.W. 130th Terrace
   Miami, Florida 33156
   305-284-4125

4. Tropical Bioindustries Development Co.
   9000 S.W. 87th Court
   Suite 104
   Miami, Florida 33156
   305-279-7026

LITERATURE CITED

Autry, A. S., V. Stewart, M. Fox, and W. Hamilton. 1973. Progress report: mangrove planting for stabilization of developing shorelines. Q. J. Fla. Acad. Sci., 36 (Suppl. to No. 1), p. 17 (abstr.).

Banijbatana, D. 1958. Mangrove forests in Thailand, pp. 22-34. In Proceedings of the Ninth Pacific Science Congress, Bangkok, Vol. II, Forest Resources.

Carlton, J. 1974. Land building and stabilization by mangroves. Environ. Conserv. 1(4): 285-294.

Chardon, R. E. 1976. A geographic history of the Biscayne Bay area, pp.235-245. In A. Thorhaug (ed.), Biscayne Bay: Past, Present and Future. University of Miami Sea Grant Special Report No. 5, University of Miami, Coral Gables, Florida.

Crafton, W. M., and B. W. Wells. 1934. The old field prisere: an ecological study. J. Elisha Mitchell Sci. Soc. 50: 225-246.

Craighead, F. C., and V. C. Gilbert. 1962. The effects of Hurricane Donna on vegetation of southern Florida. Q. J. Fla. Acad. Sci. 25(1): 1-28.

Detweiler, T. E., F. M. Dunstan, R. R. Lewis, and W. K. Fehring. 1975. Patterns of secondary succession in a mangrove community, Tampa Bay, Florida, pp. 52-81. In R. R. Lewis (ed.), Proceedings of the Second Annual Conference on Restoration of Coastal Vegetation in Florida. Hillsborough Community College, Tampa, Florida.

Durant, C. C. L. 1941. The growth of mangrove species in Malaya. Malays. For. 10: 3-15.

Goforth, H. W. and J. R. Thomas. 1979. Planting of red mangroves (Rhizophora mangle L.) for stabilization of marl shorelines in the Florida Keys, pp. 207-230. In D. P. Cole (ed.), Proceedings of the Sixth Annual Conference on the Restoration and Creation of Wetlands. Hillsborough Community College, Tampa, Florida.

Hannan, J. 1975. Aspects of red mangrove reforestation in Florida, pp. 112-121. In Lewis, R. R. (ed.), Proceedings of the Second Annual Conference on Restoration of Coastal Vegetation in Florida. Hillsborough Community College, Tampa, Florida.

Hoffman, W. E., and J. A. Rodgers. 1980. A cost/benefit analysis of two large coastal plantings in Tampa Bay, Florida, pp. 16-17. In Seventh Annual Conference on the Restoration and Creation of Wetlands. Tampa, Florida. (Draft).

Holdridge, L. R. 1940. Some notes on the mangrove swamps of Puerto Rico. Caribb. For. 1(4): 19-29.

Lewis, R. R. 1977. Impacts of dredging in the Tampa Bay estuary, 1876-1976, pp. 31-55. In E. L. Pruit (ed.), Proceedings of the Second Annual Conference of the Coastal Society: Time-stressed Coastal Environments: Assessment and Future Action. Coastal Society, Arlington, Virginia.

Lewis, R. R. 1979. Large scale mangrove restoration on St. Croix, U.S. Virgin Islands, pp. 231-242. In D. P. Cole (ed.), Proceedings of the Sixth Annual Conference on Restoration and Creation of Wetlands. Hillsborough Community College, Tampa, Florida.

Lewis, R. R. and F. M. Dunstan. 1975. Possible role of Spartina alterniflora Loisel. in establishment of mangroves in Florida, pp. 82-100. In R. R. Lewis (ed.), Proceedings of the Second Annual Conference on Restoration of Coastal Vegetation in Florida. Hillsborough Community College, Tampa, Florida.

Lewis, R. R. and C. S. Lewis. 1978. Tidal marsh creation on dredged material in Tampa Bay, Florida, pp. 45-57. In R. R. Lewis, and D. P. Cole (eds.), Proceedings of the Fourth Annual Conference on Restoration of Coastal Vegetation in Florida. Hillsborough Community College, Tampa, Florida.

Lugo, A. E., and Cintron, G. 1975. The mangrove forests of Puerto Rico and their management, pp. 825-846. In G. E. Walsh et al. (eds.), Proceedings of the International Symposium on Biology and Management of Mangroves. Vol. II. Institute of Food and Agricultural Sciences. University of Florida, Gainesville.

MacNae, W. 1968. A general account of the fauna and flora of mangrove swamps and forests in the Indo-Western Pacific region. Adv. Mar. Biol. 6: 74-270.

Mangrove Systems, Inc. 1979. Martin Marietta Alumina mangrove restoration project, pp. 1-11. In Report to Martin Marietta Corporation, 15 November.

Niering, W. A., and F. E. Egler. 1955. A shrub community of Viburnum lentago, stable for twenty five years. Ecology 36: 356-360.

Noakes, D. S. P. 1955. Methods of increasing growth and obtaining natural regeneration of the mangroves type in Malaya. Malays. For. 18: 22-30.

Odum, W. E. 1971. Pathways of energy flow in a south Florida estuary. Sea Grant Tech. Bull. No. 7, Univ. of Miami.

Odum, W. E., and E. J. Heald. 1972. Trophic analyses of an estuarine mangrove community. Bull. Mar. Sci. 22(3): 671-738.

Savage, T. 1972. Florida mangroves as shoreline stabilizers. Florida Department of Natural Resources. Professional Papers Series No. 19. 46 pp.

Savage, T. 1978. The 1972 experimental mangrove planting -- an update with comments on continued research needs, pp.43-71. In Proceedings Fifth Annual Conference on the Restoration of Coastal Vegetation in Florida. Hillsborough Community College, Tampa, Florida.

Teas, H. J. 1977. Ecology and restoration of mangrove shorelines in Florida. Environ. Conserv. 4(1): 51-58.

Teas, H. J., W. Jurgens, and M. C. Kimball. 1975. Plantings of red mangroves (Rhizophora mangle L.) in Charlotte and St. Lucie counties, Florida, pp. 132-262. In Proceedings Second Annual Conference on Restoration of Coastal Vegetation in Florida. Hillsborough Community College, Tampa, Florida.

Wadsworth, F. H. 1959. Growth and regeneration of white mangroves in Puerto Rico. Caribb. For. 20: 38-57.

Watson, J. G. 1928. Mangrove Forests of the Malay Peninsula. (Malayan Forest. Rec. No. 6) Fraser and Neave, Ltd., Singapore.

*C. E. Pennock. 1977. Two-page letter from Puerto Rican Gov't. Dept. Nat. Res. Refers to cost of planting mangrove plants.

RESTORATION OF MANGROVE ECOSYSTEMS

Howard J. Teas
Biology Department
University of Miami
Coral Gables, Florida 33124

ABSTRACT

The restoration of mangroves has become increasingly important in recent years as mangroves have become appreciated for their roles as primary photosynthetic producers, shoreline protectors, and as nursery ground and habitat for a variety of organisms. Factors involved in the development of complex mangrove ecosystems, such as planting material, planting density, size of plantings, substrate, biomass attainment and retention, fertilization, and acceleration of faunation are considered in this paper.

INTRODUCTION

Mangroves provide erosion control and shoreline stabilization, they are sources of primary productivity that are involved in complex detritus food webs (Odum and Heald 1972), and they provide habitat and nursery ground for a wide variety of organisms (MacNae 1974, Idyll et al. 1967).

Mangroves have been planted for erosion control in many areas, for example: Ceylon (MacNae 1968); Florida, along the Overseas Railway (Bowman 1917); Hawaii, on the Island of Molokai (McCaughey 1917); in the Florida Keys to stabilize shorelines (Goforth and Thomas 1979); and in Java to stabilize the banks of fish ponds (MacNae 1968). It has been suggested by Fosberg (1971) that the heavy loss of life in the 1970 storm in Bangladesh may have been a consequence of the earlier removal of thousands of hectares of mangroves.

Mangroves have been hand planted for silvicultural purposes in Malaya (Watson 1928), the Philippines (MacNae 1968), and Vietnam (Lang 1974). In recent years large-scale restoration and mitigation have been carried out as a consequence of government agency requirements or court orders, e.g., in Florida (Teas et al. 1975) and St. Croix (Lewis 1979).

Mangroves are also highly regarded aesthetically as components of the landscape (Baker et al. 1977). They are sometimes planted for this reason by homeowners and developers (Teas 1977).

E. P. Odum (1969) made extensive comparisons of young and mature ecosystems in general. The comparisons that are appropriate for mangroves are now discussed.

SUBSTRATE

Recently invading young stands of mangroves usually grow in soil that is low in organic matter; mature forests typically are found in soils that are high in organic matter. MacNae (1968) cited new mangrove soils as having 5-15% organic matter and soils of mature forests as being up to 65%. In south Florida, a shoreline sandy site can be 7% organic and a mangrove forest 25% or more (Teas 1974). Banner (1977) has used the depth of soil darkening as an index of mangrove maturity. In the change from nonmangrove alluvium or sand to mature mangrove soils there is involved large additions of organic matter as well as the activities of blue-green algae, green algae, diatoms, bacteria, an array of invertebrates and vertebrates that increase the organic matter, work the soil, and contribute nitrogen and phosphate from feces (Schuster 1952, MacNae 1968).

BIOMASS

Mature mangroves have relatively dense canopies with leaf area indices in the range of 4 to 5. Young plantings have low biomass; mature plantings have high biomass. Mangroves in south Florida are considered to reach maturity in 20-25 years (Davis 1940); however, a mangrove tree increases wood biomass until it dies.

MINERAL NUTRIENT CYCLING

Young mangrove plantings have relatively open mineral nutrient systems. Mature mangroves have efficient systems for entraping and holding nutrients for cyling within the system.

FOOD CHAINS

Young mangrove communities are characterized by limited, linear, predominantly grazing foodchains. Mature mangrove forests have complex, predominantly detritus food webs.

DIVERSITY

Young mangrove communities typically have low animal species diversity; mature communities have high diversity. The colonization of a young developing isolated mangrove forest by animals would be expected to follow the general features for recolonization of the defaunated mangrove islands studied by Simberloff (1969). Colonization would be most rapid near large sources of animals and slow for new small plantings remote from such sources. The species diversity at equilibrium also would be expected to be greater on a large island or mangrove planting than on a small one.

STABILITY

Young communities with few individuals of few species are much more vulnerable to environmental stresses than are mature communities in which population density, biotic control of grazing, and nutrient cycling provide positive feedback mechanisms that contribute to the stability (homeostasis) of the system by preventing overshoots and destructive oscillations.

These factors indicate that, in establishing communities by mangrove planting, it is desirable to shortcut the ordinarily slow succession in order to rapidly establish a mature ecosystem.

FACTORS IN RESTORATION OR MITIGATION PLANTING

The problem of mangrove planting is to attain a mature ecosystem as rapidly as possible. Therefore, the following factors of importance will be discussed.

PLANTING MATERIAL

Propagules of red mangrove (*Rhizophora mangle*), white mangrove (*Laguncularia racemosa*), and black mangrove (*Avicennia germinans*) are most often planted, but nursery-grown seedlings or transplants from nature of all these species have been utilized (Figures 1 and 2). Clearly, dense planting and the planting of larger trees can accelerate development of a mature ecosystem with its high biomass, species diversity, tightly coupled

Figure 1. Red mangrove seedlings in a nursery.

Figure 2. Red mangroves transplanted from nature.

mineral nutrient cycling, and stability.

Savage (1972) and Carlton (1974) have suggested that the black mangrove with its dense root-pneumatophore bed is superior to the red mangrove for soil stabilization. The white mangrove also forms a dense root mat, like the black. Figures 3, 4, and 5 show white mangrove roots, red mangrove roots, and the pneumatophore network around a black mangrove.

SUBSTRATE

Substrate needs to be reasonably stable. Kinch (1975) reported the failure of mangrove planting in fine dredged material that eroded and subsided. Substrate needs to be protected from wave erosion (Teas 1977, Lewis 1979). Lewis and Dunstann (1975) developed the use of cordgrass (Spartina alterniflora), as a substrate-stabilizing nurse crop in which mangroves could develop.

Mangrove plantings are made at appropriate tidal levels, generally between mean sea level and mean high water (Teas 1976). Plantings may need to be placed higher in the intertidal zone to reduce depredations if the marine isopod root borer (Sphaeroma) of mangroves is present. Sphaeroma bores into the red mangrove most often, but all three species of mangroves are attacked where the infestation is heavy.

Plantings on islands or spits should be laid out so that naturally formed berms do not isolate the trees from regular tidal flow thereby causing hypersaline basins to form. Plantings of large areas of mangroves should be ditched to ensure tidal circulation. Hypersalinity within a mangrove forest can reduce growth (Teas 1979). Watson (1928) recommended ditching Malayan mangroves to improve tidal circulation and growth.

BIOMASS PRODUCTION AND RETENTION

More rapid growth of mangroves can be achieved with fertilizer (Teas 1977). Onuf et al. (1977) found increased productivity of red mangroves on islands fertilized by a bird rookery. Darovec et al. (1975) suggested the use of organic fertilizers at the time of transplanting mangroves.

Rapid growth response occurs in Rhizophora apiculata seedlings using pelletized slow-release fertilizer. Some natural fertilization can be anticipated as a mangrove ecosystem matures because nitrogen fixation occurs in mangrove soils (Kimball and Teas 1975) and on fallen mangrove leaves (Gotto and Taylor 1976).

MINERAL ELEMENT CYCLING

Black mangrove pneumatophores effectively hold leaves, twigs and other litter, thereby retaining mineral nutrients on site (Figure 6). Early retention of nutrients in litter would probably be obtained by planting black mangroves with red mangroves.

FOOD CHAINS

The development of food webs could be accelerated by providing litter components as a source of organic matter in the form of leaves and branches.

ANIMAL SPECIES DIVERSITY

Single or small groups of mangroves have depauperate fauna compared to large forests. It is bet-

Figure 3. White mangrove root mat exposed by a storm.

Figure 4. Red mangrove roots of a tree washed out by wave action.

Figure 5. Pneumatophores (aerial, pencil-like breathing roots) around a young black mangrove.

Figure 6. Closeup view of leaf litter trapped by black mangrove pneumatophores.

ter to make large block plantings rather than scattered plantings in order to enhance faunal diversity.

SUMMARY OF RECOMMENDATIONS

To accelerate development of mature ecosystems in planted mangroves, the following suggestions are recommended:

1. Plant black or white mangroves, or both along with red mangroves to develop a better root mat.
2. If possible, use topsoil or highly organic soil for substrate and fertilize in the planting hole with slow release fertilizer pellets.
3. Space plants closely to obtain early coverage by leaf canopy.
4. After a year or two, add brush, branches, and leaves to the planting as a source of reduced carbon to help develop the ecosystem.
5. If the planting is remote from well-developed mangrove stands, establish biota by bringing in litter, mud, snails, and branches, from a well-established mangrove forest.

LITERATURE CITED

Baker, C. S., T. Hayes, and D. Smolker. 1977. Visual quality of the tidal creeks in southwest Florida, pp. 114-136. In R. R. Lewis and D. D. Cole (eds.), Proceedings of the 4th Annual Conference on the Restoration of Coastal Vegetation in Florida. Hillsborough Community College, Tampa, Florida.

Banner, A. 1977. Revegetation and maturation of restored shoreline in Indian River, Florida, pp. 13-43. In R. R. Lewis and D. D. Cole (eds.), 4th Annual Conference on the Restoration of Coastal Vegetation in Florida. Hillsborough Community College, Tampa, Florida.

Bowman, H. H. M. 1917. Ecology and physiology of red mangroves. Proc. Amer. Philos. Soc. 56: 589-672.

Carlton, J. M. 1974. Land-building and stabilization by mangroves. Environ. Conserv. 1:285-294.

Darovec, J. E., J. M. Carlton, T. R. Pulver, M. D. Moffler, G. B. Smith, W. K. Whitefield, C. A. Willis, K. A. Steidinger, and E. A. Joyce. 1975. Techniques for coastal restoration and fishery enhancement in Florida. Florida Marine Research Publications No. 15. Florida Department of Natural Resource Marine Research Laboratory. St. Petersburg, Florida.

Davis, J. H., Jr. 1940. The ecology and geological role of mangroves in Florida. Carnegie Inst. Wash. Publ. 32: 305-412.

Fosberg, F. R. 1971. Mangroves versus tidal waves. Biol. Conserv. 4: 38-39.

Goforth, H. W., and J. R. Thomas. 1979. Planting of red mangroves (Rhizophora mangle L.) for stabilization of marl shorelines in the Flroida Keys, pp. 207-242. In D. P. Cole (ed.), Proceedings of 6th Annual Conference on the Restoration and Creation of Wetlands. Hillsborough Community College, Tampa, Florida.

Gotto, J. W., and B. Taylor. 1976. N_2 fixation associated with decaying leaves of the red mangrove (Rhizophora mangle).

Appl. Environ. Microbiol. 31: 781-783.

Idyll, C. P., D. C. Tabb, and B. J. Yokel. 1967. The value of estuaries to shrimp, pp. 83-90. In Proceedings of Marsh and Estuary Management Symp., Louisiana State Univ., Baton Rouge.

Kimball, M., and H. J. Teas. 1975. Nitrogen fixation in mangrove areas of South Florida, pp. 654-661. In Proceeding First International Symposium on Biology and Management of Mangroves, Univ. Presses of Florida, Gainesville, Florida.

Kinch, J. C. 1975. Efforts in marine revegetation in artificial substrates, pp. 102-111. In R. R. Lewis (ed.), Proceedings 2nd Annual Conference on Restoration of Coastal Vegetation in Florida. Hillsborough Community College, Tampa, Florida.

Lang, A. 1974. The Effects of Herbicides in South Vietnam. Part A. National Academy of Sciences, Washington, D.C. 372 pp.

Lewis, R. R. 1979. Large scale mangrove restoration on St. Croix, U.S. Virgin Islands. pp. 231-242. In D. P. Cole (ed.), Proceedings 6th Annual Conference on the Restoration and Creation of Wetlands. Hillsborough Community College, Tampa, Florida.

Lewis, R. R. and F. M. Dunstann. 1975. The possible role of *Spartina alterniflora* in establishment of mangroves in Florida, pp. 82-100. In R. R. Lewis (ed.), Proceedings 2nd Annual Conference on Restoration of Coastal Vegetation in Florida. Hillsborough Community College, Tampa, Florida.

MacCaughey, V. 1917. The mangrove in the Hawaiian Islands. Hawaii. For. Agric. 14: 361-366.

MacNae, W. 1968. A general account of the fauna and flora on mangrove swamps in the Indo-West Pacific region. Adv. Mar. Biol. 6: 73-270.

MacNae, W. 1974. Mangrove Forest and Fisheries. Reports IOFC, International India Ocean Fisheries Survey and Development Programme, No. 74/34. 35 pp.

Odum, E. P. 1969. The strategy of ecosystem development. Science 164: 262-270.

Odum, W. E., and E. J. Heald. 1972. Tropic analyses of an estuarine mangrove community. Bull. Mar. Sci. 22: 671-738.

Onuf, C. P., J. M. Teal, and I. Valiela. 1977. Interactions of nutrients, plant growth and herbivory. Ecology 58: 514-526.

Savage, T. 1972. Florida Mangroves as Shoreline Stabilizers. Florida Dep. Nat. Resour. Prof. Pap. Ser. No. 19. 46 pp.

Schuster, W. H. 1952. Fish Culture in Brackish Water Ponds of Java. Indo-Pacific Fisheries Council Spec. Publ. 1. 143 pp.

Simberloff, D. S. 1969. Experimental zoogeography of islands: a model for insular colonization. Ecology 50: 296-314.

Teas, H. J. 1974. Mangroves of Biscayne Bay. Mimeo. Dade County, Florida 107 pp.

Teas, H. J. 1976. Productivity of Biscayne Bay mangroves, pp. 103-113. In Biscayne Bay: Past, Present and Future. Univ. of Miami Sea Grant Spec. Report 5, Univ. of Miami.

Teas, H. J. 1977. Ecology and restoration of mangrove shorelines in Florida. Environ. Conserv. 4: 51-58.

Teas, H. J. 1979. Silviculture with saline water, pp. 117-161. In Environmental Science Series, Vol. 14. Plenum Press, New York.

Teas, H. J., W. Jurgens, and M. C. Kimball. 1975. Plantings of red mangrove (*Rhizophora mangle* L.) in Charlotte and St. Lucie Counties, Florida, pp. 132-161. In Proceedings Second Annual Conference on Restoration of Coastal Vegetation in Florida. Hillsborough Community College, Tampa, Florida.

Watson, J. D. 1928. Mangrove forests of the Malaya peninsula. Malay. For. 6: 1-275.

Discussion III - Ecology of Mangroves (D. Page, R. Lewis, and H. Teas)

Statement A. Lugo: I do not dispute any of Dr. Page's science, however, I do want to make a point about his interpretations. He studied the chronic effects of the oil but missed the acute effects because his research started two years ago and the spill occurred seven years ago. Pictures taken the day after the spill show that the whole bay had oil. Also, in regard to the question of salinity stress as opposed to oil stress, Dr. Page states that the trees' dying in one area was due to salinity stress. I think that this interpretation is wrong because mortality by salinity takes a long period of time starting at the back of the mangrove and moving toward the sea. In this case the mangroves were killed on the seaside first. Also, mortality by salinity takes a long time, period; trees lose their small branches. Those at Bahia Sucia still had the small branches intact, suggesting very recent kill. Soil salinities were measured in the zone of mortality in the red mangroves and found to be below 50 to 60^{o}/oo, values that do not kill red mangroves.

When I sampled the area, there was a tremendous amount of oil in some locations. This was not shown in the presentation. The areas that Dr. Page sampled were very slightly oiled as compared with other areas where the oil is still very thick.

I feel that Page has very interesting data in regard to natural oil and the oil that originated from the spill. However, when you talk about 4,500 tonnes of oil which came into the bay from the spill as opposed to the few grams of oil produced from natural sources, the natural sources are insignificant.

Finally, the spill area is typical, not atypical, of the tropical region.

A. D. Page: I must confess that I disagree with everything that Ariel says. One of the problems we have is that we tend to be on opposite sides of the litigation. If one were to adopt an arbitration system dealing with litigation such as the system used in Great Britain or Europe, what both of us are saying would tend to indicate that mangroves do recover from an oil spill. It is a question of time.

I also take issue with the statement that the mangroves in the area are typical. I think that they are atypical. They are unique and not representative of the environment based on other studies of mangrove forests. In a typical mangrove forest you do not have the tremendous lack of freshwater input in that small area. Things are more typical even on the east side of Bahia Sucia where you have land runoff. What we are dealing with is an oil stress overlain by a salinity stress and therefore it is difficult to separate the two. Mangroves living in oiled sediments with 37^{o}/oo salinity may actually react as if living in 50^{o}/oo salinity, because of the interference of the hydrocarbons with the desalinization process.

I urge you all to support proposals which deal with finding ways of measuring stress in plants, including sublethal stress. We need a good way to measure long-term stress effects.

Statement A. Thorhaug: The restoration process that Mr. Lewis was talking about was only a change of a couple of years in regard to restoration or nonrestoration. I can show you, however, that there are decades or even 100 years difference between the recovery rate of an impacted system under natural recovery versus man-restored recovery. You should consider the following in restoration: What are the epicenters for possible natural recovery now? Are you at the limit of this species? Has man in his impact changed the physical conditions? What will happen if one waits for the natural restoration of an area?

Studies, for instance, on seagrasses have shown that sediments erode so quickly when there is no seagrass that the original seagrasses cannot recolonize the same area. If the seagrasses are immediately replaced, even with successional plants, the sediment stays somewhat intact.

Q. E. Chan: D. Page, considering that you began your study at Bahia Sucia five years after the oil spill, what measurements were taken to determine the effects of elevated salinity as opposed to those of oil on mangrove kills?

A. D. Page: We used the same pictures that Dr. Lugo mentioned and they showed clearly that the mangroves of the northern fringe were dead before the oil spill. There is ample evidence to prove that oil does kill mangroves. What is interesting to show, however, is that in tropical ecosystems, oil breaks down more rapidly than in an area such as Cape Cod or Maine.

Q. A. Banner: I would like to know about the epiphytic algae on the mangrove ground cover. Has it recovered as the mangroves have?

A. D. Page: I do not know. Unfortunately Dr. Gilfillan is not here and he was the biologist on this project. There is definitely an algal mass (blue-green algae) and there is also ample evidence that there are algal lipids throughout the sediments.

Q. R. Lee: Are there any data which indicate that shorebirds nesting in mangroves may produce stress to the mangrove environment?

A. H. Teas: I would suspect it would be a case of shore bird density. I do not have an answer yet, but clearly birds are too dense on some islands.

Q. J. Carroll: I am surprised to hear that there are no naturally impounded mangroves. We saw a slide which seemed to show impounded mangroves. Please clarify that point.

A. A. Lugo: I do not think that impounded mangroves exist. If one looks at the natural berm which isolates the black mangroves, one also sees many channels which cut across the berm. There is communication across the berm where the red mangroves are in the bay, and therefore, these are not impounded. Even though people call them impounded, there is this channeling effect.

Q. J. Carroll: Let us say the berm is continuous for miles. Would you call that a semi-impounded black mangrove?

A. A. Lugo: No, because the berm always has breaks. Berms during the dry season may be very high yet during the wet season there is ample communication between the black mangroves and the bay.

Q. J. Carroll: Isn't it true that a characteristic of the black mangrove forests is that they live in conditions of hypersalinity caused by the fact that berms are overtopped infrequently, evaporation then occurs, and the soil become hypersaline?

A. A. Lugo: Yes and no. Black mangroves are in places that are more isolated from the sea than the red mangrove. The water circulation is slower. That is why the salinity builds up. But, if they were truly impounded, the salinity would continue to build up and it does not. It always reaches a steady state. Even in the driest parts of the world where you have mangroves, soil salinity does not reach over 90^{o}/oo. If it does, you do not have mangroves anymore. I have spent two years looking for the completely isolated black mangroves and I cannot find them.

A. H. Teas: In the Lesser Antilles there is an island with several impounded red mangroves, which have been there for quite a while, as determined by calcite, aragonite ratios. These red mangroves are on the Isle of Barbuda. So, there is such a thing as truly impounded mangroves.

A. A. Lugo: You are referring to the paper by Stoddart et. al. I have a paper in press right now showing the fallacy of that argument. What happens in Barbuda is that you have ocean holes very similar to those in Ft. Myers. These allow seeps of seawater far inland. Inland you get seawater coming in through the limestone formation. The analysis by Stoddart et. al. hid the fact that fresh seawater was actually coming up through the seeps. The water flows inside the island toward a coastal berm where the salinity builds up as water evaporates. The mangroves are not impounded because of the steady flow of fresh seawater. Also, hurricanes can easily overtop the island. This is very typical in the Bahamas.

I still maintain that impounded mangroves are a myth. Whenever you see a red mangrove, you have to suspect flowing water and so far I have not seen an exception to this rule. The only incident that I know of is a picture of a red mangrove taken by Chapman where the tree was growing way up in the rocks. This was only one tree, not a naturally growing area of mangroves that are impounded.

Statement A. Banner: Mangroves are isolated. For instance, on Key Largo the berm may be overtopped in a storm situation. You actually have lower salinity than in the bay. This condition exists because of leaching by the fresh water. Black and white mangroves are found in such areas

A. A. Lugo: I don't dispute that in nature there are cases such as this. However, for example, in Guatemala I won a case of Coke because a professor collected data on red mangroves only when the salinity levels indicated that these were "fresh water" mangroves. Unfortunately, the data were collected during the summer when school in Florida let out which was also the wet season in Guatemala. At the peak of the dry season, however, there was saltwater which came up river and could be measured miles inland. So again, even in extreme cases when there seems to be a good case of isolation, there is a definite linkage to the sea.

Q. E. Chan: If the remaining oil in Bahia Sucia lost all toxic components and high concentrations of leaflets are not responsible for inhibiting recolonization of mangroves, can you explain the lack of mangrove recovery in seven years except for a narrow fringe?

A. D. Page: The mangroves' recovery is taking place in those areas where the toxicity of the oil in the sediment has been reduced to the point to permit recovery. Those include Hermit I and portions of North Mangrove and there are places in North Mangrove where in fact the oil is sufficiently toxic to preclude recolonization. Recovery is occurring at different rates throughout the impact zone depending upon numerous factors such as: the extent to which the oil originally got in there, the nature of the sediment, the bacteria and nutrients, etc. It is important to recognize that in an oil spill, recovery takes place at different rates at different places and in some places the oil has become weathered to the point where mangroves seem to be surviving. In other areas, sediments have not weathered to that point.

SLIDE SHOW AND DISCUSSION - Lower Keys Wildlife Refuges (D. Kosin)

Mr. Kosin made a slide presentation on the refuges in the Lower Keys. Excerpts of the presentation follow.

As background information: Teddy Roosevelt set aside three acres on Pelican Island in 1903, as a National wildlife refuge. Today over 1,200 hectares on Pelican Island are designated as a refuge. The three refuges in the Lower Keys, Great White Heron, National Key Deer, and Key West Refuge, encompass approximately 5,880 hectares. The area runs approximately 56 km east and west and 12.8 to 16 km north and south. Most of the islands are made of mangrove, low-line islands.

Some of the wildlife inhabiting these refuges include the great white heron, the great blue heron, blue-winged teal, red shouldered hawk, burrowing owl, and bald eagles. There are also shorebirds, gulls, pelicans, egrets, and frigate birds. We have the only nesting colony of frigate birds in North America. The birds nest on mangrove islands. The mangrove is the basis of their food chain. We feel that it is a most desirable plant. Not only does it protect our coastline but also affords nesting, resting, and breeding habitat for our wildlife.

We also have hammock areas, one of the more famous being Watson's Hammock. The majority of the trees there are gumbo-limbo. There is an abundance of air plants, and we have approximately 475 different species of plants. We have keys that look like prairie-type areas. Regarding the Key deer, in the 1940's and the early 1950's, the population was down to about 25-40 animals. Jack Watson was assigned to the area and it was mainly through his efforts in protection and law enforcement that the Key deer herd is back to its present population of 350-400 animals. The Key deer at birth weighs from 0.9 to 1.8 kg. Gestation period is approximately six months. In February and March the bucks lose their racks. Rutting season begins in September, peaks in October and gradually diminishes through December. The height of a Key deer is approximately 61 to 71 cm at the shoulder. The weight of bucks range from 25 to 34 kg. Does weigh between 20 and 25 kg. One major problem with the deer is associated with people feeding them. Feeding the Key deer not only disturbs their behavior patterns and morphology, it makes them more susceptible to road kills and to poaching.

Fresh water is one of our critical factors in the area. There are water holes which are periodically cleaned out to remove organic matter so that rain does not wash it back into the hole. The area will catch rain and provide water, not only for Key deer, but for other animals. The mosquito ditches that are found on Big Pine and throughout the area were dug in the 1960's. It is believed now that there were too many of these ditches dug. Not only does it encroach on our freshwater lens, but it is a catch basin for deer fawns. Fawns will fall into the ditches, which are from two to three feet deep, and subsequently die.

Typical raccoons are seen as well as ones with pale blond color. The mask and tail ring are almost completely gone on the blond colored variety. There is a recognized crocodile population in the lower keys. Yet, data to back this up are nonexistent. One individual was photographed and tagged. It came from the Florida mainland down to the area. There are alligators and various turtles.

Various questions were asked following the presentation.

Q. What would you say the number of crocodiles are throughout the Keys and how often do you see them?

A. There are probably less than 10. I have seen only two since 1975, and there has been little documented on their numbers.

Q. What is the southern most range of the crocodile?

A. Well, when I say the lower keys, it could be anything from the seven-mile bridge on down to Key West. I just don't know really.

Q. What's your answer to road kills of Key deer?

A. We had 61 road kills last year, mainly along Highway #1. This is the reason we say no feeding. The deer associate people and the automobile with food. They will prance right up to a moving car. The animals here do not have to be fed because there is a continuous growing season and ample food.

Q. Could you talk a little about the poaching problem here in the Keys?

A. We usually have a rash of poaching during the holidays. Instead of going out and getting a Thanksgiving turkey, some people go out and get their Thanksgiving deer. Prosecution is very difficult. I have been in areas where I have actually heard shots, maybe a block away, but I have not seen any vehicles. The deer carcasses, however, come up in dumpsters in Key West and float to the surface on Stock Island or the canals. Some animals are apparently shot for no reason.

Q. Have you had any problem with alligator poaching?

A. Not that I know of but we have had some road kills of alligators that move on Big Pine Key.

Q. What kind of public access do you have, especially on Key West Wildlife Refuge?

A. You can boat to it. It is not a typical refuge where you have a boundary line and access points. There is a subdivision surrounded by refuge land, or refuge land almost surrounded by a subdivision. Access is very difficult.

FIELD TRIPS

Two field trips were scheduled for the Workshop. Original plans called for one trip to involve a general ecology of mangroves led by Dr. Ariel Lugo and one trip to study Wacouta Corporation's permit applications for dredging and filling an area of Big Pine Key, the latter field trip to be led jointly by Mr. Joe Carroll, FWS, and Mr. Bob Routa, the attorney for Waucota Corporation.

Because the Florida Keys provide exceptional opportunities for field trips and because of the varied interests of the workshop participants and the exceptional qualifications of the speakers, field trips were added according to the availability of transportation and requests of the participants. All speakers and attendees had the opportunity to participate in at least two trips. The leaders of these trips included Dr. Ariel Lugo, Mr. Joe Carroll, Mr. Bob Routa, Mr. James Barkuloo, Dr. Robert Chabreck, Mr. Bill Becker, Dr. John Day, Mr. Donald Kosin, and Dr. J. C. Zieman.

MORNING FIELD TRIPS, FEBRUARY 20th

1. Ecology of mangroves trip.
2. Wacouta Corporation permit application trip. (A summary of this session is entitled: Litigation and Control of Ecosystems).
3. Early morning bird identification trip.
4. Scuba trip.
5. Snorkeling trip.
6. Key Deer Wildlife Refuge trip.

AFTERNOON FIELD TRIPS, FEBRUARY 21st

1. Wacouta Corporation permit application trip.
2. Fill permit application of Sugarloaf Shores trip, as requested by NMFS.
3. Snorkeling trip.

FIELD TRIP - Litigation and Control of Ecosystems (J. Carroll and R. Routa)

Mr. Carroll is the Field Supervisor, Ecological Services, for the area that includes Big Pine Key. He represented the Service throughout most of the time when Wacouta Corporation tried to develop an acceptable permit application.

Mr. Routa, an attorney and biologist, discussed the problems which one landowner encountered in trying to develop a wetland. He presented a case and had the audience look at its history. An abbreviated version of the presentation and discussion is as follows:

This application started about 1969. Two men purchased the property and formed Wacouta Corporation. Two men owned the stock and they decided that they wanted to put in a development for single family use. Try to take yourselves back to 1969 and consider what your views were of mangrove preservation. In 1967, the State of Florida started some programs of evaluating dredge and fill applications. These applicants tried to take into account in their first proposal what was happening about that time as seen throughout the Keys. Simple deep canals, to obtain enough fill to bring all the land up to grade for housing development, were typical.

The first plans were submitted to the State of Florida calling for a typical cut and fill development. Even at that time there was some consciousness for mangrove preservation and the first plan called for preservation of one of the islands. The whole area would have been developed except for this little portion. The plan was actually approved by the governor and cabinet, but there was a misprint in the agenda which left out the access channel; the applicant wished to have the access channel included. We went back a second time and at that point the whole thing was denied.

The plan was modified, taking into account various suggestions, and resubmitted. The channel was changed and there were to be some perimeter channels around the tidal pond. That also was rejected. At that point, I (Routa) might add that I was involved with the first application review but by the time of the third plan, I had gone out into the private sector. I was asked to come down and look at this to try to come up with an idea for the applicant of what might be able to be approved.

We (Wacouta Corporation) developed a plan but not one which would be approved. One of the goals through all this and all through the Keys is to have navigational access. It seemed feasible that in an area of short stunted mangroves, an elevated roadway could go back to the single family development preserving a major portion of the tidal ponds and all of the larger mangroves. This also was not accepted, but all during this review process recommendations were made as to things that might be done to make the development more acceptable. If the channel was the problem, and at this point it seemed to be, it was determined that maybe the thing to do would be to do away with that channel and use a dry storage facility with a large pier. So it was proposed then to have a large dry storage boat shed and a pier extending out into the water. Most of the roadway would be elevated trestles so that the water flow would be maintained. Again that plan was rejected.

The last plan called for preservation of all mangroves with a shallow channel to the uplands. The surprising thing at this point was that the reports generated by both the Federal and State agencies were much longer and much more adverse for this plan than they were from any of the original plans, and at this point the application was denied by the Corps of Engineers. The property was then sold to the current owners; I (Routa) do not represent them or know what their plans are.

A few comments are needed to put into perspective what has happened over the 10 years of processing this application. The people originally purchased it, paid taxes on all the land and tried any number of plans. They spent a small fortune in consultants' fees. They had a hydrographic study done at least once and many engineers worked on the plan. They followed all the different recommendations, or tried to, and the last plan which had the least impact, was rejected just as heavily as the earlier ones were.

The concept of environmental preservation, the preservation of wetlands, is good. It places a burden on all the citizens of the country. For most citizens, this burden only applies through paying tax dollars to support the agencies and pollution control equipment on their cars. People who choose to purchase and develop land on the edge of the water inherently have more of a share of the burden. In some cases the court may recognize that a particular applicant has to bear too large a share of that burden. This was the outcome of the case in Fort Meyers, now under appeal. Several attorneys feel that perhaps these applicants may have had too large a share of that burden.

Various questions were asked following the presentation - before the field trip.

Q. At what point did it become an aquatic preserve?

A. I think it would have been after the first application. But again, aquatic preserve status under Florida law only calls attention to certain bodies of water for special emphasis. Usually there is a clear exception in that law to allow for reasonable navigation channels. So, I think we can really point to aquatic preserve and say that was the reason for, or could have been the reason for, the denial of the last plan.

Q. I thought the general aquatic preserves required that there be public benefit from any change in the aquatic preserve. In short, were not providing public benefit and doing some damage to public wetlands reason for rejecting that?

A. Not specifically. It just points out that these areas should be reviewed under the normal procedures for dredge and fill. They have been given a little higher status of protection.

Q. I hear it almost implied that in land purchased for speculation there is an inherent or an unwritten right for that person to make a profit. What is your legal opinion on that?

A. If a court is going to look at this issue, it should look at the whole picture. If our applicants had purchased this land in 1976 or 1974 even, I think the court would look at it in a different light.

They purchased the property before 1969, I am not sure when, but they purchased at a time when this kind of development was being done in the Keys and everywhere unchecked They had an expectation of developing the property as planned. I think in a situation such as that, the court is going to look at their investment and their expectations for property use rights in a little different light than if someone had just come along in recent times and bought a parcel of land.

When I started working with the State, the agency that was involved with enforcing developments had a perfect record of never having won a case in court. The courts had always gone with the developers. The court decided in favor of property rights and the right to make a profit. It has only been in recent years that this has changed, especially the Federal courts.

Right now we see more inclination to slip back in the other direction and look at the economic aspects of development. The case out of Fort Meyers in particular looked at a lack of recommendations made by the agency involved in the denial. They found that the applicant was bearing more than his share of the burden for preservation. I think we are going to see more of this. I think that it is inherent and incumbent upon the people who review projects to look at them with an eye toward trying to find recommendations where perhaps not all the fish and wildlife values can be protected, but most of them can and yet the applicant is still able to make a profit.

Q. What is the extent of property ownership, the origin of that ownership, and is that not now under challenge?

A. In a case at Fort Myers, we had a meander line and the old original government meander line actually made a loop. As part of the original application there was the proposal to settle the ownership question between State and private lands. At that time the State felt that if there was not a fast mean high water line which was easily discernible, then the boundary was a meander line. There has since been a case in the Fort Meyers area where it was said indeed that was true. The State said the mean high water line could not be found because the tripod kept sinking in the mud. The judge said it was therefore the meander line.

Q. What is the meander line?

A. The Federal government commissioned surveyors back in the 1800's to survey the lands. The meander line is their attempt to separate the land from the water. In many cases it is a wonder they did as well as they did. There are a lot of erroneous meander lines and in many situations the meander lines in the Keys almost always went out offshore from the mangroves. In fact, that was looked upon by the surveying firms as the mean high water line. In the early days, in every circumstance, I think, we had to say the mean high water line as shown on application drawings was not correct because it would be shown out in the water. In fact, it is now being shown to be more or less at the landward edge of the mangroves.

Q. Do you feel the courts have settled whether the meander line or line of mean high tide is the property line?

A. There is no question now that the property line is the line of mean high tide. There is a separate statute in Florida which governs how surveyors set the mean high water line. They must get approval of their methods from the

State before they can set the line. It is a movable line. The courts recognize that as such. There are cases where the court will say the mean high water line is too difficult to be determined. In those cases, they have gone to the meander line.

Q. So, there is quite a bit of conflict and quite a bit of challenge as to the actual ownership of submerged shore tidal lands?

A. Yes, they determine this on an individual case by case basis.

Q. I believe that the permit by permit basis regarding development can destroy an ecosystem if there is no overall comprehensive plan. Even if one system is not touched directly, the overall picture may be abused. I think it is wise to reject almost any kind of individual plan. What is your reaction?

A. I agree with what you say about the cumulative impact and the lack of ability to plan. I believe, however, that the courts have looked at some long standing applications and recognized that a project is not identical to the one immediately adjacent to it because of the financial investment of the developer and his attempts to follow various recommendations.

THE FOOD WITHIN SEAGRASS BEDS AND THEIR RELATIONSHIPS TO ADJACENT SYSTEMS

Joseph C. Zieman
Department of
Environmental Sciences
University of Virginia
Charlottesville, Virginia 22903

ABSTRACT

Seagrass meadows have been shown to be extremely productive and of great value to nearshore marine regions. The earliest studies on seagrass ecosystems indicated that the dominant pathway of energy utilization was through the detrital food web. Recent research confirms that this is indeed the primary pathway for utilization of seagrass carbon, but that other pathways, notably direct herbivory and export of material from grassbeds for remote utilization, are often significant also. Energy is also exported from seagrass beds via utilization by organisms, such as grunts and snappers that reside on coral reefs, but feed in grassbeds.

INTRODUCTION

Because of their shallow sublittoral and to some extent intertidal existence, seagrass systems are subject to stresses by man's growing use of the coastal zone. Although specialized communities, seagrass beds are among the most productive, exceeding on an areal basis, for example, phytoplankton production in upwelling areas off Peru (Ryther 1969, McRoy and McMillan 1977). These seagrass beds, both temperate and subtropical-tropical, also support diverse and abundant fish and invertebrate faunas which often exceed, in terms of numbers and biomass, populations in unvegetated portions of the system.

Seagrass meadows act in several ways to control or modify the ecosystem, as shown in this scheme developed by Wood et al. (1969):

1. They provide food for a very limited number of organisms such as the parrotfishes, surgeonfishes, Australian garfishes, the queen conch, sea urchins, and some nudibranchs. The green sea turtle formerly grazed heavily on the turtle grass, hence the name.
2. They serve as hosts for large numbers of epiphytes which are grazed extensively, for example, by the mullets. These epiphytes may be comparable in biomass with the seagrasses themselves.
3. They produce large quantities of detrital material which serves as food for certain animal species and for microbes which in turn are used as food by larger animals.
4. They provide organic matter to initiate sulfate reduction and an active sulfur cycle.
5. They bind the sediments and prevent erosion. This also preserves the microbial flora of the sediment and the sediment-water interface.
6. They tend to collect organic and inorganic material by slowing down currents and stabilizing the sediments.
7. The seagrasses have a rapid rate of growth and produce up to 10 g of dry leaf per m^2 per day.

A seagrass meadow produces a great quantity of organic matter and offers a substrate for epiphytic algae, microflora, and sessile fauna. In the case of the animal assemblage associated with above-ground portions of seagrasses, epifauna may have a close correlation with the bed, while some infauna may be an extension of the benthic community of the surrounding area. Hooks et al. (1976) studied the abundance of invertebrates in several estuaries in northwest Florida and found that greatest numbers of organisms of all of the habitats were found in seagrass beds, and that the highest abundances were associated with the densest vegetation. They concluded that many organisms are abundant in the grass beds due to (1) shelter and refuge from predation and high current velocities and (2) a food source, whether leaves, epiphytes or detritus. Similar observations and conclusions have been drawn from studies on Zostera systems (Kikuchi 1961, Marsh 1973, Thayer et al. 1975). Santos and Simon (1974) studied the abundance and distribution of polychaetous annelids in Tampa Bay, in Thalassia, Halodule and sand habitats. They found that different assemblages were not associated with different habitats, but that the Thalassia habitat had the greatest density of organisms. This also appears true in most Zostera systems that have been studied (Orth 1971, Lappalainen 1973, Thayer et al. 1975).

Nekton species fall into three major categories: some are permanent residents of the bed, some reside in the bed only seasonally, and some only use the bed during their daily foraging for food. Briggs and O'Connor (1971) and Adams (1976) have shown a greater density of fishes over seagrasses than in adjacent marine and estuarine waters. Adams (1976) presents data for seagrass beds in the Beaufort, North Carolina area which showed somewhat higher fish biomass than had been reported for Spartina marsh ponds. These ponds are recognized as prime nursery area.

GRASSBED UTILIZATION

Seagrass food webs fall into three general categories: (1) direct herbivory, (2) detrital food webs within grass beds, and (3) detrital food webs of material that have been exported from the seagrass system. Classically the detrital web within the bed has been considered the main path of energy flow, and in most circumstances has been considered the only significant pathway. Studies in progress for the past several years have continued to show that this is the primary food web within a seagrass meadow, but that in some areas the other two pathways may be much more significant than previously suspected.

DIRECT HERBIVORY

The major vertebrate consumers of seagrasses in the Caribbean and temperate area are green sea turtles (Chelonia mydas), West Indian manatee (Trichechus manatus), waterfowl, and fishes. While populations of the green sea turtle are low in many areas of the Caribbean, green sea turtles are still regularly observed and may contribute to conspicuously "mowed" areas of seagrass beds (Ogden and Zieman, unpubl. observations). The impact of turtle feeding on seagrasses has never been fully evaluated. Manatees were once common in the mainland areas bordering the Caribbean, but were probably never important seagrass consumers in the smaller islands of the West Indies (Bertram and Bertram 1968). Stewart (1962) lists 20 species of waterfowl that feed on one or another species of seagrass in the Chesapeake Bay region. Black brant, pintail, and scaup ducks are the most common waterfowl species which feed extensively in grassbeds. Cottam (1934) estimated that eelgrass constitutes about 80 percent of the winter food of the black brant, and McRoy (1966) estimated that black brant and Canada geese consume about 17 percent of the standing crop of eelgrass in Izembek Lagoon, Alaska during summer and fall. When nearly all of the eelgrass along the United States coast disappeared in the 1930's, the black brant all but disappeared.

Fishes associated with seagrass beds have been studied more thoroughly. Seagrass feeding in fishes is confined almost exclusively to the Caribbean (Randall 1965, 1967) and the best studies that have been done so far on diets of Caribbean fishes are by Randall (1967) and on Gulf coast fishes are by Carr and Adams (1973). Randall (1965) indicates that the movements of fishes, feeding in part on seagrasses, from reefs into seagrass beds are responsible for the formation of "halos" around West Indian patch reefs. Invertebrate consumers of seagrasses are most prevalent in tropical systems, and in temperate systems very few species feed directly on the living eelgrass blades.

Conspicuous halos surrounding coral reefs in the West Indies and south Florida are evidence of the grazing activity of herbivorous fishes and invertebrates. The primary grazers responsible for this zone are the urchin, Diadema antillarum (Ogden et al. 1973), and parrotfish and surgeonfish (Randall 1965). Both groups use the reef for shelter and protection, venturing into the relatively narrow (10 m) zone where they may feed, but are still near the protective cover of the reef.

The small grassbed parrotfish, Sparisoma radians, also abounds in the grassbeds of the West Indies and south Florida which are under strong oceanic influence. Ogden and Zieman (1977) showed that the parrotfish grazing in the vicinity of coral reefs form two distinct groups. The smaller parrotfish, Sparisoma radians, which is a grassbed inhabitant, ventures to within about 20 m of a reef and then its abundance decreases. Similarly, the larger parrotfish of the reef zone are highly abundant in the first 5 to 10 m from the reef but the number of fish decreased greatly at 20 m distance. The canopy of the grassbed presents a three dimensional shelter for small (less than 15 cm) fishes, but is two dimensional to organisms greater than 20 cm which cannot hide in the leaves. Very large parrotfish, such as Scarus guacamia, are also seen in the grassbeds, but they are extremely wary, and the middle sized herbivores are confined to areas near the reef and its available shelter (Ogden and Zieman 1977).

Studies during the past few years in the Caribbean and in southern Florida have shown direct grazing to be a more important pathway than previously suspected. Greenway (1976) found that 48 percent of the production of Thalassia in Kingston Harbor, Jamaica, was grazed by the extremely abundant urchin Lytechinus variegatus. In St. Croix an average of 5 to 10 percent of the daily production of seagrasses is directly consumed by herbivores, with a maximum consumption of 15 to 20 percent (Zieman et al. 1979). Seagrasses are not damaged by grazing because the region of the leaf preferentially consumed is the outer portion which has ceased growing. This area of the leaf is senescent, but is often heavily colonized with epiphytic organisms with high food value.

DETRITAL FOOD WEB IN GRASSBEDS

The detrital web within grassbeds has long been considered the dominant pathway of energy flow, and in many grassbeds is the only quantitatively significant path. This pathway consists of three primary processes: (1) the initial rapid loss of soluble organic compounds, (2) the colonization of the leaf substrate by bacteria, fungi, and protozoans, and (3) physical and biological breakdown and fragmentation. This process was described in detail by Odum et al. (1973). This pathway is common to seagrasses, mangroves, and marshes (Odum et al. 1973, Thayer et al. 1978).

Mixed in with the decaying grasses and their attendant decomposers are also a complex community of microalgae, amphipods, rotifers, copepods, and many other small organisms which form the basis of a microcarnivore food chain for a variety of juvenile fishes which use the beds as nurseries.

Because of the mode of growth of the seagrasses, the leaves emerge from the short shoots clean and fresh. As the leaves grow, they become colonized by epiphytes from the oldest part of the leaf (the tip), downward, and the epiphytic community develops. As the leaves become senescent, fall over and detach, this flourishing microcommunity becomes part of the litter layer.

Organisms that feed on this rich mixture may show some degree of selectivity in feeding, but are difficult to place into a conventional trophic scheme (Odum and Heald 1975). Recent published articles and work in progress continue to reinforce the position that this is the dominant pathway of energy conversion in seagrass beds.

DETRITAL FOOD WEB EXPORTED FROM SEAGRASS

The function of seagrasses in the vicinity of the grassbeds, as discussed, has been described and elaborated upon since the studies of Petersen (1918). What has most recently been realized is the amount of seagrass export from the beds and the potential importance of these leaves as food at distances and depths quite remote from the source grassbeds. Leaves and fragments of _Thalassia_ were collected by Menzies et al (1967) in 3,160 m of water off the North Carolina coast. Leaves were found at densities of up to 48 blades per photograph, although the nearest source was 500 to 1,000 km distant. In the region of the Virgin Island basin, Roper and Brundage (1972) observed seagrass blades in nearly all of 5,000 photographs taken at an average depth of 3,900 m.

Greenway (1976) estimated that about 10 percent of the weekly production of _Thalassia_ drifted out from Kingston Harbor, Jamaica, after having been detached by urchin grazing.

The primary causes of detachment are grazing by herbivores, and wave induced severing of leaves which are becoming senescent. In addition, storm waves tear out healthy blades and rhizomes. Because of the differences in the shape of _Thalassia_ and _Syringodium_ leaves, the effects of direct herbivory on the two species are quite different.

Thalassia leaves are broad (typically 7-12 mm) and straplike, while _Syringodium_ leaves are narrow (1-1.5 mm) and cylindrical. When a parrotfish or urchin bites a _Thalassia_ blade, it only removes a portion and the blade usually remains attached. However, the same bite on a Syringodium blade will always sever the blade, and the portion above the bite (commonly 2-4 cm) will float to the surface and drift away. Thus the direct grazing of a relatively small amount of leaf material releases a proportionately large amount of leaf material for export. Because of this mechanism, Zieman et al. (1979), found that in Tague Bay, St. Croix, 60 to 100 percent of the daily production of Syringodium is exported from the system in which it is produced.

In contrast, only a small portion of Thalassia is detached before senescence. The senescent turtle grass leaves normally remain in the bed in which they were formed and decompose. In Tague Bay, only about 1 percent of the Thalassia production is exported, and this material moves primarily by bedload transport as opposed to floating.

This shows a quite different ecological function for the two dominant tropical seagrasses. Thalassia, which is the mature, climax species, promotes recycling of carbon and nitrogen within the grassbed, enhancing sediment development. Syringodium, which is not a climax species, does not contribute to the recycling and further development of the litter layer and its attendant organisms. Evidence indicates that in temperate systems, Zostera functions most closely to Thalassia in this respect.

HIGHER ORDER FEEDING RELATIONSHIPS

The organisms involved in the food webs previously described provide a rich source of food for carnivores capable of exploiting the grassbeds. The primary restraint on these small carnivores is the lack of shelter within the grassbeds. For this reason much of the predation within grassbeds occurs at night. Vast schools of snappers (Lutjanidae) in Florida, and grunts (Pomadasyidae) and squirrelfishes (Holocentridae) in the Virgin Islands, rest in the shelter of reefs by day and at night migrate large distances (1 km or further) out onto adjacent Thalassia beds to feed (Ogden and Zieman 1977, Starck 1969). The resting schools form into large streams at specific assembly points on the reef edge. They then migrate onto the grassbed along routes that remain constant for several years. As the distance from the reef increases, the individual fish leave to feed alone in the grassbeds, returning along the same routes at dawn (Ogden and Zieman 1977).

The other identifiable group of organisms is the large often pelagic top carnivores such as the jacks, tarpon, and barracuda. Of the top carnivores, only the barracuda tends to be resident in a specific location, while most others roam over large distances in search of prey in the grassbeds and over the reef.

SUMMARY

The earliest studies on seagrass ecosystems indicated that the dominant pathway of energy utilization was through the detrital food web. Recent studies and research in progress confirm that this is indeed the primary pathway for utilization of seagrass carbon, but that other pathways, notably direct herbivory and export of material from grassbeds for remote utilization, are often significant also. In addition, energy is exported from seagrass beds via utilization by

organisms, such as grunts and snappers that reside on coral reefs, but feed in grassbeds.

REFERENCES

Adams, S. M. 1976. Ecology of eelgrass, Zostera marina (L.), fish communities. I. Structural analysis. J. Exp. Mar. Biol. Ecology 22:269-291.

Bertram, G. C. L., and C. K. R. Bertram. 1968. Bionomics of dugongs and manatees. Nature 218:423-426.

Briggs, P. T., and J. S. O'Connor. 1971. Comparison of shore-zone fishes over naturally vegetated and sand-filled bottoms in Great South Bay, New York, New York. Fish and Game J. 18:15-41.

Carr, W. E. S., and C. A. Adams. 1973. Food habits of juvenile marine fishes occupying seagrass beds in the estuarine zone near Crystal River, Florida. Trans. Amer. Fish Soc. 102:511-540.

Cottam, C. 1934. The eelgrass shortage in relation to waterfowl. Amer. Game Conf. Trans. 20:272-279.

Greenway, M. 1976. The grazing of Thalassia testudinum in Kingston Harbor, Jamaica. Aquat. Bot. 2:117-126.

Hooks, T. A., K. L. Heck, Jr., and R. J. Livingston. 1976. An inshore marine invertebrate community structure and habitat association in the northeastern Gulf of Mexico. Bull. Mar. Sci. Gulf Caribb. 26:99-109.

Kikuchi, T. 1961. An ecological study on animal community of Zostera belt in Tamioka Bay, Amakusa, Kyushu. I Fish Fauna. Rec. Oceanogr. Works JPN 5:211-223.

Lappalainen, A. 1973. Biotic fluctuations in a Zostera marina community. Oikos Suppl. 15:74-80.

Marsh, G. A. 1973. The Zostera epifaunal community in the York River, Virginia. Chesapeake Sci. 14:87-97.

McRoy, C. P. 1966. The standing stock and ecology of eelgrass, Zostera marina in Izembek Lagoon, Alaska. M.S. Thesis, Univ. of Washington, Seattle. 138 p.

McRoy, C. P., and C. McMillan. 1977. Production ecology and physiology of seagrasses, p. 53-87. In C. P. McRoy and C. Helfferich (eds.), Seagrass Ecosystems: A Scientific Perspective. Marcel Dekker, New York.

Menzies, R. J., J. S. Zaneveld and R. M. Pratt. 1967. Transported turtle grass as a source of organic enrichment of abyssal sediments off North Carolina. Deep-Sea Res. 14:111-112.

Odum, W. E. and E. J. Heald. 1975. The detritus-based food web of an estuarine mangrove community, pp. 265-286. In Estuarine Research, Vol. 1. Academic Press, Inc., New York.

Odum, W. E., J. C. Zieman, and E. J. Heald. 1973. The importance of vascular plant detritus to estuaries, pp. 91-114. In Proc. 2nd Coastal Marsh and Estuary Management Symposium, Baton Rouge, Louisiana.

Ogden, J. C., and J. C. Zieman. 1977. Ecological aspects of coral reef-seagrass bed contracts in the Caribbean. Proc. Int. Coral Reef Symp. 3:277-382.

Ogden, J. C., R. Brown, and N. Salesky. 1973. Grazing by the echinoid Diadema antillarum Philippi. Formation of halos around West Indian patch reefs. Science 182:715-717.

Orth, R. J. 1971. Benthic infauna of eelgrass, Zostera marina. M.S. Thesis, University of Virginia, Charlottesville.

Petersen, C. G. J. 1918. The sea bottom and its production of food. Danish Biol. Stn. Rep. 25. 62 pp.

Randall, J. E. 1965. Grazing effects on seagrasses by herbivorous reef fishes in the West Indies. Ecology 46(3):255-260.

Randall, J. E. 1967. Food habits of reef fishes of the West Indies. Stud. Trop. Oceanogr. Univ. of Miami 5:665-847.

Roper, C. F. E., and W. L. Brundage, Jr. 1972. Cirrate octopods with associated deep-sea organisms: new biological data based on deep benthic photographs (Cephalopoda). Smithsonian Contrib. Zool. 121:1-46.

Ryther, J. H. 1969. Geographic variations in productivity in the sea, pp. 347-380. In M. N. Hill (ed.), The Sea; Ideas and Observations on Progress in the Study of the Seas, Vol. 2. John Wiley and Sons, New York.

Santos, S. L., and J. L. Simon. 1974. Distribution and abundance of the polychaetous annelids in a south Florida USA estuary. Bull. Mar. Sci. Gulf Caribb. 24:669-689.

Starck, W. A. 1969. The biology of the gray snapper (Lutjanus griseus Linnaeus) in the Florida Keys. Stud. Trop. Oceanogr.

Stewart, R. E. 1962. Waterfowl populations in the upper Chesapeake region. U.S. Fish Wildl. Serv. Spec. Sci. Rep. No. 65.

Thayer, G. W., H. Stuart, W. J. Kenworthy, J. F. Ustach, and A. B. Hall. 1978. Habitat values of salt marshes, mangroves, and seagrasses for aquatic organisms. Wetland Functions and Values: The State of Our Understanding. Amer. Water Res. Assoc. Nov. 1978.

Thayer, G. W., S. M. Adams, and M. W. LaCroix. 1975. Structural and functional aspects of a recently established Zostera marina community, pp. 518-540. In Estuarine Research, Vol. 1. Academic Press, Inc., New York.

Wood, E. J. F., W. E. Odum, and J. C. Zieman. 1969. Influence of seagrasses on the productivity of coastal lagoons, pp. 495-502. Lagunas Costeras, un simposio. Mem. Simp. Intern. Lagunas Costeras. UNAM-UNESCO, Nov. 28-29, 1967. Mexico, D. F.

Zieman, J. C., G. W. Thayer, M. B. Robblee, and R. T. Zieman. 1979. Production and export of seagrasses from a tropical bay, pp. 21-34. In R. J. Livingston (ed.), Ecological Processes in Coastal and Marine Systems. Plenum Press, New York.

RECREATIONAL IMPACTS ON CORAL REEF FISH POPULATIONS

James T. Tilmant
Biscayne National Monument
U.S. Park Service
P. O. Box 1369
Homestead, Florida 33030

ABSTRACT

The impact of recreational activities is being documented through the study of selected coral patch reefs and through the analysis of recreational fish harvest data within Biscayne National Monument, Florida. Four buoyed, frequently used, coral patch reefs have been intensively studied and compared to four similar unmarked control reefs. Approximately 3,500 persons/year have used the buoyed reefs studied. The most frequent recreational activities on these reefs were snorkeling and spearfishing. Visual species/time reef fish surveys have revealed a total of 214 fish species on the reefs studied. Similarity of the fish populations on buoyed and control reefs has ranged from 73 to 87%. Significant alteration of overall reef fish populations by present levels of recreational activites has not been evident. Parkwide, approximately 12,000 sportfishing parties/year used the Monument's reefs. None of the most frequently harvested species have shown continuous long-term declines in catch rate. However, grouper catches declined during 1979. Size class data for harvested fish indicate population age class structures have remained stable. Changes in catch rate appeared to be more closely related to total number of fishermen than to change in relative abundance of fish as determined by underwater survey.

INTRODUCTION

Florida's coral reef ecosystem is heavily subjected to a wide array of recreational activities and human uses. The fact that they are the only fully developed tropical coral reefs bordering the continental United States attracts thousands of people each year to snorkel and scuba dive. The reefs are heavily utilized for sport and commercial fishery harvest and are subjected to constant pleasure boating activities. The reef popularity is both national and local. Most local boat owners make numerous trips a year to the reefs for diving activities.

Concern for possible impact of human activity on Florida's coral reefs was documented several years ago during a coral reef workshop held at the University of Miami (October 1974). Since that first workshop, the need for research on man's impact and natural stresses has become even more urgent. Recent documentation of man-induced damages to reefs include boat anchor damage (Davis 1977), damage to coral by divers (Dustan 1977a), shipwreck damage (Dustan 1977a), and removal of live marine specimens in large numbers for aquarist trade (Jaap and Wheaton 1975). Stresses from within the reef's ecosystem, such as algal destruction of coral, hermodice predation, reduced reef vitality, and coral "shut down" reactions have also been recognized (Antonius 1977, Dustan 1977b).

In response to these concerns and to assure that the National Park Service is providing the management actions needed to properly protect the coral reefs within their trust, intensive studies of the coral reefs and their associated resources have been conducted at Biscayne National Monument during the past 4 years. These studies have included both intensive underwater investigations of the coral reefs and an assessment of organisms harvested, both sport and commercially, from the coral reef ecosystem.

It is the intent of this paper to synthesize some of the results of these two approaches in an evaluation of overall impacts of recreational activities on reef fish populations. Other aspects of our studies of the coral reefs including coral damage, studies of the reef algal communities, and observations of selected macroinvertebrates have been reported elsewhere (Tilmant et al. 1979).

Biscayne National Monument is located in the southern part of Dade County, Florida. It consists of the waters of the south end of Biscayne Bay and northern Card Sound, a northern extension of the Florida Keys, and offshore waters and coral reefs out to the 10-fathom (18-m) depth contour (Figure 1). The coral reefs occurring within the monument comprise the approximate northern limit of well-developed reef growth along the United States Coast. The Monument's reefs are a part of the coral tract that extends from Miami 360 km to the south and west terminating at the Dry Tortugas in the extreme southeastern Gulf of Mexico. The Florida reefs have been described as a bank reef system (Davis 1928) and are formed upon a broad shallow water coastal platform.

Within the area of Biscayne National Monument, the outer reefs form a discontinuous elongated barrier located approximately 7 km offshore of the keys. The outer reefs rise to within 1 m of the surface and are characterized by the corals Diploria clivosa, D. labyrinthiformis, Montastrea annularis, and Acropora cervicornis. Numerous living coral patch reefs occur between the outer reefs and the keys. These patch reefs are separated by beds of turtle grass (Thalassia testudinum) and water depth averages 6-9 m. The patch reefs generally range from 50 to 400 m in diameter and rise to within a few meters of the surface. On the patch reefs, stony coral growth is dominated by head and encrusting forms such as Montastrea annularis, M. cavernosa, Colpophyllia natans, Siderastrea siderea, and Diploria clivosa. The low-growing branching corals of the genus Porites are also common. Larger branching forms such as Acropora cervicornis and A. palmata are restricted in their occurrence. Alcyonaria grow profusely between the coral heads on the upper reef surface. Much of the reef surface and coral skeletons are covered with the hydrozoan Millepora.

METHODS

Conventional creel census techniques were employed to determine the number of reef fish species that are being harvested by sport fishermen. Fishermen returning from Park waters were interviewed at the Convoy Point boat launching ramp (Figure 1), the major access point to Biscayne National Monument. Data recorded during fishermen interviews included size of party, residence, trip hours, hours fished, area fished, species and number caught, and number of each species released. The number and species harvested was verified by the person obtaining the interview. General parkwide surveys, by boat and air, have provided data on the proportion of visitors participating in various recreational activities and enabled estimates of

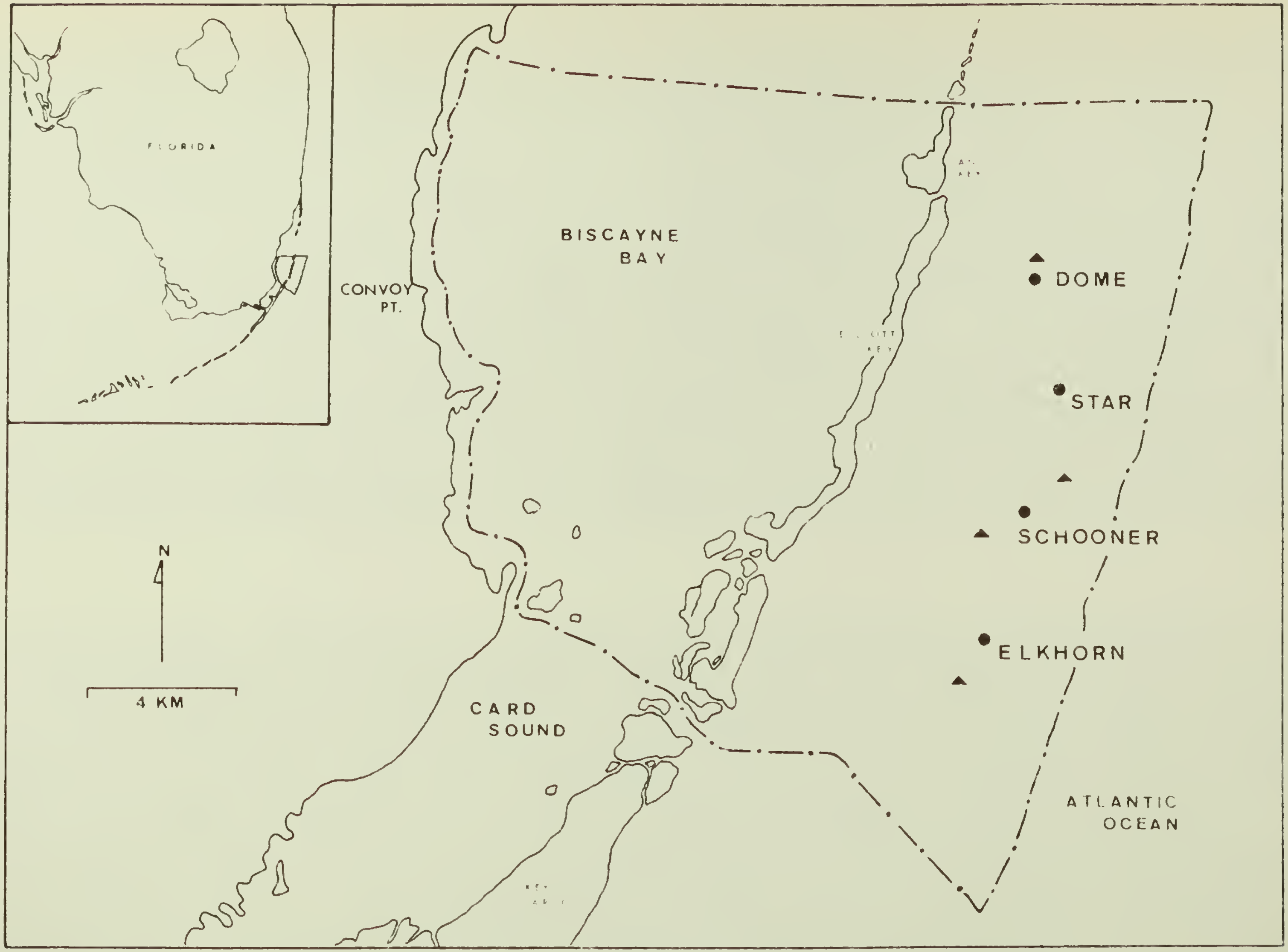


Figure 1. Biscayne National Monument, Dade County, Florida. Broken line represents the monument boundary. Location of experimental (buoyed) reefs is indicated as black circles. Black triangles represent location of control reefs.

total fishing effort and harvest from the interview samples.

Evaluation of the condition of the fishery has been based on the analysis of catch-per-unit of effort for successful fishermen and size class data of fish harvested. Size classes for selected species have been obtained by measuring fork-length, to the nearest centimeter, of a representative sample of fish in the catches observed.

Underwater observations of reef fish populations have been conducted on eight coral reefs representative of typical lagoonal patch reefs found within the Monument (Figure 1). Four of these reefs have been marked with mooring buoys and are described in a visitor brochure. By virtue of their ease of location and advertisement, these four reefs receive heavier visitor use and are considered to be experimental reefs.

The remaining four reefs were selected on the basis of their similarity in topographic relief and community structure to each of the experimental buoyed reefs and were left unmarked. These unmarked reefs are considered controls for the purpose of the study. It is believed that significant differences between communities of experimental buoyed reefs and control reefs reflect ecological impact from recreational use.

The amount of use the selected study reefs received was monitored by boat patrols designated for this purpose and by incidental observations by park staff whenever they were in the vicinity of a study reef. Patrols designated to monitor study reef use were conducted from early morning until late evening on weekends when maximum park use occurred. During such patrols, continued surveillance over all study reefs was maintained and all boat use of buoyed and control reefs was noted.

Data recorded include type of activity (snorkeling, diving, fishing), boat registration number, time of day, and number of persons per boat. The proportion of park visitors using the buoyed reefs was then determined from estimated total boat use of the park on the day patrolled. Incidental observations of the use of study reefs served to increase the total number of observations obtained per reef and provided proportional data in terms of relative frequency of use per observation.

Reef fish populations on the study reefs were assessed through a visual species/time random count technique described by Jones and Thompson (1978). This method involved assigning point values based on the amount of time required to first observe a given species during an established observation period. A series of repetitive observation periods then resulted in the most common species receiving the highest scores.

Although the species/time random count did not indicate actual numbers of individuals, it did provide a standard quantitative measure reflecting relative abundance of each species present that is comparable between study reefs. Differences in point values between buoyed reefs and their controls indicate possible impacts of recreational activity on the reef fish populations, and repeated periodic observations on the same reef might reveal seasonal changes and changes that may be attributed to various levels of visitor use.

Sixteen repetitive 50-minute counts were conducted on each study reef during each tri-annual sampling period of our study. These counts were divided equally between the outer and top reef areas yielding eight repetitive counts per reef zone. The P_k statistic of Gaufin et al. (1956) was used to determine that eight repetitive counts could be expected to reveal 95.5% or more of the possible species diversity. Comparisons between buoyed and control reef pairs and temporal comparisons of individual reefs have been made using the Shannon-Weiner diversity function and evenness values of Pielou (1966), Bray-Curtis community similarity indices (Bray and Curtis 1975), and ANOVA (one-way and multiple cell two-way) statistical tests for significance.

RESULTS AND DISCUSSION

REEF FISH HARVEST

Visitor activity surveys revealed that approximately 19% of the annual boaters used the coral reefs for one or more recreational activities (Table 1). The estimated total number of boats (based on aerial and ramp count surveys) using the park during the past 4 years and the number of these boats using coral reef areas are shown in Table 2.

Overall, approximately 35% of the boaters visiting the Monument were participating in activities consumptive of the resources (i.e., fishing, lobstering, diving for conch, or spearfishing). This percentage is higher during the winter months when other recreational activities decline. Among the boats using the reef area, 67% were conducting activities consumptive of the resources (Table 3).

A total of 126 fish species were observed harvested by recreational fishermen (including divers taking fish, lobster, and conch). Catch rates for the major reef fish families harvested during the period 1976-1978 are shown in Table 4. The six most frequently harvested reef fish species have been white grunt (Haemulon plumieri), grey snapper (Lutjanus griseus), yellowtail snapper (Ocyurus chrysurus), hogfish (Lachnolaimus maximus), Nassau grouper (Epinephelus striatus), and black grouper (Mycteroperca bonaci). Trends in catch rate for these most frequently harvested reef species are graphed in Figure 2.

It is evident from the catch-per-unit effort data that although catch rate varies seasonally, clearly declining trends have not been observed for most of the species being harvested. Two exceptions to this have been the bigeyes (Priacanthus spp.) and the black grouper. Although black grouper have declined in catch rate since 1978, overall catch rate for all groupers combined has not continually declined (Table 4). Bigeyes have never comprised more than 0.8% of the total catch and, therefore, the number of reported catches on which to evaluate catch rate has been limited. However, the annually lower catch rate for this species since 1976 indicates a decline in its population may be occurring.

There was a correlation between the total number of fishermen and resulting overall catch rates. During the period 1976 to 1978, the number of fishermen using park waters declined annually while catch rates generally increased. In 1979, reef use figures were higher than any of the previous 3 years (Table 2) and catch rates were the lowest we observed. These data indicate that present fish harvest is at or exceeding the maximum sustainable yield. Size class data obtained on several harvested species has not revealed declining trends (Table 5). A decline in size of species being harvested did not accompany the decline in catch rates observed from 1978 to 1979.

Table 1. Proportion of visitors using various park areas for recreational activities as determined by boater interviews (n = 5,254).

Park area	% of boaters
Biscayne bay	7.6
Islands and creeks	80.5
Reef zone	18.8
Gulf stream	13.0

Table 2. Estimated total number of boater visits to Biscayne National Monument and number of boaters visiting the park's coral reefs, 1976 - 1979.

Year	Total boats in park	Boats using reef zone
1976	57,250	10,900
1977	50,950	9,700
1978	46,800	8,900
1979	61,300	11,650

Table 3. Proportion of boaters using the coral reefs that participated in each recreational activity observed, Biscayne National Monument, Florida.

Activity	% of Boaters
Hook-line fishing	59.2
Snorkeling	10.2
SCUBA diving[a]	9.3
Spearfishing	8.3
Pleasure boating	7.2
Sailing	4.9
Waterskiing	0.7
Swimming	0.2
Photography	0.1

[a]Does not include spearfishermen that were using SCUBA.

Table 4. Comparison of catch rates reported by sport fishermen for the major reef fish families, April 1976 - December 1979. The percent that each species is of total catch is shown in parentheses.[a]

Family	Rate			
	1976	1977	1978	1979
Grunts	0.849 (35.0)	0.975 (26.9)	0.926 (26.3)	0.815 (30.5)
Snappers	0.506 (16.5)	0.668 (20.0)	0.552 (17.1)	0.614 (22.6)
Grouper	0.229 (6.4)	0.241 (7.0)	0.247 (7.1)	0.189 (5.9)
Wrass (hogfish)	0.407 (4.3)	0.450 (5.3)	0.437 (5.0)	0.349 (3.9)
Barracuda	0.248 (3.6)	0.210 (2.1)	0.190 (2.3)	0.247 (3.1)
Jacks	0.321 (2.1)	0.232 (1.8)	0.267 (1.4)	0.238 (2.1)
Bigeye	0.698 (0.8)	0.547 (0.8)	0.366 (0.6)	0.116 (0.1)

[a]Catch rate = Number of fish caught/man hour effort of fisherman successful in catching one or more fish of the family indicated.

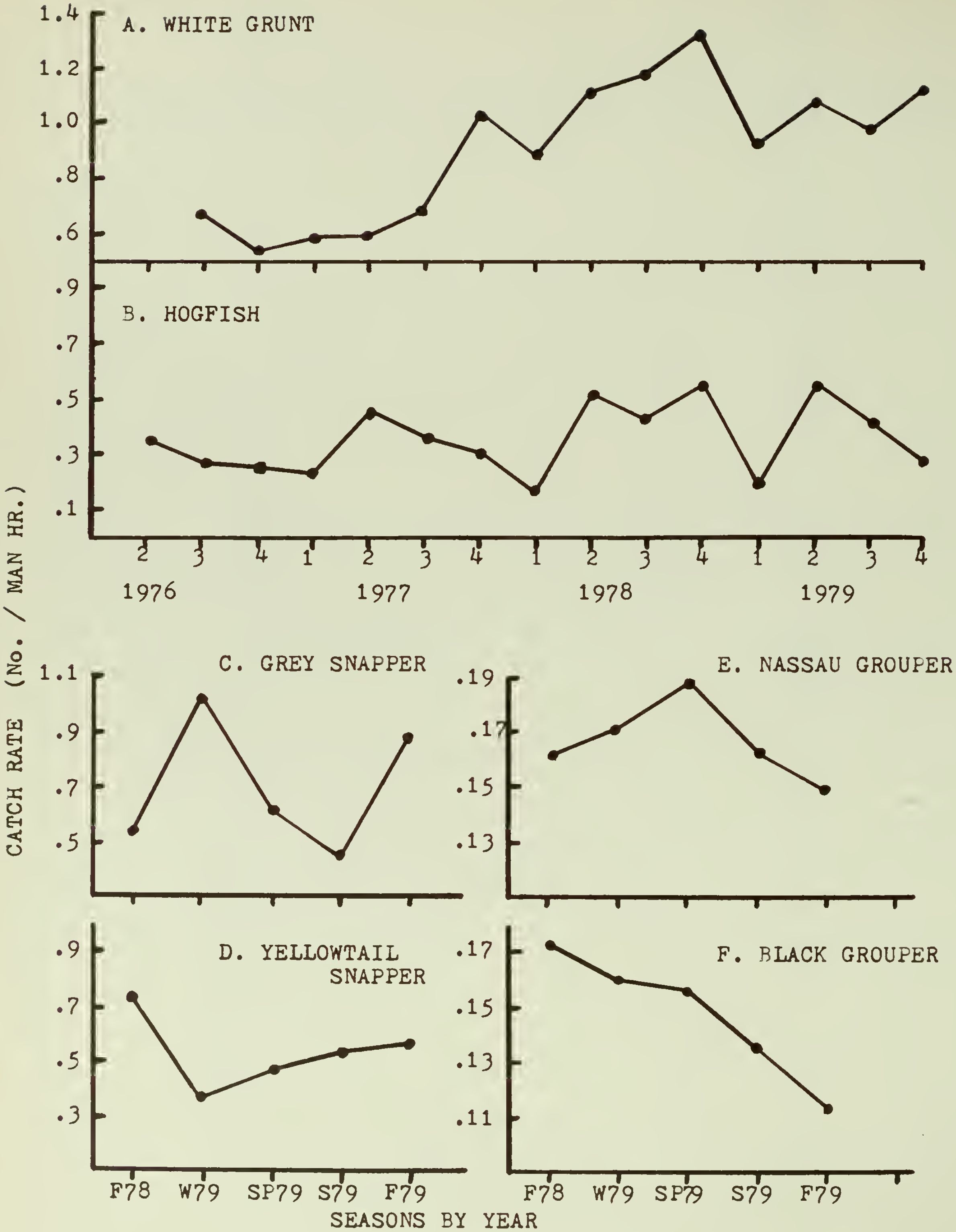


Figure 2. Changes in catch rate (Number caught/man hour effort) as reported by sport fishermen for the six most frequently harvested reef fish species, Biscayne National Monument, Dade County, Florida.

Table 5. Average size of the fish most frequently harvested from Biscayne National Monument reefs, July 1978 - December 1979.

Species	Mean size cm (standard deviation)					
	Sum 78	Fall 78	Wint 79	Spr 79	Sum 79	Fall 79
White grunt	22 (2)	22 (3)	22 (3)	34 (12)	23 (3)	23 (3)
Grey snapper	25 (6)	26 (8)	24 (5)	32 (5)	27 (7)	24 (5)
Yellowtail snapper	22 (2)	23 (4)	24 (6)	33 (8)	22 (5)	24 (4)
Hogfish	36 (9)	34 (8)	35 (10)	38 (11)	36 (9)	35 (10)
Nassau grouper	41 (8)	43 (6)	44 (12)	44 (8)	44 (7)	41 (7)
Black grouper	46 (5)	62 (17)	53 (28)	52 (12)	54 (18)	53 (14)

IMPACT AT SELECTED STUDY REEFS

Approximately 79% of the total use of the study reefs observed occurred on the buoyed reefs. The two largest reefs, Elkhorn and the Elkhorn control reef, received the heaviest amount of use. However, each of the buoyed reefs has received three or more times as much use as its corresponding control. Our observations have indictated that approximately 1.5 percent of the boaters using the park visit the buoyed experimental reefs. This represents a total annual use of from 850-900 boats (3,400-3,600 persons) on the specific reefs studied.

The most frequent recreational activities have been snorkeling and spearfishing (spearfishing is presently permitted under park fishing regulations). Approximately one third of the total recreational activity observed on the intensively studied reefs consisted of consumptive uses. This is less than the level of consumptive use on the reef tract as a whole. Approximately 70% of the consumptive use on the study reefs was spearfishing.

Underwater surveys of the reef fish populations on the patch reefs selected for study have revealed a total of 214 fish species. This exceeds the number of species reported by other investigators using the species/time random visual census on other Florida reefs. Jones and Thompson (1978) reported 146 species at a study site in the John Pennekamp Coral Reef Marine Sanctuary and 134 species at Dry Tortugas in 1975. Thompson and Schmidt recorded 137 species at the same stations at Dry Tortugas (Thompson and Schmidt 1977). Note, however, that the total number of counts over several seasons in the present study greatly exceeds the total counting time expended in these other studies.

Relative abundances of fish species were determined by accumulated point totals. Only one of the most frequently harvested fish species was found to be among the 20 most abundant species on the reef. However, this is not surprising because those species harvested by fishing generally comprise the upper level carnivores within the system and would not be expected to outnumber their prey.

In describing basic ecological conditions and assessing possible impacts of recreational activities, we have been concerned with both the number (richness) of fish species occurring on the study reefs and the relative abundance of individuals of those species. Changes in fish species richness (mean spp./count) observed during the study are shown in Figure 3. Fish abundance, as indicated by mean total point values per count, is shown in Figure 4. Seasonal changes in both species richness and fish abundance have been observed on all the reefs studied.

Total point values of abundance have fluctuated more markedly than number of species observed, but changes in abundance values have been more similar between buoyed and control reefs. Overall fluctuations in reef fish populations generally have followed a similar pattern on all the reefs. A decline in both the number of species present and the relative abundance of those species was noted on many of the study reefs during the spring of 1978. A similar decline was not evident during the spring of 1979. The spring of 1978 decline may be a result of unusually cold water temperatures during the 1977-78 winter months (Figure 3).

Two-way ANOVA tests have indicated a statistically significant difference in seasonal changes between buoyed and control reefs in five situations (Figures 3 and 4). Four of these instances involved

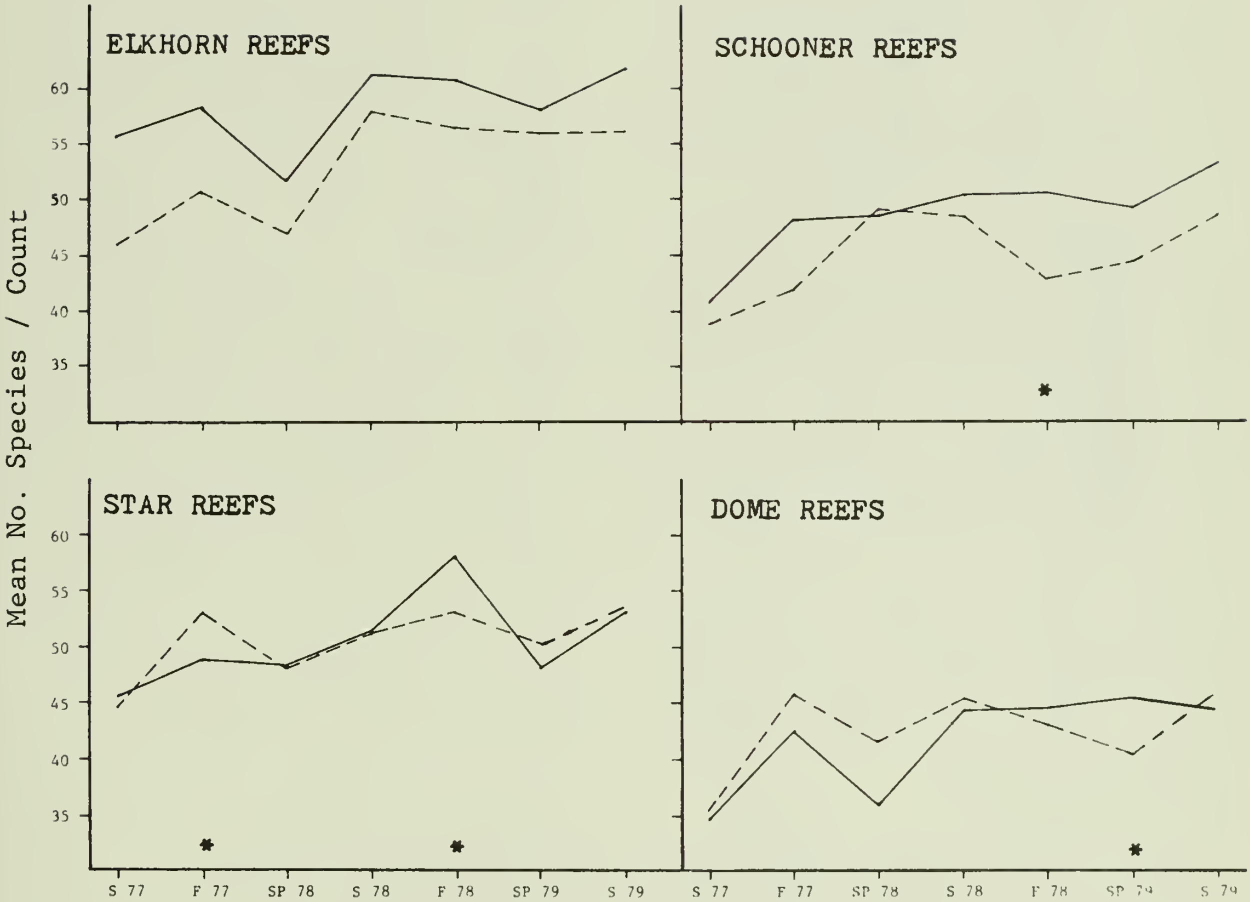


Figure 3. Mean number of fish species recorded/count on buoyed-control reef pairs, summer 1977 - summer 1979. Solid line represents buoyed reef. Broken line represents unmarked control reef. Standard error of the sample means were ± 3.0 species for all observations. A * represents significant difference ($P < 0.05$) in seasonal change between buoyed and control reefs.

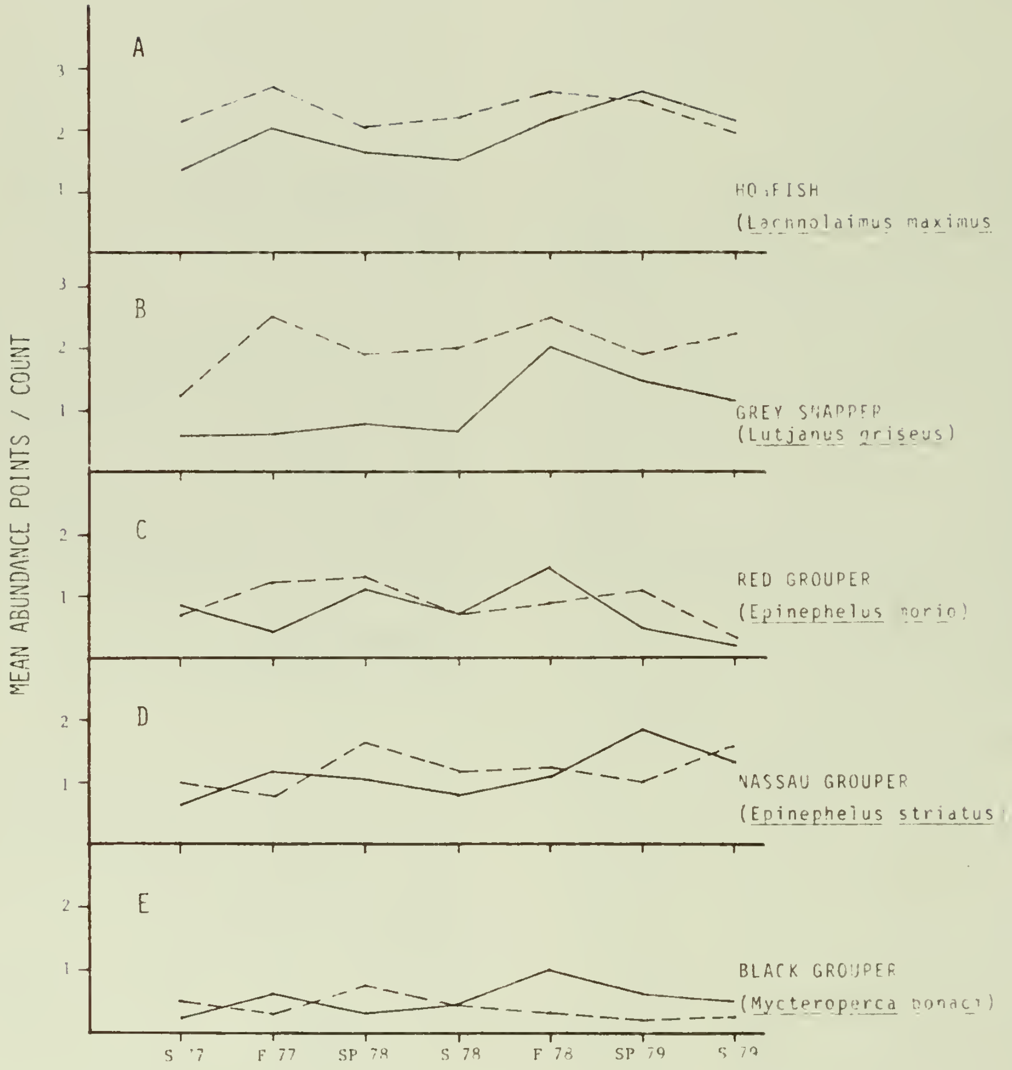


Figure 4. Mean point total/count for fish abundance observed on buoyed-control reef pairs, summer 1977 - summer 1979. Solid line represents unmarked control reef. Standard errors of the sample means were ± 10 points for all observations.

significant differences in both number of species and total fish abundance. In all but one of these circumstances (Star Reef in the Fall of 1977) the buoyed reef had either a greater increase or less decrease in species richness or fish abundance, or both, than its control.

Bray-Curtis indices have shown a relatively high similarity in species composition of fish populations (species occurring and their abundance) between each of the buoyed and control reef pairs. Although seasonal fluctuations have occurred in the populations, the community similarity indices in most cases have not greatly changed. This indicates a high similarity in species comprising the changes observed on both buoyed and control reefs.

None of the differences observed between buoyed and control reef pairs clearly indicate significant impact from human activity to the overall reef fish populations. As is evident from Figures 3 and 4, most marked differences in species richness or relative abundance between buoyed and control reefs have involved greater fish abundance and diversity on the buoyed reefs.

Spearfishing was identified as one of the most frequent activities on the buoyed reefs, so a comparison of the relative abundance of five frequently speared fish was made between buoyed and control reefs. This analysis indicates that the relative abundance of those species frequently speared has generally been lower on the more heavily used buoyed reefs. This difference has been most marked with hogfish and grey snapper between the Elkhorn reefs and Dome reefs. Differences in the abundance of groupers have not been as distinct, although for the majority of observation periods the control reefs supported a higher group repopulation than the buoyed reefs.

In the John Pennekamp Coral Reef Marine Sanctuary, where spearfishing is prohibited, Jones and Thompson (1978) reported a higher relative abundance (mean abundance point value/count) for four of these five species (Table 6). Red grouper (Epinephelus morio) was not observed by Jones and Thompson but has been observed in low numbers in Biscayne National Monument. Further comparison of these species with observations from the Dry Tortugas, where spearfishing is also prohibited, revealed that all but the Nassau grouper had a higher relative abundance at the Tortugas.

Differences in reef structure may account for differences in abundance of these fish species. However, differences between heavily used and less used reefs within Biscayne National Monument, along with overall lower populations, indicate that spearfishing activities in Biscayne National Monument may be a factor in reducing the abundance of selected reef fish species.

Results of the 1977-79 underwater surveys do not indicate continued population declines in any of the frequently harvested fish species. No declines were noted during 1979 when fishing catch rates generally declined. Long-term abundance to catch rate comparisons of frequently harvested individual species are available for only white grunt and hogfish. In both instances, relative abundance observed has roughly followed catch rate. However, seasonal short-term variation in catch rate for these species is not reflected in abundance changes. The continued decline in catch rate observed for the bigeye did correlate with a continuous decline in relative abundance of this family observed on the reefs since summer 1977.

Table 6. Relative abundance of five fish species frequently speared in three south Florida reef areas.

Species	Mean abundance point value/count			
	Pennekamp 1975[a]	Dry Tortugas 1975[a]	Dry Tortugas 1976[b]	Biscayne NM 1977-78[c]
Hogfish	2.8	3.3	3.2	1.9
Gray snapper	3.5	4.4	4.5	1.1
Red grouper	0.0	2.3	2.2	0.7
Nassau grouper	1.2	0.3	0.3	0.9
Black grouper	2.8	2.7	1.8	0.4

[a] Jones and Thompson (1978).

[b] Schmidt personal communication and as described in Thompson and Schmidt (1977).

[c] Present study (July and August observations only).

CONCLUSIONS

The data obtained at Biscayne National Monument indicate that the present level of recreational activities and consumptive uses are not depleting the coral reef fish resources. The synthesis of data obtained through fisherman interview, and through underwater observation of fish populations, indicates that reef fish populations have generally remained stable even though catch rates have shown marked declines or increases during each year.

Change in fishermen catch rate has varied inversely with number of fishermen using Park waters. This correlation suggests that total annual harvest may remain relatively constant while the number of fishermen harvesting those fish fluctuates. Under such conditions, the park fishery must be considered to be near a maximum sustainable yield. Additional data are needed, during years when the number of fishermen remained constant, to determine long term stability at present harvest levels.

Comparisons to date between closely studied buoyed and control reef pairs have indicated a high degree of similarity in overall reef fish populations. Therefore, at present levels of activity it is believed that significant alteration to reef fish populations has not occurred. It is believed these data have provided a good baseline on which to evaluate other heavily used park reefs and on which to determine impacts of future reef use.

ACKNOWLEDGMENTS

Several persons at Biscayne National Monument assisted with portions of the field work. Fishermen interviews were conducted by K. Jettmar, L. Forrester, and R. Skinner. G. P. Schmall, S. Andree, D. Morrison and R. D. Conant assisted in underwater fish surveys. G. Hendrix and G. E. Davis, Everglades National Park's Research Center, provided helpful review and comments during the study.

LITERATURE CITED

Antonius, A. 1977. Coral mortality in reefs: a problem for science and management, pp. 617-623. In Proceedings Third International Coral Reef Symposium, Univ. Miami, Coral Gables, Florida. Vol. 1.

Bray, J. R. and J. T. Curtis. 1975. An ordination of the upland forest communities of Southern Wisconsin. Ecol. Monog. 27: 325-349.

Davis, G. E. 1977. Anchor damage to a coral reef on the coast of Florida. Biol. Conserv. 11: 29-34.

Davis, W. M. 1928. The coral reef problem. Amer. Geogr. Soc. Spec. Publ. 9 as cited in: Smith, F. G. 1943. Atlantic Reef Corals. Univ. Miami Press. 164 pp.

Dustan, P. 1977a. Besieged reefs of Florida's Keys. Nat. Hist. 86(4): 73-76.

Dustan, P. 1977b. Vitality of reef coral populations off Key Largo, Florida: recruitment and mortality. Environ. Geol. 2: 51-58.

Gaufin, A. R., E. K. Harris, and H. J. Walter. 1956. A statistical evaluation of stream bottom sampling data obtained from three standard samples. Ecology 37: 643-648.

Jaap, W. C. and J. Wheaton. 1975. Observations on Florida reef coral treated with fish collecting chemicals. FDNR Mar. Res. Pub. No. 10. 18 p.

Jones, R. S., and J. J. Thompson. 1978. Comparison of Florida reef fish assemblages using a rapid visual technique. Bull. Mar. Sci. 28(1): 159-172.

Pielou, E. C. 1966. The measurement of diversity in different types of biological collections. J. Theor. Biol. 13: 131-144.

Thompson, J. J. and T. W. Schmidt. 1977. Validation of the species/time random count technique sampling fish assemblages at Dry Tortugas, pp. 283-288. In Proceedings Third International Coral Reef Symposium, Univ. Miami, Coral Gables, Florida. Vol. 1.

Tilmant, J. T., G. P. Schmahl, and D. Morrison. 1979. An ecological assessment of Biscayne National Monument's coral reefs in relation to recreational use. Proceedings 2nd National Conference on Scientific Resources in the National Parks, San Francisco, California. 15pp.

Discussion IV - Ecology of Sea Grasses and Coral Reefs (J. Zieman and J. Tilmant)

Q. M. Smith: In regard to the feeding of grunts on Thalassia in the Gulf of Mexico, do you think that this is opportunistic feeding due to the nearness of the grass beds and the shallowness of the shelf?

A. J. Zieman: The grunts in this area form schools around the patch-reef areas. These are opportunistic carnivores. They eat polychaetes, amphipods, snails, and anything along that line. These fish do not eat grass; they are strictly carnivores. Without the grass beds you would see a shifting of species away from the grunts to other species which do better in the sandy area. In the reef area there is shelter. In the grass beds there are primary production and food. Therefore, the coupling of these two systems is extremely important.

Q. A. de la Cruz: In relation to the herbivores that you have mentioned, do you have any response regarding smaller herbivores, such as isopods, amphipods, and copepods and the direct relationship on the seagrass material?

A. J. Zieman: It will be another year before I can tell you anything significant about that.

Q. R. Stewart: Are you familiar with any experimental work on the removal of seagrasses and the effects which this has on the movement of fish or the abundance of animals?

A. J. Zieman: Fortunately, to my knowledge, there has not been any work done to remove large areas like that. I do not know of any place where such a study has been done intentionally.

A. A. Banner: The converse of that is where you exclude grazing or herbivory on grass beds by caging. You can then observe the growth increase in the beds and correlate that coversely to the consumption of the grass beds which are unprotected.

A. J. Zieman: For the past three years in the Virgin Islands, the use of caging has been studied. A variety of different consumers are both kept in and kept out of the cage. In some areas you will get increases in abundance, but only in the areas where there is extremely heavy grazing such as in the actual halo zones themselves. If the exclusion cages are placed 30 or 40 m out from the grassbeds, you do not see that much change. One has to remember that even in high graze areas, 5 to 10 percent of daily production is grazed typically. The exception is in the halo areas near the reefs where you get intensively heavy grazing and effects are visible.

Q. J. Tilmant: Then are you saying that as you get away from the reef, the transient grazers only make up a small portion of the grazing that is being done and that it is the smaller invertebrates within the closure that are maintaining the same level of grazing? Do you think the smaller organisms are making up a major amount of the grazing that is going on?

A. J. Zieman: There are virtually no microcritters that are doing the direct grazing, but macrosized organisms. It is fairly easy to determine what has taken a bite of seagrass by examining the size, location, shape, etc., of the bite. For example, in the Virgin Island water, at about 75 percent of our stations, 100 percent of the grazing is done by Sparisoma. At some of the other stations, typically 30 percent to 40 percent of the grazing is done by urchins of one species or another, with some contribution by the snail Smaragnia. The queen conch are present also but have been heavily reduced by overfishing. There are no real micrograzers of living attached plants that I can tell you about right now.

Q. E. Odum: What happens if one brings shelter to the grassbeds? Would this create undesirable halos? A management question might be "Why don't we build some small halos in the seagrass bed and therefore attract fish?" That is like putting a bunch of sheep in a small pasture, however. But, if you were faced with such a management question, how would either one of you answer this question?

A. J. Tilmant: This would depend a lot upon your management objectives. In the National Park where we are trying to maintain a natural system, we would not use that approach, but if you were trying to create fish habitat in a situation where you wish as many fish as possible, you might do that. This very thing happens with fishermen in the park. They throw things overboard all the time such as old tires and cans, attempting to create artificial reefs to attract fish. In a relatively short time you can see impacts of grazing around those areas.

A. J. Zieman: I agree with Jim. It depends on your objectives. If you just want to increase fish, then they would perform that function. It is difficult to analyze a seminatural closed experiment in the field because any closure becomes an instant reef and suddenly little grunts, snappers and dozens of other little things congregate right around the shelter. Many of the grassbeds could sustain higher numbers of fish, but the numbers of fish are limited by the habitat. In some areas it would not be desirable to provide these shelters and in others it might provide a useful function.

A. A. Thorhaug: A number of developers suggested taking away a small band of seagrasses next to a shore and in place offering an artificial reef because there was no place to put more seagrasses as a mitigation tool. But, there was an opportunity to use an artificial reef as a mitigation tool. So, in those cases it has been successful. I do not know whether this is acceptable procedure and I do not know whether anyone has done a good follow-up on it.

Q. A. Thorhaug: Can you comment on whether anyone can mitigate for a seagrass bed by putting in an artificial reef?

A. L. Goldman: The policy of the Fish and Wildlife Service has been to discourage removal of one kind of habitat and substitute for another in mitigation. In regard to replacement, we try to always replace habitat loss with a similar habitat unless this is absolutely out of the question and the circumstances are greatly extenuating in nature. I also have a question for Dr. Zieman. You mentioned the effects of manatee feeding on grassbeds and I understand that this is a pretty chaotic event. I wonder if you could discuss the research which has been done on the rate of depletion of seagrasses by manatee?

A. J. Zieman: I have only observed manatee feeding in one area in Puerto Rico last year. There, we followed some around and marked some plots to find out how much they were feeding. Over a period of several months the feeding holes in beds did not recover. But, the beds that they were feeding in were unusual in that there was a very high current stress and there weren't any compacted sediments. The grasses were essentially Thalassia and Halimeda. The manatee have the ability to get down and to root into this very thick mat. In other areas where there is also very heavy and very abundant grass, where we did not find them, the substrate was more compacted. We feel that the manatee use the big bristly pads on their nose to push the sediments aside. In areas where we always found the manatee feeding, I could ram my arm down into the substrate as far as my elbow.

Q. A. de la Cruz: A few years ago in Science there was an article about the Seri Indians eating seagrasses. We also know the acumen of the Japanese regarding seaweeds and seagrasses. Direct human consumption of aquatic plants is being investigated now. Do you think there is any prospect of a seagrass aquaculture, especially in developing nations?

A. J. Zieman: All I have to say to that is try tasting seagrass. I have done everything you possibly can do to seagrass and I would not recommend it for eating. The article you are referring to involved Seri Indians. They consume Zostera but not directly. Zostera in Baja California produces prodigious seeds at a very predictable time during the year in that region. Zostera in the Gulf of California in that region is basically an annual plant. The Indians grind the seeds up and make a bread out of it and also use it as a stuffing. One of the things that you have to remember about consuming seagrasses directly is that they have an enormous amount of silica and it is very difficult to eat. Some of the species contain up to 25 percent silica content.

A. A. de la Cruz: I came across the Sundanese tribe in northern Java making salads out of the leaves of common mangroves there. Since then, I have found that there is a large direct human consumption of mangrove plants, marsh plants, seaweeds and seagrasses. There are also medicinal uses for all of these. I think this is an area quite rich in potential.

A. A. Thorhaug: In Bali, people collect the fruits of seagrasses and algae to make vegetable soups.

Q. A. Banner: Can you comment on the rate of recovery of seagrasses which have been injured by propellers or dredging of channels in this particular geographic area? Also, would you discuss the recovery of seagrasses in canal area? I am talking about any of the vascular seagrasses.

A. J. Zieman: I have seen little to change my mind on motorboat damage in the Everglades since my paper was written five years ago. Under normal conditions when most Thalassia bed sediments are damaged, it takes a long time to reestablish itself, commonly three to five years.

Obviously, canal bottoms pose a particularly difficult question when predicting what is going to happen because light is restricted as compared with an area on a shallow shelf. Thalassia has a relatively high light requirement and the other species, certainly Halodule and Syringodium, to some extent can survive in marginal habitats better than Thalassia. Canals are not extremely favorable habitats for seagrasses.

A. A. Thorhaug: I think it depends on the size of the area that was affected because the seagrasses recolonize in two major ways, one is by seeds and if you have 25 or 100 acres, you are going to have to count on seeds a great deal. The second way that they recolonize is by lateral growth of the rhizomes. With the seagrasses Syringodium and Halodule this growth can be many feet per year. With Thalassia it is only a few feet per year at most.

Recolonizing a propeller scar would take three to five years for Thalassia in a very large Thalassia area unless there would be a large seeding source. Recovery may be longer under some other conditions. For example, Howard Teas reported that in the Cutler Ridge area extremely few Thalassia have been recolonized even though the area has been closed since 1975. In Biscayne Bay, where damage was done in the late 1800s, some areas are still not recolonized. Several things affect recolonization: (1) the community just adjacent to it, (2) the availability of a seeding source and (3) the actual size of the area that has to be recolonized. Different seagrasses definitely recolonize at a different rate and this affects recolonization rate also.

A. J. Zieman: Another thing which affects recovery is the sediment itself. Despite the fact that you may think that you have the same kind of sediment as a parent bed, often you end up with very much finer material in these areas with very high organic matter. This gives you a very low redox potential and anaerobic sediments. No plants, seagrasses included, survive in a truly anaerobic environment. They maintain a slight oxygenated zone around the root created as the plant grows. If you have had a situation where the plants can slowly grow in, their roots can create this slight, fine oxygenated layer around themselves as they grow in a very slow controlled manner, much the same manner you find in the bed itself. If there is an area that has a broad expanse of anaerobic sediment, then penetration is fastest in Halodule which is a good colonizer because it is a surficial rooting plant. Roots penetrate only a few centimeters whereas Thalassia rhizomes go 20 to 25 cm and roots can go dozens of feet.

EXPERIMENTAL SEAGRASS MITIGATION IN THE FLORIDA KEYS

Roy R. Lewis III
Mangrove Systems, Inc.
504 S. Brevard Ave.
Tampa, Florida 33606

and

Ronald C. Phillips
Biology Department
Seattle Pacific University
Seattle, Washington 98119

ABSTRACT

An experimental seagrass mitigation project was initiated in February 1979 at Craig in the Florida Keys under the sponsorship of the Florida Department of Transportation. Plugs and short shoots of *Thalassia testudinum*, *Halodule wrightii*, and *Syringodium filiforme* were transplanted and are presently the subject of a two-year monitoring program. Seeds of *Thalassia* also were planted in the field and laboratory in August 1979 and laboratory - grown seedlings were moved to the field site in February 1980. A progress report on the success of the project is presented.

INTRODUCTION

Seagrass transplantation is gaining wide acceptance as a solution to the impairment of seagrass meadows. Addy (1947), using the north temperate eelgrass species, *Zostera marina*, reported the first attempts to transplant seagrasses. Several persons have attempted to transplant the tropical-subtropical species, i.e., *Thalassia testudinum*, *Halodule wrightii*, and *Syringodium filiforme*.

The evidence demonstrates that seagrasses form an ecosystem that has both physical and biological ramifications. (1) The system is as productive as any natural ecosystem on earth (McRoy and McMillan 1977). (2) It has great value in stabilizing and protecting coastlines from erosion (Wilson 1949, Ginsburg and Lowenstam 1958, Wood et al. 1969, Coull 1970, den Hartog 1970, Scoffin 1970, Taylor and Lewis 1970, Zieman 1972, Orth 1977). (3) The presence of seagrasses is essential to the occurrence and growth of many species of marine life (Davis 1913; Blegvad 1914, 1916; Petersen 1915, 1918; Allee 1923; MacGinitie 1935; Stauffer 1937; O'Gower and Wacasey 1967; Orth 1973; Santos and Simon 1974; Kikuchi and Peres 1977).

Technology in seagrass restoration is, however, still somewhat in its infancy. Only six attempts have been made to restore sea grass meadows beyond the small experimental stage (Thorhaug 1974, 1979; Churchill et al. 1978; Phillips 1978; Fonseca et al. 1979; Goforth and Peeling 1979).

In the Caribbean and Gulf of Mexico marine systems, two seagrass species form dominant growths in coastal waters and have been most tested for transplant success. Of the two, *Halodule wrightii* is a pioneering species, while *Thalassia testudinum* is a climax species (Phillips 1960; Strawn 1961; den Hartog 1967, 1970, 1971; Moore 1963). *Halodule* exhibits a wide adaptational response to substrate, temperature, salinity, and tidal zone stresses (Phillips 1960). *Syringodium filiforme* is often found mixed with *Thalassia*, but usually is less abundant (Phillips 1960). Transplant work with *Syringodium* has been limited to that of van Breedveld (1975) using plugs.

There are two forms of a seagrass that may be used in transplantation, i.e., vegetative material and seeds. Vegetative material appears to be the most logical choice because it is present throughout the year, while seed production is seasonal, abundance and germination are unpredictable, and survival of seedlings in the field is low. However, Thorhaug has described excellent success using Thalassia seedlings in the Biscayne Bay, Florida, area (Thorhaug 1974, 1976a, 1976b). Transportation of seeds may also be less expensive and therefore, should be investigated.

When vegetative material is used, experience has shown that plugs (a mass of plants removed from the bottom intact in the sediment) give the best results. In this situation, the original sediment becomes the anchor for the transplanted material, inasmuch as the root hair-sediment interface is undisturbed. A modification of this technique is the use of turfs, which are generally intact squares of sediment and plants. The removal of a turf and its placement at a distant site are best done with plants with shallow rhizomes and an intertidal planting site (Ranwell et al. 1974). Plugs have been used to transplant Thalassia, Syringodium, and Halodule in the United States (Kelly et al. 1971; Phillips 1974, 1978; van Breedveld 1975). Success has varied widely (0-100%), depending on the site. Investigation of this technique is essential.

Vegetative material in the form of turions (intact rhizomes and short shoots without sediment) also can be used. This method often involves the use of anchoring devices to keep individual turions in place until regrowth has anchored them further with new rhizomes and roots. This method has been used with Thalassia, Syringodium, Halodule, and Zostera (Kelly et al. 1971, Phillips 1974, Eleuterius 1975). Success has generally been lower than that with plugs. However, it may be a viable method for seagrass revegetation and should therefore be investigated.

All work performed on the transplantation of the three tropical species, Thalassia, Syringodium, and Halodule, except for Phillips (1978) and Thorhaug (1974), has been small experimental programs. Even with the large-scale programs, factors affecting the success or failure of a technique have not been adequately assessed. Therefore a feasibility study which closely monitors several seagrass species, under similar physical conditions, using different transplant techniques, is absolutely essential to formulate reasonable predictions about the success or failure of a large-scale program of seagrass restoration.

A rather intensive monitoring program of physical, chemical, and treatment variables is required to determine the causal factors which are responsible for the success or failure of the applied methods. In the instance of the loss of submerged vegetation due to the replacement of 37 bridges in the Florida Keys, the Florida Department of Transportation felt a small scale, well-documented, experimental project would be advisable before large-scale mitigation attempts. For this reason a contract was awarded to Continental Shelf Associates to undertake a two-year experimental seagrass mitigation project at Craig in the Florida Keys. Dr. Ron Phillips of Seattle Pacific University and Robin Lewis of Mangrove Systems, Inc., serve as consultants to Continental Shelf Associates and are co-principal investigators on the project.

SITE DESCRIPTION

The proposed planting site is located on the southeast side of Craig, Monroe County, Florida (Figure 1). The site is a 1.6-hectare burrow area that has silted in with fine calcareous sand and silt since its creation during dredging activities in the Florida Keys approximately 30 years ago. Water depths average 1.2 to 1.5 m at mean low water over the site with a shallow (0.3 to 0.6 m mlw) sill surrounding the area and probably corresponding to the original undisturbed bottom. This adjacent area is well-vegetated with *Thalassia testudinum*.

A large portion of the site is presently vegetated with green algae, or colonizing seagrasses (*Thalassia*, *Halodule*, *Thalassia*-*Halodule* mixture). Only approximately 25% of the site is largely barren of vegetation.

MATERIALS AND METHODS

Three types of plant material have been used in this experimental study. These include plugs, turions, and seeds. Plugs and turions for all three species, *Thalassia*, *Halodule* and *Syringodium*, were planted 13-16 February 1979. *Thalassia* seeds and seedlings were planted at the Craig site on 16 August 1979. (Seeds germinate very rapidly into seedlings and the seedlings were much more abundantly available than the seeds.)

Plugs consisted of intact sediment and plant material in the dimension of approximately 22 cm x 22 cm x 10 cm high. Turions consisted of individual plants with rhizomes and roots cleaned of existing sediment. Turions were attached to small concrete anchors with plastic tiewraps before planting. Seeds and seedlings were abundant and collected in the intertidal zone of Craig and Lower Matecumbe Key. Small plastic tiewraps were investigated for use as seed or seedling anchors but were not used due to anticipated detrimental effects to the small seeds and delicate blades of the seedlings.

Table 1 provides a summary of the planting materials and techniques utilized. Each plot contains seven rows by seven rows of plant material for a total of 49 sites planted in each plot. One plug or turion was planted at each site. Five seeds or seedlings were planted at each site for a total of 245 seeds or seedlings per plot.

Spacing of 2 m, 1 m or 0.33 m was obtained by planting the seeds at points identified by tying marked lines between the corner stakes and then again between the lines connecting the corner stakes. All lines were removed after planting was completed. The corner stakes, which protrude approximately 15 cm from the bottom, were marked with identification tags and left as permanent plot markers. Elevation stakes were placed within each 1-m spaced plot for elevation determinations. Elevations of these stakes relative to msl were determined by relating them to a USGS benchmark by using standard survey techniques.

During 13-18 August 1979, cultivating tanks were set up to investigate utilizing laboratory-reared *Thalassia* seedlings.

Four 114-liter aquariums with filters were set up in the Florida Department of Transportation (DOT) laboratory trailer in Marathon, Florida. Overhead lighting consisting of two 120-cm cool white florescent bulbs on a 12-hour on and 12-hour off basis were installed. A 1.8-m diameter pool tank was set up outside the labora-

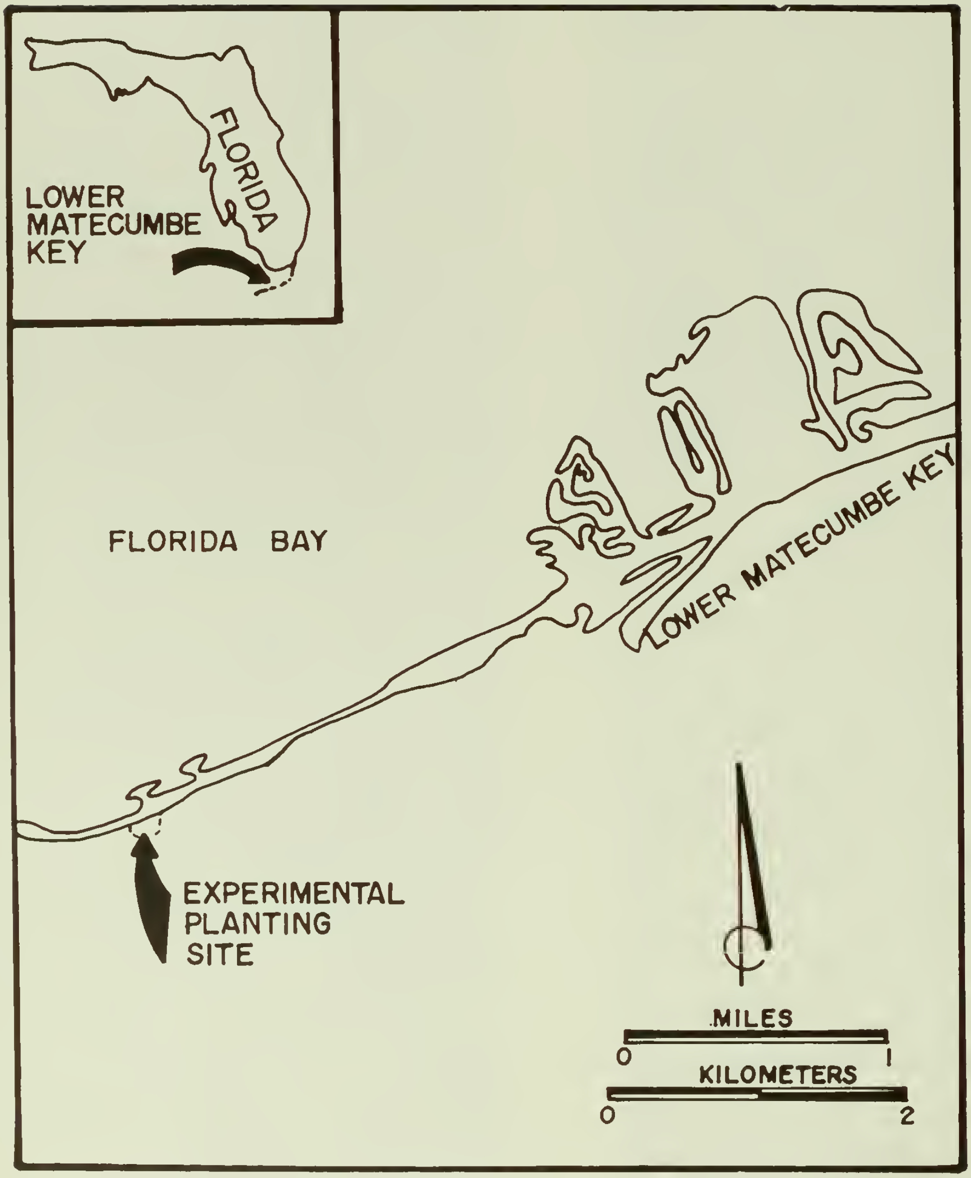


Figure 1. Location of experimental planting site.

Table 1. Summary of planting material and techniques.

Experiment plot	Species planted	Materials	Spacing	Planting sites per plot	Number of planting materials per planting site
TP-1	*Thalassia*	plug	1 m	49	1
TP-2	*Thalassia*	plug	2 m	49	1
TT-1	*Thalassia*	turion	1 m	49	1
TT-2	*Thalassia*	turion	2 m	49	1
TS-1/3	*Thalassia*	seed	1/3 m	49	5
TS-1	*Thalassia*	seed	1 m	49	5
TS-2	*Thalassia*	seed	2 m	49	5
HP-1	*Halodule*	plug	1 m	49	1
HP-2	*Halodule*	plug	2 m	49	1
HT-1	*Halodule*	turion	1 m	49	1
HT-2	*Halodule*	turion	2 m	49	1
SP-1	*Syringodium*	plug	1 m	49	1
SP-2	*Syringodium*	plug	2 m	49	1
ST-1	*Syringodium*	turion	1 m	49	1
ST-2	*Syringodium*	turion	2 m	49	1
TS/H-1[a]	*Thalassia*	seed	1 m	49	5

[a]*Thalassia* seeds planted among colonizing *Halodule*.

Table 2. Surviving seagrass transplants as of 17 August and 18 November 1979 (Planted 12-16 February 1979).

Transplant plot	Number planted	Number surviving 17 AUG	Number surviving 18 NOV
TP-1	49	49	37
TT-1	49	19	9
HP-1	49	33	2
HT-1	49	14	0
SP-1	49	30	30
ST-1	49	14	0
TP-2	49	39	34
TT-2	49	12	12
HP-2	49	24	0
HT-2	49	14	0
SP-2	49	30	7
ST-2	49	7	0
TS-1	245	245	8
TS-2	245	245	0
TS-1/3	245	245	0
TS/H-1	245	245	0

tory trailer with a flow through saltwater system.

Sediment for the tanks was collected from natural Thalassia beds adjacent to the experimental site at Craig, Florida. Saltwater was obtained from the northwest side of Vaca Key behind the DOT laboratory trailer in Marathon, Florida. Seeds and seedlings for planting in the tanks were collected from the intertidal zone on the southeast side of Craig at Lower Matecumbe Key.

Fifty seeds or seedlings were planted in each of the four 114-liter aquariums for a total of 200 planted indoors. Two hundred seeds or seedlings were planted in the 1.8-m outdoor pool tank.

The aquariums and outdoor pool tank are being monitored by DOT personnel during the laboratory growth phase to insure continuous operation of the systems.

Six-month old seedlings were moved from the tanks to the field site in February 1980.

RESULTS TO DATE

In all instances the plug material has shown greater survival than turions, regardless of spacing. Among the three species planted, Thalassia plugs show the best survival over Syringodium and Halodule plugs. This probably reflects the difference in the total amount of sediment moved with the plant material.

In contrast to the greater survival of the Thalassia plugs, the general (unqualified) observed spread was much greater for the Halodule and Syringodium. The only observed sites of coalescence (meeting of spreading rhizomes from adjacent planting sites) were in the Halodule plug (1-m spacing) area. Before September 1979, some areas of Syringodium were approaching coalescence. Spread from the Thalassia plugs was generally poor.

Survival of turions was approximately the same for all species for the first six months, with spread being greatest for Halodule, least for Thalassia, and somewhere in between for Syringodium (visual estimates only). During September 1979, two hurricanes passed close to the planting site and winds as high as 50 mph were recorded in the Keys. Table 2 lists the survival of all plant materials at the end of six months (before hurricanes) and at the end of nine months (after the hurricanes). It is obvious that there has been a significant loss of Halodule and Syringodium planted materials. There was also nearly a 100% loss of all the Thalassia seedlings.

During the February 1980 site visit the six-month old lab grown seedlings were installed and 49 additional Halodule plugs were placed on 1-m centers. Future reports on this project will be available from the author.

LITERATURE CITED

Addy, C. E. 1947. Eelgrass planting guide. Md. Conserv. 24:16-17.

Allee, W. C. 1923. Studies in marine ecology: III. The distribution of common littoral invertebrates of the Woods Hole region. Biol. Bull. 44:167-193.

Blegvad, H. 1914. Food and conditions of nourishment among the communities of invertebrate animals found on or in the sea bottom in Danish waters. Rep. Danish Biol. Stn. 22:41-78.

Blegvad, H. 1916. On the food of fish in the Danish waters within the Skaw. Rep. Danish Biol. Stn. 24:17-72.

Churchill, A. C., Cok, A. E., Riner, M. I. 1978. Stabilization of subtidal sediments by the transplantation of the seagrass Zostera marina L. New York Sea Grant; NYSSGP-RS-78-15. 48 pp.

Coull, B. C. 1970. Shallow meiobenthos of the Bermuda platform. Ecologia. 4:325-357.

Davis, B. M. 1913. Part 1, Section 2. Botanical and biological survey of the waters of Woods Hole and vicinity. Bull. Bur. Fish. 31(1911):443-544.

den Hartog, C. 1967. The structural aspect in the ecology of seagrass communities. Helgol. Wiss. Meeresunters. 15(1-4):648-659.

den Hartog, C. 1970. The seagrasses of the world. North-Holland, Amsterdam.

den Hartog, C. 1971. The dynamic aspect in the ecology of seagrass communities. Thalassia Jugoslavica 7(1)101-112.

Eleuterius, L. N. 1975. A study of plant establishment on spoil areas in Mississippi Sound and adjacent waters. Final Report to Corps of Engineers, U.S. Army for the period 1 July 1971 to 30 Nov. 1974. Gulf Coast Research Lab., Ocean Springs, Mississippi 327 pp.

Fonseca, M. S., W. J. Kenworthy, J. Homziak, and G. Thayer. 1979. Transplanting of eelgrass and shoal grass as a potential means of economically mitigating a recent loss of habitat, pp. 279-326. In D. P. Cole (ed.), Proceedings of the Sixth Annual Conference on Wetlands Restoration and Creation. Hillsborough Community College, Tampa, Florida.

Ginsburg, R. M., and H. A. Lowenstam. 1958. The influence of marine bottom communities on the depositional environment of sediments. J. Geol. 66:310-318.

Goforth, H. W., and T. J. Peeling. 1979. Intertidal and subtidal eelgrass (Zostera marina L.) transplant studies in San Diego Bay, California, pp. 327-356. In D. P. Cole (ed.), Proceedings of the Sixth Annual Conference on Wetlands Restoration and Creation. Hillsborough Community College, Tampa, Florida.

Kelly, J. A., C. M. Fuss and J. R. Hall. 1971. The transplanting and survival of turtle grass, Thalassia testudinum, in Boca Ciega Bay, Flordia. Fish. Bull. 69(2):273-280.

Kikuchi, T., and J. M. Peres. 1977. Consumer ecology of seagrass beds, pp. 147-193. In C. P. McRoy and C. Helfferich (eds.), Seagrass Ecosystems: a Scientific Perspective. Marcel Dekker, New York.

MacGinitie, G. E. 1935. Ecological aspects of a California marine estuary. Amer. Midl. Nat. 16:629-765.

McRoy, C. P., and C. McMillan. 1977. Production ecology and physiology of seagrasses, pp. 53-87. In C. P. McRoy and C. Helfferich (eds.), Seagrass Ecosystems: a Scientific Perspective. Marcel Dekker, New York.

Moore, D. R. 1963. Distribution of the seagrass, Thalassia, in the United States. Bull. Mar. Sci. Gulf Caribb. 13:329-342.

O'Gower, A. K., and J. W. Wacasey. 1967. Animal communities associated with Thalassia, Diplanthera, and sand beds in Biscayne Bay. I. Analysis of communities in relation to water movement. Bull. Mar. Sci. 17:175-210.

Orth, R. J. 1973. Benthic infauna of eelgrass, Zostera marina, beds. Chesapeake Sci. 14: 258-269.

Orth, R. J. 1977. The importance of sediment stability in seagrass communities, pp. 281-300. In Coull, B. C. (ed.), Ecology of Marine Benthos. Univ. of South Carolina Press, Columbia.

Petersen, C. G. J. 1915. A preliminary result of the investigations on the valuation of the sea. Rep. Danish Biol. Stn. 23:29-33.

Petersen, C. G. J. 1918. The sea bottom and its production of fish food. A survey of the work done in connection with valuation of the Danish waters from 1883-1917. Rep. Danish Biol. Stn. 25:1-82.

Phillips, R. C. 1960. Observations on the ecology and distribution of the Florida seagrasses. Fla. St. Bd. Conser. Mar. Lab. Prof. Pap. Ser. No. 2.

Phillips, R. C. 1974. Transplantation of seagrasses, with special emphasis on eelgrass (Zostera marina L.). Aquaculture 4(2):161-176.

Phillips, R. C. 1978. Seagrass bed development on dredged spoil at Port St. Joe, Florida, pp. 1-11. In Lewis, R. R., and D. P. Cole (eds.), Proceedings of the Fourth Annual Conference on Restoration of Coastal Vegetation in Florida, 1977 May 14, Hillsborough Community College, Tampa, Florida.

Ranwell, D. S., D. W. Wyer, L. A. Boorman, J. M. Pizzey, and R. J. Waters. 1974. Zostera transplants in Norfolk and Suffolk, Great Britain. Aquaculture 4(2):185-198.

Santos, S. L., and J. L. Simon. 1974. Distribution and abundance of the polychaetous annelids in the South Florida estuary. Bull. Mar. Sci. 24(3):669-689.

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

Stauffer, R. C. 1937. Changes in the invertebrate community of a lagoon after disappearance of the eelgrass. Ecology 18(3): 427-431.

Strawn, K. 1961. Factors influencing the zonation of submerged monocotyledons at Cedar Key, Florida. J. Wildl. Manag. 25(2):178-189.

Taylor, J. D. and M. S. Lewis. 1970. The flora, fauna and sediments of the marine grass beds of Mabe, Seychelles. J. Nat. Hist. 4(2):199-220.

Thorhaug, A. 1974. Transplantation of the seagrass Thalassia testudinum Konig. Aquaculture 4(2):177-183.

Thorhaug, A. 1976(a). The vascular plants of Biscayne Bay, pp. 301-312. In Biscayne Bay Symposium Volume 1. University of

Miami Sea Grant Special publication No. 5.

Thorhaug, A. 1976(b). Transplantation techniques for the seagrass Thalassia testudinum. University of Miami Sea Grant Tech. Bull. No. 34.

Thorhaug, A. 1979. Growth of restored Thalassia in a multiply impacted estuary, pp. 236-276. In Cole, D. P. (ed.), Proceedings of the Sixth Annual Conference on the Restoration and Creation of Wetlands, 1979 May 19, Hillsborough Community College, Tampa, Florida.

van Breedveld, J. F. 1975. Transplanting of seagrasses with emphasis on the importance of substrate. Fla. Mar. Res. Publ. No. 17.

Wilson, D. P. 1949. The decline of Zostera marina at Salcombe and its effects on the shore. J. Mar. Biol. Assoc. U. K. 28 (2):395-412.

Wood, E. J. F., W. E. Odum, and J. C. Zieman. 1969. Influence of seagrasses on the productivity of coastal lagoons, pp. 495-502. In Lagunas Costeras, un Simposia. Mem. Simp. Intern. Lagunas Costeras. UNAM-ENESCO.

Zieman, J. C. 1972. Origin of circular beds of Thalassia (Spermatophyta: Hydrocharitaceae) in South Biscayne Bay, Florida, and their relationship to mangrove hammocks. Bull. Mar. Sci. 22(3):559-574.

RESTORING THE FLORIDA EVERGLADES

Arthur R. Marshall
Ecologist
P. O. Box 613
Interlachen, Florida 32048

ABSTRACT

The conversion of the Florida Everglades from a free-flowing, solar-driven natural system into a petroleum-intensive technological system has caused severe reductions in valuable natural resources. The established petroleum-intensive agriculture may be short-lived. Massive urban expansion also presents serious difficulties. "First stages" of restoration of the Everglades must be planned and instituted to enable solar energy to resume a prominent role.

INTRODUCTION

The Everglades is the dominant and largest ecologic system of the southern coastal plain of Florida. The source of the Everglades drainage basin is the Kissimmee "Chain of Lakes" south of Orlando, not Lake Okeechobee as many imagine. The downstream flows of these lakes coalesce in Lake Kissimmee and then flow via the lower Kissimmee River into Lake Okeechobee. Lake Okeechobee and all of its distributaries to the east, west, and south follow in the system, eventually leading to the sawgrass Everglades, Everglades National Park and its environs, and the northern reaches of Florida Bay. (Figures 1 and 2--historic and present).

The Everglades is an array of interdependent and integrated lakes, rivers, canals, ponds, sloughs, marshes, swamps, tree hammocks, mangrove forests, shorelines, islands, estuaries, and bays. It is a large and formidable system. In its pristine condition, the Everglades system was able to:

1) Maintain about 13,000 km^2 of wetland marshes and swamps.
2) Support abundant freshwater fish populations throughout its 320 km long interior basin.
3) Support large and highly diverse populations of native and migratory wildlife, including terrestrial, semiaquatic, and aquatic forms.
4) Contribute to the abundance of estuarine and marine populations in a 320 km long arc of coastal bays and estuaries lying around the southeastern and southern shores of the peninsula.
5) Accumulate more than 2,600 km^2 of peat and muck soils thick enough for the needs of modern agriculture.
6) Yield more fresh water of high quality than south Floridians could even now use.

The three great geophysical components of the Everglades system--its lithosphere, hydrosphere, and atmosphere--were energized to accomplish the above solely by the force of the sun. The use of fossil fuels, however, has brought about a characteristic change in the Everglades system--largely for the dual purposes of drainage and water management. Consequently, there is a reduced ability of the system to yield its former solar products.

About 3,900-5,200 km^2 of wetlands have been drained or severely degraded by partial drainage. (Compare Figures 1 and 3.) Freshwater fishes can no longer use the drained wetlands and can use those partially drained only intermittently.

Eight or more endangered or threatened wildlife species are in

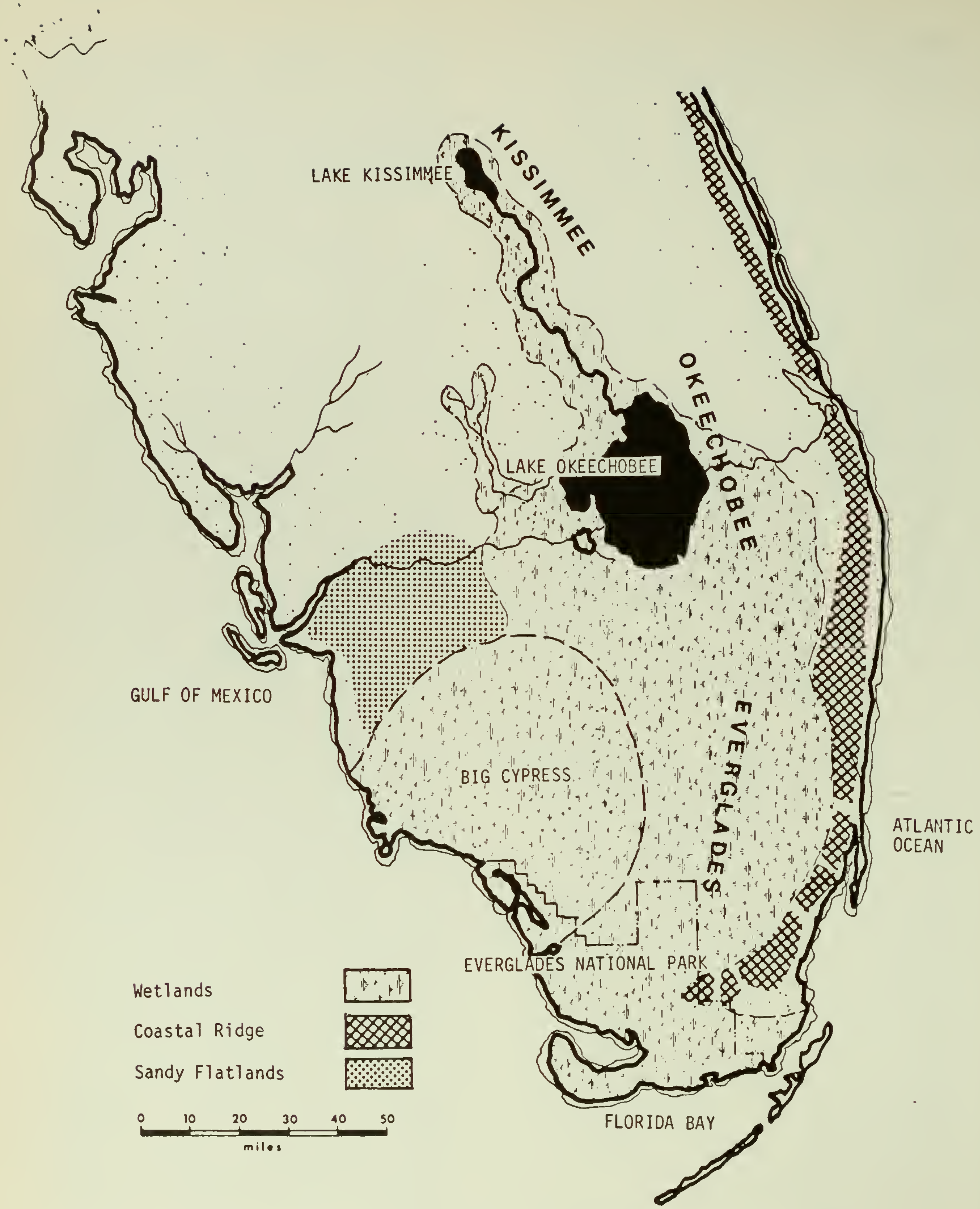


Figure 1. Historic wetlands of Florida Everglades.

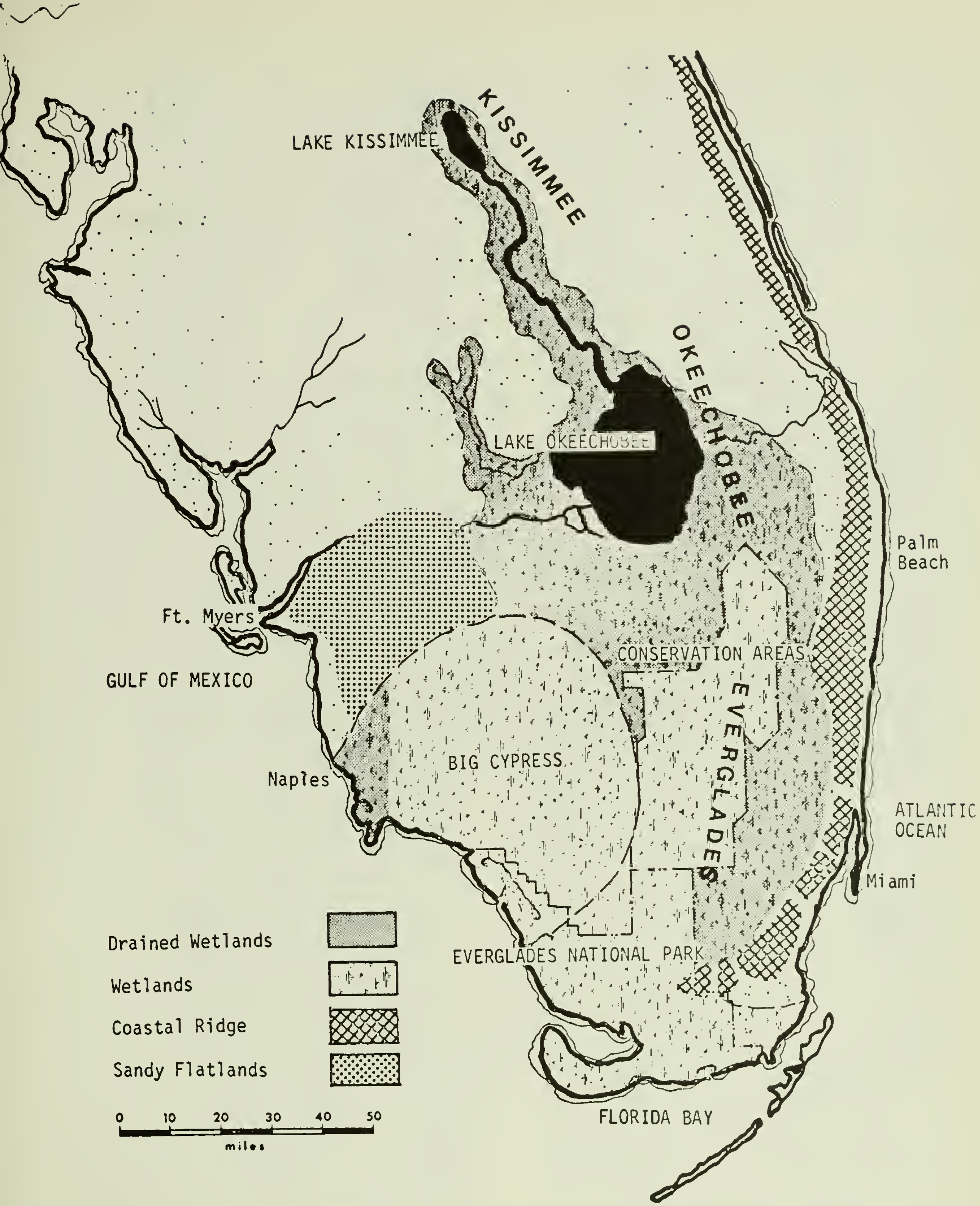


Figure 2. Present wetlands of the Florida Everglades.

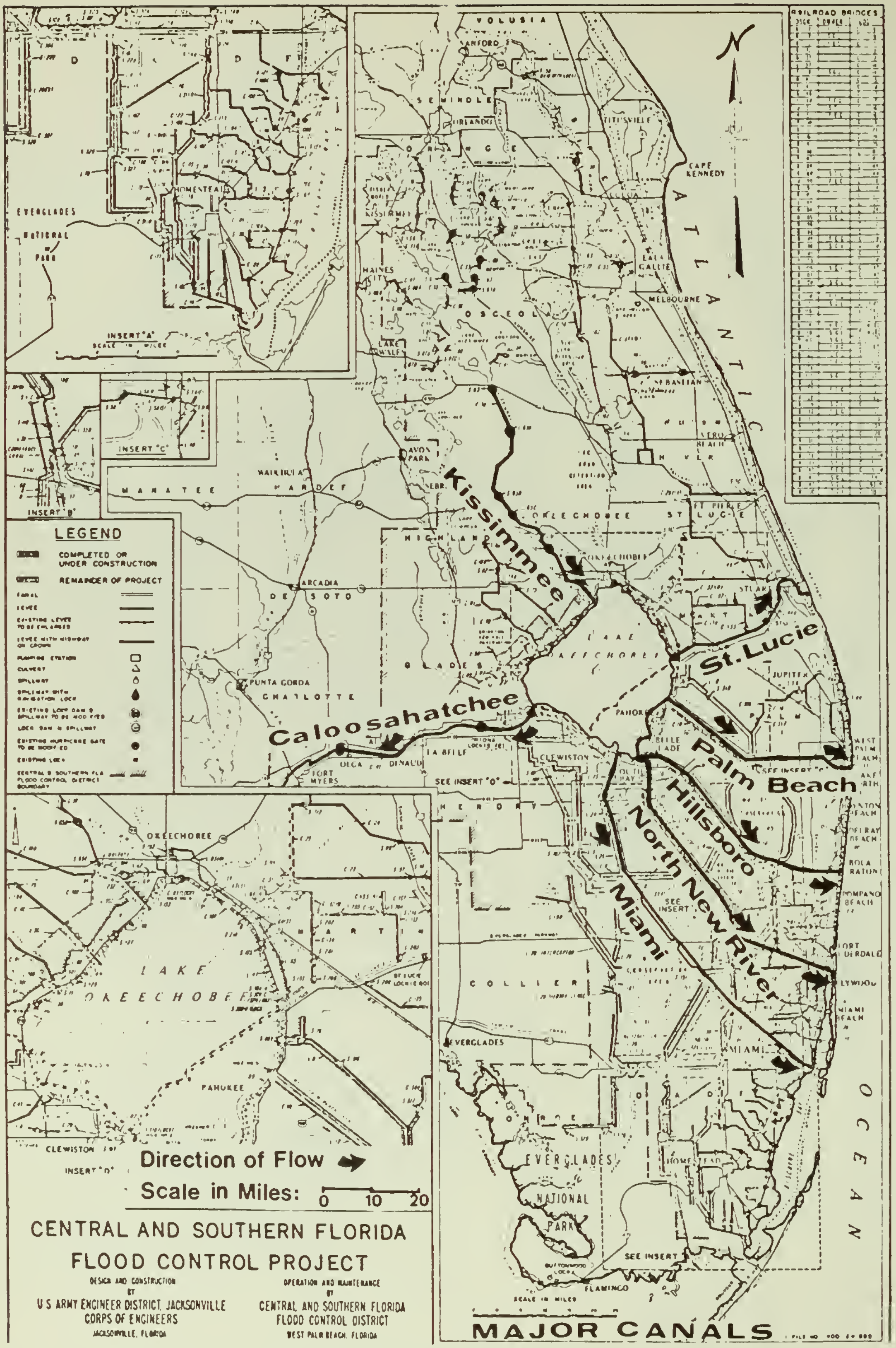


Figure 3. Central and southern Florida flood control project.

the system--the number varying between State and Federal lists; colonial wading bird populations have declined from about 1.5 million individuals in 1935 to about 0.25 million today; frog populations have been critically reduced from the standpoint of commercial harvesting; alligator (Alligator mississippiensis) populations are high in some areas and obliterated from others; the Florida white-tailed deer (Odocoileus virginianus seminolus) populations expand periodically in areas made more available to them by lowered water levels and then undergo mass mortality when water levels rapidly rise.

Thousands of acres of freshwater wetlands of the southern Everglades, which historically had shallow and seasonal flooding, have been drained or are flooded in the wrong months. The young of dozens of marine and estuarine fishes and invertebrates can no longer use Florida Bay as nursery grounds because of habitat changes. Many other bays and estuaries receive devastating surcharges of fresh water diverted from the interior basins or receive none at all when it is needed biologically for reproduction, growth, or both.

The process which produced peat and muck soils has been eliminated from the 3,120-km^2 agricultural area south of Lake Okeechobee and from other areas peripheral to the central basin which have been drained. In the basin's deeper central portions which are still seasonally flooded, organic soils now oxidize more than they accumulate because the dry seasons have been lengthened critically relative to a gain in muck.

Water levels in the interior basins have been reduced by about 1.5 m. At the same time, demand for freshwater has greatly increased, partly owing to drainage which has made former wetlands available for extensive urban expansion. Water quality problems in the canals which discharge freshwater to the coasts include heavy loads of finely divided muck and an array of pollutants picked up from both agricultural and urban runoff.

These major losses of solar-derived products of the Everglades system demonstrate that human environmental welfare is directly involved in the exchange for fossil fuel use. Every product listed as lost or degraded is growing in importance in south Florida, in the State, and the Nation. The benefits to agriculture from drainage and water management are destined to be short-lived--about another 20 years--as the organic soils continue to oxidize to effective depletion, and energy investments in fossil-fuel dependent agriculture continue to mount. Urban expansion, made possible by drainage, will either continue to prove beneficial or will be adjudged by a harsh array of imminent factors which include:

- The ability of governments to finance needed services and to govern.
- The consequences of the determination of many leaders of government to provide increasingly energy-intensive facilities for nurturing further urban growth.
- The degree to which energy use in the cities by individuals, commerce, and by government becomes conservative and efficient.
- The ability of south Florida to rely on its own resources for recreation, esthetics, water, food (seafood and farm crops), and as a base for tourism.
- The ability or will of the OPEC nations to supply fuels which south Florida needs to maintain its life support systems in the Everglades and in its cities.

MORE DEVELOPMENT TO COME

The wild and urban systems of south Florida are not static. Although many millions have been spent on research, the amounts spent to change them are infinitely greater. Costs of drainage and water management now exceed one half billion dollars. Millions are to be spent extending Interstate 75 across the Everglades to Broward County and then south into Dade County--largely in remnant wetlands. A new jetport is to be built in the eastern Everglades basin. Millions are also proposed to be spent to finish draining the partially drained wetlands on the eastern periphery of the old Everglades.

MANAGING THE EVERGLADES

COMPLEXITY--A PERSONAL VIEW

First there is the question of complexity. In my circumstance as an employee of the U.S. Fish and Wildlife Service from 1955 to 1970, I felt little confidence in comprehending Everglades complexities at least in my first five years. It was a great learning experience. In the grist mill of confrontation one encounters as a government resource manager, I sensed that I not only had to know the system at least as adequately as anyone else but I also had to go far beyond the confines of my formal education in marine fisheries science.

This awareness took me into expanded studies of the geology of south Florida; terrestrial and aquatic biology; topography of the coastal plain; hydrology of the system; engineering terms and concepts including design memoranda of the U.S. Army Corps of Engineers; wildlife management principles; the genesis, significance, and depletion of muck; chemistry of fresh and salt waters; weather; authorities and policies of many city, county, State and Federal agencies and their interrelationships; and an acquaintance with political and administrative officials and with officers and members of many conservation organizations of Florida.

Although the Everglades is unique in some ways, I doubt that resource managers of other ecosystems can succeed in their efforts for those systems in the absence of an approach much as I have described.

I know what Everglades resource managers must contend with and while I sympathize for their burdens I believe that the greatest rewards come from the most exacting tasks.

SPECIALIZATION AND HOLISM

It seems especially difficult for employees of government to hold to holistic principles of ecologic systems, even when they are well understood. Agencies of government have historically been assigned specialist roles. Highway departments built highways; the Corps of Engineers built public works projects; one agency dealt with saltwater and another with freshwater; one agency dealt with water quantity and another with its quality. Clear-cut authorities and objectives often produced combat and fostered disregard for the holistic nature of living systems.

Recent legislative and judicial actions and events in Florida and nationally, however, have enabled progress in taking a holistic view. Expanded responsibilities have been placed on agencies such as the Corps, water management districts, highway departments, and even on housing agencies. An expanding awareness of realities seems to be realized. The imminent reduction in energy supplies will emphasize that man is a part of and depends on nature--a rational proposition recognized by those who comprehend the holistic nature of life.

PROCESS

Although there are cases in point, it is difficult to conceive of a natural resource problem which is generated or can be solved suddenly. The deterioration of water quality in some lakes of the Everglades has required decades to occur. The loss of Everglades muck in the agricultural area will continue for another 20 years in addition to the 30 years of oxidation which has already passed. The reduction of colonial wading bird populations has involved a span of 45 years. The severity of problems in the urban Gold Coast is only now being widely noted after 40 or 50 years of continual growth. Our present peaking use of petroleum has evolved over 100 years.

Just as there is often a lag in ecosystem deterioration, recovery can also be expected to lag. If the opportunity to restore the Everglades is realized, researchers and students of the system should pursue the elements of its recovery just as carefully as they have documented its decline.

Resource managers should think in terms of process--long-term viewing. Some Everglades problems are expected to respond quickly to restoration efforts--most notably the rejuvenation of wetlands and their aquatic populations. Others, such as muck accumulation, will take a long time.

The goal of resource managers should be to recreate habitat conditions which return productivity to a system. These processes in the Everglades would allow solar energy to assume an increased role relative to fossil fuels, again producing resources of interest and value to man.

MONOCULTURE

The introduction of fossil-fuel energies into systems such as the Everglades is done largely for the purpose of simplifying those systems and of reducing their large number of products to a few of greater economic interest. By such means, systems are often tailored toward monoculture. Modifications of the Everglades, however, is aimed at two goals: agriculture and urban growth. If one takes the long-term view--which in reality is not far off--there are other beneficial purposes which the Everglades must be revamped to serve. As ecologists often say, monoculture is accompanied by hazards and strengths that emerge from systems characterized by diversity.

RESTORATION OF THE EVERGLADES

It is evident that: (1) efforts to restore the Everglades require departures from conventional goals. More than anything else, success in the effort will require a social determination stemming from the reality which now compels us to redefine our goals for the system; and (2) it is neither possible nor desirable to undo the whole system of water management at this time.

Many Floridians have worked for years to achieve restoration of the Loxahatchee River, the St. Johns River, the lower Kissimmee River, and the Oklawaha River, and they continue to do so. Accomplishments have occurred for the Loxahatchee and St. Johns Rivers but the major task for the other two lies ahead.

Owing to its earnest concern for the declining fish populations of

Florida Bay, an organization of south Florida fishermen known as the Everglades Protection Association is moving to institute the first stages of restoration of the Everglades. Their program is ambitious. Their first aims are to seek support of many conservation organizations and assistance from the Department of the Interior.

A proposal which I and six of my colleagues--all scientists and engineers with long experiences in the Everglades--drafted for the Everglades Protection Association has been submitted for consideration to Assistant Secretary of the Interior Robert L. Herbst. The proposal asks that the Department provide funds, personnel, and essential physical facilities to enable the preparation of a plan to accomplish five first-stage objectives. Those objectives are:

1. Restoration of the Turner River in the Big Cypress Reserve.

2. Reestablishment of surface water connections (both in wet and dry seasons) between the Big Cypress Reserve and Conservation Area Three, now separated by the south half of Levee 28.

3. Restoration of sheet flow in the Holey Land and Rotenberger Tracts just north of Conservation Area Three and in Conservation Area Three itself.

4. Refilling of portions of Canal 111 lying astride of and east of U. S. Highway 1 and those portions of Canals 109 and 110 which were dug before their construction was halted by the Cabinet of Florida.

5. Reestablishment of sheet flow in the northeastern sector of the Shark River Slough.

If the request is approved, the report on the plans will be submitted to the Assistant Secretary within six months.

The persons who will prepare the report are well-qualified for the undertaking. Our combined knowledge constitutes the holistic view which, as emphasized, is required. We understand the complexity, the problems of specialization and holism, monoculture, and the importance of process. Each of us is also in a position to work with freedom from agency constraints.

The projects to be covered were selected for a variety of reasons including: (1) relative speed and ease of accomplishment, (2) the fact that most of the lands involved are publicly owned or held as State flood easement lands, (3) that all projects, when instituted, will benefit Everglades National Park, (4) that projects are less likely to generate the massive opposition inherent in restoration of the Oklawaha, the St. Johns, and the lower Kissimmee Rivers, (5) that the benefits of each project can be readily documented after installation, and, (6) that each project presents an approach which rational people, knowing of their benefits, can emulate elsewhere.

I am hopeful for this first stage restoration project and ambitiously feel that it is within the reach of our society to solve this local problem. Solution of this local problem can yield the maturation and development needed to undertake extended global concerns.

SEAGRASSES IN THE GULF OF MEXICO, FLORIDA AND CARIBBEAN INCLUDING RESTORATION AND MITIGATION OF SEAGRASSES

Anitra Thorhaug
Department of Biological Sciences
Florida International University
600 Grapetree Drive
Miami, Florida 33149

ABSTRACT

Seagrasses are frequently the dominant nearshore organism in clear coastal, estuarine, lagoonal, and back reef areas throughout the Gulf of Mexico, Florida East coast estuaries, and Caribbean. The dominant species in much of the Caribbean and Gulf of Mexico is Thalassia testudinum. Both Halodule and Syringodium filiforme can be stages in seagrass succession to a dominant Thalassia community. The food web associated with the various seagrasses differs markedly between Thalassia and Halophila. In many locations, the Halodule community has less faunal diversity and abundance, fewer epibionts, and less benthic macroalgae associated with it than a Thalassia community. Restoration of Thalassia by seed has been moderately successful in South Florida. Thalassia plugging was not successful in the middle west Florida coast. Thalassia turion planting was successful on the Texas coast and not on the upper Gulf of Mexico. Halodule wrightii was successfully plugged in South Florida, middle west Florida, and Texas, but not successfully in the Florida Panhandle. Ruppia has been successfully planted in north Florida in fresh to estuarine environments.

DISTRIBUTION OF SEAGRASSES IN THE GULF OF MEXICO AND CARIBBEAN

SPATIAL DISTRIBUTION

Basic Environments

There are two basic kinds of environments for the Caribbean seagrass community. First is a high energy windward community which in some instances is protected from the wave action by a barrier reef. This is found in the northern islands of the Caribbean, toward the Atlantic Ocean, generally on the north or east coasts. Frequently there is a narrow continental shelf.

The second kind of environment is on the lower energy leeward side, which occurs frequently on the south or west coasts. There are frequently large continental shelves associated with this, for example in Cuba, Jamaica, Puerto Rico, Dominican Republic, Panama, Venezuela, and of course the Bahama Banks. To apply this windward-leeward model to the Florida region, the eastern coast would be the windward and the shallow extensive continental shelf area of the western Florida coast would be the leeward side. This pattern is reversed in Panama and Columbia so that the Caribbean side is leeward.

The areas adjacent to the shore are most likely to have extensive seagrass beds. The seagrass becomes patchy away from shore, less abundant and in general the associated animal communit, also decreases. This is unfortunate because most of man's impacts occur adjacent to shore.

The southern Gulf of Mexico and Caribbean are generally dominated by Thalassia testudinum; in areas of lower salinity, such as mouths of rivers and in intertidal zones, Halodule wrightii frequently dominates. In the less saline areas of

Table 1. Outline of major seagrass studies in the Gulf of Mexico and Carribbean.

Site	Primary investigator or major review	Date of publication	Groups of organisms	Pollutant
S. E. FLORIDA				
Biscayne Bay	Thorhaug	In press	seagrass, macro & microalgae, & animals	heat, heavy metals, & salinity
	Thorhaug	1974a	plants & animals	
	McLaughlin & Thorhaug	1978	animals in restored seagrass	heat
	Thorhaug	1976a	whole bay system	all
Card Sound	Thorhaug et al.	1979	plants & animals	
GULF OF MEXICO				
Florida Bay	Tabb et al.	1962	plants & animals	
	Zieman	1976	seagrass	propeller sears
Rookery Bay	Yokel	1975	seagrass & animals	
Tampa Bay	Phillips	1960	seagrass	dredge & fill
	Blake et al.	1976	seagrass & animals	thermal
	Simon and Dauer	1977	animals	red tide, urban problems, & oil
	Blake et al.	1973	continental shelf animals	
Anclote Anchorage	Baird et al.	1971-73	plants & animals	
	Mayer & Maynard (eds.)	1975	plants & animals	
	Ford et al.	1975	seagrass	
	Thorhaug et al.	1977	plants & seagrass	
Crystal River	Snedaker (ed.)	1974	animals	heat
	Odum et al.	1974	ecosystem model	heat
	Van Tine	1974	plants	heat
ESCAMBIA BAY	Livingston	1976	animal & plant community	chemical
	Livingston et al.	1974		
LOUISIANA	Eleuterius	1975	seagrass restoration	

(continued)

able 1. (concluded)

Site	Primary investigator or major review	Date of publication	Groups of organisms	Pollutant
ISSISSIPPI	Gunter et al.	1974	nearshore & offshore animals	salinity
EXAS				
Galveston	Strawn et al.	1974 numerous dates	animal community	heat
Corpus Christi	Carangelo et al.	1979		dredge
EXICO	Lot-Helgueros	1977	seagrass	baseline
ARIBBEAN				
Mexico Cancun Cozumel Isla de Mujeres	Jordan	Government reports	corals & seagrass community	
Cuba	Buesa	1974, 1977	seagrass	baseline
Jamaica South Coast	Greenway	1974, 1976	seagrass & animal feeding	urban
Puerto Rico				
Guayanilla Bay	Schroeder	1976	seagrass	heat & chemicals
	Vicente	1975, 1977	seagrass	heat & chemicals
	Kolehmainen et al.	1974	seagrass-mangrove	heat & chemicals
Jobos Bay	Martin	1972	animal in seagrass	heat
Various SW Coast	Montgomery	1975	fish & seagrass	baseline & chemical
Virgin Islands				
St. Thomas	Sprogis	1975	epiphytes on seagrass	baseline
St. Croix	Ogden	1976, 1977	animal interactions with seagrass	baseline
	Ogden et al.	1973	epiphytes	baseline
Venezuela	Reyes	unpublished		

the northern Gulf, e.g., the bayous of Louisiana and Mississippi, Ruppia maritima is frequently the dominant species.

The seagrass Syringodium filiforme is sometimes found intertidally, but frequently as a successional stage in the development of a Thalassia community. Syringodium grows rapidly and colonizes an area aggressively. Facts are not clear about the distribution of Syringodium in terms of invasion and loss of this seagrass.

Available Reviews

Extensive reviews of studies about seagrass distribution in the Gulf of Mexico have been done by Humm (1956, 1964) and by Humm and Hildebrand (1962). These studies of seagrass communities are scattered in location and an extrapolation of knowledge between the sites studied is difficult. Certain study sites where substantial data have been accumulated are listed in Table 1. Far more is known about the inshore seagrass community than is known about the offshore community, such as large continental shelf areas in the Gulf of Mexico, off South Cuba, and Panama.

Caribbean

The Caribbean, in terms of marine primary productivity, is in essence a coastal state. There are large stretches of deep sea which have fairly clear water and fairly low productivity. The problem with the Caribbean is that there are large distances between many of the small islands which have rather specific microsystems. It is not clear how data can be extrapolated from one island to another throughout this extensive area.

TEMPORAL DISTRIBUTION

Much less is known about the temporal distribution of any of the seagrasses. Thalassia is by far the best studied in terms of temporal distribution. Major studies were conducted at: Biscayne Bay [Thorhaug, 1971, 1972, 1973, 1974a and 1974b, Thorhaug and Roessler 1977, Zieman 1975, Thorhaug (in press)]; Anclote (Ford et al. 1975, Thorhaug et al. 1977); Texas, Puerto Rico (Schroeder 1976, Vicente 1977); Virgin Islands (Zieman, this proceedings), and Jamaica (Greenway 1976).

It appears that in the subtropics, in the Gulf of Mexico, there are large differences between cold- and warm-period standing crops of seagrasses. In the winter and late fall, a severe drop in the amount of productivity and biomass occurs. Nearer the center of the tropics, as in Jamaica, there is less biomass change, but still a change between a rich late spring and early fall crop and a standing winter crop.

Halodule and Syringodium have been studied by Ford et al. (1975) and Thorhaug et al. (1977) at Anclote and also by Thorhaug and Roessler (1977) at Biscayne Bay. These species also have minimum standing crops in winter and maximum in late spring.

FUNCTIONS

PRODUCTIVITY OF CARBON MATERIAL FOR ANIMAL CONSUMPTION

The seagrass Thalassia generally has a high productivity ranging from 500 to 2,000 g dryweight/ m^2. This productivity is in the same range as highly productive mature stands of mangroves and marsh grasses. Not all seagrasses produce the same amount of carbon material. Thalassia testudinum, with broad leaves and high abundance, appears to produce more material than Halodule or Syringodium and a great deal more than Halophila.

Thalassia

The most thorough studies of Thalassia productivity have been done by Thorhaug (Thorhaug 1971, 1972, 1973, 1974a, 1976a) over six years at Turkey Point and Thorhaug (in Thorhaug and Roessler, 1977) over four years at Card Sound. This length of study is necessary to detect annual variations (Table 2).

Based on data in Table 2, productivity of Thalassia (which has been studied by a similar method at Anclote, Biscayne Bay, and Card Sound, Florida, and at Kingston, Jamaica) appears to increase from the subtropics toward the tropics. The standing crop of Thalassia also generally increases. Geographic comparisons of Syringodium and Halodule are extremely difficult to make because of insufficient productivity data.

Two general articles on seagrass epiphytes are by Harlin (1980) and Penhale and Sprogis (1976). Other epiphyte studies include benthic macro-algae as epiphytes by Humm (1976), detailed monthly epiphytic biomass and species by Humm (in Thorhaug et al. 1977), and detailed work by Eisenman (1976) and Ballentine and Humm (1975).

The only piece of detailed tropical or subtropical epiphyte productivity work known by this author is by Penhale and Thorhaug (1977) and Thorhaug et al. (1977), using a C^{14} uptake method. Productivity of blue-green algae epiphytes on Thalassia was reported by Capone (1978) in a detailed thesis.

ANIMAL INTERACTION

A geographic summary of animal communities associated with seagrass is seen in Table 1. Much more is generally known about animal communities in the northern Caribbean, Florida, and Gulf of Mexico than other places. Biscayne Bay, Card Sound, Rookery Bay, Tampa Bay, Anclote, Escambia Bay, Galveston, Kingston Harbor, Guayanilla Bay, Jobos Bay, and St. Croix are the best studied.

One of the largest studies in the Gulf of Mexico involving interaction between fishes and plants was conducted at Anclote. A preoperational study of invertebrates was made by Baird et al. (1971a, 1972), and Baird and Rolfes (1973). An extensive animal study was done during the first operational year of a power plant (Thorhaug et al. 1977). Three zones of seagrass existed: an inner Halodule zone, a mid bay Thalassia zone, and an outer Syringodium zone. Animal communities, different both in quality and quantity, were associated with each of these three zones. Unfortunately, the extensive statistics included only the effects of the power plant versus nonaffected stations. Statistical differences between animal communities within the different seagrass beds were not calculated. However, Thorhaug et al. (1977) believe that there were both qualitative and quantitative differences between the animal communities. Thalassia had the most abundant and diverse animal community, Syringodium the second, and Halodule substantially less in biomass and number of species.

Biscayne Bay

There are several extensive summaries of animal reports involving Biscayne Bay (Roessler and Tabb 1974, Roessler et al. 1975, Thor-

Table 2. The production of blade material of Thalassia testudinum in Card Sound, Florida, in grams dry weight per square meter per day for various stations, based on bi-weekly measurements, 1971-74 (from Thorhaug and Roessler 1977).

Station	1971	1972	1973	1974	Mean	S.D.
104	3.585	3.833	5.622	2.758	3.95	1.21
204	2.730	3.001	3.314	2.227	2.82	0.46
304	1.026	1.154	1.248	0.750	1.04	0.22
403	1.358	1.288	1.227	1.207	1.27	0.07
404	0.544	0.367	1.564	0.386	0.72	0.57
405	1.525	1.339	1.298	0.995	1.29	0.22
503	0.312	0.392	0.443	0.206	0.34	0.10
504	0.673	0.536	0.923	0.822	0.74	0.17
603	0.353	0.397	0.389	0.161	0.33	0.11
604	0.591	0.539	0.829	0.496	0.61	0.15
606	0.555	0.470	0.739	0.431	0.55	0.14
703	0.288	0.372	0.445	0.519	0.41	0.10
704	0.620	0.489	0.632	0.411	0.54	0.11
803	0.261	0.354	0.332	0.396	0.34	0.06
805	0.778	0.814	0.708	0.449	0.69	0.16
1103	1.898	1.594	2.253	1.410	1.85	0.78
Mean	1.070	1.060	1.370	0.850	1.14	
S.D.	0.950	1.020	1.370	0.730		

haug and Roessler 1977, and, Thorhaug et al. 1979). Roessler found 480 species (632,255 individuals) of animals among the seagrass specimens collected by trawling from 1968 to 1973. Twenty-one taxa made up 81% of the total catch. Thorhaug and Roessler (1977) reported dominant species of animals in Biscayne Bay and Card Sound in order of decreasing abundance. Vegetation weight was shown to be the primary variable affecting catches of animals in Biscayne Bay. A multiple regression analysis showed that amount of vegetation was the controlling factor for 13 of the 14 indicator species (9 mollusks, 4 crustaceans and 1 sponge) present. This relationship gives a strong indication of the importance of vegetation.

Also, as reported by Thorhaug et al. (1973), when the vegetation died because of heat poisoning from the power plant, most animals left the area.

The third piece of evidence of seagrass animal interaction is the work of McLaughlin and Thorhaug (1978). When Thalassia was restored to denuded areas where thermal pollution had occurred at Grand Canal and Turkey Point, Florida, the animal community after four years was not statistically distinguishable from control areas. Areas still barren of seagrasses have significantly different species within the community.

Thorhaug and McLaughlin (1978) investigated a series of seagrass beds in the multiply impacted North Biscayne Bay. They also are presently investigating the animal community which is returning to a restored seagrass bed in north Biscayne Bay. They found appreciable differences in animal communities between the Halophila and Thalassia beds.

Preliminary observations of restored North Biscayne Bay Thalassia communities showed that within weeks of restoration fishes and invertebrates were using the restored Thalassia blades for habitat, a place of attachment, and a place for eggs.

SEDIMENT INTERACTION WITH SEAGRASS

Thalassia generally has a dense rhizomal and root system which frequently binds the sediment 1.2 - 1.8 m below the surface. Fossil rhizomes of Thalassia have been located many meters below the surface still binding sediment around it. Both Halodule and Syringodium have rhizome and root systems which only penetrate a few centimeters below the surface. The latter two are easily uprooted by storms, boats passing by, and by other high energy events.

The genus Halophila (several species found in the Gulf of Mexico and Caribbean) has extremely light rhizomal and root structure in comparison to the other three. Binding capacity is perhaps 50% greater for Thalassia as compared with Halophila and Syringodium. There is little difference in binding capacity between Syringodium and Halodule. There may be as much as another 40% difference in binding capacity between Halophila and Syringodium and Halodule. There may be a 90% difference in binding capacity between Thalassia and Halophila.

The loss of seagrasses in muddy and sandy mobile substrates leads to winnowing and in turn depletes the abundant infauna (Wanless 1975 and 1976). In areas where seagrasses have recolonized, the opposite effect occurs; sediment accumulates and is bound. More detailed data are necessary to understand the interactions between turbidity, sediment, quality, and quantity of sediment binding and the species of seagrass.

POLLUTANTS

The effect of pollutants on seagrasses has attracted considerable attention. However, complete information on limits of pollutants on all four major species of seagrasses in the Gulf of Mexico and the Caribbean and differences in geographic location are not clear. The only comparative study was one in which Biscayne Bay and Caribbean seagrasses were studied for their upper thermal limit (Thorhaug et al. 1977, Thorhaug and Greenway 1978, Thorhaug and Schroeder 1979).

Comparable studies, done with sufficent replication and comparable methods over a series of locations, have not been undertaken. The data are patchy at best and caution is necessary when utilizing the present generalizations, but pressing needs of decisionmakers require that preliminary general patterns be drawn.

DREDGE AND FILL

Among the most prevalent and most harmful sources of pollution to seagrass in the Gulf of Mexico and the Caribbean are: dredge and fill projects required for real estate development; large waterfront industries such as power plants; causeway construction and other Department of Transportation projects; U.S. Army Corps of Engineers' maintenance of intracoastal waterways and other channels, including marine dumping of the spoil associated with these channels, ports, and private marinas; inlet authorities who must continually dredge and spoil to keep important inlets open for navigation; and boat propellers causing small but long-lasting effects. The political problems associated with some of these are evident.

The technology for minimizing biological impact associated with most instances of dredge-fill is presently available, but the political-economic framework is often the stumbling block to minimizing damage. (One of the most important examples is the long legal battle between the Corps of Engineers and Marco Island.) The political problems in the Caribbean are even more intense, such as in Puerto Rico, where the siting of a large industrial complex allowed many effluents to pollute fish nurseries in Guayanilla Bay.

Advice for potentially polluting developments includes the following: (1) Use the best possible design which minimizes dredging or filling. (2) Curtains should be used in all instances to reduce turbidity effects. The construction party should be completely responsible for a good curtain and the satisfactory use of curtains. (3) Spoil should be deposited upland as much as possible. Joe Caroll (U.S. Fish and Wildlife Service) had the excellent idea of using leftover spoil to fill pre-NEPA dredge holes so that after filling, the area was brought up to the photosynthetic zone. Revegetation could then occur after the spoil had settled. This type of disposal is an excellent possibility for excess spoil from Corps and inlet authority maintenance dredging.

One of the most important problems with dredge and fill, besides either dredging seagrasses directly or filling on top of them, is that large adjacent areas become turbid even when curtains are used, especially for periods during winter coldfronts. Also, as witnessed when Miami Beach was filled, large amounts of sediments, if not compacted with rip-rap or other bulkheads, continue to erode away for a very long period, causing substantial increased turbidity in the adjacent waters (Wanless 1976).

The side effects of dredging are that suspended matter remains in the water column for long periods of time, blocking necessary light for growth of seagrasses, and siltation from dredging often smothers adjacent grass beds completely, causing them to die.

Bulkheading has damaged extensive areas of very productive seagrass beds.

Sand removal from the bay bottom destroys the seagrass growing on the sand. In one area well studied by Wanless, the Thalassia removed in a burrow pit had not returned after seven years. Some areas are far better for sand removal than others due to great differences in density of grasses. Areas in the central Bay with sparse seagrass would be better for burrow pits (Thorhaug 1976a).

Second review of dredging and filling is found in Zieman (1975).

OIL

Oil pollutants have been studied by Diaz-Piferrera (1962). Recent data on oil pollution on Texas seagrasses have not yet been collated and reported (Farrington et al. 1980). Intertidal seagrasses especially seem to be very vulnerable. Benthic seagrasses which do not come into immediate contact with oil slicks appear to be much less affected than are their associated communities.

CHEMICAL POLLUTANTS

Most of the chemical pollution data have been reported by Schroeder (1976), Thorhaug and Schroeder (1978), Schroeder and Thorhaug (1980), and have been reviewed by Thorhaug (in press) in detail. Uptake of chemicals can be either through the blades or through the roots. Chemicals such as heavy metals are concentrated in large quantities by seagrasses; however, no upper limit of direct chemical toxicity has been ascertained. The effects of chlorine, pesticides, and other industrial organometallics have not been established for seagrasses.

THERMAL POLLUTION

The effects of thermal pollution on seagrasses have recently been completely summarized by Thorhaug (in press). Thorhaug et al. (1978) have summaries (including tables) showing the differences between the Gulf of Mexico and the Caribbean seagrasses. Basically, the lethal temperature limit for seagrasses is only a few degrees above their summer ambient temperature, which is between 32° and 34°C (depending on geographic location). Thalassia seedlings from many places were tested and a small difference was seen between tropical and subtropical species.

The seagrass Halodule has a temperature limit of perhaps 1°C greater than Thalassia. Syringodium seems to be more sensitive than Thalassia; that is, its upper temperature limits would probably range between 30° and 33°C within subtropics-tropics regions. Temperature limits for Syringodium in the tropics have not yet been reported.

RESTORATION, MITIGATION, AND ENHANCEMENT OF SEAGRASSES

Mitigation, in the opinion of this author, includes the best possible siting of developments, the least biological damage, and public necessity. Mitigation should be differentiated from restoration or enhancement. In the permitting process, seagrasses should be restored only after the best possible site has been chosen for the project (which causes minimal biological damage) and the project is clearly necessary. Restoration, enhancement, or rehabilitation should occur to minimize biological damage of a project. Seagrass restoration should not be used to justify a project which could not be justified without restoration.

It is important for permitting officials to understand that seagrass mitigation was not successful until the early 1970's, although some early phases of it were begun in 1945. Thus, it is a much younger technique than rip-rapping, mangrove planting, or marsh planting, and is still developing. Different investigators had vastly different success using the same species; in different localities there have been different degrees of success (summarized in Thorhaug 1976a) (Table 1).

The best possible assurance that the restoration will be successful comes from preliminary tests (which take a year or more to validate) by the investigator who is to attempt the proposed mitigation. The investigator who successfully restores seagrasses in an area and is willing to guarantee the success of the mitigation or restoration under question has demonstrated desirable evidence of probable success.

There are several severe problems which hamper restoration or mitigation, e.g., disease, energy and sediment regimes, and hurricanes. These problems complicate recovery, but good planning is important to increase the probability of success.

It is important to have good aerial photographs and maps of grassbeds to make an intelligent site selection. Frequently, if a channel development, effluent discharge, or other pollutants are moved slightly, much less damage may occur.

It is important to know the history of an area. Those areas which are multiply impacted frequently are better for development than those which are pristine.

Public necessity and least damage are two of the important criteria to consider. The cost of mitigation and other aspects of the project are important to keep in mind for a balanced picture. For example, a small landowner developing a private marina could not possibly bear the economic costs for restoration to the same extent that a large port authority could.

It is generally best to write permits so that restoration occurs before the project (if it is to be done in a different location than the mitigated project). The restoration should occur as soon as possible so that sediment and water quality would not change.

After a single impact, when the water quality and sediment quality are good and after multiple impacts where conditions are returned to near original, high success is possible for Thalassia seedling restoration. The northern limit for successful implantation of Thalassia is not yet known.

For additional information, interested readers are referred to Thorhaug and Austin (1976). This includes an economic analysis of all the major factors involved in seagrass restoration.

DECISIONS BY GOVERNMENT AGENCIES CONCERNING SEAGRASS RESTORATION

Until recently, restoration of submerged vegetation was not considered possible, and waterfront construction was expected to do a certain amount of irreversible damage to adjacent sublittoral communities. We can no longer afford to have our remaining nearshore submerged resources damaged by development interests. Therefore, there are two alternatives: (1) save areas immediately adjacent to the coast as a natural strip with no development and build behind this, or (2) carefully write permits limiting what developments can do to submerged land and then enforce these measures.

In establishing guidelines for rational restoration of seagrasses (or other plant species), the agency with authority immediately encounters questions which it may often not be prepared to answer in the early stages, but which are essential for a successful final product. What size area should be restored? What species do you want planted? What density do you wish to achieve? What time period can you permit to achieve this density?

Site specific information is necessary to answer the above questions. The developers' report may not contain this information or may not be credible. The question of the size area to restore is a site specific one. Filling valuable waterfront acreage may be judged to warrant from 3:1 to 10:1 (restored acres:filled acres) ratios. Marina building or navigational channels may possibly be assessed at a 1:1 to 4:1 (restore: fill ratio). The Port of Miami has been asked to plant 4:1.

The next question is where the restoration will occur. At many sites the exact area to be impacted will be restored after the impact has occurred. Other sites will require adjacent areas restored because the original site will not be on land or is too deep for growth of seagrasses (as in the instance of channels). Often a previously damaged site is chosen at some distance from the impacted site. In choosing a second site, one should keep in mind suitability of this site for successful restoration (physical, chemical, and geological characteristics) and the biological suitability of this site as a substitute for the original (in terms of nursery area, and other aspects).

The species to be planted is usually the dominant species found in the impact survey. However, there are several exceptions. If the area had previously been impacted by man's activities, such as by drainage canals or other effluents, the original vegetation may have been supplanted by other species. Re-establishing the original vegetation, rather than those presently dominant in such circumstances, would usually be preferable unless the water quality had changed sufficiently not to permit this. If there are two or more abundant seagrass species present, one of the following plans can be chosen. (1) Restore several species simultaneously. (2) Restore the fastest growing species first to stabilize sediment and prepare the area for revegetation; then restore the slower growing species into this matrix. (3) Restore only the species which will return very slowly by natural means and allow the naturally faster growing species to invade. (4) Restore only the species needed for a specific purpose (such as a food source or nursery-related purposes). Information is often incomplete for such a decision.

The decision of which species to plant may have a large effect on the cost of the effort. Nevertheless, the first decision should be based strictly on the biological rationale and only after this is made should economic considerations and compromises be considered. To plant the wrong species because of economic considerations might do more harm than good.

Cost considerations will demand a compromise between size of restored area and what is planted. If cost is the determining factor, it is better to restore a smaller area correctly than a large area incorrectly. An exception would be when sediment stabilization is the only desired effect of restoration.

The desired density to be achieved and the time period are highly dependent on density of seagrasses currently present in the area. The usual situations would be to reestablish the same density within a reasonable time scale (that is about 3-6 years). If the ultimate density is to be established in a very short time scale (such as months), the cost may become economically unfeasible (Austin and Thorhaug 1977). The question of what density is present is a seasonal consideration in most areas, with late spring peaks and winter lows (Thorhaug and Roessler 1977). Use the highest seasonal density in the estimations.

Spatially, the density of the seagrass may not be even throughout the area. One might choose an average density of the entire area as the restoration goal, but it is more advisable to restore the area in several different densities. If, for example, nearshore peat wedge sustains a higher standing crop than offshore sediment, restore it in that ratio. The time period for recovery to a given density is a function of the rate of growth of the plants. (Seagrasses spread laterally by rhizomal growth.) This rate is highly dependent on species and environmental conditions and must be environmentally determined. Best estimates are provided when a pre-impact growth study has been done in that area.

Information about rationale, historical detail, methods, results, and economic cost analysis of planting seagrasses can be found in Austin and Thorhaug (1977) and Thorhaug (1976b).

LITERATURE CITED

Austin, B. and A. Thorhaug. 1977. The economic costs of transplanting seagrasses, pp. 69-75. In D. Cole and R. R. Lewis (eds.), Conference on Restoration of Coastal Vegetation in Florida, May 14, 1977. Hillsborough Community College Press, Tampa.

Bader, R. G. and M. A. Roessler (eds.). An ecological study of south Biscayne Bay and Card Sound. Progress report to U.S. Atomic Energy Commission (AT (40-1)-3801-4) and Florida Power & Light Company, RSMAS, University of Miami, Miami, Florida.

Baird, R. C. and J. K. Rolfes. 1973. Fish in Anclote environmental project report, Sec. F., pp. 120-132. Prepared by Marine Sci. Inst., Univ. of South Fla., St. Petersburg, Florida.

Baird, R. C., P. I. Baird, K. L. Carden, T. L. Hopkins, T. E. Pyle, H. J. Humm. 1971a. Fish in Anclote environmental project report. Prepared by Marine Sci. Inst., Univ. of South Fla., St. Petersburg, Florida.

Baird, R. C., K. Rolfes, B. Causey, W. Fable, A. Feinstein, D. Milliken. 1971b. Fish in Anclote environmental project report, Sec. F., pp. 176-210. Prepared by Marine Sci. Inst., Univ. of South Fla., St. Petersburg, Florida.

Baird, R. C., W. A. Fable, B. D. Causey, A. Dietz, A. Feinstein, D. M. Millilien, and K. J. Rolfes. 1972. Fish in Anclote 1972, Sect. 5. pp. 142-183. Report to Florida Power Corp.

Ballentine and Humm. 1975. Benthic algae of the Anclote Estuary I. Epiphytes of seagrass leaves. Fla. Sci. 38: 148-162.

Blake, N., J. Studt, R. Zimmerman and R. Ernest. 1973. Benthic community, pp. 105-119. In Department of Marine Science, University of South Florida Anclote Environmental Project Report 1973, St. Petersburg, Florida.

Blake, N. J., L. J. Doyle and T. E. Pyle. 1976. The macrobenthic community of a thermally altered area of Tampa Bay, Florida. pp. 296-301. In G. W. Esch and R. W. McFarlane (eds.), Thermal Ecology II. Technical Information Center, ERDA, Washington, D.C.

Buesa, R. J. 1974. Population and bibliographical data on turtlegrass [Thalassia testudinum (Konig, 1805)] on the northeastern Cuban shelf. Aquaculture 4: 2.

Buesa, R. J. 1977. Photosynthesis and respiration of some tropical marine plants. Aquat. Bot. 3: 203-216.

Capone, D. G. 1978. Dinitrogen Fixation in Subtropical Seagrass and Macroalgae Communities. Ph.D. Dissertation, Univ. of Miami, Miami, Florida. 93 pp.

Carangelo, P. D., C. H. Oppenheimer and P.E. Picarazzi. 1979. Biological application for the stabilization of dredged materials, Corpus Christi, Texas: submergent plantings. The University of Texas Marine Science Institute. Port Aransas Marine Laboratory, Port Aransas.

Diaz-Piferrera, M. 1962. The effect of an oil spill on the shore of Quanica, Puerto Rico (Abstract), pp. 12-13. In Assoc. Island Marine Laboratories, 4th Meeting, Curacao.

Eisenman, N. J. 1976. The Marine Algae of Point o'Rocks, Florida West Coast. Unpubl. Ph.D. Diss. Univ. South Florida, Tampa. 201 pp.

Eleuterius, L. N. 1975. Submergent vegetation from bottom stabilization, pp. 439-456. In Estuarine Research, Vol. II, Academic Press, New York, New York, 545 pp.

Farrington, J. W., D. K. Atwood, and J. A. Benjamin. 1980. The specific mission of the RESEARCHER/PIERCE IXTOC-1 Cruise and the physical situation existing in September 1979 in the southern Bay of Campeche. Address at Program for RESEARCHER/PIERCE IXTOC-1, Miami, Florida, June 9-10, 1980.

Ford, E., S. Moore and H. J. Humm. 1975. A study of the seagrass beds in the Anclote estuary during the first year of operation of the Anclote power plant. A final report submitted to the Florida Power Corp. Unpaged.

Greenway, M. 1974. The effects of cropping on the growth of Thalassia testudinum (König) in Jamaica. Aquaculture 4:199-206.

Greenway, M. 1976. The grazing of the Thalassia testudinum, in Kingston Harbor, Jamaica. Aquat. Bot. 2: 117-126.

Gunter, G., B. S. Ballard & A. Venkataramiah. 1974. A review of salinity problems of organisms in United States coastal areas subject to the effects of engineering works. Gulf Res. Rep. 4: 380-475.

Harlin, M. M. 1980. Seagrass epiphytes In R. C. Phillips and C. P. McRoy (eds.), Handbook of seagrass biology. Garland STPM Press, New York. 353 pp.

Humm, H. J. 1956. Sea grasses on the northern Gulf coast. Bull. Mar. Sci. Gulf Carib 6: 305-308.

Humm, H. J. 1964. Epiphytes of the seagrass, Thalassia testudinum, in Florida. Bull. Mar. Sci. Gulf. Carib. 14:306-341.

Humm, H. J. 1976. The benthic algae of Biscayne Bay. In A. Thorhaug (ed.), Biscayne Bay: Past/Present/Future. Sea Grant Special Report No. 5, Univ. of Miami, Coral Gables, Florida. 315 pp.

Humm, H. J. and H. H. Hildebrand. 1962. Marine algae from the Gulf coast of Texas and Mexico. Publ. Inst. Mar. Sci. Univ. Texas 8: 227-268.

Jordan, E. 1977-1978. Unpublished reports to the government of Mexico on sublittoral resource of Cancun area.

Kolehmainen, S. E., T. Morgan and R. Castro. 1974. Mangrove root communities in a thermally altered area in Guayanilla Bay, Puerto Rico, pp. 371-390. In J. W. Gibbons and R. R. Sharitz (eds), Thermal ecology. Tech. Information Center, ERDA, Washington, D.C.

Livingston, R. J. 1976. Diurnal and seasonal fluctuations of organisms in a north Florida estuary. Estuarine Coastal Mar. Sci. 4: 373-400.

Livingston, R. J., R. L. Iverson, R. H. Estabrook, V. E. Keys and J. Taylor, Jr. 1974. Major features of the Apalachicola Bay system. Physiography, biota and resource management. Fla Sci. 37: 245-271.

Lot-Helgueros, A. 1977. General states of research in seagrass ecosystems in Mexico. In C. Peter McRoy and Carla Hilfferich, (eds.), Marine Science Vol. 4, Seagrass Ecosystems: A Perspective. Marcel Dekker, New York.

Martin, F. D. 1972. Puerto Rico nuclear center research report of algae of Jobes & Guayanilla Bays, pp. 42-114. In Puerto Rico Nuclear Center, Aguirre Power Project Environmental Studies 1972 Annual Report.

Mayer, G. F. and V. Maynard (eds.). 1975. Anclote environmental report, 1974. Dept. Mar. Sci., Univ. of South Florida (prepared for Florida Power Co.), 526 pp.

McLaughlin, P. A. and A. Thorhaug. 1978. Preliminary report on recolonization of invertebrates into a Thalassia testudinum restoration site. Fla. Sci. 41(S): 19 (abstract).

Montgomery, J. R. 1975. Unpublished report for the Puerto Rico Nuclear Center. Concentration of Zn, Cu, Ni, Mn, Fe and Co in reef face, Halophila and algal flat sediments off the west coast of Puerto Rico, 11pp.

Odum, H. T., W. M. Kemp, W. H. B. Smith, et al. 1974. Power plants and estuaries at Crystal River, Fla. An energy evaluation of the system of power plants, estuarine ecology and alternatives in management. In: Contract #GEC-159,918-200.188.19 with the Florida Power Corp. Systems Ecology Group, Dept. of Env. Eng. Sciences, University of Florida, Gainesville, Fla. 32611. A report to the Florida Power Corp and Government agencies concerned with licensing, October, 1974. Crystal River Power Plant: Env. Consids. A final report to the Interagency Res. Adv. Comm., Florida Power Corporation. Vol. I. 417 pp.

Ogden, J. C. 1976. Some aspects of herbivore - plant relationships on Caribbean reefs and seagrass beds. Aquat. Bot. 2: 103-116.

Ogden, J. C. 1977. Estimates of carbonate sediment production by some common fish and echinoid grazers in reef areas of the Caribbean. In S. Frost and M. Weiss (eds.), Reefs and related carbonates - ecology and sedimentology. Am. Assoc. Petrol. Geol. Special Paper 4.

Ogden, J. C., R. A. Brown and N. Salesky. 1973. Grazing by the echinoid Diadema antillarum Phillipi: formation of halos around West Indian patch reefs. Science 182: 715-717.

Penhale, P. A. and J. M. Sprogis. 1976. The role of epiphytes in seagrass systems, pp. 65-69. In A. Thorhaug (ed.), Biscayne Bay: Past/Present/Future. Sea Grant Special Report No. 5, Univ. of Miami, Coral Gables, Florida. 315 pp.

Penhale, P. A. and A. Thorhaug. 1977. Macrophyte-epiphyte productivity in a subtropical Thalassia community. Abstract, Bot. Soc. Amer. 63:24.

Phillips, R. C. 1960. Observations on the ecology and distribution of the Florida seagrasses. Prof. Pap. Ser. No. 2, Florida State Board Conserv. Mar. Lab., 72 pp.

Reyes, G. Unpublished data. Rosenstiel School of Marine and Atmospheric Studies. University of Miami, 4600 Rickenbacker Causeway, Miami, Florida 33149.

Roessler, M. P. and D. C. Tabb. 1974. Studies of effects of thermal pollution in Biscayne Bay, Florida. EPA 660-3-74-014. 145 pp.

Roessler, M. A., G. L. Beardsley, R. Rehrer and J. Garcia. 1975. Effects of thermal effluent on the fishes and benthic invertebrates of Biscayne Bay-Card Sound, Florida. Univ. of Miami RSMAS Tech. Rep. 214 pp.

Schroeder, P. B. 1976. Thermal Stress in Thalassia testudinum. Ph.D. Dissertation, Univ. of Miami, Coral Gables, Florida.

Schroeder, P. B. and A. Thorhaug. 1980. Trace metal cycling in tropical-subtropical estuaries dominated by the seagrass Thalassia testudinum. Amer. J. Bot. 67(7): 175-188.

Simon, J. L. and D. M. Dauer. 1977. Reestablishment of a benthic community following natural defaunation. In B. C. Coull, (ed.), Ecology of Marine Benthos. Univ. South Carolina, Columbia.

Snedaker, S. C., (ed.). 1974. Final Report to the Florida Power Corporation, Vols. II, III: Crystal River Power Plant Environmental Considerations. Resource Management Systems Program, Institute of Food and Agricultural Sciences. University of Florida, Gainesville.

Sprogis, J. 1975. Changes in Benthic Diatom Assemblages Within the Thermal Effluent at Turkey Point, South Biscayne Bay, Florida. M.S. Thesis, University of Miami, Coral Gables, Florida. 115 pp.

Strawn, K., K. Johnson, T. McFee, P. DeBusk and G. Williams. 1974. Species diversity and abundance of the bottom fauna, macroplankton, commercially important shrimp, and fishes, before and after the construction of the Cedar Bayou Generating Station. Progress report for 1973 submitted to the Houston Lighting and Power Company. 151 pp.

Tabb, D. C., D. L. Dubrow and R. B. Manning. 1962. The ecology of northern Florida Bay and adjacent estuaries. Fla. Board Conserv. 39: 1-81.

Thorhaug. A. 1971. Plant community investigation, pp. XII-1-XII-10. In Bader, R. G. and M. A. Roessler (eds.), An Ecological Study of South Biscayne Bay and Card Sound. Progress Report to U.S. Atomic Energy Commission (AT(40-1)-3801-3) and Florida Power & Light Company, RSMAS, University of Miami, Miami, Florida.

Thorhaug. A. 1972. Grasses and macroalgae, pp. VIII-1-VIII-73. In Bader, R. G. and M. A. Roessler (eds.), An Ecological Study of South Biscayne Bay and Card Sound. Progress Report to U.S. Atomic Energy Commission (AT(40-1)-3801-4) and Florida Power & Light Company, RSMAS, University of Miami, Miami, Florida.

Thorhaug, A. 1973. Grasses md macroalgae temperature studies. Annual Report (1972-1973) to the Atomic Energy Commission and Florida Power & Light. University of Miami, Miami, Florida.

Thorhaug, A. 1974a. Transplantation of the seagrass Thalassia testudinum König. Aquaculture 4: 177-183.

Thorhaug, A. 1974b. Effect of thermal effluents on the marine biology of Southeastern Florida, pp. 518-531. In J. W. Gibbons and R. R. Sharitz (eds.), Thermal Ecology. AEC Symp. Series (Conf. 730505).

Thorhaug, A. (ed). 1976a. Biscayne Bay: Past/Present/Future. Sea Grant Special Report No. 5, Univ. of Miami, Coral Gables, Florida. 315 pp.

Thorhaug, A. 1976b. Tropical macroalgae as pollution indicator organisms. Micronesica 12(1): 49-65.

Thorhaug, A. In press. Restoration of seagrass communities: strategies for lessening man's impact on nearshore marine resources. Proceedings 5th International Symposium on Tropical Ecology, Kuala Lumpur, Malaysia.

Thorhaug, A. and B. Austin. 1976. Restoration of seagrasses with economic analysis. Environ. Conserv. 3: 250-267.

Thorhaug, A. and M. Greenway. 1978. A comparison of seagrass dynamics in a tropical and subtropical estuary. Amer. J. Bot. 65(5):4. (Abstract).

Thorhaug, A. and P. McLaughlin. 1978. Preliminary report on recolonization of invertebrates into a Thalassia testudinum restoration site. Fla. Sci. 41(5):19. (Abstract).

Thorhaug, A. and M. A. Roessler. 1977. Seagrass community dynamics in a subtropical estuarine lagoon. Aquaculture 12: 253-278.

Thorhaug, A. and P. Schroeder. 1978. Uptake of cations by tropical marine organisms: uptake of Zinc-65, Manganese-54, Cesium-137, Strontium-85 and Sodium-22 by macroalgae. Fla. Scientist 41(5):22. (Abstract).

Thorhaug, H. and P. Schroeder. 1979. Synergistic effect of temperature, salinity and heavy metals on subtropical versus tropical populations of the seagrass Thalassia testudinum, pp. XI-B-72-XI-B-90. In S. Sengupta (ed.), Proc. Waste Heat Symposium II. University of Miami, Coral Gables, Florida.

Thorhaug, A., M. Roessler, D. Segar, R. Bader and S. Gerchakov. 1973. The environmental impact of a power plant on a subtropical bay. Trans. Amer. Nucl. Soc. 16: 15.

Thorhaug, A., P. Penhale, and P. Schroeder. 1977. An ecological study of the effects of power plants on benthic macroplant microcosms in subtropical and tropical estuaries. Progress report to U.S. Energy and Research Development Administration (E(40-1)-9493). University of Miami, Miami, Florida. 32 pp.

Thorhaug, A., N. Blake and P. Schroeder. 1978. The effect of heated effluents from power plants on seagrass (Thalassia) communities quantitatively comparing estuaries in the subtropics to the tropics. Mar. Poll. Bull. 9: 181-187.

Thorhaug, A., M. Roessler, S. Bach, M. Josselyn, R. Hixon and I. Brook. 1979. Biological effects of power-plant thermal effluents in Card Sound, Florida. Environ. Conserv. 6: 127-137.

Van Tine, R. F. 1974. Comparisons of the benthic flora in estuaries adjacent to the Crystal River Power generation facility. In Snedaker, S. C. (ed.), Final Report to the Florida Power Corporation, Vols. II, III: Crystal River Power Plant Environmental Considerations. Resource Management Systems Program, Institute of Food and Agricultural Sciences. University of Florida.

Vicente, V. P. 1975. Seagrass bed communities of Jobos Bay, Aguirre Environmental Studies, Jobos Bay, Puerto Rico. Final report Vol. 1. Puerto Rico Nuclear Center 196: 27-45.

Vicente, V. P. 1977. The impact of heated effluents on Thalassia beds: a comparative study. Center for Energy and Environment Research. University of Puerto Rico/U. S. Dept. of Energy. 73 pp.

Wanless. H. R. 1975. Sediments and sedimentary processes in natural and artificial waterways, Marco Island area, Florida. Scientific Report UM-RSMAS, No. 74032, Univ. of Miami, Miami, Florida. 127 pp.

Wanless. H. R. 1976. Geologic setting and recent sediments of the Biscayne Bay region, Florida, pp. 1-32. In A. Thorhaug & A. Volker, (eds.), Biscayne Bay: Past/Present/Future. Univ. of Miami, Sea Grant Special Report No. 5.

Yokel, B. J. 1975. Estuarine biology. Study No. 5 in Rookery Bay Land Use studies. The Conservation Foundation, Washington, D. C. 112 pp.

Zieman, J. C. 1975. Seasonal variation of turtle grass, *Thalassia testudinum* König, with reference to temperature and salinity effects. Aquatic Bot. 1:107-123.

Zieman, J. C. 1976. The ecological effects of physical damage from motor boats on turtle grass beds in southern Florida. Aquatic Bot. 2:127-139.

Discussion V - Ecology of Sea Grasses and Coral Reefs (A. Marshall, R. Lewis, and A. Thorhaug)

Q. A. de la Cruz: In previous discussions it was emphasized that transplants were to be in the right environment; otherwise it will be a waste to the person's time. If the physical features were considered, why were there so many failures in the transplantings Lewis and Thorhaug have done?

A. A. Thorhaug: All plants used for transplanting must be almost disease free; otherwise there are monumental problems with survival. Disease syndromes of seagrasses are not well understood. The physical conditions with regard to turbidity may also be a major factor in growth. Weather conditions can also cause problems. For instance, one seagrass bed under study was exposed and frozen during unusual conditions. Also, many other considerations have to be taken into account, such as effluent.

When seagrasses are taken out, the sediment stirs up and is uncompacted. This stirring up of the sediment causes a decrease in light penetration and even if the grasses are restored there, it is very difficult to get them to grow. Dredging should be confined to as limited a space as possible and the seagrasses should be replaced as soon as possible after the dredging incident. Without the seagrasses, increasing turbidity and erosion occur. The sediment changes and as it changes, it eliminates the environment for the seagrass itself.

Q. A. de la Cruz: Ecological succession occurs as one community prepares the environment for another. For example, *Spartina alterniflora* acts as a base in mangrove succession. What other plants are there that would prepare a bed for planting seagrasses?

A. A. Thorhaug: There are four successional stages which occur. The first is the blue-green algae or microalgae. This is followed by the green algae which have a lot of spores so that they are able to reproduce very, very rapidly. Then a successional seagrass usually comes in and finally the climax seagrass. The blue-green algae and green algae can be planted; however, this step could be skipped relatively easily using a fast growing successional seagrass such as *Halodule*.

Q. R. Lewis: What is the estimated cost of seagrass planting?

A. A. Thorhaug: The cost of planting ranges from two to four thousand dollars an acre based on a study which was done on an experimental basis. Costs are site specific in relation to density and species. The cost factor also is determined by how rapidly one wants to have the environment back to, or close to, the original environment. The density of seagrass is a policy decision with regard to planting, whereas the species used is a biological decision. These costs are for easily accessible Biscayne Bay areas.

Q. J. Tilmant: Your work at the Turkey Point site seems to be relatively successful after four years. What were your controls? What plants came in as a result of planting, as compared to those which came in but were not planted?

A. A. Thorhaug: Unfortunately, at Turkey Point 3,000 seeds were spilled and approximately 20-25 percent of the plants of a neatly planted grid were lost. Thus, clusters of seeds of unknown origin were found in the area. Therefore, it was not an ideal control situation. At a similar site, eight miles north of Turkey Point, however, control studies were more successful. After four years, thirty Thalassia recruits were found on 1.6 hectares at Cutler Ridge; 1/3 were three years old, 1/3 were two years old, and 1/3 were one-year-old plants. By using these data, it is estimated that it may take over 20 years to restore such as area.

The seeds tend to move and therefore it is very difficult to determine whether the epicenters came from far away or from the restoration itself. But, based on this other location within a few miles of Turkey Point, complete restoration by man is estimated to occur within four years as opposed to 20 years or so under natural recovery.

Q. C. Peterson: Those of us in the northern zone, North Carolina for instance, have another seagrass to deal with, the eelgrass Zostera. Your comments as well as those of Zieman indicate that we have to know something about the specific seagrass with which we are dealing before restoration can occur. I wonder if you and Zieman would like to comment briefly and amplify on what you have said to include Zostera for us who have Zostera as an important seagrass.

A. J. Zieman: In Alaska, Zostera blades get to be 3.5 m long in one growing season and reach densities of about 2,000 to 5,000 blades per square meter. In North Carolina there are often equal quantities of Zostera and Halodule. This is the southern limit of Zostera and northern limit of Halodule and dominance by either plant varies from year to year.

Grazing: Gordon Thayer has been working on this for a number of years. The pin fish does a modest amount of grazing on both Zostera and Halodule. There have been traces of Zostera found in their stomach contents. There are a few species of crabs which make scallop cuts around the grass blades in all areas studied. This is about all we know about direct grazing of Zostera.

Export: Gordon Thayer has shown that within a year's period, one to twenty percent of the production of Zostera within an embayment is exported to offshore waters.

There is no such thing as a typical grass bed. Therefore, we have come up with a term that the medical profession uses. This is for a situation that is not abnormal but different. A patient or condition is said to be "unremarkable." This is probably going to be one of the buzz words now for an area that meets all of the criteria to be typically healthy, but it is not exactly the same as another grass bed. The bed is slightly different just because of the slight changes in environment.

Q. L. Stith: In our Ecological Services work, from time to time we see urban runoff increasing as urbanization increases and this, of course, decreases salinities in bays. What effects are produced by these decreases in salinities and what problems do you see occurring as a result? Also, what can be done about these problems?

A. A. Thorhaug: Point source runoff in the flood control districts here in Florida has lowered salinities in specific places. This has altered the seagrass community from a dominance of Thalassia to a dominance of Halodule in canal areas. During a very rainy year, extensive die-offs of Thalassia occur and it is replaced by Halodule. Specific sites in North Biscayne Bay show decreases in Thalassia because of the sheet flow which is now point source. The exact lower limits of salinity tolerance of Thalassia are not known. I think it averages about 20%. But what the plant can take for several days after a run-off is not clear. It is known that Halodule does tolerate much lower salinities.

Tom Odum did a lot of work on this in Redfish Bay where there were different years of drought and rainfall. He saw different sequences of seagrasses come through the bay. The question is, how long will this occur and will it be altered permanently?

A. R. Lewis: I want to make a quick comment for those persons interested in Zostera transplants. One of Zieman's students has done some Zostera transplanting. There are no easy answers because people are trying different techniques such as weaving of the rhizomes and placing them into the sediment. This is extremely tedious. Yet, it may be effective.

Q. B. Teytaud: Does anyone have an idea on the upper limits regarding parameters, such as turbidity, to assure restoration of seagrasses? Also, do you have some thoughts on how you recognize a grassbed that is in trouble?

A. A. Thorhaug: One thing that frequently happens with a grassbed in trouble is that the leaves begin to turn brown. I would say that if you had an unusual amount of brown leaves, very large patches on the leaves, or a lot of very old leaves during the spring or fall that this is a sign of stress. A second kind of stress is a lighter color. In many places the Thalassia, Syringodium, and Halodule become fairly light green, especially when there is a chemical pollutant of some kind or another. They tend to get necrotic yellow.

Unfortunately, the turbidity level is a very difficult thing to study in the laboratory. When storm conditions stir the sediment, there are periodic high turbidities followed by fairly low turbidities. This is very hard to duplicate in the lab.

A. J. Zieman: One is far better off dealing with the absolute light level that the plants need rather than turbidity. Sometimes the particles are brown and organic in nature, and they have tremendously high light absorption. In shallow waters of Florida and the Caribbean, many particles may be stirred up, but they are basically carbonate. These have a very high light absorption and therefore light penetrates deeper than would be the case in more northerly regions. It is not a simple thing to deal with right now.

Q. S. Gilbert: One thing that has always intrigued me about seagrass beds is their patchy nature. Would anyone care to speculate on the possible causes of patches in seagrass beds?

A. A. Thorhaug: Speculating, one of the reasons they are so patchy here is due to the rock outcrops that you find in south Florida and the Caribbean. Where you only have a thin sediment, the type of seagrass changes as well as the whole plant community. Thalassia needs several centimeters of sediment for it to grow. On the whole, you will have Halophila or Halodule coming in when there are only thin sediment layers. Another thing that J. Zieman found in Biscayne Bay is that there were thick patches of old Thalassia in mangrove areas with peat circles. These circles had more nitrogen in them and therefore more Thalassia.

Dr. Richard Cheshire found in the back reef that there was competition between burrowing animals, in his case sea biscuits. Eugene Shinn found competition between burrowing shrimp and crab with seagrass rhizomes. These animals turn up the sediment, thereby changing the environment. Seagrasses may be wiped out by armies of urchins. This looks like the effects of a lawn mower. The middle is all wiped out and the two sides are not. There is also an age factor where there is no outbreak of man or predators. The bed just migrates along. There is a young growing part and an old senescing part. A portion is dying while another part is growing. We are in the infancy of understanding this. The patchy phenomenon is quoted by everyone but not explained to the satisfaction of anyone up to now.

A. D. Page: In the Bahia Sucia oil spill area, which has extensive Thalassia beds, there was a lot of initial damage due to apparent mechanical oil accumulation into the leaves. Subsequently, the leaves washed ashore. Two years afterward, the EPA studied the beds and there was no apparent damage to the beds. Subsequent studies have confirmed that. The regulatory problem that I see dealing with seagrasses and oil spills and other toxic chemicals is the big push to use treating agents, dispersants. I think that once you convert these water insoluble forms into a dispersed or soluble form that can interact more closely with subtidal vegetation, you might find far more damage to the subtidal community than if you had not treated it.

Q. R. Lee: Is there any research into site preparations in areas where there are significant anaerobic silt deposits?

A. R. Lewis: One suggestion is to move the sediments with the seagrass. If you are careful, you move the system that the seagrasses are surviving in and then the grass gradually may get out into a system where it may not originally have been appropriate. This can become very expensive. It is very labor intensive to move a plug.

Using seeds, far less material is needed and also the seeds have the generative material right in the rhizome and therefore grow faster. We are back to the site specific determination. You cannot say, "Just prepare the site for seagrass." You have to ask the question, "What will the site water quality tolerate in regard to what will grow there?" You are back to the problem of knowing what the requirements are.

Q. R. Lee: If you have an area where you wish to transplant back to the original and it was, for example, dredged, can you remove the silt and replace the grasses?

A. A. Thorhaug: What you have to do is look at the current and the patterns and determine whether there have been severe physical or chemical changes to the site from the time that the grassbed was removed to the time you try to recover it. If there were no severe changes, it certainly is worth a try to replace the grassbed. If, however, you have large changes to the quality or quantity of the sediment or to the chemicals in the water or the light, then it gets really difficult to determine whether you should go in and plant or not.

A. R. Lewis: If a bed was buried, you might be able to carefully remove the sediment. The sediment and even the grasses should still be there depending on how long ago the dredging took place.

A. A. Thorhaug: The amount and composition of the bed determines whether grasses will grow. If you have five feet of appropriate sediment, it does not make any difference if you took the top four inches off; but if you only have four inches of sediment, it is very important that you do not take that off.

A. R. Lewis: I would think the best thing to do is to take a core of the area to determine the nature of the sediment.

Q. W. Larned: I'm concerned with the shoregrasses in regard to redhead ducks. The majority of the northern redhead ducks winter in the Gulf of Mexico; these amount to just about 80% of the North American population, around 800,000 birds this year. Virtually all of them feed on the rhizomes of shoregrasses. Most of the birds that feed on shoregrass are in the Laguna Madre area which has been almost directly affected by an oil spill last year. The tides and current will change this year and we again may have a problem with the oil (the Coast Guard did a good job of keeping it out last year). Could you speculate in regard to the shoregrass beds if we do have an oil slick or dispersal type oil influence in this area?

A. A. Thorhaug: Based on research of other scientists, if the thick crusty oil is dispersed, certainly the blades will be killed. The roots may survive until the currents and tides take the oil away. The roots are capable of regrowth, but it is not clear exactly what happens.

Q. Not identified: I would like Art Marshall to comment on the effects of the Everglades drainage system and fisheries in the Florida Bay area.

A. A. Marshall: With regard to fisheries statistics, I cannot give an answer. There are data, but they are very insufficient. I think that many things have happened to the Everglades ecosystem such as the C-111 canal's leading freshwater to the east side of U.S. Highway 1. This diversion reduced the sheet flow through the eastern arm of Everglades National Park and thereby influenced a major economic change.

On the U.S. 1 embankment, which is many years old, dating back to the time of railroad construction to Key West, there are scrub mangroves right up to the road. The road embankment clearly intercepted the historic sheet flow which went down through that whole southeastern area to the bays. That flow does not occur anymore; it cannot. If C-111 were to be closed, the plugging should not be east of U.S. Highway 1. It does not matter whether the plug goes all the way along the canal bed. The canal has to be fully plugged where it passes under U.S. Highway 1. Ariel Lugo mentioned yesterday the differences in opinion regarding freshwater and saltwater mangroves. His view was that while mangroves occur in fresh water, the roots are in salty soil. It is essential to remember that under extreme conditions such as hurricanes, the salt water moves far inland and salts the soils. Dr. Lugo is absolutely right on that subject.

THE ECOLOGICAL ROLE OF MUD FLATS IN ESTUARINE SYSTEMS

Charles H. Peterson
University of North Carolina
at Chapel Hill
Institute of Marine Sciences
Morehead City, North Carolina 28557

ABSTRACT

Intertidal mud flats appear barren and unproductive because of the lack of macrophytic vegetation. Benthic microalgae are abundant and productive on mud flats, but they do not accumulate biomass as do marsh plants and many seagrasses. Microalgae are nutritious and highly edible, leading to their rapid utilization and low standing stocks.

Intertidal mud flats contribute a substantial amount of primary production to estuarine systems. The microalgal production need not go through an energetically costly bacterial or fungal intermediate before it can fuel consumer food chains. Some valuable consumers are especially dependent upon algal production and would not be adequately nourished by macrophytic detritus alone.

Mud flats also play a vital role in the conversion of primary production into consumer biomass. Plant material from all estuarine habitats is deposited on the mud flat in large quantities, where it is transformed into benthic invertebrates. These benthic invertebrates are, in turn, heavily preyed upon by larger predators, such as shorebirds, crabs, and bottom-feeding fishes. Thus the mud flat habitat plays a critical role in the functioning of the entire estuarine system.

INTRODUCTION

Of all the major habitats in an estuarine ecosystem, the salt marsh is the most studied and the intertidal mud flat is the most ignored. The well-known work of Smalley (1959) and Odum and Fanning (1973), which revealed that a natural salt marsh in temperate latitudes is more productive than most of the world's highly managed, terrestrial food crops, has stimulated considerable subsequent research on the productivity of marsh plants (reviewed by Keefe 1972). In contrast, the functional aspects of intertidal flats have been little studied. Mud flats have been assumed to be relatively unimportant merely because they appear, at a glance, to be barren and generally unpopulated. Such apparent emptiness is largely a consequence of one structural characteristic of intertidal flats: they are inhabited not by macrophytes but rather by microscopic, benthic algae. Ironically, this structural characteristic has tended to inhibit extensive studies of the functional roles played by mud and sand flats in estuarine systems. The processes which occur on intertidal flats deserve much more attention, and intertidal flats deserve recognition as a habitat of great importance in the functional life of an estuary.

DEFINITIONS

For the purposes of this paper, only five major habitats are distinguished which, together, comprise an estuarine ecosystem: (1) salt marsh, (2) intertidal mud flat, (3) seagrass bed, (4) unvegetated subtidal bottom, and (5) water column. These five habitats often occur in sequence as one progresses away from dry land. The salt marsh occurs high in the intertidal zone with mud flats below it in the lower intertidal zones. Shorelines which lack salt marshes possess either sand or mud flats over the entire intertidal zone. Seagrass beds occur in a narrow band of depths in the shallow subtidal zone, although they occasionally extend upwards into the very low intertidal zone. Unvegetated subtidal bottom is found everywhere at depths below the seagrass zone and also within the seagrass zone wherever grasses are absent. The water column overlies all of these habitats at high tide and covers only the subtidal habitats at low tide.

The term mud flat is used here to refer to any unvegetated shoreline of a sound, lagoon, estuary, or river mouth that becomes exposed by the tides. This definition includes intertidal flats which are composed of sandy sediments as well as those dominated by true muds (silts and clays).

FUNCTIONAL ROLES OF A MUD FLAT

Any habitat should be judged not by what is found there but rather by what happens there. Intertidal flats must be viewed in the perspective of the entire estuarine ecosystem and must be evaluated by the functions that they serve in that system. There are two very broad functional roles played by intertidal flats. First, they contribute substantial primary productivity in a highly nutritious form to estuaries. Second, intertidal flats serve as a primary locus wherein plant matter, derived from several estuarine habitats, is transformed into invertebrate animal tissue and ultimately into fishes, birds, and larger crustaceans (Peterson and Peterson 1979).

CONTRIBUTIONS TO PRIMARY PRODUCTION

Rate Of Primary Production

In part because it is relatively difficult to estimate, the rate of primary production of benthic microalgae (mostly diatoms, dinoflagellates, filamentous greens, and blue-greens) has seldom been measured on mud flats. In modeling estuarine systems and in developing management goals for coastal lands, the primary productivity of intertidal flats is often considered negligible. This attitude is based on very little data and upon a bias toward macrophytic vegetation. In a salt marsh composed of the grasses Spartina and Juncus or, to a lesser degree, in a marsh dominated by shrubs like Salicornia, Batis, and Sueda, the plants begin each growing season with very little aboveground vegetation. Through the warm season, primary production is accumulated and held in situ in the form of living plant tissue. Very little is sloughed off and very little is consumed by grazers (Odum and de la Cruz 1967). Therefore, at the end of the growing season, an entire year's growth is evident as the standing crop of marsh plants.

Benthic microalgae, in contrast, are seldom visible except as a discoloration to the sediments. They also turn over rapidly so that no build-up of biomass is evident. These characteristics of microalgae can easily lead to an underestimation even of their quantitative productivity. Like salt marsh plants, benthic microalgae seem to show a latitudinal gradient in productivity (Stiven and Plotecia 1976). Studies of mud flats in Georgia and southern California demonstrate a productivity of about 200 g C/m^2/yr (Pomeroy 1959, Onuf et al. in press), whereas in the higher latitudes of Denmark and Washington, primary production of benthic microalgae is lower, about 116-178 g C/m^2/yr (Grøntved 1960, Pamatmat 1968). Although less than half as high as the usual productivities of marsh plants, these values are still substantial and cannot be ignored in any estuarine system where mud flats occupy a significant proportion of the total acreage of the estuary. "Mud algae" may contribute as much as a third of the total estuarine productivity in Georgia (Pomeroy 1959).

Form Of Primary Production

Microalgae do not accumulate *in situ* during the growing season like marsh plants as a direct consequence of their edibility and immediate usefulness to consumer organisms. Various herbivorous, deposit-feeding, or grazing invertebrates rapidly consume the benthic microalgae of mud flats. Thus the primary production of a mud flat is in a form (microalgae) that is directly utilizable by consumers. In contrast, the productions of a salt marsh (grasses and shrubs) and marine grass bed (seagrasses) are low in protein and are dominated by relatively inedible, nutritionally lacking structural compounds (Fenchel 1972). Very small percentages of the marsh grasses (Teal 1962, Odum and de la Cruz 1967) and of the seagrasses (Thayer et al. 1975) are consumed directly by herbivorous animals. The majority of the production of macrophytes from these two habitats is sloughed off to become detritus which fuels the detrital-based food chains of the estuary and coastal marine system.

For the same reasons that the living marsh grasses and seagrasses go almost untouched by consumers, the fresh detritus is also not directly usable. Before it becomes a worthwhile food source, it must be colonized and broken down by bacteria (Fenchel 1972). The so-called detritivores, in most instances, are actually digesting only the bacteria (Fenchel 1972). The detritus is returned, after some mechanical breakage in feces, to the bottom, where it can be colonized by another round of bacteria (Frankenberg and Smith 1967). This process of energy flow from marsh plant or seagrass to consumer thus requires a trophic intermediate, either bacteria or perhaps fungi (Figure 1).

Such an additional transformation of energy from one chemical form to another chemical form necessarily occurs with energy loss. The application of the second law of thermodynamics to ecological systems has produced the generalization that only about 10% of the energy available on one consumer trophic level is successfully passed on to the next highest level. There are reasons to believe that microbial transformation of detritus occurs with higher efficiency (perhaps at 40% instead of 10% efficiency). Nevertheless, it remains true that a substantial portion of the energy bound up in marsh and seagrass plant detritus will never appear in bacterial biomass, which is the edible form of that energy. This means that the productivity of marsh plants or of seagrasses must be depreciated by some factor equal to the bacterial conversion efficiency before it can be compared to the productivity of microalgae from a mud flat (Figure 1). In other words, it may take approximately 2 1/2 kg of marsh grass production to provide the same amount of food to consumer trophic levels as only 1 kg of benthic diatoms. The need for such a

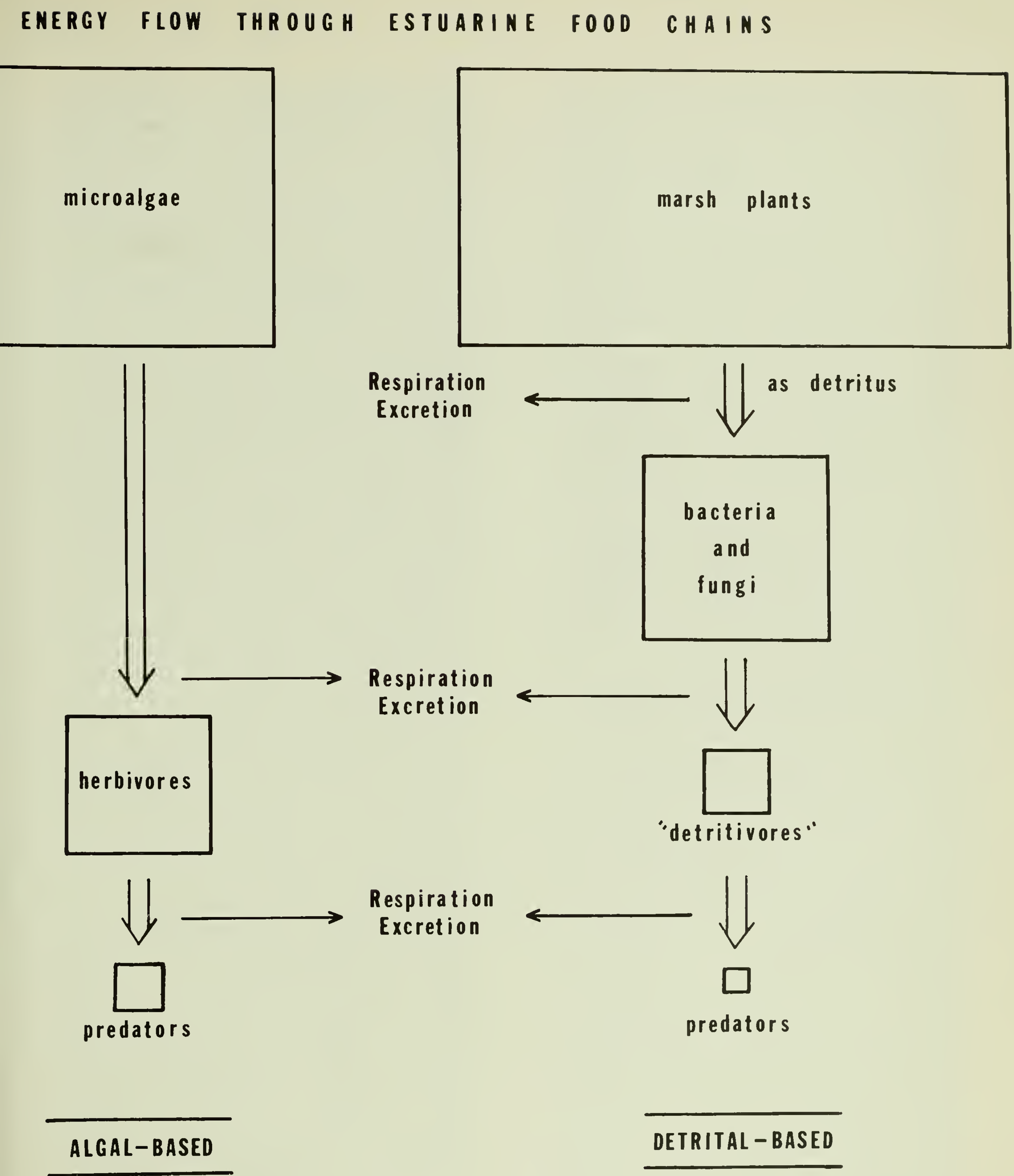


Figure 1. Energy flow through estuarine food chains.

conversion to what might be called usable food units has not been widely recognized or appreciated.

Putting an exact number on this energy transfer efficiency will remain a difficult task. The bacteria on detrital surfaces not only break down the detritus themselves but also grow by harvesting dissolved organic matter from the water column. In this latter process, the bacteria thereby package energy in a particulate form that would otherwise be largely unavailable to consumer food chains. This process could be of some significance because estuarine waters are so rich in dissolved organic matter.

The question of transfer efficiency is greatly complicated by the dissolved organic matter which comes from all primary producers, algae as well as grasses. Thus, not all the energy contained in bacteria found on detritus was derived from the primary production of the plant which produced the detritus. Because algae are so notoriously "leaky," it is even possible that a substantial proportion of the energy represented by bacteria on detritus was actually derived from the photosynthesis of microalgae (phytoplankton and benthic diatoms). This process clearly complicates the difficulty in putting a number on the transfer efficiency of bacterial conversion of marsh and seagrass detritus. However, the point remains that a kilogram of benthic (or planktonic) microalgae provides more food to consumers than a kilogram of marsh grass or seagrass. This makes the productivity of algae on mud flats appear even more significant to the functioning of the estuary than raw productivity values alone would suggest.

Fate Of Primary Production

Although it seems obvious that algae, which are eaten directly, may involve entirely different food chains than marsh grasses, which can only be utilized by detritivores (after bacterial colonization), little attention has been given to identifying these specific pathways of energy flow in estuaries. Procedural problems have greatly hindered such work. For instance, although analysis of gut contents is possible for most vertebrates and some larger invertebrates, it is virtually impossible for detritivores and algal grazers. Even adequate identification of the often amorphous gut material does not suffice to demonstrate what these invertebrates are actually digesting and, therefore, utilizing. Much of the ingested material passes through unaltered.

It is difficult to make any definite generalizations about the differences between the detrital-based and algal-based pathways in estuarine food chains because of the lack of detailed information on assimilation. However, it is entirely possible that the organisms of greatest value in estuarine and coastal marine systems are much more dependent upon the algal pathways than upon the detrital flow. Commercial shellfishes like oysters, hard clams, and scallops are almost completely dependent upon algae, both phytoplankton and suspended benthic microalgae (Haines 1979). It is even possible that the substantial production of marsh grasses ultimately fuels food chains dominated by "unimportant" species, such as marsh snails, dipteran larvae, and the like. Haines' (1977) observations on the nature of the detrital pool in the estuaries of Georgia certainly force one to question the fate of this marsh plant production and help one realize that productivity alone is an insufficient measure of importance of a habitat or plant type. More must be learned about the fate of that production to demonstrate exactly how various energy sources are utilized in estuarine food chains.

SITE OF ENERGY TRANSFORMATION

Conversion Of Plant Matter Into Invertebrate Animal Tissue

At the end of the growing season after marsh plants and, to a lesser degree, seagrasses have reached their maximum standing crop, most of the aboveground plant material is shed into the water column. The majority of the plant detritus is then carried by water currents and tidal flow out of the habitat in which it has been produced (Odum and de la Cruz 1967, Thayer et al. 1975). Much of this is then deposited by the fall of the tides in the intertidal mud flat habitat. Especially at the highest tide mark in the intertidal habitat, huge quantities of macro-detritus are left behind by receding waters. Here various physical processes and the biological activities of fiddler crabs, amphipods, and other detritivores help to break up that detritus into smaller fractions and to work it into the sediments. Through these processes, some substantial portion of the production of other estuarine habitats is made available to the consumer organisms of the mud flat habitat.

Not only does the mud flat serve as an important site for the transformation of detrital material into animal biomass, but it also plays an analogous role in providing an important habitat for many herbivorous invertebrates which feed directly upon algae. The phytoplankton in the water column is heavily grazed by benthic invertebrates on the mud flat. Benthic microalgae from the mud flat tend to be consumed there directly because they are in the immediate vicinity of the benthic deposit feeders and grazers. Thus, the mud flat habitat is a major site of conversion of plant biomass into the tissues of invertebrate animals which ultimately serve as prey for various larger estuarine predators.

It is apparent that much of the energy converted in a mud flat from plant to animal biomass has been fixed by plants in other estuarine habitats. The importance of such transport among estuarine habitats helps emphasize the importance of dealing with holistic approaches to understanding the value of various habitats in an estuarine ecosystem. That energy fixed by plants undergoing photosynthesis is, of course, important. However, it is equally important to recognize how and where the energy is passed on to consumers. The mud flat is the site of much of that energy transfer.

Conversion Of Invertebrates Into Predator Biomass

The mud flat not only serves as the place where plant matter is converted into invertebrate biomass, but it also is a major site of feeding for the predators of those herbivorous and detritivorous invertebrates. Recent caging and feeding studies have demonstrated that benthic invertebrates on mud flats possess low densities because of the high levels of predation upon them. In other words, turnover of these invertebrates is generally quite rapid. Shorebirds (Schneider 1978), crabs (Carriker 1959, Naqvi 1968, Virnstein 1977, Lee 1978) and fishes (Blegvad 1928, Reise 1977, Virnstein 1977) all play roles in this process of feeding upon mud flat invertebrates. Similar caging experiments done in the grass bed habitat have shown that predation upon infaunal invertebrates is greatly reduced by the presence of the seagrasses, probably because the roots and rhizomes inhibit the predators' access to the prey (Reise 1977). In unvegetated sediments, and in mud flats, no root mats exist and predation rates are usually quite substantial.

It is no surprise to bird watchers that mud flats are an important feeding ground for large predators in estuarine systems. Most shorebirds are absolutely dependent upon the mud flat habitat to supply their dietary needs. This is especially true of the shallow-probing and surface-searching shorebirds. Deeper probers, too, do the majority of their feeding on mud flats, even though they can also wade in very shallow subtidal areas at the lowest tides. Although mud flats are not always covered with shorebirds, this does not imply that they are not critical feeding grounds. Virtually all shorebirds are migratory so that they are only abundant at any given latitude for a fraction of the year. However, when present, they feed heavily to support their high energy demands which result from homeothermy and migratory behavior.

Waders (e.g., herons and egrets) are also strongly dependent upon the intertidal mud flat as a feeding ground. Instead of benthic invertebrates, they take small bait fishes and crustaceans in their diets, many of which have themselves fed upon food resources from the mud flat habitat. Without the shallow waters of mud flats and shallow subtidal areas, waders would have no place from which to do their hunting and few prey to capture. Other coastal birds are strongly dependent upon intertidal mud flats as feeding grounds. Some gulls, especially the herring gull, forage at low tide for large invertebrates and carrion on the flats. Some ducks feed on the mollusks of intertidal flats.

Whereas birds of various types are the major predators found on intertidal flats at low tide, crabs, shrimp, and fishes replace them at higher tides. Shallow estuarine waters are especially important habitat for juvenile fishes, which can live and grow unmolested by larger, pelagic predators. Especially at night, when the risk of predation by wading birds and other visually-operating predators is low, crabs and bottom-feeding fishes can be found foraging out over tidal flats. During daylight, the abundance of small fishes, crabs, and shrimp is far higher in the cover of seagrass beds. At night these small, bottom-feeding predators are more evenly distributed over vegetated and unvegetated bottom (Summerson 1980). It is difficult to estimate how important the mud flat habitat is to fishes, crabs, and shrimp which also can feed in deeper waters. Various caging experiments done to measure their impact on the benthos do show, however, that they often have a substantial effect. Such experiments help to demonstrate that the intertidal mud flat is an important site of energy transfer from the small invertebrates to the larger predators of estuarine systems.

CONCLUSIONS

Knowledge of the dynamics of estuarine systems is necessary to understand the critical role played by the intertidal mud flat habitat. Only by recognizing the important processes which occur on tidal flats and by realizing that they play crucial roles in the functioning of the total estuarine ecosystem, can one appreciate the value of the mud flat habitat. The appearance of low densities in plants, herbivorous invertebrates, and higher-order consumers is deceiving. Turnover rates are high because the mud flat is the active site of dynamic processes of energy transfer which underlie the value of the entire estuarine ecosystem.

It remains impossible to provide an answer to the question of what are the optimal proportions of each habitat type in an estuarine system. Yet, we do know that mud flats should be included at some level substantially greater than zero. Mud flats provide a nontrivial amount of primary production in a form (algae) which is directly usable by consumers and which may lead to food chains of great commerical, aesthetic, or recreational importance. Furthermore, the mud flat habitat serves as a major site of energy transformation. Plant material derived from other estuarine habitats, especially salt marshes, and benthic algae produced in situ, are consumed by detritivorous and herbivorous benthic invertebrates on the mud flat. These benthic invertebrates are, in turn, heavily preyed upon by higher-order consumers, especially shorebirds at low tide and various crabs and bottomfeeding fishes at high tide. These important functional processes provide a basis for placing great value on the mud flat habitat.

LITERATURE CITED

Blegvad, H. 1928. Quantitative investigations of bottom invertebrates in the Limfjord 1910-1927 with special reference to the plaice food. Rep. Dan. Biol. Stn. 34:33-52.

Carriker, M. R. 1959. The role of physical and biological factors in the culture of Crassostrea and Mercenaria in a salt-water pond. Ecol. Monogr. 29:219-266.

Fenchel, T. 1972. Aspects of decomposer food chains in marine benthos. Verh. Dtsch. Zool. Ges. 65:14-22.

Frankenberg, D., and K. L. Smith, Jr. 1967. Coprophagy in marine animals. Limnol. Oceanogr. 12: 443-450.

Grøntved, J. 1960. On the productivity of microbenthos and phytoplankton in some Danish fjords. Medd. Danm. Fisk. Havund. 3:55-92.

Haines, E. B. 1977. The origins of detritus in Georgia salt marsh estuaries. Oikos 29:254-260.

Haines, E. D. 1979. Interactions between Georgia salt marshes and coastal waters: A changing paradigm, pp. 35-46. In R. J. Livingston (ed.), Ecological Processes in Coastal and Marine Systems. Plenum Press, New York.

Keefe, C. W. 1972. Marsh production: a summary of the literature. Contrib. Mar. Sci. 16: 163-181.

Lee, H. 1978. Seasonality, Predation, and Opportunism in High Diversity Soft-bottom Communities in the Gulf of Panama. Ph.D. Thesis, Univ. North Carolina, Chapel Hill. 180 pp.

Naqvi, S. M. Z. 1968. Effects of predation on infaunal invertebrates of Alligator Harbor, Florida. Gulf Res. Rep. 2:313-321.

Odum, E. P., and A. A. de la Cruz. 1967. Particulate organic detritus in a Georgia salt marsh-estuarine ecosystem, pp. 383-388. In G. H. Lauff (ed.), Estuaries. Amer. Assoc. Adv. Sci. Publ. 83.

Odum, E. P., and M. E. Fanning. 1973. Comparison of the productivity of Spartina alterniflora and Spartina cynosuroides in Georgia coastal marshes. Bull. Georgia Acad. Sci. 31:1-12.

Onuf, C. P., M. L. Quammen, G. P. Shaffer, C. H. Peterson, J. W. Chapman, J. Cermak, and R. W. Holmes. (in press). An analysis of the values of central and southern California coastal wetlands. In National Symposium on Wetlands, American Water Resources Assoc.

Pamatmat, M. M. 1968. Ecology and metabolism of a benthic community on an intertidal sand flat. Int. Revue Gesamten Hydrobiol. 53: 211-298.

Peterson, C. H., and N. A. Peterson. 1979. The Ecology of Intertidal Flats of North Carolina: A Community Profile. U.S. Fish and Wildlife Service, Office of Biological Services. FWS/OBS-79/39. 73 pp.

Pomeroy, L. R. 1959. Algal productivity in salt marshes of Georgia. Limnol. Oceanogr. 4: 386-397.

Reise, K. 1977. Predator exclusion experiments in an intertidal mud flat. Helgol. Wiss. Meeresunters. 30:263-271.

Schneider, D. 1978. Equalization of prey numbers by migratory shorebirds. Nature 271:353-354.

Smalley, A. E. 1959. The growth cycle of Spartina and its relation to the insect populations in the marsh, pp. 96-100. In Proceedings of the Salt Marsh Conference, Marine Institute Univ. Georgia, Sapelo Island.

Stiven, A. E., and R. K. Plotecia. 1976. Salt marsh primary productivity estimates for North Carolina coastal counties: projections from a regression model. Univ. North Carolina Sea Grant Publ., UNC-SG-76-06, Raleigh. 17 pp.

Summerson, H. C. 1980. The Effects of Predation on the Marine Benthic Invertebrate Community in and around a Shallow Subtidal Seagrass Bed. M.S. Thesis. Univ. North Carolina, Chapel Hill. 118 p.

Teal, J. M. 1962. Energy flow in the salt marsh ecosystem of Georgia. Ecology 43:614-624.

Thayer, G. W., D. A. Wolfe, and R. B. Williams. 1975. The impact of man on seagrass systems. Amer. Sci. 63:288-296.

Virnstein, R. W. 1977. The importance of predation by crabs and fishes on benthic infauna in Chesapeake Bay. Ecology 58: 1199-1217.

THE RELATIONSHIP OF ESTUARINE PRODUCTIVITY TO WOODED SWAMPS AND BOTTOMLAND FORESTS IN THE SOUTHEASTERN U.S.

John W. Day, Jr.
William H. Conner
G. Paul Kemp
David G. Chambers

Coastal Ecology Laboratory
Center for Wetland Resources
Louisiana State University
Baton Rouge, Louisiana 70803

ABSTRACT

Swamps and bottomland forests are very productive ecosystems. Many extensive tracts are located in close proximity to estuaries and may be important in the functioning and productivity of an estuary. Net primary productivity values range from 200 g dry wt/m^2/yr for impounded areas to 1500 g dry wt/m^2/yr for seasonally flooded areas. Nutrient chemistry in swamp water and sediments is strongly affected by O_2 levels which are a function of water exchange.

Swamps and bottomland forests are coupled to estuarine processes in a number of ways. They may serve as nursery habitat for marine species. Water, nutrient, and organic export from these areas may be considerable and affect the salinity balance and productivity of estuaries.

Human activities have affected swamps and bottomland forests in many ways. Large areas have been drained and cleared for agricultural and urban development. Impoundments have lowered swamp and bottomland forests' productivity. Canals and channelization have led to more erratic hydroperiods and have affected water quality and caused land-loss problems. Management should consider the key role of hydrology in functioning of estuaries, swamps, and bottomland forests. The drainage basin is the most appropriate level of management.

INTRODUCTION

Cypress (<u>Taxodium distichum</u>) swamps and bottomland forests are important ecosystems in the southeastern United States. Some of the largest are well known, including the Atchafalaya in Louisiana, the Okefenokee in Georgia, and the Big Cypress in Florida. However, most rivers have swamps and bottomland forests associated with them, especially in their lower reaches.

The value of these ecosystems for wildlife habitat, water regulation, and other aspects are well recognized. However, studies of the ecology and mangement of estuaries have rarely considered that swamps and bottomland forests are important to estuaries. Recent evidence suggests that in many instances, swamps and bottomlands play an important role in estuarine productivity. The four objectives in this paper are to: (1) review the ecology of swamps and bottomland forest, (2) describe ecological coupling between these systems and estuaries, (3) discuss the impacts of human activities on both swamp ecology and swamp-estuary couplings, and (4) briefly suggest some management approaches.

ECOLOGY OF SWAMPS AND BOTTOMLAND FORESTS

PRODUCTIVITY

Forested wetlands of the southeastern United States are highly productive (Conner and Day 1976, Brown et al. 1979). This high productivity is related to water flow (Table 1). Odum (1979) hypothesized that both frequency and intensity of flooding are important (Figure 1); the highest productivity is at sites characterized by seasonal flooding. Productivity is lower with less water flow and for very strong flow. Brown et al. (1979) gathered all available data on forested wetlands and reported net productivity that was 40% greater in forested wetlands with flowing water than in those with still water.

Studies in Louisiana support the hypothesis that flowing water and fluctuating water levels are best for the growth of tree species. Conner and Day (1976) reported that bottomland forests are very productive (1,574 $g/m^2/yr$), even more so than cypress-tupelo (*Nyssa aquatica*) swamps (1,140 $g/m^2/yr$). The bottomland hardwood forests are flooded each year from a few weeks to months. The rest of the year the water table is near the soil surface. In these areas, cypress are present although not as abundant as in the true swamp forest.

The cypress-tupelo swamps are flooded for many months of the year, sometimes year-round, thus species diversity is low. These areas only drain when rainfall is extremely low. Cypress and tupelo only germinate under nonflood conditions. Therefore, it is during these drought years that new trees become established. This characteristic is probably the reason one finds large even-aged stands of these species.

The greatest productivity rates for a Louisiana swamp forest have been measured in an area managed as a crawfish farm, an area flooded from late fall through early spring and drained the rest of the year. While it is flooded, fresh water is constantly being flushed through the area to ensure high oxygen for crawfish. This type of management has proven to be very beneficial to tree growth. Net primary productivity for this area is estimated to be 1,755 $g/m^2/yr$ (William Conner, per. comm., Center for Wetland Resources, Louisiana State University).

In the swamp forest around Lake Pontchartrain, Cramer and Day (1979) studied two types of swamp forest--one continually flooded and the other with naturally fluctuating water levels. The natural swamp forest was the most productive (1,091 $g/m^2/yr$ vs. 618 $g/m^2/yr$).

COMPOSITION

Wetland forests are characterized by standing water for part of the year. Cypress is the most common tree associated with this environment, but depending upon the hydrologic conditions, other trees are also found. Bottomland riverine forests which have short hydroperiods tend to be dominated by red maple, ash, box elder, cottonwood, and water oak with cypress and tupelo scattered throughout. Cypress and water tupelo tend to form nearly pure stands in areas where drainage is poor and the hydroperiod is long. In Louisiana, Conner and Day (1976) found that 52% of the trees in the bottomland forest were ash, box elder, cottonwood and water oak; cypress and tupelo were only 13% of the total trees. In the cypress-tupelo swamp, 71% of the overstory was cypress and tupelo. Red maple and

Table 1. Comparative swamp productivities for the Southeastern United States.

Area	References	Stem Growth g/m^2/yr	Litterfall g/m^2/yr	NPP g/m^2/yr
Des Allemands, LA (seasonal flooding)				
Cypress-Tupelo	Conner & Day 1976	500	620	1120
Bottomland Hardwood	Conner & Day 1976	800	574	1374
Cypress-Typelo	Conner, pers. comm.	538	417	955
Crawfish Farm	Conner, pers. comm.	917	549	1466
(stagnant) Impounded	Conner, pers. comm.	296	328	624
Lake Pontchartrain	Cramer & Day 1979			
Seasonal flooding		618	473	1091
Continually flooding		376	242	618
Big Cypress Swamp, FL (riverine)	Carter et al. 1973			
Drained		120	267	387
Undrained-Edge Strand		485	373	858
Undrained-Cent. Strand		-	756	-
Withlacoochee St. Forest, FL	Mitsch 1975			
Combined riverine & cypress dome (average of 23 sites)		-	-	600
Cypress Domes, FL	Mitsch 1975			
Drained		-	-	416
Undrained (stagnant)		-	-	192
Okefenokee Swamp, GA	Schlesinger 1978			
Very slowly flowing		-	-	692
Tar River, NC (seasonal flooding)	Brinson 1977	-	528-577	-
Florida	Mitsch & Ewel 1979			
Cypress-hardwood (riverine) Cypress-tupelo		-	-	760

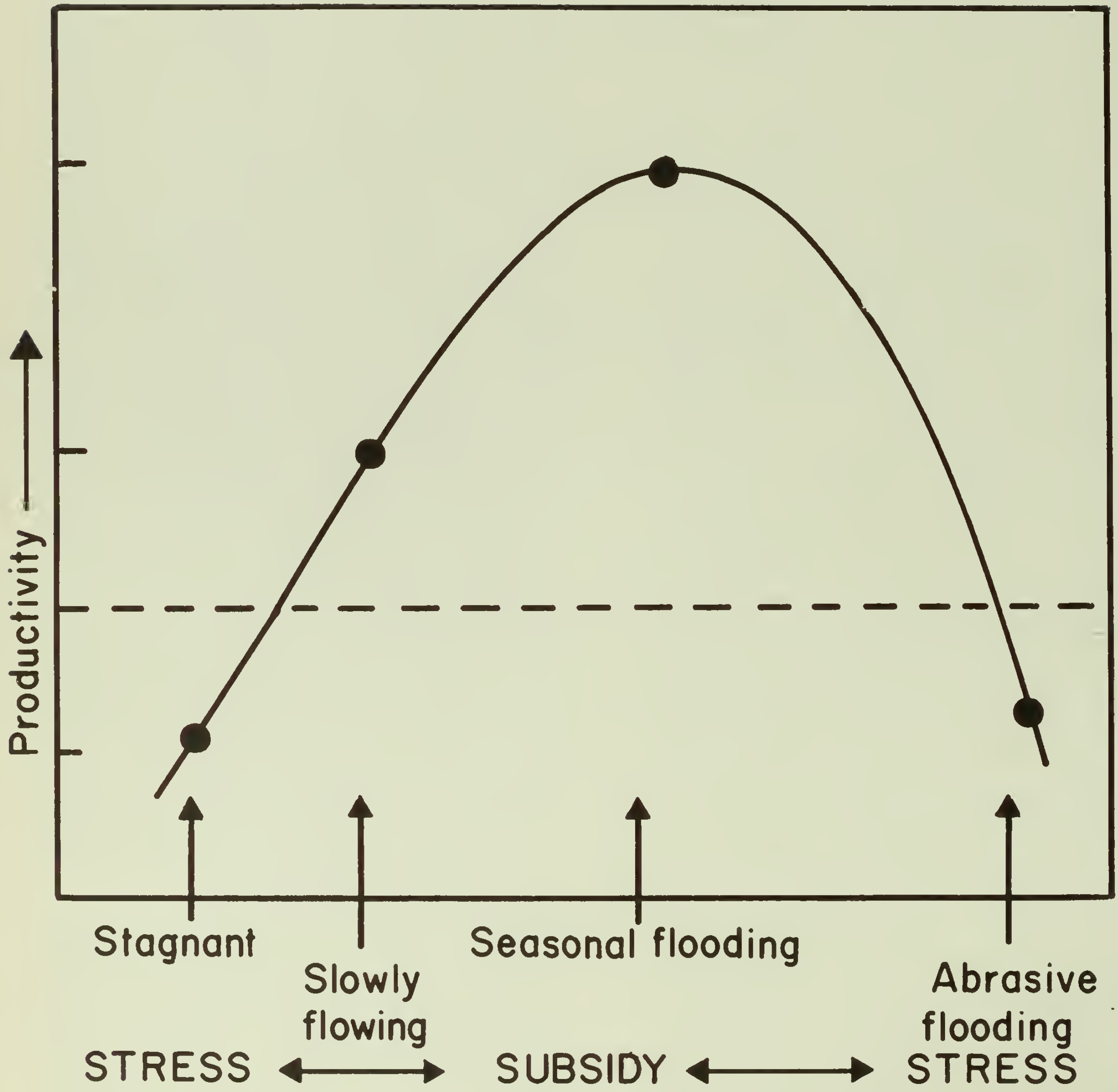


Figure 1. Model (partly data-based, partly hypothetical) of swamp subsidy-stress response to flooding (from Odum 1979).

pumpkin ash were the most common understory species.

CHEMISTRY

The chemistry of swamp floodwaters is determined by complex biological and geochemical interactions occurring at the sediment-water interface or forest floor. Many of these processes are mediated by specific parameters such as sediment geology and flooding regime, but a few generalizations may be made. There are few shrubs or grasses in a mature swamp because of light limitation and the rigor of seasonal flooding. Thus, the swamp floor is often a bare mud-water interface broken only by the trunks of well-spaced trees. Vegetative uptake of nutrients and other constituents, then, primarily in the tree root zone, does not directly affect floodwater concentrations.

Oxygen demand caused by large seasonal inputs of organic matter may strip oxygen completely from the water column during much of the year except when low temperatures do not inhibit microbial metabolism. Underlying sediments are almost always reduced.

Swamps act as catchment basins for sediments introduced in upland runoff. As water runoff spreads out and slows, particles settle out. Thus, swamp drainage waters, while often highly colored by dissolved organic substances, are generally low in suspended matter. Consequently, for upland runoff entering the swamp, there is initially a loss--primarily of oxygen and suspended load.

Then the water spreads over an often reduced sediment interface which is the site of intense anaerobic decomposition. During this stage, there are marked changes in the chemical composition of the water due to physical, chemical, and microbial activity--primarily at the mud-water interface. The relative intensity of this alteration is determined by the hydrology of the swamp, i.e., the residency time, and by the chemistry of the underlying sediments.

The following discussion will focus mainly on studies of nitrogen and phosphorus dynamics in Louisiana (Butler 1975, Kemp 1978, Seaton 1979). Much of what will follow is also true of other floodwater constituents.

Dissolved nutrient concentrations in swamp surface waters are in dynamic balance with concentrations in the sediment poor waters which are in turn in equilibrium with the sediments. The magnitude of the labile sediment pool is to some degree fixed by mineralogy and sedimentary history, but it is also strongly influenced by pH and Eh.

The swamp forest in the upper Barataria Basin, Louisiana, is an interdistributary swamp formerly subject to overbank flooding from the Mississippi River. Core data indicate an interlayering of peat deposits with alluvial silts and clays. The surface sediments are highly organic peats (carbon 17%) rich in both nitrogen and phosphorus (1.1% and 0.1%, respectively).

The swamp is poorly drained and much of it is generally inundated at least 10 months of the year. Floodwater pH is stable at neutrality. Dissolved oxygen is generally less than 1 ppm except during the winter months of January and February when it may approach saturation (8 ppm). Sediments are strongly reducing at a depth of 2 cm.

Concentrations of the dissolved nitrogen and phosphorus are generally high compared to other aquatic systems (Table 2). This is particularly true of organic nitrogen (1 mg/1) and organic phosphorus (0.2 mg/1) and orthophosphate (0.2 mg/1). Nitrates, however, are

Table 2. Comparison of nitrogen and phosphorus values in Barataria Bay estuary and other eutrophic areas (annual mean in mg/l) (from Butler 1975).

	Annual mean					
	Total-N	Organic-N	$(NO_3^- + NO_2^-) - N$	NH_4^+-N	Total-P	PO_4^{-3}-P
Bayou Chevreuil	2.13	1.63	0.28	0.25	0.34	0.15
Bayou Boeuf	1.79	1.36	0.14	0.19	0.20	0.12
Lac des Allemands	1.60	1.35	0.24	0.16	0.27	0.08
Lower Estuary						
Brackish bay		1.27	0.08	0.25	0.10	0.05
Saline bay		1.05	0.04	0.066	0.08	0.02
Lake Mendota	6.7-1.29					
(Domogalla et al. 1925)						
Central Florida Lake						
eutrophic		1.98				
meso-eutrophic		1.25				
(Shanon and Brezonik 1972)						

quite low (0.05 mg/l) as would be expected in a reducing environment. Ammonia concentrations (avg. 0.1 mg/l) are highly variable and appear related to the degree of stagnation--high in areas of low flushing and lower elsewhere.

A nutrient budget computed for a section of swamp receiving agricultural drainage indicates that this system is effective in removing nitrate nitrogen but that orthophosphate, organic nitrogen and organic phosphorus are, on the average, added to the water. However, during the winter, when oxygen levels rise, phosphate is removed by the sediments, thus indicating the redox related reversibility of uptake-release phenomena for this nutrient form.

The impact of oxygen and organic matter concentration is illustrated by unpublished results of an experiment we carried out at Louisiana State University. A number of microcosms were set up to simulate swamp floor conditions. Each had a layer of swamp sediment overlain with swamp water. Dry, dead tupelo leaves were added to half of the microcosms. All microcosms were sealed and either pure O_2, air, or argon gas (no oxygen) was slowly passed over the water surface. The experiment was run for 360 days and samples were taken every 60 days.

Oxygen levels were highest in microcosms without leaves and with pure oxygen atmosphere (Figure 2). PO_4 and NH_4 were high under reduced conditions while NO_3 + NO_2 was very low and undetectable. The presence of decomposing leaves allowed a larger surface area for microbial populations, which increased metabolism and lowered oxygen levels. This led to higher PO_4 and NH_4 and lower NO_3 and NO_2 in the microcosms with leaves. Kitchens et al. (1975) studied nutrient dynamics in the Santee swamp in South Carolina. There was a decrease in turbidity and nutrient levels (particularly PO_4) as river water flowed through the swamp, but there was little or no oxygen depletion.

In summary, chemical dynamics of swamps are very complex and strongly affected by local physical, hydrological, and geological conditions. Higher water flow generally leads to more aerobic conditions, but this is affected by sediment type (sands, peat, or clay). The development of an oxygenated water column and sediment surface promotes the uptake of most inorganic forms of nitrogen and phosphorus. Anerobic conditions promote leakage of most forms of these elements.

HYDROLOGY

Much of the ecology and chemistry of swamps and bottomlands is determined by hydrological conditions. Obviously, the presence of water is part of the definition of swamps. However, such factors as the rate, seasonality, and amount of water flow are crucial in determining community structure and composition, and chemical cycling.

However, swamps and bottomlands have a marked effect on hydrological patterns. The vegetation, soils, and topography of swamps cause an internal stabilization of often erratic water regimes (Littlejohn 1977). Water stored during wet periods is released slowly during dry periods.

An excellent example of these processes, and one we believe is generally applicable to many coastal areas, is described in a report on a study of the Gordon River Basin near Naples, Florida (Littlejohn 1977). Before human settlement, the area consisted of upland communities, swamp wetland, mangroves, and estuarine waters. Much of the area is now urbanized. Most water needs are supplied by wells in sandy aquifers. Littlejohn (1977) conducted a model study of

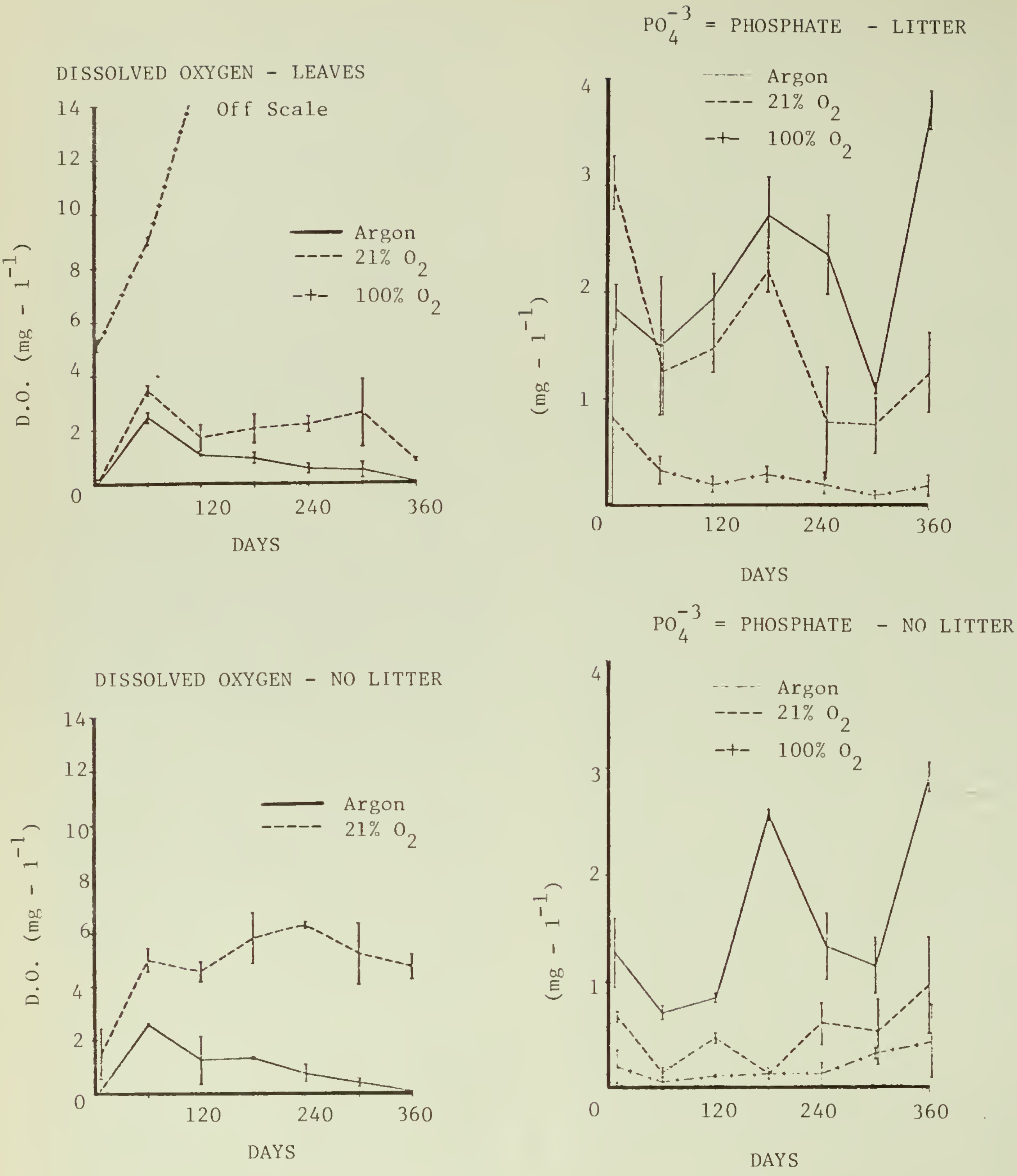


Figure 2. Variations in concentration of dissolved O^2, PO^4, NO^2, + NO^3, and NH^4 in swamp sediment microcosms with atmospheres of Argon (0% O^2), 21% O^2 and 100% O^2.

(continued)

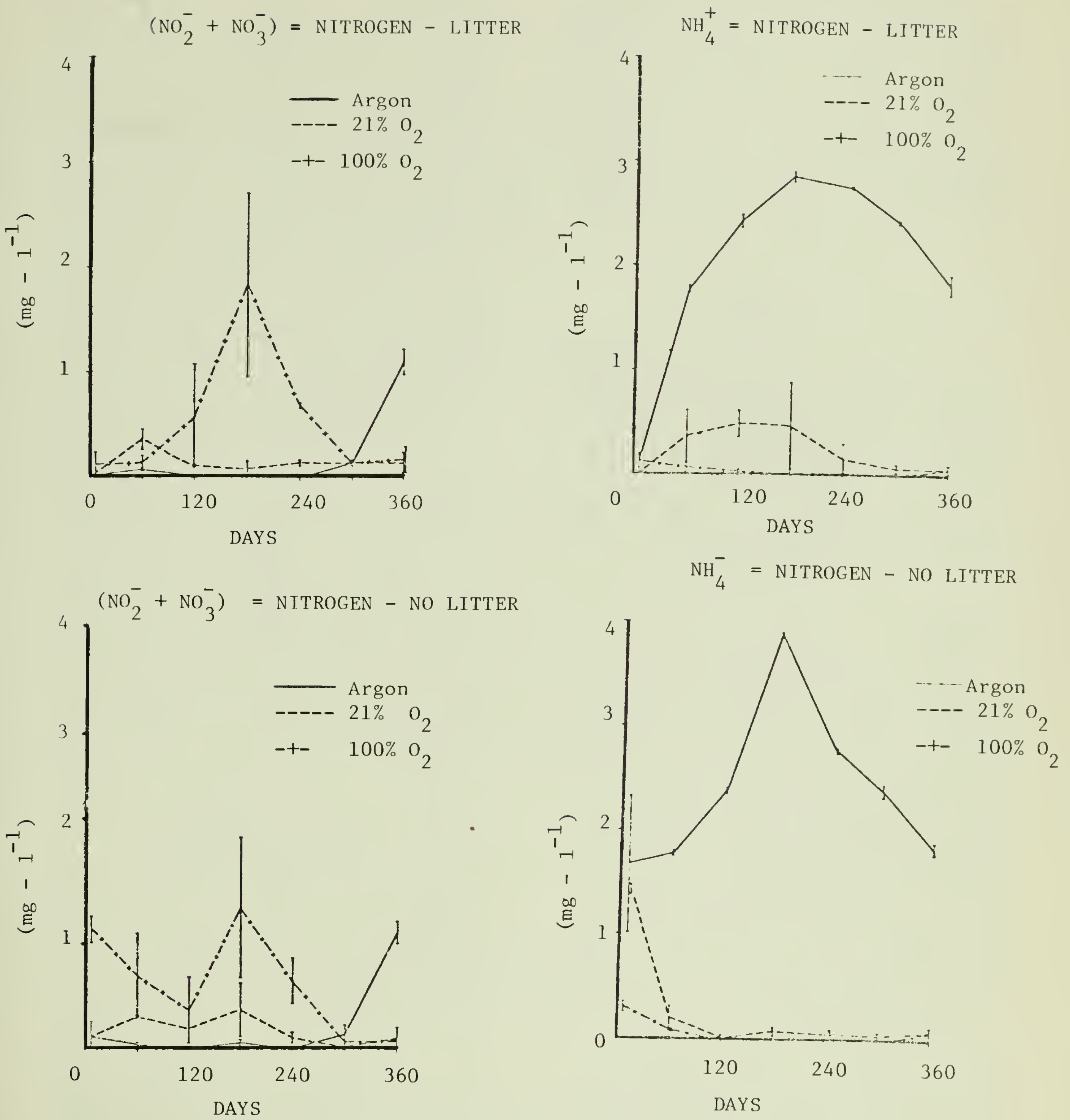


Figure 2. (concluded)

the effects of drainage of much of the swamp area for development.

The area is characterized by seasonal rainfall (Figure 3). Even with strong precipitation seasonality, aquifer storage and discharge into Naples Bay were relatively constant (Figure 3). These results exemplify the buffer effect of wetlands on water flow. Similar findings have been reported for Louisiana (Hopkinson 1979).

SWAMP ESTUARY COUPLINGS

There are three principal ways that swamps can affect estuarine productivity: habitat, nutrient inputs, and hydrological effects. Obviously, these couplings are more pronounced the closer a swamp system is to the coast. Most are found in the coastal plain, many can have significant effects.

HABITAT

Where swamp systems border the coastal zone, estuarine dependent species can use them as nursery habitat. Hinchee (1977) reported that swamps bordering Lake Pontchartrain served as important habitat for a number of estuarine species including shrimp, blue crab, menhaden, and seatrout. McIntire et al. (1975) listed a number of marine and estuarine species which penetrated into freshwater along the Louisiana coast. These included rangia clams, blue crabs, and numerous fishes.

A study of the upper Barataria basin (Chambers 1980) showed extensive use of the low salinity and fresh marsh areas by marine nektonic organisms. Samples were collected using an otter trawl and a surface push trawl along a transect from freshwater swamp lakes in the upper basin to brackish bays in mid-basin.

Figure 4 shows the relative contribution (percent of total biomass) of each species at each station. Figure 4a illustrates the catch at station 1, a freshwater swamp lake located in the uppermost portion of the basin. Included in the catch were the blue crab (Callinectes sapidus), an important commercial species, and the bay anchovy (Anchoa mitchilli), an abundant estuarine forage fish. Other commercially important marine species which reached the freshwater swamp lakes (but in fewer numbers) included the Gulf menhaden (Brevoortia patronus) and the Atlantic croaker, (Micropogon undulatus).

Figure 4b depicts the catch from station 3, a lake surrounded by fresh and intermediate marsh and subject to occasional low salinity conditions. Juvenile and adult marine species comprised a greater percentage of the total catch (87%) at station 3 than at station 1 (39%). The catch at station 10 (Figure 4c), a slightly brackish bayou, reflected an even greater percentage of marine and estuarine species (89%), and included the following commercially important species: blue crab, Atlantic croaker, Gulf menhaden, brown shrimp (Penaeus aztecus), white shrimp (Penaeus setiferus), white trout (Cynoscion arenarius), and southern flounder (Paralichthys lethostigma).

Station 15, at the head of Barataria Bay, was characterized by higher salinities and a higher percentage of marine species (98%). Two additional commercial species, spot (Leiostomus xanthurus) and spotted seatrout (Cynoscion nebulosus), were encountered here along with those found at station 10. The entire basin appears to function as a nursery area for juvenile marine species but, as expected,

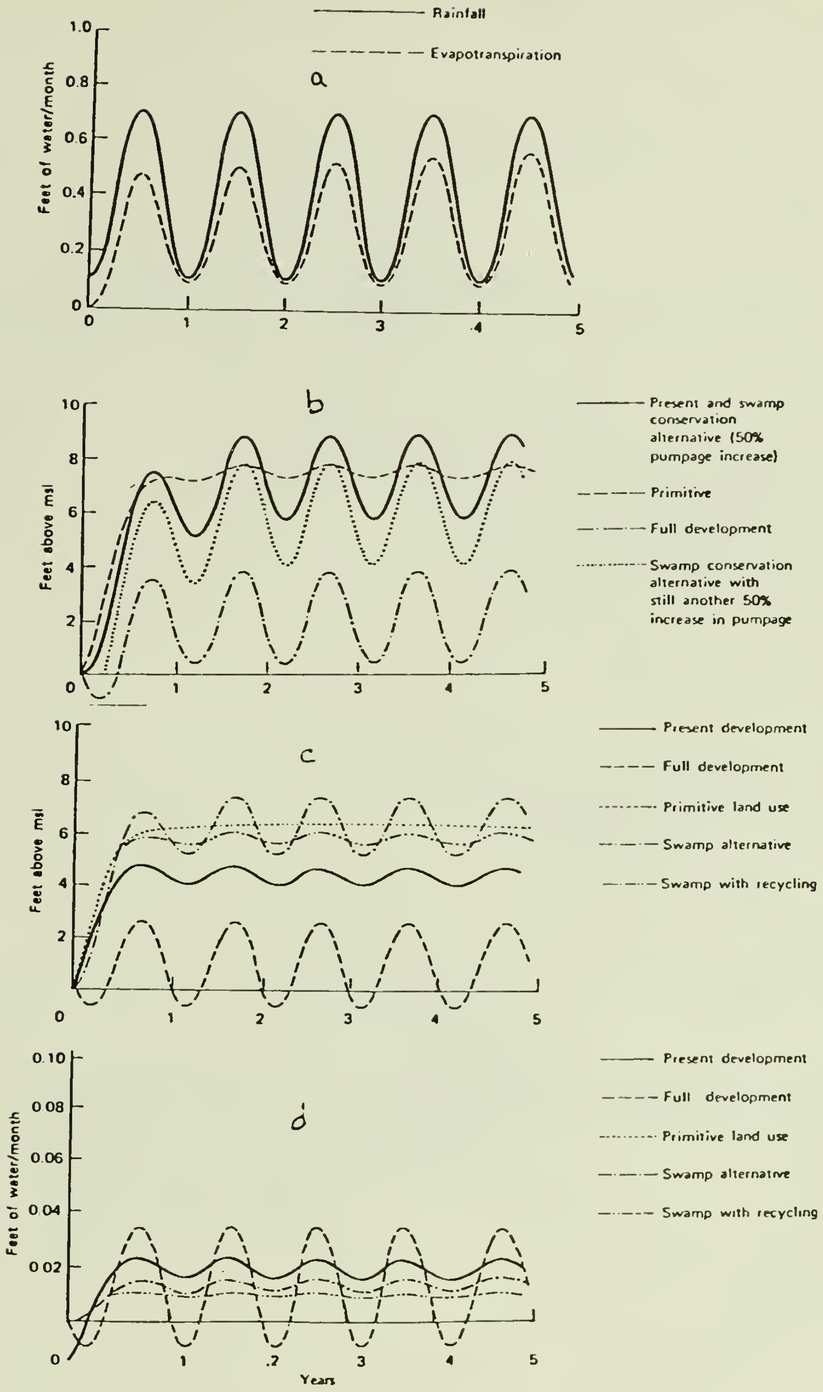
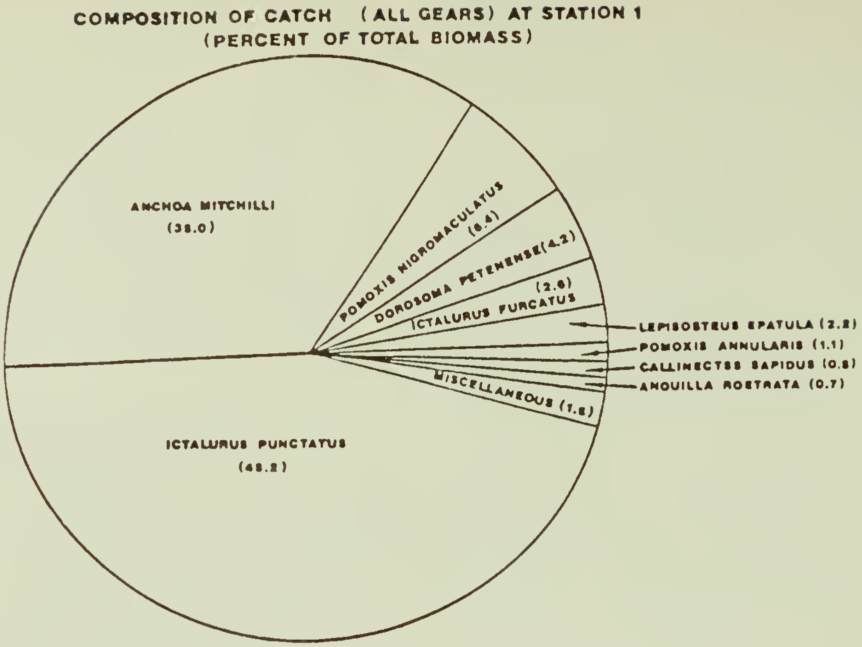


Figure 3. (a) Coastal-ridge flows simulating primitive conditions; (b) coastal-ridge aquifer storage for comparison (the swamp-conservation alternative results in aquifer behavior almost identical to that presently observed, although municipal pumpage is increased to 50%); basin aquifer storage (c) and; variations in surface discharge (d) for each alternative of land use (from Littlejohn 1977).



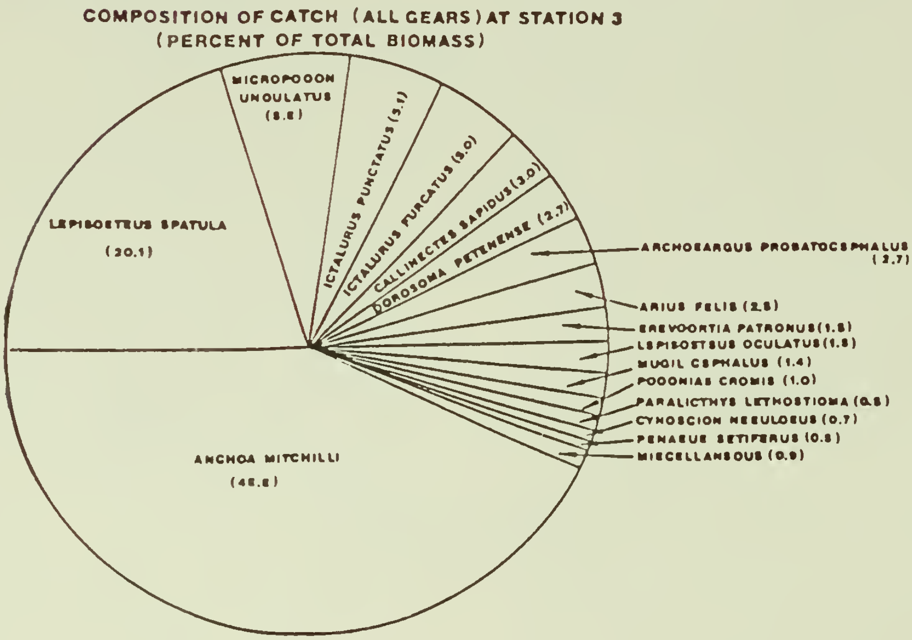
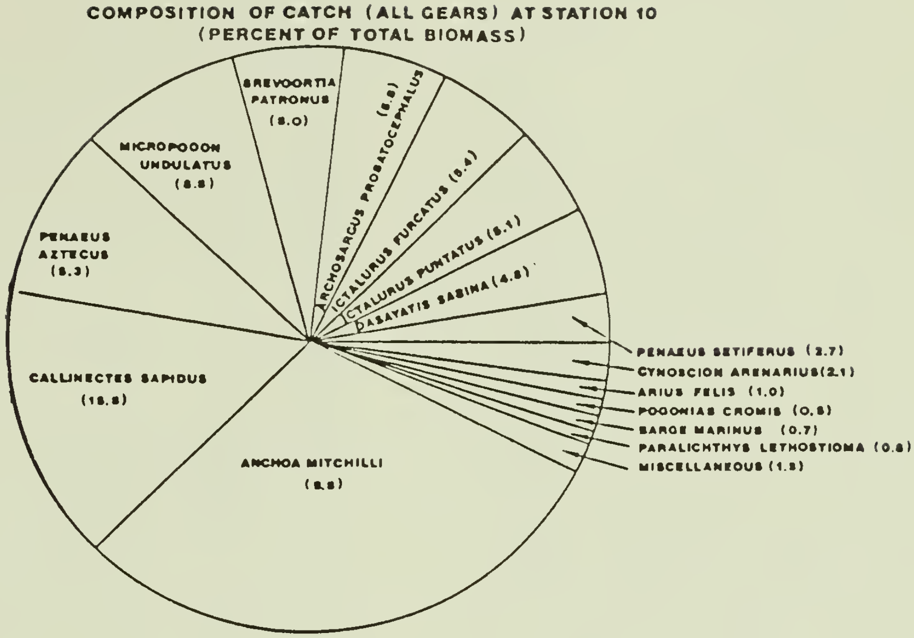


Figure 4. Composition of the nektonic community at four stations in the Barataria Basin. Mean annual salinity at the stations were stn. 1 - 0°/oo; stn. 3 - 3°/oo; stn. 10 - 7 °/oo; and stn. 15 - 15°/oo.

(continued)



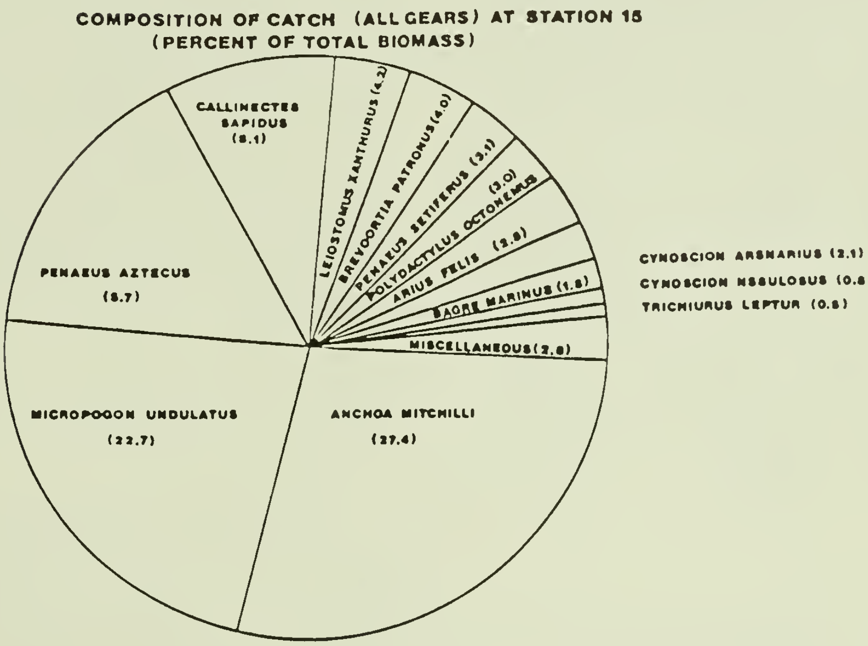


Figure 4. (concluded)

the percentage of marine species using the area increases toward the Gulf.

Euryhaline larval, postlarval, and juvenile marine nekton migrate far up the basin in the winter and spring, and then gradually move downbay as they grow, eventually emigrating to the Gulf in later summer and fall (Figure 5). In the fall and early winter, juveniles and adults of freshwater species move southward into these areas and replace the emigrating marine species. Reduced competition and decreased salinities in the upper basin at this time presumably enable the freshwater species to better exploit the resources available to them.

As salinities and water temperatures increase in the late winter and spring, the marine species again begin their upbasin migration, while the freshwater species retreat to the fresher water of the northernmost lakes. During the warmer months, mesohaline juveniles of certain marine species move up to the mid-basin during periods of high salinity, and later return to the lower bays and Gulf in the late fall and winter as salinities decrease.

Some euryhaline species appear to spend their entire life cycles in the estuary and often may be found anywhere from the freshwater swamps in the north, to the lower bays and barrier islands bordering the Gulf. Figure 5 illustrates the coupled migrations above and gives examples of specific organisms typical of each pattern.

NUTRIENT INPUTS

Swamps can be important sources of nutrient for estuarine systems. Day et al. (1977) reported that large quantities of nitrogen, phosphorus, and carbon were exported from the upper Barataria Basin into the lower estuarine zone. A large part of this was introduced during the highly productive spring. Cramer (1978) measured high levels of nitrogen and phosphorus in swamp water flowing into Lake Pontchartrain, Louisiana.

Rivers introduce large quantities of nutrients into coastal systems. Important chemical changes take place if these waters flow through swamps (Kitchens et al. 1975, Kuenzler et al. 1977, Seaton 1979, Kemp 1978). These changes were outlined earlier.

HYDROLOGICAL EFFECTS

Brackish water is one of the main characteristics of estuaries. A brackish gradient is maintained by upland freshwater input. Swamps can help stabilize erratic freshwater pulses. Littlejohn (1977) showed that swamps stabilized aquifer storage and discharge into Naples Bay, Florida, even in the face of a sharp seasonal pulse in precipitation (Figure 3).

In Louisiana, Day et al. (1977) measured water flow from swamp forests into the lower Barataria Basin. Freshwater was discharged into the lower Bay from September through May, but there was little net flow in the summer because of high evapotranspiration and southerly winds.

HUMAN IMPACTS

Since the first settlers, forested wetlands have been viewed as land that needed to be reclaimed. Toward this goal, the Swamp Land Acts of 1849 and 1850 transferred all "swamp and overflowed lands" to individual States under the condition that they sell the land and use the money to build levees and drains necessary to reclaim the

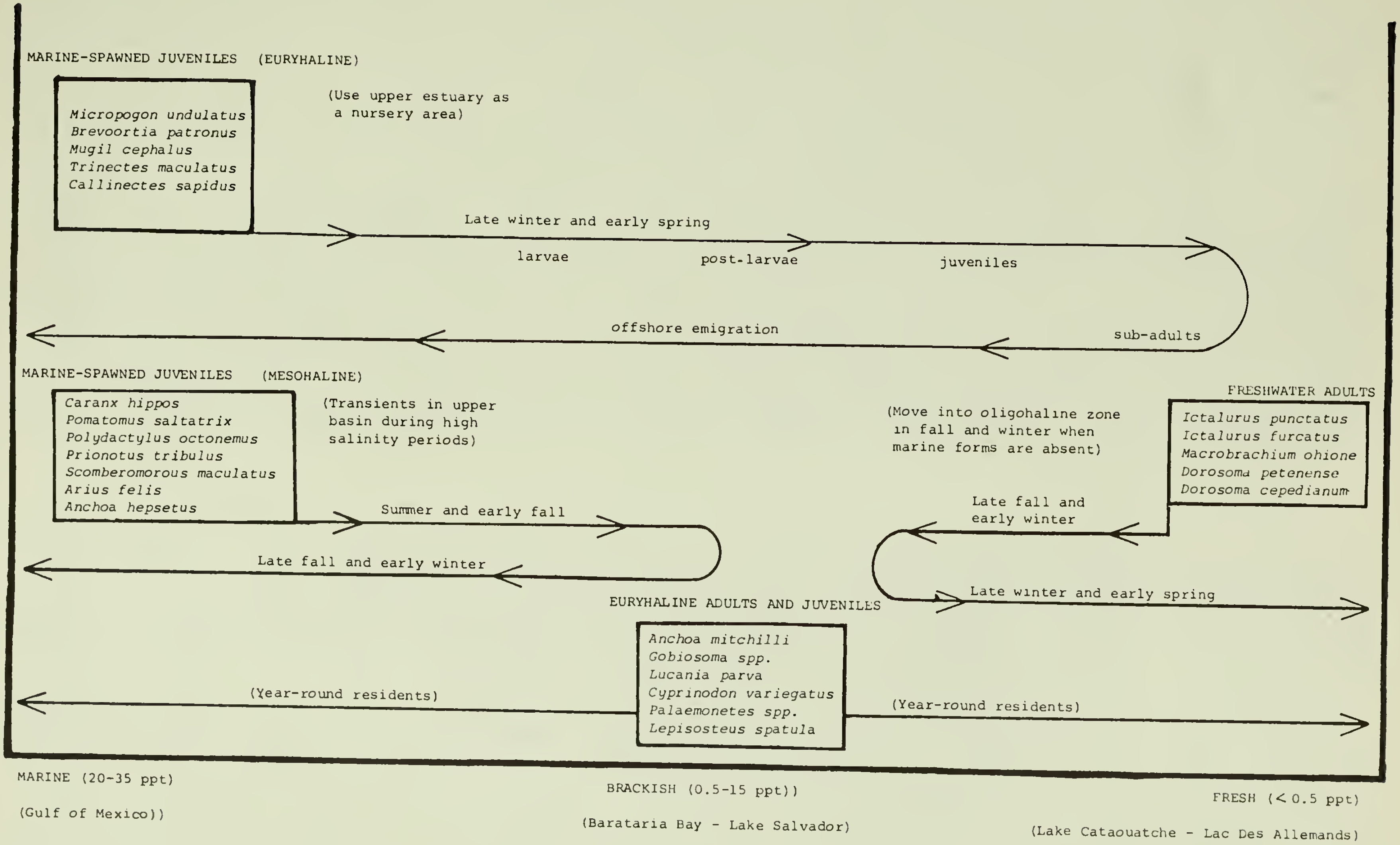


Figure 5. Patterns of estuarine use by nektonic organisms in the Barataria Basin, Louisiana.

land (Harrison 1951). Thousands of acres of wetland forests have been cleared. In Louisiana alone only 5.6 million acres remain of the original 9.4 million acres of forested wetlands (R. Eugene Turner, pers. comm., Center for Wetland Resources, Louisiana State University).

Those forests not cleared for agricultural use have also been affected by man's activities. Nearly every mature stand of bottomland hardwood and cypress forest in the U.S. has been cut at least once. Canals and pipelines crisscross many swamp lands. Existing streams have been dredged or shortened, or both, for navigation, flood control, and drainage. All of these activities in one way or another affect the hydrologic regime of the wetland areas.

Most food chains in floodplain environments are detritus-based. The clearing or clearcutting of wetland forests, whose trees are the source of detritus, deprives organisms of a major food source. Day et al. (1977), Kemp (1978), and Seaton (1979) found that pulses of carbon, nitrogen, and phosphorus are released to the adjacent estuary during periods of runoff.

Productivity of Apalachicola Bay, Florida, is regulated by annual pulses of organic matter and silt from upstream and by major high water flows every 6-8 years (Livingston 1978). Clearcutting and ditching in the Apalachicola delta and adjacent Tate's Hell area have severely damaged marine productivity in East Bay (Livingston 1978).

In the swamp forests themselves, canals with their associated spoil banks altered or interrupted water flow. In many instances, areas of forest have been impounded. With constant flooding there is no recruitment of new trees to replace those that die or are blown over. Productivity of these areas declines yearly. Conner (per. comm.) reported the productivity of an impounded swamp forest (impounded for 25 years) as 822 $g/m^2/yr$ as compared to 989-1,755 $g/m^2/yr$ for natural swamp forests. Along with the lowered productivity there is very little export of nutrients or organics out of the area. Thus, this loss affects life in the stream and the marsh areas below the swamp forests.

Upland runoff combined with hydrological changes can lead to altered nutrient dynamics. Channelization and canals can speed nutrient-laden waters past swamps and into receiving water bodies. This change leads to lower productivity in the swamps and potentially to eutrophication of water bodies (Day et al. 1977, Kemp 1978). For example, Kemp found the N/P ratios in Bayou Chevreuil in the upper Barataria Basin, Louisiana, were closely related to runoff patterns (Figure 6). N/P ratios in the Bayou were low (2:1) between rainfall periods and closely approximated values in the swamp. If sampling occurred during or immediately following (within 5 days) a significant rainstorm, N/P ratios in the Bayou were elevated, in one instance as high as 20:1. There were, then, two types of water flowing into Bayou Chevreuil: natural levee upland runoff and swamp drainage. If the swamps are adjacent to the coastal zone, entrophication of estuarine waters can result (Cramer 1978, Hopkinson and Day 1979, Seaton 1979).

It is obvious that hydrology is a key to understanding swamp dynamics, swamp-estuary couplings, and human impact. In Littlejohn's (1977) work in Florida, loss of swamp wetlands was related to altered hydrologic patterns and saltwater intrusion (Figure 3). In Louisiana wetlands, canal density has been related to land loss (Craig et al. 1979) and water qual-

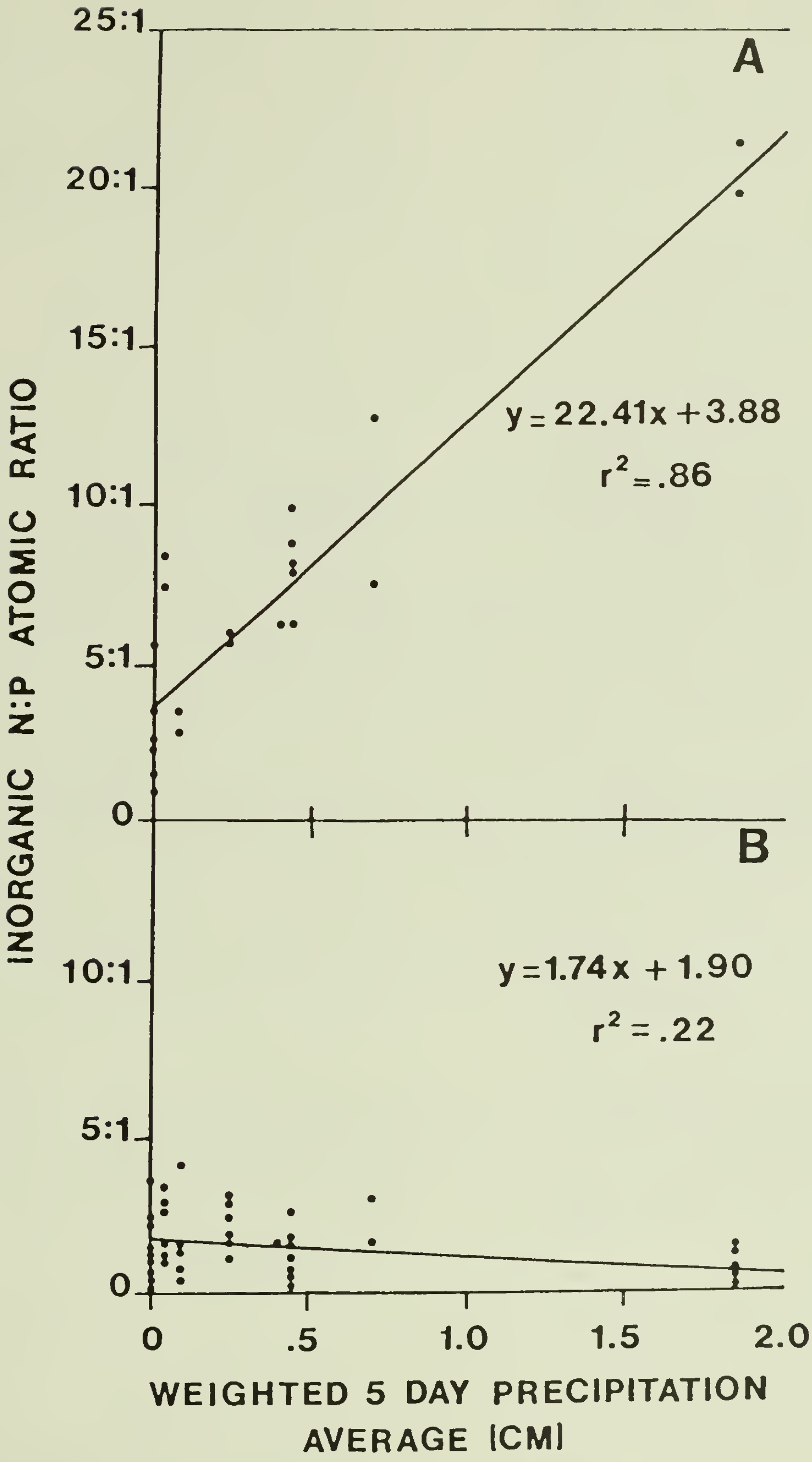


Figure 6. Relationship between recent precipitation and inorganic N:P atomic ratio. A: Bayou Chevreuil; B: swamp floodwater (Kemp 1978).

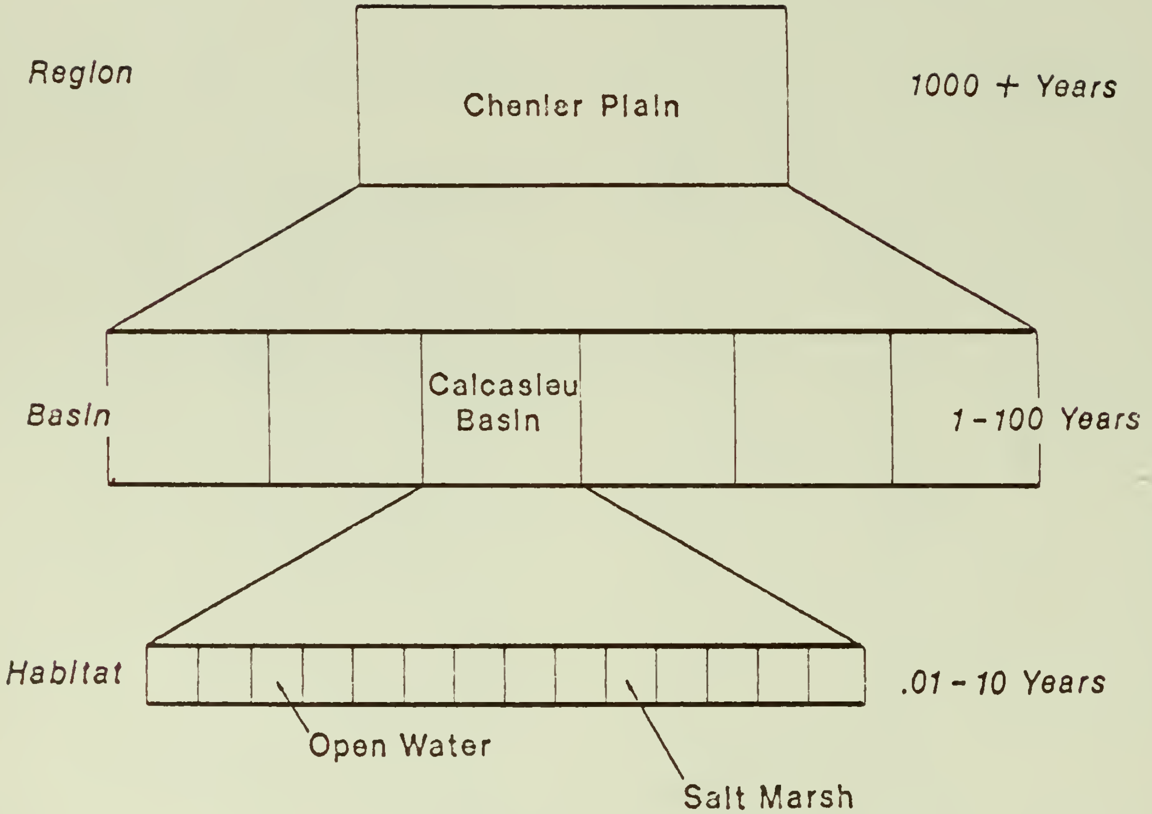


Figure 7. Hierarchical conceptual model of the Chenier Plain in Louisiana and Texas. (Gosselink et al. 1979)

ity (Gael and Hopkinson 1979). Hopkinson (1979) constructed a model of the swamp forest surrounding Lake des Allemands, Louisiana. Simulation of the removal of all canals and levees and of a more "natural" condition resulted in smoother hydrographs, higher swamp productivity, and lower trophic status of the lake.

MANAGEMENT

In terms of management the foregoing information suggests a central theme. Hydrology is a key consideration in both the mangement of swamps and swamp-estuary couplings. This includes land management as it affects water movement. Important topics for management include channelization, canal construction, spoil placement, water quality, and impoundment.

A second consideration is the level of management. Bahr et al. (1977) constructed a conceptual model of the Chenier plain of Texas and Louisiana. They concluded, from the standpoint of time scale and areal extent of important events and structure, that the drainage basin was the most appropriate level for management (Figure 7).

For large river systems it is not practically possible to include the whole river basin; thus an important question is what is the most reasonable cutoff point in terms of coastal management.

LITERATURE CITED

Bahr, L. U., J. Day, T. Gayle, J. G. Gosselink, C. S. Hopkinson, D. Stellar, J. Harris. 1977. Construction of a conceptual model of the Chenier Plains coastal ecosystem of Texas and Louisiana, pp. 75-92. In C. Hall and W. Preston (comps.), Program Review Procedures; Environmental Effect of Energy Related Activities on Marine Estuarine Ecosystems. EPA Report. EPA 600/7-77-111.

Brinson, M. M. 1977. Decomposition and nutrient exchange of litter in an alluvial swamp forest. Ecology. 58(3):601-609.

Brown, S., M. M. Brinson, and A. E. Lugo. 1979. Structure and function of riparian wetlands, pp. 17-31. In R. R. Johnson and J. F. McCormick (tech. coord.), Strategies for Protection and Management of Floodplain Wetlands and other Riparian Ecosystems. Gen. Tech. Rep. WO-12, Forest Service, U.S. Dept. Agri., Washington, D.C.

Butler, T. J. 1975. Aquatic Metabolism and Nutrient Flux in a South Louisiana Swamp and Lake Ecosystem. M.S. Thesis, Louisiana State University, Baton Rouge. 58 pp.

Carter, M. R., L. A. Burns, T. R. Cavinder, K. R. Dugger, P. L. Fore, D. B. Hicks, H. L. Revells, and T. W. Schmidt. 1973. Ecosystems Analysis of the Big Cypress Swamp and Estuaries. U.S. Environmental Protection Agency, Region IV, South Florida Ecological Study. 387 pp.

Chambers, D. G. 1980. Analysis of Nector Communities of the Upper Barataria Basin. M.S. Thesis, Louisiana State University, Baton Rouge. 286 pp.

Conner, W. H., and J. W. Day, Jr. 1976. Productivity and composition of a bald cypress-water tupelo site and a bottomland hardwood site in a Louisiana swamp. Amer. J. Bot. 63: 1354-1364.

Craig, N. J., R. E. Turner, and J. W. Day, Jr. 1979. Land loss in Louisiana, pp. 227-254. In J. W. Day, Jr., D. D. Culley, Jr., R. E. Turner, and A. J. Mumphrey, Jr. (eds.), Proceedings Third Coastal Marsh and Estuary Management Symposium. Louisiana State University, Division of Continuing Education, Baton Rouge.

Cramer, G. W. 1978. A Nutrient Study in the St. Charles Parish Wetlands Adjacent to Lake Pontchartrain, Louisiana. M.S. Thesis, Louisiana State University, Baton Rouge. 51 pp.

Cramer, G. W. and J. W. Day. 1979. Productivity of the Swamps and Marshes Surrounding Lake Pontchartrain, La. Final report to the U.S. Army Corps of Engineers, New Orleans, Louisiana. 58 pp.

Day, J. W., Jr., T. J. Butler and W. H. Conner. 1977. Productivity and nutrient export studies in a cypress swamp and lake system in Louisiana, pp. 255-269. In M. Wiley (ed.), Vol. II, Circulation, Sediments, and Transfer of Material in the Estuary. Academic Press, New York.

Domogalla, B. P., C. Juday, and W. H. Peterson. 1925. Forms of nitrogen found in certain lake waters. J. Biol. Chem. 63(1): 269-285.

Gael, B. T., and C. S. Hopkinson. 1979. Drainage density, land use and eutrophication in Barataria Basin, Louisiana, pp. 147-163. In J. W. Day, Jr., D. D. Culley, Jr., R. E. Turner, and A. J. Mumphrey, Jr. (eds.), Proceedings Third Coastal Marsh and Estuary Management Symposium. Louisiana State University, Division of Continuing Education, Baton Rouge.

Gosselink, J. G., C. L. Cordes, and J. W. Parsons. 1979. An ecological characterization study of the Chenier Plain coastal ecosystem of Louisiana and Texas. 3 vols. U.S. Fish and Wildlife Service, Office of Biological Services. FWS/OBS - 78/9 through 78/11. 302 pp.

Harrison, R. W. 1951. Swamp Land Reclamation in Louisiana 1849-1879. U.S. Dept. Agric., Bureau of Agricultural Economics, Baton Rouge, Louisiana. 95 pp.

Hinchee, R. E. 1977. Selected Aspects of the Biology of Lake Pontchartrain, Louisiana. M.S. Thesis, Louisiana State University, Baton Rouge. 71 pp.

Hopkinson, C. S. 1979. The Relation of Man and Nature in Barataria Basin, Louisiana. Ph.D. Thesis, Louisiana State University, Baton Rouge. 236 pp.

Hopkinson, C. S., and J. W. Day, Jr. 1979. Aquatic productivity and water quality at the upland-estuary interface in Barataria Basin, Louisiana, pp. 291-314. In Proc. Conf. on Ecological Processes in Coastal and Marine Systems.

Johnson, R. R., and J. F. McCormick (tech. coord.). 1979. Strategies for protection and management of floodplain wetlands and other riparian ecosystems. In Proc. Symp. Gen. Tech. Rep. WO-12, For. Serv., U.S. Dep. Agri., Washington, D.C. 410 pp.

Kemp, G. P. 1978. Agricultural Runoff and Nutrient Dymanics of a Swamp Forest in Louisiana. M.S. Thesis, Louisiana State University, Baton Rouge. 62 pp.

Kitchens, W. M., Jr., J. M. Dean, L. H. Stevenson, and J. H. Cooper. 1975. The Santee Swamp as a nutrient sink, pp. 349-366. In Howell, F. G., J. B. Gentry, and M. H. Smith (eds.), Mineral Cycling in Southeastern Ecosystems. ERDA CONF - 740513.

Kuenzler, E. J., P. J. Mulholland, L. A. Ruley, and R. P. Sniffen. 1977. Water Quality in North Carolina Coastal Plain Streams and Effects of Channelization. Water Resources Research Institute, University North Carolina, Raleigh. Rept. No. 127. 160 pp.

Littlejohn, C. 1977. An analysis of the role of natural wetlands in regional water management, pp. 451-476. In C.A.S. Hall and J. W. Day, Jr. (eds.), Ecosystem Modeling in Theory and Practice. John Wiley and Sons, N.Y.

Livingston, R. J. 1978. Short and Long-term Effects of Forestry Operation on Water Quality and the Biota of the Apalachicola Estuary (North Florida, U.S.A.). Tech. Pap. No. 5. State Univ. System, Fla. Sea Grant College Programs, University of Florida, Gainesville. 157 pp.

McIntire, W. G., M. J. Hershman, R. D. Adams, K. D. Midboe, and B. B. Barrett. 1975. A Rationale for Determining Louisiana's Coastal Zone. Louisiana State University, Center for Wetland Resources, Baton Rouge. Sea Grant Publ. No. LSU-T-75-006. 91 pp.

Mitsch, W. J. 1975. Systems Analysis of Nutrient Disposal in Cypress Wetlands and Lake Ecosystems in Florida. Ph.D. Thesis, University of Florida, Gainesville. 521 pp.

Mitsch, W. J., and K. C. Ewel. 1979. Comparative biomass and growth of cypress in Florida wetlands. Amer. Midl. Nat. 101: 417-426.

Odum, E. P. 1979. Ecological importance of the riparian zone, pp. 2-4. In R. R. Johnson and J. F. McCormick (tech. coord.), Strategies for Protection and Management of Floodplain Wetlands and Other Riparian Ecosystems. Gen. Tech. Rep. WO-12, Forest Service, U.S. Dept. Agric., Washington, D.C.

Schlesinger, W. H. 1978. Community structure, dynamics and nutrient cycling in the Okefenokee cypress swamp-forest. Ecol. Monogr. 48: 43-65.

Seaton, A. M. 1979. Nutrient Chemistry in the Barataria Basin:A Multivariate Approach. M.S. Thesis, Louisiana State University, Baton Rouge, Louisiana. 124 pp.

Shanon, E. E. and P. L. Brezobik. 1972. Limnological Characteristics of North and Central Florida Lakes. Limnol. Oceanogr. 17(2):97-110.

REDUCED FRESHWATER INFLOW
IMPACTS ON ESTUARIES

Nicholas A. Funicelli
and Harvey M. Rogers
U.S. Fish and Wildlife Service
Austin, Texas 78701

ABSTRACT

This paper presents information on freshwater inflows and their importance to estuary maintenance. Nutrients, detritus, sediments, flushing action, timing on a seasonal basis, and the magnitude and duration of inflows are discussed. Reductions in freshwater inflows to estuaries cause widespread and diverse impacts on habitats and many species in the food chain (web). This paper alludes to impacts attributed to salinity changes, flushing actions in palustrine or marsh environments, biota impacted, and the benefits to be derived with ample supplies of nutrient and detritus on a seasonal basis.

INTRODUCTION

Estuaries are coastal zones where freshwater mixes with saltwater. These are very productive niches for fish and wildlife resources, and vary in magnitude, morphology, and characteristics ranging from inundated rivers, to fjord-like bays, to coastal plains or to vast embayments in Chesapeake and San Francisco to shallow bays as seen along the Texas coast. Estuaries also vary in characteristics of change. They have been impacted directly by alterations such as channelization, urban and industrial developments, or indirectly by changing the quantity and quality of freshwater inflows.

Estuaries provide about 85 percent of the commercial fishing in the United States. Shrimp, oyster, crab, and finfish (except tuna), which account for most of the cash crops of our commercial fishermen, are all dependent at some stage of their life cycle on the estuaries. These estuaries also account for over 120 million man-days of sport fishing annually. Estuarine productivity is closely related to the quality, quantity, and timing (seasonal distribution) of its freshwater inflows.

BENEFITS OF HIGHER FLOWS

The term "freshwater inflow" is somewhat misleading. "Freshwater" arriving at the estuary brings with it much more than freshwater. It is a transport system for various nutrients and sediments. Sediments contribute to delta formation, development and maintenance, and they influence coastal marshes. Nutrients may be limiting factors for many of our coastal biotic resources. Periodic river flooding is beneficial to delta marshes and the estuaries. Such flooding transports large volumes and a variety of nutrients along with the freshwater. Marsh flooding also increases the amount of low salinity habitats in the coastal ecosystem. Thus, freshwater inflows to the estuary provide many benefits. They act as a transport system for sediments, nutrients, and detritus; they increase the amount of salinity habitats and hydrologically alter the salinity gradient deemed essential for coastal biota maintenance. Alteration or reduction of one physical parameter (freshwater inflow) appears to have far reaching impacts in the ecosystem.

Although an ecosystem approach to impact assessment is generally preferred, unavailable site specific data, high cost of collection, and the undeveloped state-of-the-art, impede such assessments. "Key species" or other specifically designed approaches for predicting impacts or managing the total ecosystem are alternatives to total ecosystem analysis. Management of marsh plants, sea grasses, shellfish, or finfish in coastal areas may profit from these alternative assessments.

ADVERSE IMPACTS OF FRESHWATER INFLOWS

Decreased freshwater inflows to estuaries can have significant adverse impacts on the ecosystem. The salinity structure influenced by freshwater inflows is manifested in bays or coastal seas and in tidal zones. Reducing freshwater inflows, by definition, will increase the magnitude of salinities as well as salinity gradients. Distributions and numbers of salinity-dependent organisms are affected. Moreover, inflows are important in flushing and delivery of both organic and inorganic matter from the river to the marshes and from these deltaic marshes to the bay proper. Copeland and Fruh (1970) regarded estuaries as "nutrient traps" and emphasized the importance of maintaining river flows into these areas.

BIOLOGICAL IMPACTS - A SPECIES APPROACH

The biological impacts of freshwater inflow alterations relate to the indirect physical changes in salinities and changes in organic and inorganic nutrient inflows and outflows.

MARSH PLANTS PRODUCTIVITY IN RELATION TO INFLOWS

Freshwater inflow reduction can decrease productivity of *Spartina alterniflora* by increasing salinity levels above those needed for growth and fertility of the plants (Penfound and Hathaway 1938, Chapman 1976). Optimum primary productivity for *S. alterniflora* occurs at a salinity of 5 ppt (Mooring et al. 1971). Increases in salinity above the optimum result in lower productivity.

Reduced nutrient flows can impact marsh grasses such as *S. alterniflora*, *S. patens*, *Juncus roemerianus*, *Salicornia* spp., and *Batis maritima*. These grasses obtain their nutrients mostly from sediments (usually of delta origin) in which they grow. The role of freshwater inflow transport is believed to be important in replenishing sediment nutrients. Furthermore, loss of sediment load and reduced delta formation through flow reduction can be significant because less marsh sediment replenishment occurs. Decreases of nutrient concentrations in the water column adversely impact marsh plants because sediment nutrients are transported by the water.

Marsh plants are significantly impacted by the magnitude, distribution and timing of marsh inundation. Upstream reservoir regulation reduces freshwater discharges and alters the timing, magnitude, and duration of marsh inundation.

SHELLFISH

Freshwater inflow reductions can affect pelagic shellfish environments by modifying salinity and nutrients and, therefore, possibly the habitats of certain shellfish life stages. A number of studies have dealt with the relationship between commercial fishery harvest and freshwater inflows (Gunter and Hildebrand 1954, Chapman 1966, Copeland 1966, Copeland et al. 1972, Armstrong and Hinson 1973, Henley and Rauschuber 1979, Ward and Armstrong 1979). Salinity levels and nutrient influxes are considered to be the most important variables although the exact mechanisms producing this relation are unclear.

White Shrimp (Penaeus setiferus)

Reduced freshwater inflow impacts white shrimp in several ways. Although juvenile white shrimp can tolerate salinities between 0.3 ppt (Joyce 1965) and 48 ppt (Hildebrand 1958), they prefer salinities lower than 10 ppt (Williams 1955). Salinity preference for adult white shrimp is more complex. Salinity interactions with other variables have been documented by numerous authors. Copeland and Bechtel (1974) plotted white shrimp catch versus temperature and salinity. They found maximum catches between salinities of 0-10 ppt and temperatures of 7°-34°C.

Christmas and Langley (1973) reported highest catches in salinities of 5-25 ppt and temperatures between 10°-35°C. Johnson and Fielding (1956) and Zein-Elden and Griffith (1969) reported a complex relationship among salinity, food type, and food abundance. They concluded that postlarval and small white shrimp seek marginal waters because of the high concentrations of plankton and organic detritus in which low salinities were coincidental. Reduced freshwater inflows act against all of the above findings. Reduction of freshwater inflow usually results in:

(1) reduced area (habitat) of low salinity, secondary and tertiary bays, and reduced nursery grounds;
(2) elevation of estuarine salinities; and
(3) a decrease in organic and inorganic nutrients that serve as the basis of the white shrimp food web.

Brown Shrimp (Penaeus aztecus)

Brown shrimp postlarvae in the estuary can tolerate salinities between 2-40 ppt and their optimum range lies between 21-40 ppt. Juveniles have a wider tolerance of 0.22-60 ppt, but they have a limited optimum range of 10-30 ppt (Gunter et al. 1964). Like the white shrimp, brown shrimp have complex interactions among salinity, temperatures, and food.

Shrimp production (brown shrimp and white shrimp) can be reduced if a decrease of organic and inorganic nutrient influx to the estuary results in decreased inflows. Reductions in nutrient inflows yield less organic nutrients directly available to the shellfish and organics produced through photosynthesis utilizing inorganic nutrients. In both situations, food availability would be limited.

If shellfish production is based on organic nutrient sources, then phytoplankton would be considered the major source, but they are influenced by inorganic nutrient influxes which may result more substantially from freshwater sources. If food sources are not limiting, then perhaps salinity is the most important component of freshwater inflow. In summary, whether nutrients or salinity is the most important aspect cannot be generalized. Perhaps one is more important at a given site or perhaps they cannot be separated but rather work in synergism.

Blue Crabs, (Callinectes sapidus)

The effects of decrease in freshwater inflow upon blue crab production vary with sex and life stage. Salinity range for larval development is 10-25 ppt, with the lower salinities needed in the shallow regions of the estuary where freshwater is delivered to the bay. Reduction of freshwater inflows could increase salinities in the upper reaches of the estuaries, making these areas less suitable for juvenile blue crabs.

Increased salinities could be beneficial. Concentrations above 20 ppt are needed for spawning activities (More 1969). This dichotomy in salinity preference is also observed for each sex. Mature males can move around the estuary at random (10-50 ppt) but seem to prefer salinities less than 20 ppt. Females prefer salinities between 26-36 ppt. Impact assessment relative to blue crabs and salinities may well be dependent upon the populations' limiting life stages in any specific estuary.

Food availability must also be considered as a possible limiting factor for blue crabs, especially for the juveniles which inhabit tidal marshes, and secondary bays (More 1969). Flushing of organics, which may be altered by reductions in river inflows, is important to food production.

Oysters (Crassostrea virginica)

Reduced freshwater inflow with resultant increases in salinity would not be expected to stress any oyster life stage physiologically or osmotically. Note, however, that seasonal variations of inflows, coupled with modifications in the magnitude of peak discharges, can exert an impact on some decimating (or limiting) factors for this species. An example would be provision of flows capable of reducing salinities sufficiently to control parasitic organisms such as the oyster drill (Thais haemastoma). Historical records of peak flows to the estuary are needed for this type of impact assessment or evaluation.

FINFISH

Small increases in salinities caused by reductions in freshwater inflows should not cause significant changes in finfish populations. Site specific changes in the secondary and tertiary bay margins, bayous, and marshes are, therefore, likely to be greater than changes in the average salinities. These impacts could be substantial. The most serious impact is likely to be the loss of suitable low salinity, nutrient (both organic and inorganic) rich habitats required for most finfish in their larval and/or juvenile stages. The following estuarine finfish larvae and juveniles are dependent upon these nursery areas. They rely on the rich sources of detritus, phytoplankton, epiphytic algae, microcrustaceans and other such organisms for food at this life cycle stage: spotted seatrout (Cynoscion nebulosus sp.); spot (Leiostomus xanthurus); Atlantic croaker (Micropogon undulatus); striped mullet (Mugil cephalus); redfish (Sciaenops ocellata); bay anchovy (Anchoa mitchilli).

The larvae of menhaden (Brevoortia patronus), mullet (M. cephalus) and southern flounder (Paralichthys lethostigma) develop and feed offshore and are not dependent on the above mentioned habitats. The juvenile stages of these species are, however, dependent upon the richer, near-shoreline habitats. Any losses or reduction in these habitats, caused by increased salinities, could reduce the populations of the stated finfish in the estuary ecosystem. Note that increased salinities can be lethal to the food sources of these juveniles. A significant reduction in nutrient influx, caused by reductions in freshwater inflows, would also adversely impact these juveniles.

The adults of the finfish species studied are impacted indirectly by altering (reducing) of their food sources, such as forage fish, shrimp, crabs, benthic and other organisms. Forage species, i.e., menhaden, mullet, bay anchovy, longnose killifish, and sheepshead minnow, depend on detritus, phytoplankton, microcrustaceans, and benthic animals, but spotted seatrout, spot, croaker, redfish, and southern flounder are dependent upon forage fishes, shrimps, crabs, and similar organisms. Reductions in freshwater inflows could reduce these foods and thereby adversely impact these study species.

CONCLUSION

Biologists working on water developments far removed from the coastal zone have frequently overlooked the impacts directly related to those projects. Reductions in freshwater inflows to estuaries cause widespread and diverse impacts on habitats and many species in the food chain (web). This paper has alluded to impacts attributed to salinity changes, flushing actions in palustrine or marsh environments, biota impacted, and the benefits to be derived with ample supplies of nutrients and detritus on a seasonal basis.

ACKNOWLEDGMENTS

The authors would like to thank Drs. Henley, Armstrong, Ward, and Mr. Rauschuber for collecting most of the information presented in this paper.

LITERATURE CITED

Armstrong, N. E. and M. O. Hinson, Jr. 1973. Galveston Bay ecosystem freshwater requirements and phytoplankton productivity, pp. II-1 through II-98. In Oppenheimer, C. H., W. B. Brogden, and K. G. Gordon (eds.), Toxicity Studies of Galveston Bay Project. Univ. of Texas, Mar. Sci. Institute.

Chapman, C. R. 1966. The Texas basins projects. Amer. Fish. Soc. Spec. Publ. 3: 83-92.

Chapman, C. R. 1976. Coastal Vegetation. 2nd ed. Pergamon Press, Ltd., New York.

Christmas, G. W., and W. Langley. 1973. Estuarine Invertebrates, Mississippi, pp. 255-317. In G. W. Christmas (ed.), Cooperative Gulf of Mexico Estuarine Inventory and Study. State of Mississippi Gulf Coast Research Lab. Ocean Springs, Mississippi.

Copeland, B. J. 1966. Effects of decreased river flow on estuarine ecology. J. Water Pollut. Control Fed. 38(11): 1831-1839.

Copeland, B. J., and T. J. Bechtel. 1974. Some environmental limits of six Gulf coast estuarine organisms. Contrib. Mar. Sci. 18: 169-204.

Copeland, B. J., and E. G. Fruh. 1970. Ecological studies of Galveston Bay, 1967. Final report, Galveston Bay Study Program, Texas Water Quality Board.

Copeland, B. J., H. T. Odum, and D. C. Cooper. 1972. Water Quality for Preservation of Estuarine Ecology. Water Resources Symposium No. 5. Center for Research in Water Resources, University of Texas at Austin.

Gunter, G., and H. Hildebrand. 1954. The relation of total rainfall of the State and catch of the marine shrimp (Penaeus setiferus) in Texas waters. Bull. Mar. Sci. Gulf Caribb. 4: 95.

Gunter, G., H. Hildebrand, and R. Killebrew. 1964. Some relations of salinity to population distributions of motile estuarine organisms, with special references to penaeid shrimp. Ecology 45: 181-185.

Henley, D. E., and D. G. Rauschuber. 1979. Studies of Freshwater Needs of Fish and Wildlife Resources in Nueces-Corpus Christi Bay Area, Texas. Tech. Rep. to U.S. Fish and Wildlife Service.

Hildebrand, H. H. 1958. Estiedeas biologicos preliminares sabre la Laguna Madre de Tamaulipas. Ciencia 17: 151-175.

Johnson, M. C., and J. R. Fielding. 1956. Propagation of the white shrimp, Penaeus setiferus (Linn.) in captivity. Tulane Stud. Zool. 4: 173-190.

Joyce, E. A. 1965. The commercial shrimps of the northeast coast of Florida. Prof. Pap. Ser. Mar. Lab., Fla. 6: 1-224.

Mooring, M. T., A. W. Cooper and E. D. Seneca. 1971. Seed germination response and evidence for height ecophenes in Spartina alterniflora from North Carolina. Amer. J. Bot. 58(1): 48-55.

More, W. R. 1969. A contribution to the biology of the blue crab Callinectes sapidus in Texas, with a description of the fishery. Tech. Ser. No. 1, Texas Parks Wildlife Department. 26 pp.

Penfound, W. T., and E. S. Hathaway. 1938. Plant communities in the marshlands of southeastern Louisiana. Ecol. Monogr. 8: 1-56.

Ward, G. H., and N. E. Armstrong. 1979. Studies of the effects of alterations of freshwater inflows into Matagorda Bay Area, Texas. Tech. Rep. to U.S. Fish and Wildlife Service.

Williams, A. B. 1955. A contribution to the life histories of commercial shrimps (Penaeidae) in North Carolina. Bull. Mar. Sci. 5:116-146.

Zein-Elden, Z. P., and G. W. Griffith. 1969. An appraisal of the effects of salinity and temperature on growth and survival of post-larval Penaeids. FAO Fisheries Rep. 57(3): 1-12.

Discussion VI - The Ecology of Other Coastal Environments (C. Peterson, J. Day, and N. Funicelli)

Statement

A. de la Cruz: John Day mentioned that wetlands act as a big sponge. A sponge can only take so much water. However, a significant feature of wetlands is the ability to evapotranspirate large quantities of water so that marshes can continuously absorb water. I would appreciate any data on the transpiration processes that occur in wetlands. Let us say you wanted to put this land into other land use. The hydrology would not be affected too much if a sugar plantation or a golf course would be developed. To pave it would be disastrous. Also, Dr. Peterson asked us to consider the mudflats and the marsh as one system, but when he compared the microalgal productivity and the Spartina productivity, he separated them. In a whole system the microalgae mudflat community is really fed upon by nutrients oozing out from the saltflats during low tide. Water seeps out of little creeks through the mudflats providing nutrients for the microalgae. The productivity of the microalgae is dependent upon the nutrients they can get from the system, mostly the salt marshes.

Comment

J. Day: I do not think there is much disagreement to that.

Statement

A. Thorhaug: It seems to me that the last few speakers have been looking at a management problem which is only a part of a larger problem. I think that the general problem in the United States is the human population versus the carrying capacity of the land. In other words, uncontrolled development with no regard to carrying capacity. For example, do the Florida Keys have the capacity for each person to use 280 - 560 gallons of water per day?

To me it seems that the natural environment is low man on the totem pole. Under NEPA law, the environment has to be emphasized. Humans are being sustained by the rich vegetative systems we have. It seems that wetlands are of such low priority that we are going to be manuevered out of our wetlands resources. Ecosystems will just gradually fade away. I think this problem should be handled on a level where the Interior Department is cooperating with other conservation groups of the government.

A comment in regard to Dr. Peterson's presentation; one of the most important things about seagrasses is the increase in surface area from barren, unvegetated bottom by several orders of magnitude. This surface is completely covered by microalgae. The macroalgae growing on seagrasses afford another matrix for further microbial production. So, it is not simply the 2,000 g which the seagrass is producing, but the surface area provided within the water column. I have been in a number of areas where the water column is completely clogged with vegetation. This vegetation is completely covered with bacteria and microorganism. I think that we are vastly underestimating microbial productivity in seagrass beds.

Q. A. Mueller: You mentioned that the bottom land hardwoods influence detrital contribution to the estuary if they are close enough. How close is close enough?

A. J. Day: If you move upstream, the influence is evident. I do not think there is an exact answer, however. One thing I wanted to mention was that in Louisiana they determine the boundary of the coastal zone by determining the boundaries between the pleistocene and the recent alluvion, the absence or presence of certain species, and soil types. You just have to measure as many different characteristics as possible so that you have data that indicate whether these are important to an estuary or not.

Q. W. Odum: Suppose you are in a situation where dredge and fill is to take place. The only choice you have is whether the fill comes from the intertidal mudflats or the subtidal benthos. Indirectly, which do you think is more important in regard to a source for the spoil?

A. C. Peterson: If you remove intertidal substrate, you remove an area which is receiving light and is active in contributing primary production. On that basis you might make a distinction. Furthermore, you might make a distinction by determining what lives in a given system and try to make an estimate of relative contributions by comparing deeper areas to the shallows. For instance, you might ask what invertebrates live there, and are they important in the food webs in which you are interested.

Q. J. Zieman: Is there a difference between mudflats which are close to marshes as opposed to those that are not near sources of detritus?

A. C. Peterson: I do not have any data; however, there is a complex interrelationship between the production of detritus and its breakdown and the microorganisms that one finds on that detritus such that marshes can influence mudflat production. Oysters, for example, may benefit from the fact that marshes cast out some detritus and nutrients. This then increases the productivity of the mud algae on the flats. A fine experimental design might be to look at mudflats that are ringed by marshes and those which are otherwise similar yet have no marsh. I do not know of anyone who has done this.

Q. J. Zieman: Are significant numbers of your algae the blue-green?

A. C. Peterson: Not in the systems that I have studied, but there are blue-greens that are very important. They often tend to be in areas that are only intermittently flooded. These systems of blue-greens opposed to the generally seen systems include some amphipods that feed on the blue-greens efficiently. There are some amphipods that seem coadapted with the blue-greens because they are a permanent part of the environment.

A SUMMARY OF IMPACTS OF NAVIGATIONAL DREDGING AND DISPOSAL ON FISH AND WILDLIFE

Joe W. Hardy
National Coastal Ecosystems Team
Office of Biological Services
U. S. Fish and Wildlife Service
USAE Waterways Experiment Station
Vicksburg, Mississippi 39180

ABSTRACT

Literature on the impacts of navigational dredging and disposal on wildlife, fish, and other aquatic biota is summarized in this report. Habitat development and enhancement opportunities arising from dredged material disposal, types of dredging equipment being used, characteristics of dredged material, and evaluation of dredged material pollution potential are discussed. The discussion on impacts and habitat development focuses primarily on coastal waters with limited mention of activities on rivers and inland lakes.

INTRODUCTION

Assessing the environmental impacts of navigational dredging and disposal is often a controversial endeavor. Direct and related impacts to fish and wildlife resources appear obvious. The degree and duration of impact, however, have gone undocumented in most instances before the mid-1970's. A number of studies since then have helped to gain a more thorough understanding of the situation.

Morton (1977) abstracted published results and compiled a comprehensive review of the literature on the physical, chemical, and biological effects of dredging and disposal in estuaries. The Environmental Laboratory (EL), Waterways Experiment Station (WES) of the U. S. Army Corps of Engineers, Vicksburg, Mississippi, also conducted a major investigation, the Dredged Material Research Program (DMRP), from 1973 to 1978. The results of the DMRP studies are published in more than 250 detailed technical reports and 21 synthesis documents. Findings from this investigation are abstracted and thoroughly cross-referenced by Saucier et al. (1978) and Herner and Company (1980).

Since 1975, a Fish and Wildlife Service employee has been assigned to the Waterways Experiment Station to act as coordinator with the DMRP. Dr. Kenneth O. Allen served in that capacity from 1975 through 1978. I assumed the coordination position in 1979. A document entitled "Impacts of Navigational Dredging on Fish and Wildlife: A Literature Review" resulted (Allen and Hardy 1980). The document summarized the vast body of technical information and results of new research since 1974, including the DMRP plus other significant studies. This paper summarizes the review with emphasis on environmental impacts to fish and wildlife resources within the Southeastern United States.

THE LITERATURE SUMMARY

The majority of the dredging in the United States is accomplished by hydraulic dredges, primarily pipeline dredges. Mechanical dredges are often used in situations where hydraulic dredges are not practical. Sediments from maintenance dredging have a much greater pollution potential than those from new channel construction.

Most material from maintenance dredging is fine-grained organic material and contaminants in varying degrees. (However, sediments from rivers and intracoastal waterways are often relatively free of contaminants.) Options for the disposal of maintenance sediments are limited because of the presence of contaminants and because engineering properties are inferior. The pollution potential of dredged material cannot be precisely determined. However, the elutriate test and bioassays are helpful. Bulk analysis has limited value in predicting long-term impacts.

In coastal waters the most serious impacts are from new works dredging, as opposed to maintenance dredging due to physical alterations to the bottom topography. Physical changes resulting from the construction of new channels and material disposal from both new and old channels alter circulation patterns, tidal prisms, salinity gradients, and sediment budgets. These changes, in turn, impact the biota.

Disposal of dredged material, either confined or unconfined, into shallow water or terrestrial locations often destroys valuable fish and wildlife habitat. The effluent from dike construction activities, and from completed and filled confinement facilities, also can cause water quality problems. However, proper engineering and operation of containment facilities eliminate most effluent problems.

Impacts to the water column, from the disposal of maintenance material, is usually of a short-term minor nature. Turbidity is generally transitory and seldom has lasting effects. Iron, manganese, ammonia, and phosphorus are released to the water column, but dilution and dispersion normally render them harmless. Exceptions can occur in poorly circulated waters. Recovery of organisms buried by dredged material usually occurs in a matter of a few months to 2 years. Fluid mud, particularly from pipeline dredges, can cause serious short-term impacts to bottom organisms. Long-term impact of polluted materials to bottom organisms is not well understood. Uptake of various toxicants has been documented, but no clear pattern of uptake is apparent.

The impact of dredging disposal is likely to decrease due to greater dilution, better mixing, and assimilative capacities as disposal sites are moved seaward along the continental shelf and into the deep ocean. Also, offshore waters are not as productive as estuaries nor are they the scene of as many critical physical-chemical-biological processes.

Dredged material potentially can be utilized for developing aquatic, island, wetland, and terrestrial habitat. However, new habitat generally must be developed on existing habitat and, thus, trade-offs have to be carefully evaluated. Dredged material islands have proven to be of great value to colonial nesting waterbirds. Marsh and upland habitat development techniques are currently available. Aquatic habitat development has potential as an alternative means of disposal, but has not been fully explored.

In riverine dredging, as in coastal dredging, the construction of new channels or deepening of existing channels causes more severe problems than maintenance dredging. River dredging, whether new works or maintenance dredging, often adversely impacts the stream bottom, backwaters, wetlands, or riparian vegetation. Impacts to the water column are generally slight and temporary.

Placing dredged material above

the normal water level usually results in "setting back" vegetation to an earlier successional stage or even to bare soil. The rate of recolonization and succession depends on factors such as elevation and composition of the dredged material.

Dredged material is often deposited into stream margins or wetlands or is placed on existing islands or land masses where it may spill into shallow water (including backwaters). Productive shallow waters are usually changed to less productive sandy areas and backwaters are often blocked or filled.

Certain impacts of channel maintenance dredging and aqueous deposition of the material are generally transitory in nature. Turbidity is not generally a problem and bottom organisms, with the exception of mollusks, recover rapidly. However, up to 10 years have been reported to be necessary for the recovery of mollusk populations. Disposal of dredged material into the main channel poses the least threat to aquatic life.

Adverse impacts of terrestrial placement of dredged material can be mitigated to a great extent through the application of well-established agriculture and wildlife management techniques. Establishment or enhancement of wetlands is often practical but not widely practiced at the present. Judicious plugging or opening of cuts to side channels can be used to enhance the productivity of backwaters.

The limited available literature on the Great Lakes and other inland lakes indicates that dredging impacts are generally similar there to impacts that have been recorded for estuaries. As is true with estuaries, new works dredging often poses a greater threat than maintenance dredging.

The quality of the effluent from confined disposal areas apparently has varied widely. Increased settling time and the related retention of suspended solids help retain contaminants within the disposal facility.

Near-shore, shallow water disposal of dredged material poses greater threats than disposal in the less biologically active deep-water areas. Releases of nutrients and potential contaminants to the water column have been documented but adverse impacts of these releases to the aquatic biota have not been demonstrated. Beneficial and detrimental impacts have been noted for benthic invertebrates and demersal fish. Benthic biomass may be suppressed for a few months to a few years and the species composition may be altered when dredge material is disposed of in shallow, nearshore waters.

LITERATURE CITED

Allen, K. O., and J. W. Hardy. 1980. Impacts of Navigational Dredging on Fish and Wildlife: A Literature Review. U. S. Fish Wild. Serv., Biological Services Program. FWS/OBS-80/07. 81 pp.

Herner and Company. 1980. Publication Index and Retrieval System: Dredged Material Research Program. U. S. Army Engineer Waterways Experiment Station, Vicksburg, Miss. Tech. Pap. DS-78-23.

Morton, J. W. 1977. Ecological Effects of Dredging and Dredge Spoil Disposal: A Literature Review. U. S. Fish Wild. Serv., Tech. Pap. 94, Washington, D. C.

Saucier, R. T., C. C. Calhoun, Jr., R. M. Engler, T. R. Patin, and H. K. Smith. 1978. Executive Overview and Detailed Summary: Dredged Material Research Program. U. S. Army Engineer Waterways Experiment Station, Vicksburg, Miss. Tech. Pap. DS-78-22.

STATUS OF MARINE HABITAT EVALUATION PROCEDURES (MARHEP)

Carroll L. Cordes
National Coastal Ecosystems Team
U.S. Fish and Wildlife Service
NASA-Slidell Computer Complex
Slidell, Louisiana 70458

ABSTRACT

The Fish and Wildlife Service has initiated development of estuarine-marine habitat evaluation procedures, as part of the system of Habitat Evaluation Procedures (HEP). An overview of the development status of the estuarine-marine procedures is presented.

INTRODUCTION

In 1973, the Fish and Wildlife Service initiated efforts to develop a system that would provide a quantitative evaluation of resource-habitat considerations for water-related project planning. Since this time, considerable effort has gone into development of Habitat Evaluation Procedures (HEP) that provide an inventory of baseline environmental conditions and an assessment of project impacts on fish and wildlife resources in terrestrial and freshwater habitats. Development of comparable evalution procedures for estuarine-marine habitats is needed if the Service is to have a fully operational HEP system during the 1980's. The purpose of this paper is to provide an overview of the current development status of the marine habitat evaluation procedures.

DEVELOPMENT OF ESTUARINE-MARINE HABITAT EVALUATION PROCEDURES

Over the past two years, attempts to apply terrestrial and freshwater HEP in the evaluation of project impacts in estuarine-marine habitats have been made by Fish and Wildlife Service field biologists, and by field personnel in other resource agencies (Kumpf, unpublished data). These applications have generally not been successful and a cooperative effort between the Service's Coastal Ecosystems Team and Western Energy and Land Use Team has been initiated to develop specific evaluation procedures for estuarine-marine habitats.

During fiscal year 1980, the primary emphasis will be on developing a logical conceptual approach to development of estuarine-marine habitat evaluation procedures. A significant task will involve an examination and evaluation of existing concepts and methods used in environmental analysis and impact assessment. After the conceptual design for the estuarine-marine evaluation procedures is selected, a supportive regional data base and a prototype evalution system will be developed and tested. Development of the prototype system is tentatively scheduled for fiscal year 1981. A fully operational marine habitat evaluation system supported by a national estuarine-marine data base conceivably could be completed during the mid-1980's if appropriate funding and manpower are provided for the development program.

LITERATURE CITED

Kumpf, H. (National Marine Fisheries Service, Southeast Fisheries Center, Miami, Florida). Saltwater application of habitat evaluation procedures: workshop proceedings, 14-16 August 1979, Ft. Collins, Colorado. (Unpubl.)

IMPROVING INTERAGENCY COORDINATION

Charles W. Hollis
US Army Corps of Engineers
PO Box 1890
Wilmington, North Carolina 28402

ABSTRACT

Operational unit managers in all Federal agencies are pressed with a burden of constant coordination with other agencies and the public, often with seriously conflicting viewpoints. Personnel management techniques and human relation theories may be the key to solving not only individual project disputes, but improving interagency coordination by improving interagency staff relationships. The Ecological Services Field Office Supervisor is in a unique position to be close enough to the problem on the one hand and to agency policy on the other to play an especially important role as "bridge builder" between his office, other agencies, and the public. The Supervisor must recognize the interpersonal conflicts present in situations, and bridge respect for and understanding of the opposition.

IMPROVING INTERAGENCY COORDINATION

Today's Field Office Supervisor finds himself faced with a seemingly impossible task of responding to an ever-increasing number of requests for agency comments and assistance. A usually understrength staff is asked to develop an agency position often received by a somewhat hostile requesting agency. The Supervisor may then be thrust into a conflict resolution arena to argue the position established by staff with whom he has little contact. He must justify the position to his own agency and often to local or national political interests. He must rectify his own personal position with that of the public, the law, the agency policy, the requesting agency, and the news media. As a human being, he is fallible but as a supervisor, he is not permitted to be; it is a narrow path. Improved coordination may relax most of those pressures. This may appear simplistic, yet it warrants pursuit.

The term, "interagency coordination," has wide use today in most agency regulations. Unfortunately, the coordination generally takes the shape of form letters without personal contact. Agency counterparts continue their separate ways and bask in their well-established misunderstandings of each other. This situation exists within and between local, State, and Federal agency personnel. It may be most prevalent between agencies on the same political level such as the city planning department and engineering department, or the State Department of Transportation and Department of Fisheries, or the United States Fish and Wildlife Service and the Corps of Engineers.

Most of us at this Coastal Ecosystems Workshop had nothing to do with creating whatever resistance there may be toward any other agency, but each one of us is responsible for every day the situation continues. Each one of us has to establish a framework of cooperation and understanding with our counterparts and thereby relieve personal stress on ourselves. More importantly, however, we must offer the public what they are paying for--a coordinated review and swift answer more closely in line with National policy and the public interest.

Interagency coordination in

eastern North Carolina is alive, well, and growing. The agencies there are no different than others; their missions are the same; their policies are the same, but I believe the people may be different. Now I am not suggesting that special people were shipped into eastern North Carolina to build a special agency coordination program. What happened there was generally accidental--a fortunate collection of circumstances thrust upon a few program managers who were able to learn several rather well-established management principles.

My discussion obviously stems from experiences with the Corps' regulatory program in Wilmington, North Carolina, and our interface with sister Federal agencies as well as State and local agencies. I have been in the middle of this program and its necessary coordination from a time in the first year or two of the 1970's when each agency would grit its teeth and stand its ground along some ill-defined line of policy dispute so as to effectively bring any decision for or against a permit to a grinding halt. In those days there were only two or three agencies with changing regulations and court decisions caught up in a predictable turmoil of policy dispute.

Now we are in daily contact with dozens of local agencies, approximately a dozen State agencies, and a formidable group of Federal agencies, some very new and struggling to get organized. Most of the policy disputes are the same but the arguments now take place in an atmosphere of openness and understanding of each other as agencies. More importantly there is an understanding of each other as individuals who make up these agencies and who have a mutual trust to uphold as public servants.

How might you bring about a change in your organization? Two decades ago, Douglas McGregor (1960) introduced his "Theory X - Theory Y" principles of personnel management in a book entitled The Human Side of Enterprise. Theory X assumes that people dislike work and must be coerced, controlled, and directed toward organizational goals. Furthermore, most people prefer to be treated this way, so they can avoid responsibility. Theory Y, the integration of goals, emphasizes the average person's intrinsic interest in his work, his desire to be self-directing and to seek responsibility, and his capacity to be creative in solving business problems.

In the factory assembly line situations, Theory X is not totally abandoned because it is of such high importance that the line not be shut down. Individual discipline is absolute and expected. Most other jobs and professions are managed with more of the Theory Y principle. The value of the individual is recognized. Interestingly, it may be that when more personal latitude and freedom are given by the manager, less personal latitude and freedom are left for the manager.

Morse and Lorsch (1970) state that the managerial style in working with individualistic problem solving should remain focused on the overall goals of the organization or else the workforce may become segmented and uncoordinated. The article stressed the importance of this especially with a workforce of scientists or other professionals with their inherent individualistic drives. These authors added what they called a "Contingency Theory" to the classic Theory X - Theory Y, which centers on the importance of a competence motive. Their theory has four points:

1. Human beings bring varying patterns of needs and motives into the work organization, but one cen-

tral need is to achieve a sense of competence.

2. The sense of competence motive, although it exists in all human beings, may be fulfilled in different ways by different people --depending on how this need interacts with the strengths of the individual's other needs--such as those for power, independence, structure, achievement, and affiliation.

3. Competence motivation is most likely to be fulfilled when there is a fit between task and organization.

4. Sense of competence continues to motivate even when a competence goal is achieved; after one goal is reached, a new, higher one is set (Morse and Lorsch 1970).

How does this apply to the Field Office Supervisor, the Corps' Branch Chief, or other managers in most Federal programs who are dependent on their staff? The success of achieving the goals of the organization and acquiring a "sense of competence" is the product of the collective staff. Yet each staff member has his own need for a sense of competence best met (according to Morse and Lorsch) when he is capable of accomplishing his assigned task within the framework of the office organization.

The manager has two challenges here: One is to design an organization that allows the staff member to innovatively solve the varied problems assigned to him. The second is to select staff members who can do the job. Neither task is easy. Tests and grades do not always reveal the true person. Interviews are limited and may fall short. After a good staff member is on the job, however, his values can be recognized, even if they were difficult to predict. A number of variables are commonly attributed to successful staff members. A few of these are recognized as:

Drive--willingness to work long and hard.

Desire--to reach goals.

Selfishness--believes his ideas-programs are better.

Intelligence--rational thinking.

High Ego--self esteem.

Ability to Accept Authority--resolve conflicting authority.

The manager should assign tasks to keep the "circle of responsibility" no smaller than the "circle of competence." His people should be encouraged to enlarge their circle of competence by training, advanced course work, and developmental assignments, ready for even larger circles of responsibility. The manager must set the tone and style of interaction by his own interaction with his staff and others.

Interaction with people is determined by the motives of the manager which are in turn dictated by his morality. I believe this to be true of all of us, managers or not. When the manager believes in the value of the individuals with whom he comes in contact, and treats them with an obvious respect for their own human makeup (needs, drives, desires), this action evokes a similar human response of respect. A bridge is built across which other differences can be communicated and problems solved.

McGregor's Theory Y and Morse and Lorsch's Contingency Theory show that offices must be organized to provide a framework for each staff member to spread his circle of competence to innovatively approach his task of problem solving. Selected staff members with drive, desire, selfishness, intelligence, high ego, and ability to accept authority flourish in such an environment. The management's responsibility is to implement the goals and policies of national and regional mandates with consistency and fairness, enabling the staff to function with a respect for the public that will dispel visions of a Federal bureaucrat. Management process must be an example for not only our own staff, but for other agency managers and their staffs.

In World War II, the Corps of Engineers developed a method of building a military bridge from one side of the river with no support from the other side until the bridge reached shore and was secured. There is a management lesson in this example: bridges can be initiated by one party. Each of us can begin to build new bridges and strengthen old ones on our own with no support from the other side. This must be done to avoid the waste generated by confusion and delay associated with Federal agency reviews. We must concern ourselves with interpersonal differences in order to bridge chasms which oppose success.

Interpersonal differences exist between anyone: our family, our staff, our sister agency counterpart, or a member of the public. However, even though our position or ideas in our statements or written communication may be overtly resisted, our covert resistance may be more serious. Opposition, delay, failure to support, or sabotage of a position may actually occur without full awareness of our intention to resist or obstruct.

Communications may be effected by failing to pick up a message, failing to return a call, or just avoiding contact. We may lose motivation and lack a desire to start, to continue, to finish. Only that which is required may be done. A person may not lend a hand or change priorities for outside matters. We may resist suggestions or postpone decisions or agree to some unsatisfactory compromise. Schutz (1955) points out that every human being must establish an equilibrium between himself and his human physical environment. He must satisfy his interpersonal needs while avoiding a threat to himself. According to Schutz, there are three basic interpersonal needs:

1. The need for inclusion--maintaining a satisfactory relationship between self and others. Some need more togetherness; some need more privacy. All have need of proper balance. There is an expressed behavior (toward others) and a behavior preferred that others express toward us--a wanted behavior.
2. The need for control--to maintain a satisfactory relationship with others with respect to power and authority; everyone has need to exercise some control over his situation, to cause life to be somewhat predictable. Usually expressed as control over others, each person varies with this need and therefore needs to exercise varying control over others.
3. The need for affection--the need to maintain a satisfactory relationship with others with respect to affection. Everyone has a level of intimacy at which he is comfortable. This is usually some point between affection and impersonal and distant.

As we recognize these interpersonal needs in ourselves, we must also recognize them in others to include those offices and their staff members with whom we must coordinate. When we reach out to bridge interpersonal differences we may have to extend that bridge against the other shore with no support from that shore but eventually, as the bridge is maintained, it will become a welcomed means of clearing up misunderstandings.

What is to be gained? In eastern North Carolina, Federal and State agency personnel work closely together. They often travel in the same vehicles and stay in the same motels as they conduct their business. They are friends. They understand one another. They have a sincere respect for each other as well as the agency policy positions which each represents. They understand each other's programs, strengths, weaknesses, and common goals. They support one another. They trust one another.

The public sees this open cooperation and seems to appreciate it. The continuous daily telephone calls between people to solve problems or just to keep each other informed are not seen by the public.

Policy level differences exist, but not on a personal level. We may go to court with the State over a perceived need for a State permit for Federal dredging. But, we will go there as friends seeking a judicial decision on a sticky legal issue. If we do not go, it will be because no practical operational changes will be brought on by the State permit requirement, because our level of operational coordination and cooperation is already beyond the scope of the permit regulations.

When serious differences arise there is time for you as a manager to get into the action. Invite yourself into a meeting with the opposition. Extend your bridge of respect and understanding. Recognize their interpersonal needs. Let them know you understand their position and try to get them to understand yours. Explore any middle ground for a solution. Leave the bridge in place. You will be surprised how often you succeed and how your sense of competence will be fulfilled.

LITERATURE CITED

McGregor, D. 1960 The Human Side of Enterprise. McGraw-Hill Book Co., Inc., New York. 246 pp.

Morse, J. J. and J. W. Lorsch. 1970. Beyond Theory Y, Har. Bus. Rev. 48(3):61-68.

Schutz, W. C. 1955. What makes groups productive? Human Relations 8(4):429.

Discussion VII - Problems of and Possible Assistance for Resource Managers (J. Hardy, C. Cordes, and C. Hollis)

Q. A. Banner: I have heard that the Waterways Experiment Station is developing classifications for jurisdiction of various types of habitats. Is the Fish and Wildlife Service going to participate in that? If so, is not that quite a turn around?

A. J. Hardy: This has been a major charge given to Waterways to come up with a 404 Wetlands classification scheme. Terry Hoffman of the Army Corps of Engineers is initiating the program. Currently he has two or three people working that are full-time permanent people at Waterways; he is also looking for other Federal agency people for an interagency team to work full-time with him. This is a $400,000 program this year. There is contemplation of doubling the program in two or three years in order to get this classification system out.

Statement
A. Banner: My understanding is that many of the districts regard the establishment of jurisdiction of boundaries their prerogative and that if the Service disagrees with that, that is too bad.

A. J. Hardy: I have noted a great difference from one district to the next as to what a wetland is or when a permit should be required. Many times there is much more agreement between Waterways Experiment Station people and Fish and Wildlife Service on what a wetland should be, for example, than there is between Waterways and the District Engineer or the division people at LMVD or a lower Mississippi River Division at Vicksburg.

A. R. Huber: There is a search for someone who would probably come out of Region 4 in a full-time permanent position to go to Waterways and assist Hoffman as they get this effort going. They will be looking at 404 Wetlands but not from planes. We are charged to be able to say something on the ground about where dredge material is piled.

Q. R. Huber: Can you see how EPA fits into that in light of their staff and responsibility?

A. C. Hollis: In general terms, the 404 charges EPA with the responsibility of saying what a wetland is. But, by regulation, this was delegated to the Corps on an interim basis. I believe that the Corps has delegated it to the District Engineers so that the District Engineer, during this interim, will have the responsibilty of coming up with specific guidelines.

A memorandum of understanding between the EPA and the chief's office in Washington is being developed. There will be opportunity, as there is now for EPA, to challenge the District position and that challenge has to be elevated to the Washington level for resolutions.

Q. M. Thompson: How does one communicate with District Engineers on some of the issues when they do not seem to want to deal with certain conditions?

A. C. Hollis: I like to think we are doing something by example. I have talked a lot with Corps and District personnel, and we have tried to support one another in what we are doing. We have, by developing responsibilities for individuals and putting them on paper, had the personnel recognized. The people now have target grades of

GS-11 and with some management this can be raised to GS-12. That is part of what I regard as placing responsibility on individuals.

It seems that we are wearing two different hats and in many cases we seem to be beating the small operators over the heads in relation to construction operations. For example, a private contractor, who just completed a Corps job where we built a road across a marshland, is later told that the Corps will not let him construct a short road somewhere else in the marsh. He cannot understand that. He says, "Well, I just built one on the other side of the creek there. Go look at that." Situations have changed considerably in the few years that I have been involved in the regulatory program. I think that maybe we have had different mandates, stronger language, and better court decisions.

Court time is generally spent on the regulatory program. We are rarely in court on the (Corps) operational program, particularly in maintenance projects. We are taking the lead in environmental awareness. The Corps needs to get in line with their other elements as well. I think it is going to happen; it is going to take time.

Q. S. Spiller: Several years ago there was a government accounting office report that highlighted the inconsistencies which existed in various districts around the Nation regarding inventory functions. Will there be directives from the Chief of Engineers, directed at District Engineers, to take a more uniform approach? Will that approach be slanted toward the way that your District operates or will it be slanted the other way?

A. C. Hollis: The greatest organizational problem we have is the inconsistency of the Districts. The thing that we had set up early last summer is now in motion as some of you are aware. In the Army agencies, there is an annual inspection by the Inspector General (IG). He comes around and looks into all your files and you know that he goes through to see that you are filing by the records. This year the regulatory program is a special subject for the IG. He has about a three-page questionnaire which asks: "What are you doing about this?" "How are you doing this?" "What kind of resources?" "What kind of people do you have on the staff?" "Do you have these kinds?" "Why?" and "Why not?" and "What are you doing about environmental awareness on the job or in the job?" We put together that paper for the IG and that is why I wasn't here yesterday. Ours was the first district he visited in the South Atlantic Division and he will be there all through next week. I believe that could be good for this program because it will be assessed thoroughly.

Statement J. VanDerwalker: I feel that it is necessary to say something about the comments that have been made about the adequacy of the habitat evaluation procedures.

One of the problems that HEP has suffered from is vague policy direction. The Fish and Wildlife Service has not provided firm direction to this program during the last several years. They have given general directions but no follow-up with an institutionalized mechanism for feedback that says, "Yes, you are on the right track." What has occurred instead is a series of ad hoc groups that come together for two or three months, look at the project, say it is a disaster, and then leave. They leave some new directions which the HEP program people have attempted to follow. This has been a thank-less task because the next review group has different ideas and the cycle is repeated.

Another thing is that people are pursuing "the single answer." They want the methodology. They want the number. As long as we continue to think that there is some kind of magic out there, we are going to have this problem. There has to be more than one evaluation method because obviously there are many different needs.

I would also like to say that there has been an awful lot of destructive criticism. A lot of people have commented about what a disaster HEP has been and many of them have never read the documents. This is something that underlies a lot of Fish and Wildlife activity.

The basic conflict seems to me to be between those people who want technical simplicity and those who want to apply "State of the Art" systems ecology. On one hand is the desire for a system that can be quickly applied. We don't want any mathematical models. Don't give us any of that statistical stuff. We want it so that the run of the mill entry level biologist can go out and do the job with a windshield survey. Don't collect any data. Develop a system which can be used for evaluation without data.

At the other end, the "State of the Art" systems ecologists want to use ecosystems modeling which are data intensive. This demands a multi-disciplinary approach. These methods cannot be made without having the biologist, the hydrologist, the plant ecologist, and a variety of other expertise available. Above all, the statistician is needed.

I would say that the people who are going to develop MARHEP have a difficult task ahead of them, probably not so much in the area of science, as in the area of policy and administration. If you don't get your act together at the front end, you are going to suffer from the same problems we had with HEP. One last thing I would like to say is, if you want to be a critic, I applaud that. But, if you are going to be a critic, read the documents and make substantive comments.

FISH AND WILDLIFE SERVICE ACQUISITION OF LANDS IN COASTAL AREAS AND RELATED PROBLEMS

William A. Swanson
Associate Senior Staff
Specialist Realty
U. S. Fish and Wildlife Service
75 Spring Street, S.W.
Atlanta, Georgia 30303

ABSTRACT

The U. S. Fish and Wildlife Service now administers over 700,000 acres as national wildlife refuges in coastal areas of the southeast region. Expanded land acquisition programs scheduled for future years have the potential of greatly increasing the acreage for migratory birds, endangered species, and nationally significant fish and wildlife resources. Problems related to land acquisition in coastal areas involve: (1) "title" to lands that are below the line of mean high tide because of the Doctrine of The Public Trust and (2) value or just compensation for lands now that environmental and land use controls are being exercised over the development of both wetlands and uplands.

INTRODUCTION

Coastal areas have always been very important to the Fish and Wildlife Service and the National Wildlife Refuge System because of their inherent value to nationally significant fish and wildlife resources. In fact, the first national wildlife refuge established was a small island on the east coast of Florida known as Pelican Island. Withdrawn from the Public Domain, it was set aside as a national wildlife refuge in 1903 by President Theodore Roosevelt for use by colonial nesting birds--primarily the eastern brown pelican.

In the years following the acquisition of Pelican Island, additional lands were set aside from the Public Domain, and some lands acquired for big game ranges. The Migratory Bird Conservation Act of 1929 stimulated the first major effort to purchase lands for the National Wildlife Refuge System. The focus of this Act was concern over the Nation's migratory waterfowl resource and the need to preserve and set aside lands and waters as refuge areas. Land acquisition was financed by the "Duck Stamp" and since then the "Duck Stamp" has served as a major funding source for acquiring national wildlife refuge lands. Most of the refuge areas along the Atlantic and Gulf coasts were areas acquired because of their importance to migratory waterfowl.

In 1965, Congress passed the Land and Water Conservation Act which has provided an additional source of funds for land acquisition. The money for the Land and Water Conservation fund comes primarily from the revenue the United States receives from oil and gas leasing in the outer continental shelf. The intent of the Act is to appropriate money derived from use of one of our natural resources, in this case oil and gas, to programs which help preserve other natural resources and provide recreational opportunity.

Other legislation such as the Endangered Species Act and Recreation Act have broadened the Services' authority to acquire land. The Service has the authority, the need, and broad support to acquire areas, not only because of their migratory bird values or endangered species values, but because the makeup of an area--the land, water, fish and wildlife--all together are nationally significant resources that should be preserved. This attitude has launched the Fish and Wildlife Service into one of its largest land acquisition programs to date and will involve many areas lying within the coastal zone.

The land acquisition work carried on in the Florida Keys for the Great White Heron National Wildlife Refuge is an example of an area of nationally significant fish and wildlife resources. The Service is very active in this area and has acquired between 4,000 and 5,000 acres in the last four years.

SCOPE OF COASTAL LANDS AND WATERS UNDER SERVICE ADMINISTRATION

The Service now has approximately 1.8 million acres in the southeast region under its administration as national wildlife refuges. Slightly less than one-half of this area lies along the coast which includes the Atlantic coast north to Virginia and the Gulf coast west to Texas. Although this is a very small part of the entire coast, it does represent some of the most important areas to the Nation's wildlife resources and does mean that vestiges of the coastal area will be set aside, mostly natural and unspoiled, for protection of wildlife, wildlife interpretation, recreation, and scientific study for the future.

CURRENT AND FUTURE GOALS

Much of the future acquisition work of the Service in the southeast region will be in coastal areas. Two of the newest national wildlife refuges which have been considered for acquisition are the Lower Suwannee National Wildlife Refuge (approved for acquisition in 1979), located on Florida's coast where the Suwannee River enters the Gulf and the Crocodile Lake National Wildlife Refuge (proposed for approval), located on Key Largo, the first of the Keys as one leaves the Florida mainland. This area and the coastal area of the Florida Everglades contain the only United States population of the endangered American crocodile.

The past two years have been spent in a large resource inventory effort, identifying areas important to migratory birds, endangered species, and nationally significant wildlife resources that we believe should be preserved. The areas have been cataloged in planning documents called "Concept Plans" and from these plans will come the national wildlife refuges of the future. Because our money resources are limited, our first goal will be to try to have the areas preserved by others--State or local government or private conservation groups. If all else fails and areas become threatened, the areas will be considered for acquisition by the Service.

This is the year of the Barrier Island. Congress is now considering legislation authorizing the National Park Service to acquire the remaining undeveloped barrier islands to be administered as national parks. This will certainly have a favorable effect on coastal areas by assuring that these barrier islands will remain undeveloped and the associated coastal ecosystem will not be adversely impacted by those events that follow development.

PROBLEMS ASSOCIATED WITH THE ACQUISITION OF COASTAL LANDS

Acquisition of land in coastal areas carries with it some unique problems in a real estate sense. One of the major problems involves the "title" to lands and water in coastal areas. What property rights do private owners have? What can they do with these properties--which relates to value--and what can they convey?

To understand the problem, we must go back to the Doctrine of the Public Trust. From the time of Roman law, the shores or tidelands and submerged lands, collectively those lands below mean high tide, have been held by the sovereign (or the States) in trust for people to be used for the purposes of commerce, navigation, and fisheries.

Until the 1950's, the major interest in coastal areas in this country was for development and the coastal States passed laws allowing conveyances of lands below mean high tide for development. Florida was one of the States that did this. In the last 20 years, we have become aware of the effect of this development on the environment and the tremendous resource value of unspoiled coastal areas. As an outgrowth of this awareness, some persons concerned with the environment are demanding that the States exert their responsibility under the Public Trust Doctrine and have effectively challenged the title to and use of lands below mean high tide. This challenge has created one of the greatest areas of litigation, affecting real property rights nationwide, that exists today. Title to all property now privately held, that is or was, below the line of mean high tide, is being challenged.

The Department of Justice, which approves title to lands acquired by the United States, has established standards by which: (1) a warranty deed can be accepted from a private owner for only those lands he owns lying above mean high tide and (2) a quit claim deed can be accepted to any lands, lying below mean high tide, that are subject to the Public Trust and possible State claims.

For many landowners, this is the first time their ownership of land below the line of mean high tide has been questioned. This question creates a difficult climate in which to carry on negotiations. We are currently working with the State and the landowners to resolve these questions of title for lands being acquired in Florida.

An aspect of this problem is that the Department of Justice requires a survey and a determination of the acres above mean high tide in all acquisition cases. Many times this determination has been a difficult task because of dense vegetation or an imperceptible shoreline. We have overcome this problem by use of aerial photographs and, with known mean high tide elevations, are able to make an on-the-ground inspection and determination of the area above mean high tide that will be acceptable for our purposes.

The other major problem that we have in acquiring lands in coastal areas is the question of value or just compensation. This problem arises because of the regulatory controls now being placed on the development of lands below mean high tide. In some situations, today's appraised value of underdeveloped property is considerably less than the investment the owners have in the property. This is especially true in those instances where lands have been in the same ownership for considerable time and were acquired to speculate on future development. It again creates a difficult climate for negotiations and in some situations the owners refuse to sell their property at its present market value in hopes that the challenges now in the courts, on the prevention of wetlands development, will be successful.

In closing, I would like to invite you to visit the refuges in your area and take part in the enjoyment of the wildlife they provide and, for those in coastal areas, the relationship they serve to the surrounding coastal ecosystem.

Discussion VIII - Problems of and Possible Assistance for Resource Managers (W. Swanson)

Q. A. Mueller: In regard to purchase of land below mean high tide, how does the Service gain control of oil and gas rights?

A. W. Swanson: Generally we cannot. If we could, we would have control because refuge lands are not available for oil and gas leasing.

Q. A. Mueller: If you can't buy the land below the mean high tide, will individuals be required to get a special use permit from the refuge?

A. W. Swanson: No. Not on areas we do not have administrative control over.

Q. A. Mueller: So we will not have any control over oil and gas activities?

A. W. Swanson: Understand of course, in this day and age it is extremely difficult to acquire oil and gas rights. We have mixed emotion about oil and gas activity. We have a lot of it on our National Wildlife Refuges at this time. In most cases it works fine. This is one of the activites we hope will disappear some day after the oil and gas have been taken out. But, in lands below mean high tide we are not able to control gas or oil activities through land acquisition.

Q. B. Halstead: In a recent case in Texas the Federal government purchased some land. The land was originally purchased by the Nature Conservancy. Is it normal for us to work with them and are they not taking a chance to rely on the Federal Government because we do not always have the funds to purchase land from them?

A. W. Swanson: We work with conservation groups. The dominant one is the Nature Conservancy. Our planning process to get funding to acquire lands takes about three years. As you know, real estate that goes on the market does not stay on the market for that length of time. If we have a strong interest in an area, we will work with various conservation groups to acquire it for us. We find that this works out very well. I do not think there is much danger on the part of the conservation group participating. I know of no case where any dealings have not succeeded. Of course, if it should turn out that the Service would not be able to acquire the lands, then the conservation group has the opportunity to sell or do what they want with the property.

Q. J. Day: I would like to know where you can get the information on the natural values of these lands.

A. W. Swanson: Inventories of fish and wildlife resources have been cataloged recently in documents we call Concept Plans. They are available from the Regional Offices. They are not all approved yet, and only those that are approved will be released. Initially, these Concept Plan documents will contain 20 or 30 of the most significant resource areas. The inventory for significant fish and wildlife resources is done on a State by State basis. Migratory Bird Concept Plans are regional in as far as the Mississippi delta being a region, Louisiana coastline being a region, the Atlantic coast being a region, etc. The documents have been circulated widely. The States were involved in the development of those Concept Plans as were private conservation groups.

Q. L. Lewis: In regard to the acquisition of lands below mean high water, when the Fish and Wildlife Service is considering acquisition of such lands, does one actually survey those lands below mean high water, or is the burden of proof on the property owner? If a survey is required, should the assistance of Federal agencies such as the National Ocean Survey be requested concerning techniques for mapping the mean high water line?

A. W. Swanson: The burden falls on us. If we were involved in litigation on lands that are in coastal areas and affected by the line of mean high tide, the type of thing that we are doing now would not be admissible as evidence as to the line of mean high tide. We basically are satisfying the Department of Justice that there are Federal lands above mean high tide and secondly, trying to determine, within a reasonable degree of accuracy, the upland involved. We can pay the same amount of money that anybody in the market would pay for the property. Determining the line of mean high tide does not affect the value of the property. We can look at the land above mean high tide just as any other prospective buyer would look at those lands. That is, the uplands have the value. Any contribution for the area below mean high tide may be considered and compensation made to the landowner accordingly.

Q. L. Goldman: Have any drastic changes taken place within recent months in terms of what Congress says can or cannot be done? What is their opinion in terms of priorities we should have? If so, how will that affect our approach to acquire land in the State of Florida or in any other State in the southeast?

A. W. Swanson: Congress is becoming very interested in what the Fish and Wildlife Service is doing. I say this in the sense that we are probably the only land acquisition agency within the Federal Government which can acquire lands merely on the approval of the Director of the Fish and Wildlife Service. Migratory bird land purchases are approved by the Migratory Bird Conservation Commission. But, as it applies to Land and Water Conservation Funds, we are not like the Park Service or others who have to go to Congress on every project and get congressional authorization.

The climate today is changing in that Congress wants to view areas which the Service acquires under general authorities. There are also the additional requirements that Federal agencies prepare environmental impact statements, hold public meetings, etc., which basically is new to us. So Congress and the public are having substantial input into the area of land acquisition.

REGIONAL PLANS FOR INFORMATION AND TECHNOLOGY TRANSFER

Billie H. Hix
Information Transfer Specialist
Regional Information and
Technology Management Team
U.S. Fish and Wildlife Service,
Region 4
Richard B. Russell
Federal Building
75 Spring Street, SW
Atlanta, Georgia 30303

ABSTRACT

This paper discusses the goals, organization functions, and services (Information and Computer Assistance) of the Information Transfer Specialist of the Regional Information and Technology Management Team (RITMT). The RITMT functions to create and sustain efficient linkages between an organized network of primary users and suppliers of information and technology. Five basic steps are involved in this transfer and each step has specific associated tasks. The RITMT offers services to help transfer information to those needing technical assistance for use in natural resources management decisions.

INTRODUCTION

The Regional Information and Technology Transfer Team is a relatively new operation in the U. S. Fish and Wildlife Service (FWS), Region 4. The Service's suppliers of information and technology are located in various programs and projects, National Teams and Groups, and Research Centers and Laboratories; however, the intended users are diverse and geographically dispersed. The various users are separately organized for their own purposes; they are not collectively organized to integrate their information and technology requirements. Combined requirements, frequently overlapping, must be identified, sorted, and given overall priorities. The Regional Teams will act as "brokers" between information suppliers and users.

RITMT FUNCTION

Since the world has become industrialized and the work and knowledge of individuals more specialized, professional information transfer specialists have become necessary to help coordinate or "broker" use of information. The information industry, broadly defined, is the largest industry in this country.

Regional operations of the FWS must be balanced between action and reaction. Reaction to project proposals and license or permit applications must be balanced with action to undertake advance planning for major resource development projects. The reactive or review mode limits adaptive project design. This causes problems with project construction and operation because of time constraints in the review process. A long-range, areawide approach using quantitative criteria is required to augment and provide perspective to site-specific analysis. The Regional Teams will work with information and technology suppliers to obtain broad-gauged, cumulative planning and evaluation technologies.

Access to informatior and technology and adaptation to the exact needs of resource planners and decisionmakers are the keys to responsible biological planning and problem solving. Ensuring such access requires the capability to transmit synthesized information and technology, together with techniques for their effective utilization, within the Service and to a wide variety of other Federal, State, intergovernmental, and private users. The actual application of relevant information and technology to the solution of problems relating to the preservation and enhancement of the nation's fish and wildlife resources is therefore the primary benefit to be derived from the proposed effort.

Many people in the Service have urged greater efforts to synthesize data and research findings into products that focus more on the priority information and technological needs of the Service. Information and technology transfer should occur as a tailored response to needs. Aspects of information such as format and specificity should be prescribed. Furthermore, special efforts must be made to ensure the actual use of information and technology. In summary, the need for information transfer can be best stated by the axiom--although the total costs of getting and keeping information current are high, the costs of not having good current information are even higher.

GOALS OF REGIONAL INFORMATION AND TECHNOLOGY MANAGEMENT TEAM

A good information and technology transfer program will provide:

1. Identification of primary users and their information and technology needs.
2. Improved adaptation of information and technology to user's priorities.
3. Dissemination of information and technology products that are packaged to meet users' needs.
4. Monitoring the utilization of information and technology, including obtaining feedback on user satisfaction.

FUNCTIONS OF REGIONAL INFORMATION TRANSFER MANAGEMENT TEAM

The central function of the Regional Information and Technology Transfer Team is to create and sustain efficient linkage between an organized network of primary users and suppliers of information and technology.

There are five basic steps in the full cycle of regional information and technology transfer:

1. Identify needs and priorities by analyzing regional fish and wildlife resource planning and decisionmaking processes.
2. Communicate needs and priorities to appropriate suppliers. (The technique will vary depending on the scope and timing of the need.)
3. Develop information and technology in response to user needs.
4. Transfer information and technology to users.
5. Evaluate use and effectiveness of information and technology and the transfer process.

The specific tasks envisioned for each step in the overall procedure are as follows:

1. Identify needs and priorities.
    a. Identify regional information and technology needs.
    b. Determine overlapping needs.
    c. Determine timing requirements.
    d. Categorize information requirements by classes of technology output (survey and synthesis, applied research, and technical assistance).

e. Help prospective users define and analyze their needs.
f. Gauge capability of Service suppliers.
g. Survey Service information and technology suppliers for planned information output to show users what will be available.

2. Communicate needs and priorities.
a. Develop a scheme for screening and matching needs and sources to meet requirements for information synthesis or technical assistance.
b. Screen and match user needs and supply sources.
c. Prescribe the nature, priority, timing, and phasing of desired survey and synthesis and applied research.
d. Identify the supplier best suited to respond effectively to each information and technology need and communicate requirements in accordance with established procedures.
e. Define how the Regional Team will continuously assess users' needs and the benefits of information and technology utilization.

3. Develop information and technology. Information and technology are developed by many Service components. The Regional Team works with other suppliers to ensure that products are useful to the Region. To some extent, the Regional Teams are, themselves, the information suppliers. Activities may include the following:
a. Coordination with suppliers:
1) Develop the Regional Annual Work Plan for Information Transfer in coordination with research centers, laboratories, and cooperative units; national teams, groups, and projects; and regional offices.
2) Monitor the activities of Service information and technology suppliers to ensure that information and technology generated will be applicable to identified needs.
b. Production of information and technology:
1) Survey and synthesize information.
2) Assemble and maintain comprehensive information bases.
3) Analyze and manipulate selected data bases for very specialized applications.
4) Provide technical assistance to users (to include advice and consultation, information search and processing, and conferences and short courses).

4. Transfer information and technology to users.
a. Integrate, package, and repackage information.
b. Match media and format to user requirements.
c. "Market" technology products to potential users.

5. Evaluate use and effectiveness.
a. Establish procedures for evaluation of the effectiveness of products, services, and the transfer system.
b. Document benefits resulting from information and technology transfer activities.
c. Assess gains in resource enhancement or losses pre-

vented by impact mitigation that are attributable to the availability of Regional Team information and technology.

d. Advise on needed refinement and redirection of the activities of both the Regional Team and the other information and technology suppliers.

The Regional Information and Technology Management Team, located in the Regional Headquarters in Atlanta, is composed of:

1. Regional Team Leader - Dr. Richard Wade
2. Regional Activity Leaders -Coordinators
   a. Coastal Ecosystems - Dr. James B. Kirkwood
   b. Power Plant Siting - Dr. Harold Wahlquist
   c. Coal/Minerals - Dr. Ronnie J. Haynes
   d. Water Resource Analysis -Ellison Madden
   e. National Wetland Inventory - John M. Hefner
   f. Information Transfer Specialist - Billie H. Hix

The Regional Information Transfer Specialist (ITS) is trained in information science, with a background in environmental science, and will support the Regional Team by providing:

1. The tools and techniques necessary for transfer of information and technology from suppliers to users.

2. The primary regional link in the Information Transfer Network of the Service that connects the information search and data processing capabilities of the Network to the FWS and other Federal agencies and the associated States.

The Regional ITS has and will apply skills in the uses of libraries, computer storage and retrieval, publications, workshops, and many other information repositories and communication media. The primary participation of the Regional ITS in the Regional Team activities will involve preparing the Transfer Plan, guiding the delivery system, and monitoring technology utilization.

A Region 4 Information Center has been established. Some services are available now; others will be added in the future. There will be a review procedure to annually adjust the services, i.e., add, expand, change or discontinue others. In the near future, we will publish a brochure telling what services are offered.

The primary service offered by the ITS is research assistance in locating and obtaining information. Contractual agreements have given access to most of the available major data bases: Lockheed Dialog Services (101 Data Bases), SDC ORBIT services (41 Data Bases), Bibliographic Retrieval Services, Inc. (BRS) (25 Data Bases) and Ohio College Library Catalog System (OCLC). The total number of data bases is approximately 150 because of some overlap among these brokers.

These bases may be searched for information in order to furnish the results of the search to you. Selective Dissemination of Information (SDI) is also available. An SDI search is a search that is established with a data base to continue to notify you (usually monthly) of all new material entering that data base that meets your SDI search parameters. In other words, you can be notified automatically of most new publications efforts in a given area.

In order to receive this service you must request it from us. You should request and use the information as you would any resource that costs money. Just make sure the information requested is needed to support a mission requirement, not a simple curiosity. Remember that we (FWS) pay for this information and you, the user, should help us use our resources wisely.

A second service offered users is help in locating cited information. This may be done by loan or by providing a free copy. We may borrow a copy elsewhere for you or as a last resort, tell you where you can purchase it.

Another service is to improve an existing system to make it operate more effectively. We plan to make extensive use of the new FWS Mailing List system to send information to those we think can use it. This system allows selective factors to be used to create mailing lists. We plan to use this system to send information to those who have requested certain types of information. An information form is available from the regional ITS so that information in the areas you select is forwarded to you as it becomes available.

The final service currently offered is advice on current information systems. I am the Regional Automatic Data Processing (ADP) Coordinator. If you have an idea which might involve some automated equipment (e.g., computer, word processor, microfilm), contact me to discuss it. There are two computers in the Regional Office and I have access to others. Also, since January 1980, all purchases and leases of ADP services or equipment by the FWS in Region 4 must be coordinated through the Regional Team.

Plans are underway to expand and add services. I would like to invite you to contact me with your information needs so that we can help you find needed services elsewhere. It has been said that, "The second best thing in the world is to know where to find the best thing." Knowing where and how to find the best thing is the ITS' business. Let us help you.

Discussion IX - Problems of and Possible Assistance for Resource Managers (B. Hix)

Comments. B. Hix:

The National Information and Technology Management Team has on tape somewhere between 9,000 and 20,000 references, bibliographies, abstracts, and now is looking for a commercial vendor to make these available. The information includes coastal areas. There is a very interesting data base on the island chains around the United States. There is also a manual which describes one of the broker's information services.

If you have a problem, the Team works at it. In the commercial area, an attempt is being made to reduce cost. Services range from \$5 to \$10 per request. A demonstration for this workshop was run for 54¢ to search the information on the University of Michigan's computer.

Mr. Hix then gave a demonstration of how efficient the computerized system is. He invited all to participate.

SUMMARY AND EVALUATION OF WORKSHOP

James B. Kirkwood

Paul S. Markovits

The workshop was formally completed the morning of 22 February 1980. An evaluation questionnaire was given to each person who participated. Forty-one individuals elected to complete the form. The general comments about the workshop were overwhelmingly favorable. Most people recommended that the next workshop should be more personalized (i.e., smaller groups) and deal with specific problems rather than literature or scientific concepts. Perhaps the comments can be summed up by the comment that "the workshop went well and provided information which could be used in dealing with real issues. It showed areas where information on specific problems is needed."

A copy of the verbatim responses to the questionnaire and percentile rankings of each question is available upon request from James B. Kirkwood, Regional Activity Leader, Coastal Ecosystems, Biological Services, U. S. Fish and Wildlife Service, 75 Spring Street, S.W., Atlanta, Georgia 30303.

BIOGRAPHICAL SKETCHES

(Alphabetically Arranged)

Bill Becker

Bill Becker received a B.S. in Biological Oceanography, 1969, City College of New York and a M.S. in Marine Biology in 1971 from the University of Delaware. Since 1971 Mr. Becker has been an instructor and assistant director of the Newfound Harbor Marine Institute at Seacamp, Big Pine Key, Florida. He has coordinated numerous conferences and workshops for groups visiting the Florida Keys. He has been an active leader of numerous local organizations, and is an accomplished scuba diver and photographer.

Melvin S. Brown

Melvin S. Brown obtained his B.S. degree in forestry and wildlife management at the University of Florida in 1975. After graduation, he became a staff member in the Resource Management Systems Program in the School of Forest Resources and Conservation at the University of Florida. Mr. Brown's field of interest covers natural and pollutant stressors in mangroves and the nearshore marine environment. He is engaged in oil spill assessments in mangroves in Puerto Rico and Florida, and in a study of mercury pollution around Cartegena, Colombia. He is co-author of several research papers, and is preparing a major review and synthesis of mangrove litterfall patterns around the world.

Robert H. Chabreck

Robert H. Chabreck earned a Ph.D. in botany from Louisiana State University in 1970 and has an M.S. in wildlife management received from the same institution in 1957. He has experience in wildlife and wetlands research and management with Louisiana Wildlife and Fisheries Commission, 1957-67; U.S. Department of the Interior, 1967-72; and Louisiana State University, 1972-75. In 1975 he worked for the U.S. Department of the Interior, National Coastal Ecosystems Team identifying problems and designing research projects in U.S. coastal areas. Since 1976 he has been with Louisiana State University focusing on wildlife, wetlands, forestry research and teaching.

Dr. Chabreck has published 80 scientific papers dealing with wildlife and wetlands and is a member of a wide variety of learned societies and professional organizations. He has also been a part-time consultant for numerous agencies investigating wetlands.

Judith F. Cooley

Judith F. Cooley received her B.A. in geological oceanography from Brown University in 1973 and a M.S. in oceanography from the University of Rhode Island in 1976. Her thesis topic was "Some Effects of the Water-Accommodated Fraction of #2 Fuel Oil on a Predator-Prey System: Asterias forbesi and Mytilus edulis."

Since 1976, she has been a Research Associate in the Bowdoin College Chemistry Department as part of a research group studying the chemical and biological fate and effects of petroleum in the environment.

Carroll L. Cordes

Carroll L. Cordes received his M.S. degree in animal ecology in 1965 and his Ph.D. in zoology in

1971 from North Carolina State University. He served on the graduate faculty of the University of Southwestern Louisiana at Lafayette for eight years before joining the U.S. Fish and Wildlife Service in 1977.

Dr. Cordes is a member of several honorary and professional societies and was named the Alumni Foundation Outstanding Professor for Research and Teaching at the University of Southwestern Louisiana in 1977. He has published a number of ecological papers and is a coauthor of the three-volume report entitled, An Ecological Characterization Study of the Chenier Plain Coastal Ecosystem of Louisiana and Texas.

John W. Day, Jr.

John Day received his B.S. and M.S. degrees in zoology from Louisiana State University. He received his Ph.D. in marine sciences from the University of North Carolina in 1971. He is currently employed as a professor at Louisiana State University. His main interests are estuarine systems ecology, ecological modeling, human impacts in estuaries, and coastal zone management. He has worked in estuaries of Louisiana, Mexico, Florida, and North Carolina.

Armando A. de la Cruz

Armando A. de la Cruz is a Professor of Zoology in Biological Sciences at Mississippi State University. He received a Ph.D. in ecology from the University of Georgia in 1965; an M.S. in biology, the American University in 1962; and a B.S. in zoology, the University of the Philippines in 1958. His special training includes radiation ecology, tropical biology, estuarine ecology, marine physiology, marine ecology, and university biology teaching.

Dr. de la Cruz is a member of five honorary societies and 20 national and international professional societies. He is recipient of A.I.D., SEATO, and Guggenheim Fellowships and three graduate scholarships. In 1975 he was awarded the Mississippi State University Sigma Xi Research Award and, in 1979, the Alumni Foundation Outstanding Faculty Award for Research. He has published 70 scientific papers and 4 laboratory manuals and has engaged in research on estuaries and wetlands funded by NSF, USDA, EPA, and SEA GRANT.

Nicholas A. Funicelli

Nicholas A. Funicelli is currently with the U.S. Fish and Wildlife Service, Biological Studies Program. He is currently leader of the Contract Management Team located in Austin, Texas. Among other contracts, he is project officer for the freshwater inflow studies in Matagorda and Corpus Christi bays, Texas.

Prior to joining the U.S. Fish and Wildlife Service, Nick was an ecologist with the EPA in New York and a biologist with Con Edison, New York. His experience also includes a staff position with the Corps of Engineers in Savannah. He was a member of the graduate faculty at Long Island University.

He received his Ph.D. in 1975 from the University of Southern Mississippi and his B.A. and M.S. from Long Island University.

Ray P. Gerber

Ray P. Gerber received a B.S. in zoology from the University of Miami, Florida in 1970. In 1970, he entered the Graduate School of Oceanography, University of Rhode Island, and received an M.S. in 1973 and Ph.D. in 1976. His thesis was entitled "Ingestion of detritus by the lagoon pelagic community at Enewetok Atoll" and his dissertation was entitled "Ecology of lagoon zooplankton at Enewetok Atoll, Marshall Islands." He joined the Bigelow Laboratory for Ocean Sciences, W. Boothbay Harbor, Maine in 1976 and the Marine Research Laboratory at Bowdoin College in 1977.

His research interests include the cycling of organic matter in tropical pelagic ecosystems and the physiological ecology of marine organisms stressed by pollutants.

Edward S. Gilfillan III

Edward S. Gilfillan received his B.A. in zoology from Yale University in 1963. His M.S. and Ph.D. in oceanography were received in 1967 and 1970, respectively, from the University of British Columbia. His dissertation was entitled "The physiology and ecology of Euphausia pacifica (Crustacea)." In 1970 he joined the University of Massachusetts Marine Station at Gloucester, Massachusetts and in 1974 joined the Bigelow Laboratory for Ocean Sciences, W. Boothbay Harbor, Maine. In 1977 he became a member of the Bowdoin College faculty.

His recent research programs have included studies on excretion and biodeposition by mussels and the effects of petroleum hydrocarbons in the marine environments.

Larry Goldman

A native of Wauna, Washington, Mr. Goldman was a commercial salmon fisherman and earned his B.S. at the University of Washington. He joined the Fish and Wildlife Service in 1968 as a Student Trainee in the Sacramento, California Ecological Services Office. He held positions in the Portland, Oregon and Olympia, Washington Ecological Services field offices between 1969 and 1973. In 1973 he was selected to participate in an assignment to the State of Mississippi's Marine Resources Council under provisions of the Intergovernmental Personnel Act. While on that assignment, he led development of Mississippi's Coastal Zone Management Program and was involved in administration of the State's Coastal Wetlands Protection Act. Upon completion of this assignment in 1975, he was assigned the position of the Service's Coastal Zone Management Coordinator in the Washington, D.C. office. In 1977, he joined the staff of the newly formed Jacksonville Area Manager's office as Senior Staff Specialist - Environment, the position he holds today. Mr. Goldman has been honored by the Washington Environmental Council as its Public Official of the Year (an honor shared with other Olympia office staff) and by the Mississippi Wildlife Federation as its Water Conservationist of the Year.

Joe W. Hardy

Joe W. Hardy received his M.S. from Virginia Polytechnic Institute-University (Wildlife) in 1961 and was a NIPA Fellow for Natural Resource Public Policy at the University of Washington, 1967. He served as a research biologist for the Tennessee Game and Fish Commission from 1961-68 and the Fish and Wildlife Service, Gainesville, Florida, 1968-71. From 1971-73 he was an Enhancement Specialist-Regional Supervisor for Wildlife Services, Atlanta, Georgia and also served as Environmental Specialist for the FWS in Washington, D.C., 1973-75. He was the FWS Ecological Services Field Supervisor, Vicksburg, Mississippi from 1975-79 and presently is a biologist for the National Coastal Ecosystems Team, Office of Biological Services.

Billie H. Hix

Billie H. Hix received his B.S. degree from Middle Tennessee State University in 1967, an M.P.S. degree from Auburn University in 1971, and has some graduate work beyond the M.P.S. at Auburn. He completed the Air Force's Air War College Seminar Program in 1977. Mr. Hix was selected to supervise the implementation of the long-range plans as Chief of the Technical Systems Division, Albert F. Simpson Historical Research Center. He supervised the overall functional operation of USAF Southeast Asia Information System (DABIN) from April 1971 to October 1979, made major modification to DABIN in 1971-72 that improved the overall operation and saved time and money; supervised microfiliming of all USAF Historical Documents in Albert F. Simpson Historical Research Center from 1969 to October 1979; supervised and had a major individual role in designing and implementing the new USAF Historical Program Information System (IRIS) from 1971 to October 1979; and established and supervised the research and publication of a series of Research Guides to Air Force historical materials.

Mr. Hix has had various memberships in societies and was a member of the Alabama Governor's Committee on Libraries and Information Science from 1977-79 and a delegate to the 1979 Alabama Governor's Conference on Libraries and Information Science.

Charles W. Hollis

Mr. Hollis is a native of Wilmington, North Carolina, and attended local schools including Wilmington College (now the University of North Carolina at Wilmington) and North Carolina State University in Raleigh, North Carolina. He began his career with the U.S. Army Corps of Engineers in 1956 with the Wilmington Corps of Engineers District. While on assignment in 1961 with the Corps to the Atomic Energy Commission Deep Mine Waste Storage Study in Augusta, Georgia, he was transferred to the Savannah (Georgia) District where he remained in various programs until 1970. At that time Mr. Hollis returned to the Wilmington District to assume his current duties as Chief of the Regulatory Functions Branch.

Janet R. Hotham

Janet R. Hotham received her B.S. in chemistry from Merrimack College in 1977. She joined the Marine Research Laboratory at Bowdoin College in 1978 as a research assistant. Her research has been in the detection of hydrocarbons and trace metals in marine systems.

James B. Kirkwood

James B. Kirkwood began his biological career as a freshwater fishery biologist in Kentucky in 1952. In 1957, he moved to Alaska to work for the Bureau of Commercial Fisheries (FWS) as a marine biologist and, after obtaining a Ph.D. in 1962 in zoology (ecology) from the University of Louisville, he worked as a program manager for king crab and shrimp investigations.

In 1967, he accepted a position

with Battelle Columbus Laboratories as the technical coordinator for the Atomic Energy Commission's Bio-environmental Studies associated with the nuclear weapons testing program at Amchitka, Alaska. After the termination of the Amchitka work, Dr. Kirkwood was promoted to Manager of Batelle's marine biology laboratory, the William F. Clapp Laboratories at Duxbury, Massachusetts.

Dr. Kirkwood assumed his current duties as Coastal Ecosystems Activity Leader for FWS in July 1975.

He has published about 50 technical and semi-technical papers. He is certified as a fishery biologist by the American Fisheries Society and as a fellow by the American Institute of Fishery Research Biologists. He is listed in Who's Who in American Men and Women of Science and is a member of Sigma Xi.

Donald Kosin

Donald Kosin is the Manager of the National Key Deer Refuge, Big Pine Key. He received his B.S. in wildlife management from Miami University, Oxford, Ohio in 1961 and did graduate work in wildlife management at Ohio State University. In 1966 he joined the staff of the Soil Conservation Service in Mississippi and one year later became a member of the Fish and Wildlife Service, working at Merritt Island National Wildlife Refuge, Florida. From 1968 to 1972 he worked at the Okefenokee Wildlife Refuge, Georgia, and then spent three years at Wapanocca Wildlife Refuge, Arkansas. He has been the manager at National Key Deer Refuge sine 1975.

Roy Robert "Robin" Lewis III

Mr. Lewis received a B.S. degree in biology from the University of Florida in 1966 and a M.A. degree in marine biology from the University of South Florida in 1968. He has taught in several community colleges in the State of Florida, reaching full professorship at Hillsborough Community College in Tampa in 1973, where he still teaches full time.

Mr. Lewis founded Mangrove Systems, Inc., an ecological consulting firm, in 1975. The company specializes in management, restoration, and creation of coastal wetland communities, including tidal marshes, mangrove forests, and seagrass meadows. Mr. Lewis has served as consultant to the U. S. Navy, U.S. Army Corps of Engineers, U.S. Fish and Wildlife Service, Martin Marietta Corporation, Westinghouse Electric Company, Borden Chemical Company, Florida Environmental Land and Water Management Study Committee, and other clients in the public and private sector.

Ariel Lugo

Ariel Lugo obtained his Ph.D. at the University of North Carolina in Chapel Hill (1969) and taught at the University of Florida between 1969 and 1979. He was also Assistant Secretary of the Department of Natural Resources in Puerto Rico (1973-1975) and Staff member of the President's Council on Environmental Quality in Washington (1977-1979). He is now Project Leader at the Institute of Tropical Forestry of the U.S. Forest Service in Puerto Rico. His publications exceed 70.

Paul S. Markovits

Paul Markovits received his Ph.D. in science education from Syracuse University in 1976. His work has been in the areas of general science and environmental education with an emphasis in biology. He presently is Assistant Professor of Science Education at Montana State University where he teaches elementary science methods and secondary general science methods. He has also been a public school biology and general science teacher and has taught physical science and genetics at the college level. His publications are about science education, environmental attitudes, and futuristic education.

Arthur R. Marshall

Arthur R. Marshall was born in Charleston, South Carolina and served in the Armed Forces during WWII. He received his B.S. in general biology from the University of Florida, 1953, and an M.S. in marine fisheries science from the University of Miami, Florida, 1956. He is a Phi Beta Kappa, NSF Fellow, and received the Distinguished Service Award, U.S. Department of Interior, 1968.

Mr. Marshall has major publications in the area of environmental impact and was with the U.S. Fish and Wildlife Service from 1955-70. From 1970-71 he was director of the Laboratory for Estuarine Research, School of Marine and Atmospheric Services, University of Miami and Director of the Division of Applied Ecology, Center for Urban and Regional studies, 1971-73. During 1973-74 he was professor and consultant to the Urban and Regional Development Center, University of Florida.

Mr. Marshall is presently a consultant for the FWS.

Eugene Odum

Dr. Eugene Odum is a graduate of the University of North Carolina, A.B., 1934, and A.M., 1936. He served as instructor at Western Reserve University, Cleveland, 1936-1937, and in 1937 continued graduate studies at the University of Illinois where he received his Ph.D. in 1939.

In 1939-40 he served as the first Resident Biologist at the Edmund Niles Huyck Preserve, Rennselaerville, New York. He went to the University of Georgia as instructor in zoology in 1940. He was appointed Alumni Foundation Professor of Ecology in 1972. Dr. Odum is also the Director of the Institute of Ecology at the University of Georgia, which he founded in 1961.

Dr. Odum became an early pioneer in the field of radiation ecology. In 1952 he began, with Atomic Energy Commission support, what is now the Savannah River Ecology Laboratory (SREL). In the summer of 1962, Dr. Odum was appointed Chief Scientist, Special Training Division, Oak Ridge Associated Universities and served as codirector of the first training program in radiation ecology at Oak Ridge.

In 1968, Dr. Odum received special recognition as Georgia's Scientist of the Year. He was elected to the National Academy of Science in 1970 and has been thrice honored by the Ecological Society of America. In 1975, Eugene Odum received, jointly with his brother, Howard T. Odum, the international prize awarded by the French "L'Institut de la Vie." He was elected a Fellow in the American Academy of Arts and Sciences in that same year. In 1977, he received the Tyler Ecology Award which includes a cash award of $150,000, most of which he contributed to the University Foundation for an endowment fund for the Institute of Ecology at Georgia. In 1978, Dr. Odum was honored by the American Institute of Biological Sciences with a Distinguished Service Award and in that same year by the Association of Southeastern Biologists with a Meritorious Teaching Award.

This biographical summary does not permit a complete listing of publications, awards, and honors. He is a respected scholar and teacher and has frequently served the country, state, and local community in both professional and personal capacities.

William E. Odum

William E. Odum received his Ph.D. in Marine Sciences from the University of Miami in 1970. He was a postdoctoral fellow at the Institute of Resource Ecology of the University of British Columbia from 1970-71. Since 1971 he has been a faculty member in the Department of Environmental Sciences of the University of Virginia. He has taught courses in basic ecology, aquatic and estuarine ecology, fisheries and wildlife management, and the ecology of land use management.

Dr. Odum has published approximately 45 papers, book chapters, and short books on a variety of subjects including mangrove ecology, marsh ecology, aquaculture, herbivore grazing, the effects of heavy metals and pesticides, wetlands management, decomposition processes, barrier island dynamics, limnology, and aquatic microbiology.

David S. Page

David S. Page received his B.S. in chemistry from Brown University in 1965. In 1970 he received his Ph.D. in physical chemistry from Purdue University with a dissertation entitled, "The reaction mechanism of L-amino acid oxidase." In 1970 he became a faculty member of Purdue University as a Visiting Assistant Professor. In 1971 he joined the chemistry faculty of Bates College, Lewiston, Maine as an assistant professor and in 1974 joined the Bowdoin College chemistry faculty where he was promoted to associate professor in 1975.

Since 1975, he has conducted research on the effects and fate of petroleum in the environment as part of a group of chemists and biologists at Bowdoin specializing in this area.

Charles H. Peterson

Charles H. Peterson received his Ph.D. in 1972 in biology with a major in population biology and minor areas of concentration in oceanography, biometry, and paleoecology. From 1972 through 1976, he held a position as assistant professor of biological sciences at the University of Maryland, Baltimore County where he taught classes in population biology and ecology. From 1976 on, Peterson has been an associate professor of marine sciences and zoology at the Institute of Marine Sciences and in the Marine Sciences Curriculum of the University of North Carolina at Chapel Hill.

Dr. Peterson has been awarded several National Science Foundation Grants to support his research on coastal marine and estuarine soft-bottom communities and several Sea Grants to fund his work on the management of coastal wetlands and of hard clam populations. He has published numerous papers on the ecology of soft-sediment, benthic invertebrates, the paleoecology of lagoonal molluskan communities, species diversity indices, migration in mullets, the community ecology of marine epifuana, and estuarine management practices.

Ronald C. Phillips

Ronald Phillips served as a research marine biologist from 1957 to 1961 at the Florida State Board of Conservation (now Department of Natural Resources), St. Petersburg. From 1961 to the present he has been at Seattle Pacific University. He is a consultant to the Fish and Wildlife Service, the Army Corp of Engineers, several environmental firms, and several State agencies in Washington and Florida. Since 1974 he has been working with an NSF/ IDOE Seagrass Ecosystem Study.

He has transplanted seagrasses in Alaska, Pudget Sound, Texas, Florida, and U.S. Virgin Islands. He has completed a comprehensive phenology study of Zostera marina and Thalassia testudinum. The data were analyzed using a computer program which will allow predictions to be made for flowering events by latitudinal location. Dr. Phillips has studied seagrasses in every ocean of the world and has approximately 65 published papers on seagrasses and algae and one seagrass book.

Harvey M. Rogers

Harvey M. Rogers entered on duty with the Service in its Division of Ecological Services, Region 4, in January 1961. He subsequently worked in Ecological Services in Regions 1 and 2. Before joining the Service, he worked for Colorado Game and Fish Department, Wyoming Game and Fish Commission, and the Phillips Petroleum Company. He received his B.S. degree from Colorado State University in 1955 and worked for the Colorado Cooperative Fishery Research Unit while in college.

He now works in the Austin Area Office which has responsibility for Service functions in Oklahoma and Texas. He is the Staff Specialist for Environment.

Robert Routa

Mr. Routa is a graduate biologist from the University of Florida. He gained experience with the Florida Game and Fresh Water Fish Commission and then the Florida Department of Natural Resources, Division of Survey and Management; that group of biologists was established as a result of passage of the Randall Act in 1967 to inspect dredge and fill projects.

Mr. Routa then worked with the Trustees of the Internal Improvement Fund - where he proved himself a capable administrator. While preparing for a law degree, he was hired to evaluate dredge and fill permits for the Service and is now a legal representative of various individuals.

Thomas J. Smith III

Thomas Smith received a B.S. in zoology from the University of Florida in 1976 and an M.S. in environmental sciences (ecology) from the University of Virginia in 1979. Mr. Smith was employed for five years with the USFWS, working on national wildlife refuges in Florida and North Carolina. He is currently engaged in research on habitat utilization and niche dynamics of waterfowl along estuarine salinity gradients. He is a member of several scientific societies and has published articles dealing with estuarine productivity, grazing in coastal salt marshes, and habitat values of freshwater tidal wetlands.

Samuel C. Snedaker

Samuel C. Snedaker has a B.S. (agriculture), B.S. (forestry), M.S. (botany), and a Ph.D. (tropical forest ecology) from the University of Florida. Following the doctorate (1970) he held joint faculty appointments at the University of Florida in Aquatic Sciences, Forestry, and Environmental Engineering Sciences. His field of interest is in systems ecology with emphasis on the tropical mangrove coastal zone in both the Eastern and Western Hemispheres. He is presently Chairman of the UNESCO/ SCOR Working Group on Mangrove Ecology and is a member of the IUCN Commission on Ecology. He has numerous papers on mangroves and is currently preparing a world inventory and status report on mangroves for a monograph to be titled, "Mangroves: an endangered ecosystem." Dr. Snedaker is frequently asked to serve as an expert witness for the State and Federal Government in litigation involving the malicious destruction of mangroves.

William A. Swanson

William A. Swanson received his B.S. degree in forest management from the University of Minnesota in 1960. He began his work with the Fish and Wildlife Service that year and continued until 1969 working on the acquisition of migratory bird breeding habitat in the midwest States of North and South Dakota, Minnesota, and Nebraska.

After five years of service in private industry, he returned to the Service's Atlanta Regional Office in 1974 and has worked since in the Service's land acquisition programs in the southeast region. He presently serves as Associate Senior Realty Officer for Region 4.

Howard J. Teas

Howard J. Teas has a B.S. Degree from Louisiana State University (1942), an M.S. degree from Stanford University (1946), and a Ph.D. from California Institute of Technology (1947). His field is plant physiology, and plant physiological genetics and ecology. He has worked in Puerto Rico, the University of Florida, and the University of Georgia. He is professor of biology at the University of Miami, Coral Gables, Florida, where he teaches tropical botany, environmental biology and economic botany. He has studied mangroves in India, Vietnam, Singapore, Fiji, Central and South American, and the Caribbean. He has carried out mangrove planting in Florida, Puerto Rico, India, and Vietnam. He has published a number of papers on mangrove planting and ecology. He also consults in wetland and mangrove ecology and restoration.

Anitra L. Thorhaug

Anitra Thorhaug received a B.S. in zoology (1963), M.S. in marine biology (1965) and a Ph.D. in marine science (1969) from the University of Miami. She also did postdoctoral work in chemical oceanography with the Environmental Sciences Services Administration (now NOAA).

To highlight her achievements, she was a research scientist with the School of Medicine from 1971 to 1972 and School of Marine Sciences from 1970 to 1971 at the University of Miami. She was also a member of the workshop on critical problems of the coastal zone at Woods Hole in 1973.

Dr. Thorhaug has been an exchange delegate to the People's Republic of China from the U.S. Botanical Society of America and has participated in numerous symposiums and conferences. She was elected to the Editorial Board of the American Journal of Botany in 1979 and appointed International Editor of Plant and Science Bulletin. In 1975 she was awarded the diamond award by the American Botanical Society.

Dr. Thorhaug has been a consultant for several government agencies including EPA and the Army Corps of Engineers and has been the organizer and chairperson of various conferences including the American Institute of Biological Sciences Symposium on Restoration of Major Plant Ecosystems in the United States, Conference on Restoration of North Biscayne Bay, Conservation Committee of the Botanical Society of America, and Endangered Ecosystems in the United States. She is the author of numerous publications.

James T. Tilmant

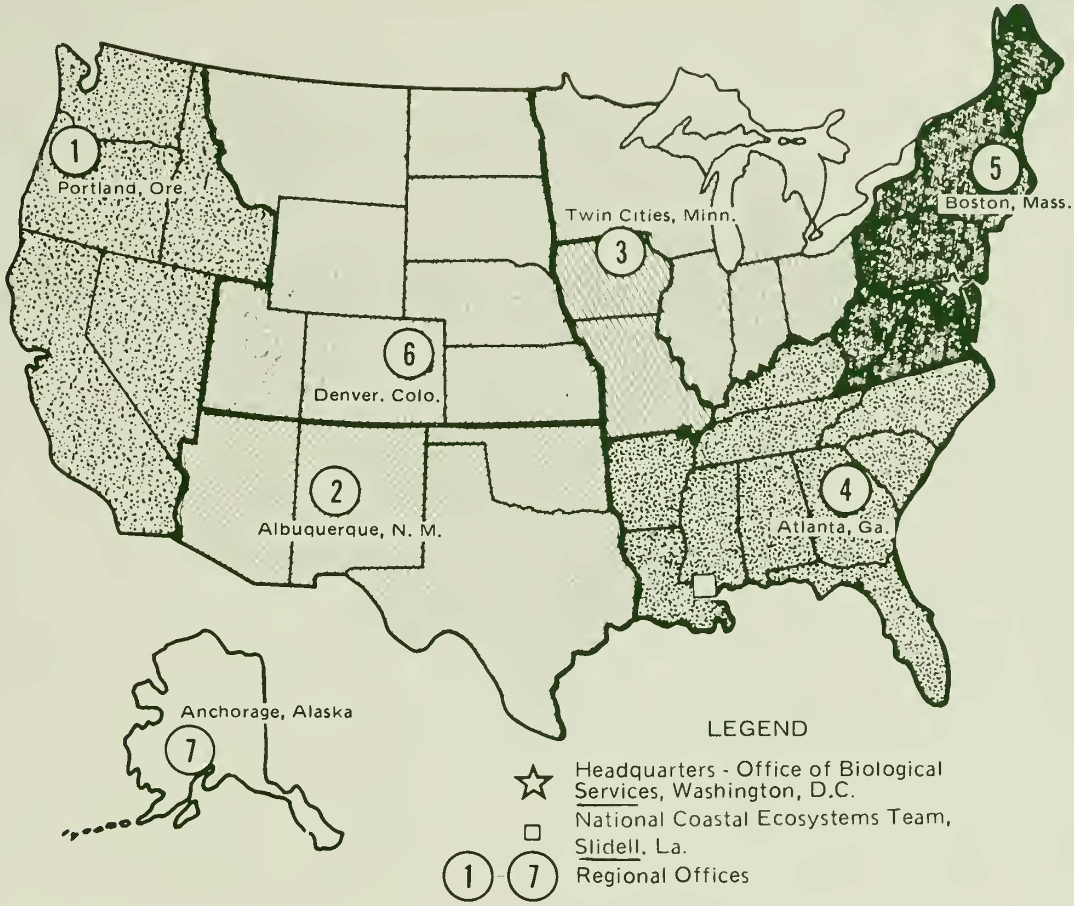
James T. Tilmant earned his B.S. in biology from New Mexico State University in 1968 and has an M.S. in biology from Humboldt State University. He has experience in wildlife management as a result of his employment first at Shenandoah National Park, White Sands National Monument, Everglades National Park, and Biscayne National Monument where he is currently the Park Biologist.

Mr. Tilmant has presented over 20 scientific papers dealing with wildlife and wetlands management and is a member of many professional organizations.

Joseph C. Zieman

Joseph C. Zieman received his Ph.D. in marine sciences from the Institute of Marine Sciences of the University of Miami in 1970. He was a postdoctoral fellow at the Institute of Ecology of the University of Georgia from 1970-71. Since 1972 he has been a faculty member in the Department of Environmental Sciences of the University of Virginia. He has taught courses in marine and estuarine ecology, systems analysis, and basic ecology.

Dr. Zieman has published approximately 35 papers, book chapters and reports on a variety of subjects including the ecology of seagrass ecosystems, the ecology of coral reefs, mangrove and salt marsh systems, the effects of stress on seagrass systems, the effects of thermal pollution in the tropics, and simulation modeling of seagrasses, coral reefs, mangrove, and salt marsh systems. His current research centers on consumer and successional processes in tropical seagrass systems, as a participant in the Seagrass Ecosystem Study of the International Decade of Oceanographic Exploration.



U.S. FISH AND WILDLIFE SERVICE
REGIONAL OFFICES

REGION 1
Regional Director
U.S. Fish and Wildlife Service
Lloyd Five Hundred Building, Suite 1692
500 N.E. Multnomah Street
Portland, Oregon 97232

REGION 2
Regional Director
U.S. Fish and Wildlife Service
P.O. Box 1306
Albuquerque, New Mexico 87103

REGION 3
Regional Director
U.S. Fish and Wildlife Service
Federal Building, Fort Snelling
Twin Cities, Minnesota 55111

REGION 4
Regional Director
U.S. Fish and Wildlife Service
Richard B. Russell Building
75 Spring Street, S.W.
Atlanta, Georgia 30303

REGION 5
Regional Director
U.S. Fish and Wildlife Service
One Gateway Center
Newton Corner, Massachusetts 02158

REGION 6
Regional Director
U.S. Fish and Wildlife Service
P.O. Box 25486
Denver Federal Center
Denver, Colorado 80225

REGION 7
Regional Director
U.S. Fish and Wildlife Service
1011 E. Tudor Road
Anchorage, Alaska 99503

DEPARTMENT OF THE INTERIOR

U.S. FISH AND WILDLIFE SERVICE

As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering the wisest use of our land and water resources, protecting our fish and wildlife, preserving the environmental and cultural values of our national parks and historical places, and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to assure that their development is in the best interests of all our people. The Department also has a major responsibility for American Indian reservation communities and for people who live in island territories under U.S. administration.