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Biological Services Program

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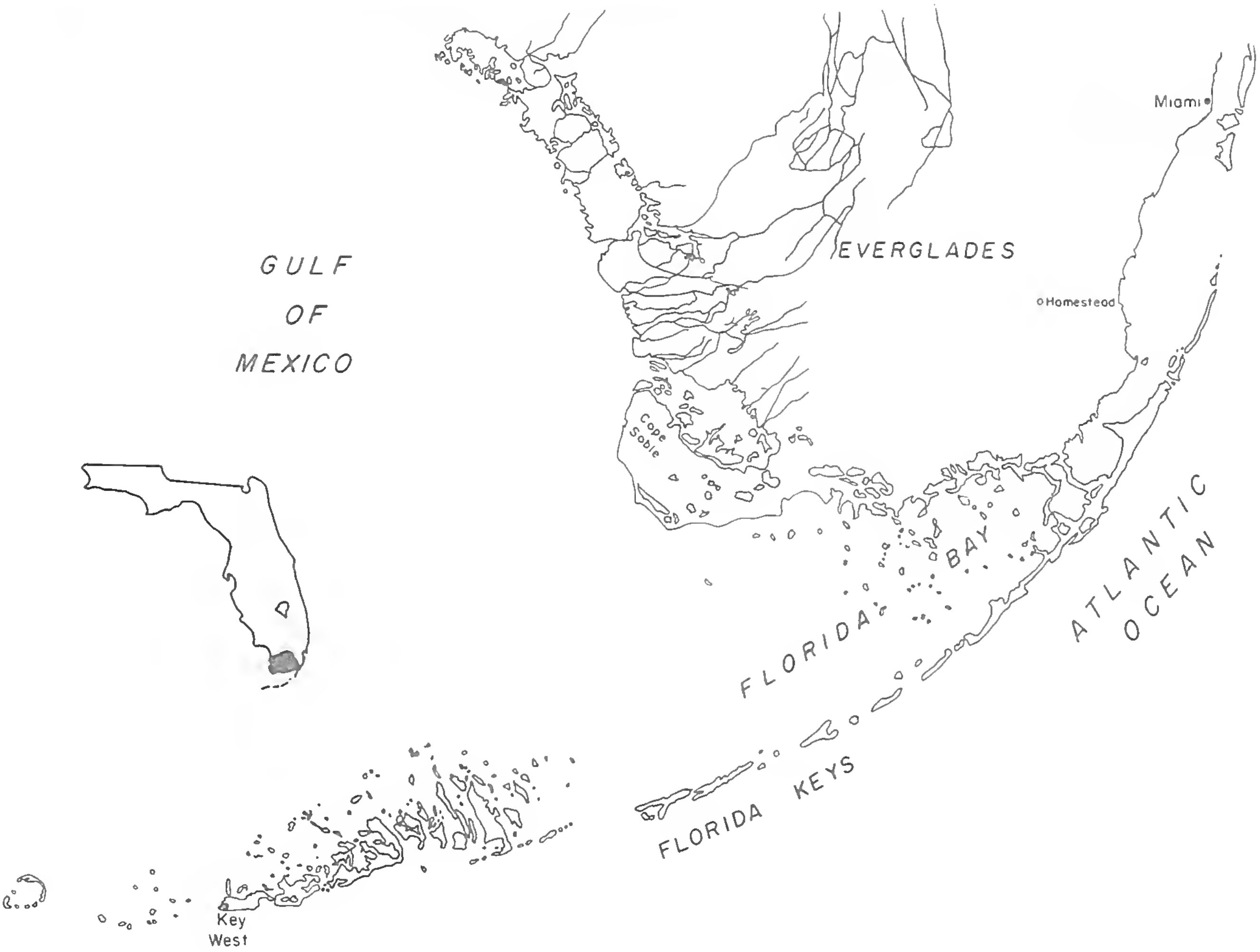
AN ECOLOGICAL CHARACTERIZATION OF THE LOWER EVERGLADES, FLORIDA BAY, AND THE FLORIDA KEYS



Bureau of Land Management
h and Wildlife Service
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AN ECOLOGICAL CHARACTERIZATION OF THE LOWER EVERGLADES, FLORIDA BAY AND THE FLORIDA KEYS

by

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PREFACE

This report is one in a series that provides an ecological description of Florida's gulf coast. The region treated herein, with its myriad tropical and subtropical communities, produces many benefits to man. The maintenance of this productivity through enlightened resource management is a major goal of this series. This report will be useful to the many participants in the democratic process that governs the use of the natural resources of this region.

Any questions or comments about or requests for this publication should be directed to:

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SUMMARY

A conceptual model of the study area identifies four major ecological zones; 1) terrestrial and freshwater wetlands, 2) estuarine and saltwater wetlands, 3) Florida Bay and mangrove islands and 4) the Florida Keys. These are geographically delineated from one another by a combination of elevation gradient and positioning relative to one another and to major outside influences such as upstream watersheds, the continental shelf and major ocean current systems. These zones are delineated by differences in basic physical-chemical background factors such as substrate, climate, hydrology and water chemistry which in turn promote characteristic ecological communities. Many of these communities are similar between zones but localized differences do exist, as do significant shifts in relative abundance of community types. The terrestrial and freshwater wetlands support pinelands, sawgrass marshes, wet prairies, sloughs and occasional tree islands on freshwater peat, marl and limestone soils. The estuarine and saltwater wetlands support mangrove forests, salt marshes and oscillating salinity systems on mangrove peat, marine marl, sand or "liver mud" substrates. Florida Bay exhibits oscillating meso-to hypersaline waters over grassbeds on marine lime mud sediments. These mud banks form an anastomosing pattern surrounding deeper "lake" areas having only a thin veneer of sediment. The exposed tips of the mud banks frequently support mangrove or salt prairie vegetation. The Florida Keys support almost all of the above communities to some small degree but are more prominently characterized by extensive offshore coral reefs. The upper keys are themselves a relict reef exposed by global lowering of sea level. The lower keys are composed of rock hardened Miami oolite, a limestone formed via chemical precipitation rather than biological deposition. The productivity of these communities with regard to fish and wildlife reflects 1) the diversity and type of habitats available to species that are potentially capable of exploiting them, 2) the degree of alteration of these habitats by man and natural forces, and 3) historical, biogeographic and random factors that restrict organisms to specific environments or prohibit them from exploiting a potential habitat.

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The authors wish to acknowledge the assistance of a number of people who contributed to the preparation of this document. Many public and private agency representatives cooperated with our search for published and unpublished data sources. Noteworthy among these were the staffs of Everglades National Park, the South Florida Water Management District, the National Marine Fisheries Service, the South Florida Regional Planning Council, the University of Florida's Center for Wetlands, and the University of Miami Rosenstiel Institute. Two individuals in particular, Alison Lewis and Carol Knox provided continual and invaluable support to the completion of this work. Ms. Lewis's persistence and efficiency in managing a virtual mountain of computerized bibliographic information greatly simplified our task. Ms. Knox's patient revision and completion of the tables and figures was carried out in an expert and timely manner. Valuable editorial review and comment was provided by Mr. Joe Carroll of the U.S. Fish and Wildlife Service, Ms. Mimi Drew and Mr. Eric Livingston of the Florida Department of Environmental Regulation. Grateful appreciation is extended to Ruth Gray, Alisa Gregory, and Tish Elliott, who prepared draft manuscripts of the synthesis paper and the bibliography, and to Francie Stoutamire who prepared the final manuscript. Finally the authors wish to express special thanks to our project officer, Mr. Ken Adams, for his constant support and expert guidance in directing our efforts and bringing this document to publication.

CHAPTER 1
INTRODUCTION

1.1 PURPOSE AND ORGANIZATION OF THE REPORT

In recent years man's cultural and economic development have accelerated at an unprecedented pace. Inevitably this development precipitates rapid change in the environmental conditions to which plants and animals have adapted. Widespread habitat destruction, sewage and industrial effluent discharge, ground and surface water diversion, and urban and agricultural runoff are but a few of the inevitable by-products of development that exert acute as well as chronic effects on the land, water, and biota.

Particularly within the highly developed and rapidly changing coastal zone, a fine line is emerging between what is considered healthy economic development and what must be conserved to insure a healthy and productive balance between man and nature. Often, in deciding where this line lies, there is much confusion as well as uncertainty over exactly what natural resources exist in an area, and how they function. This report is an attempt to alleviate this confusion and uncertainty.

This document is the culmination of an extensive review of published and unpublished literature on pertinent ecological processes within the study area. In contrast to conventional literature reviews and syntheses, the present document deliberately crosses disciplinary boundaries in an effort to focus on how the watershed functions as an integrated ecological system. At the core of this focus is the basic question, "How do energies and materials flow through the lower Everglades, Florida Bay, and Florida Keys watershed?"

In answering this question, the document is divided into two parts, one on physical/chemical background conditions, and the other on structural and functional ecological patterns of energy utilization. The first part identifies spatial and temporal patterns in the distribution of physical/chemical forces which drive the metabolism of the study area. In this regard chapters 2 through 5 are presented, covering the physiography of the study area, its climate, its geology, and characteristics of hydrology and water quality. The second part describes the overall habitat zonations that develop in response to physical/chemical controls, as well as pertinent patterns of resource partitioning (e.g., productivity, species utilization and dependence, succession, etc.) between and within individual habitats. Our treatment of these patterns is divided into four chapters (6 through 9) corresponding to major ecological zones as explained in Section 1.4.

1.2 THE STUDY AREA

The study area includes three major subunits: (1) the lower Everglades; (2) Taylor Slough/Florida Bay; and (3) the Florida Keys (Figure 1). The central component of the lower Everglades is Shark River Slough, a broad expanse of sawgrass marsh studded with occasional tree islands, or hammocks. The lower Everglades sub-area is bounded on the northeast by the intersection of Tamiami Trail and South Florida Water Management

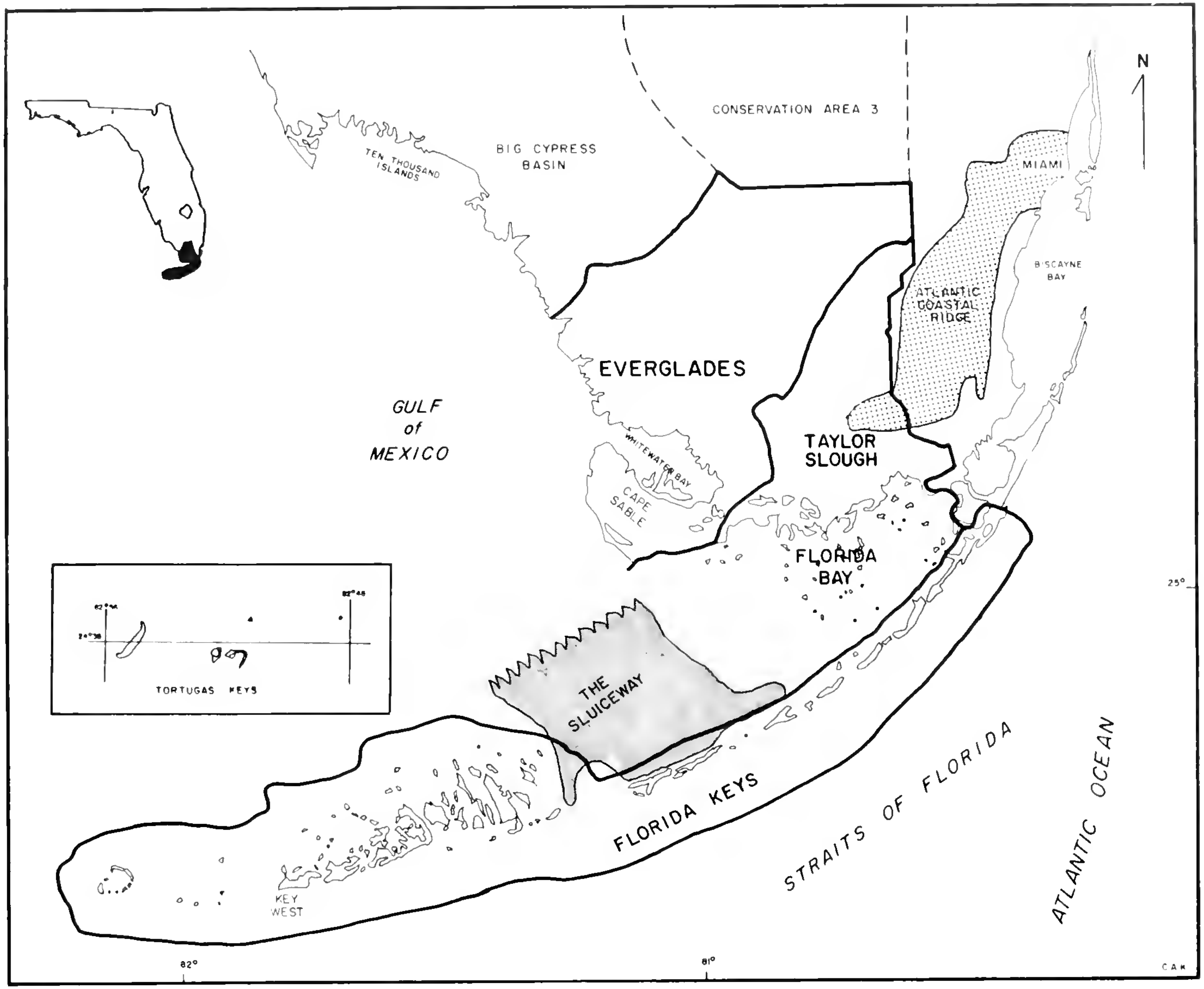


Figure 1. Map of study area identifying subunits.

District (SFWMD) canal-levee L-31. The area is bounded on the northwest by the delineation of a hydrologic boundary between the lower Everglades and the Big Cypress Basin. The southwestern boundary begins approximately 13 km (8 mi) south of Tamiami Trail on SFWMD canal-levee L-31 and runs southwest to the vicinity of Flamingo on Florida Bay. This somewhat hazy line follows State Road 27.

The Taylor Slough/Florida Bay segment is bounded on the east by SFWMD canal-levee L-31 W and on the southeast by U.S. Highway 1. To the south the intracoastal waterway, which doubles as the southern boundary of Everglades National Park, forms a convenient physiographic marker between the present segment and the Florida Keys. The park boundary from Long Key northwest to East Cape Sable forms the gulf-side boundary of this segment.

The third segment, the Florida Keys, forms a gradually arching chain of islands extending from the southeastern tip of the Florida peninsula (Soldiers Key just south of Miami Beach) southwestward to the Dry Tortugas, a distance of approximately 376 km (234 mi). The arc is bounded on the convex side by the Atlantic Ocean and the Straits of Florida, and on the concave side by Florida Bay and the Gulf of Mexico.

Throughout this report the study area in Figure 1 is often referred to as a "watershed" though it does not readily conform to the classic model of a distinct hydrologic unit. Historically, this watershed once incorporated the entire 22,500 km^2 (8,688 mi^2) of the Kissimmee River Basin north of Lake Okeechobee. The effective drainage area of the watershed has decreased significantly, however, as a result of hydrologic modifications of the Kissimmee, the drainage of the Everglades south of the lake, and the construction of dikes and levees surrounding the lake. The drainage area from Lake Okeechobee to the Gulf of Mexico is now estimated to be around 2,059 km^2 (795 mi^2) (Browder and Moore 1980). For our purposes, however, we consider the "watershed" to be only that portion which is relatively untouched by direct physical modifications. The boundaries of this area correspond in large part to those of the Everglades National Park. In addition, the fact that much of the freshwater used on the Florida Keys originates from the hydrologic budget of the lower Everglades necessitates that the keys also be considered a part of the watershed.

1.3 ENERGY AND MATERIALS FLOW THROUGH THE COASTAL WATERSHED

The hydrologic boundaries of watersheds form distinct, though somewhat amorphous "membranes" across which considerable energy and materials flow. Within these boundaries, various forms of energy and matter are constantly being tapped, transformed, and modified to yield a wide range of products including fish and wildlife as well as industrial and agricultural goods. These processes and pathways of production and consumption within the watershed are collectively responsible for what we call "watershed metabolism."

In addressing watersheds as living metabolic units, we concern ourselves with two broad categories of work being performed within their boundaries: (1) inorganically mediated work; and (2) biologically mediated work.

Inorganically mediated work refers to the forces attendant to basic physical/chemical background conditions, such as climate, which affect all aspects of watershed metabolism. Forces such as sunlight, winds, tidal fluctuations, heat flux, rainfall, atmospheric chemical fallout, and osmotic gradients form the basic energy sources, or forcing functions, that drive the metabolism of the watershed. These naturally occurring energy sources "work" for the watershed in the sense that they both force and allow changes to occur in the composition of the biota, soils, and water.

Biologically mediated work refers to the processes involved in the transformation and storage of energy and matter into plant and animal biomass, and its subsequent degradation. In the context of watershed metabolism, organisms form sites at which complex energy and material processing occurs, such as the uptake of nutrients from the soil and water, the evolution of oxygen or carbon dioxide, or the transformation of fish biomass into bird feathers.

Within the boundaries of a watershed, these two forms of work are integrated at every ecological level of organization. At the species level, individual populations are continually fine-tuned to their environment through adaptations in behavior, physiology, and anatomy. Simultaneously, species also develop interdependencies that promote mutual survival and exploitation of physical/chemical energies. This process results in the formation of characteristic environments referred to as habitats, or communities.

At higher ecological levels ("higher" meaning greater spatial and temporal coverage), this integration becomes increasingly complex. The linkage may be direct as in very specific reproductive needs; or indirect as in trophic web relationships between producers and consumers in widely separated habitats. When these factors are superimposed onto natural fluctuations in climate, invasions of species into new environments, and continual habitat alteration, it becomes necessary to focus on integration at the ecosystem level.

For our purposes the term "ecosystem" refers to any series of interrelated habitats. An "estuarine ecosystem", for instance, encompasses numerous habitats such as mud flats, grass beds, oyster reefs, sand bottoms, muck bottoms, open waters, salt marshes, and mangroves. These habitats are interconnected by wind and tidal mixing, freshwater flushing, and by a broadly tolerant and wide ranging variety of resident and seasonal species, each with their own adaptive strategy for survival. In an upland ecosystem setting, the movements of birds, mammals, and insects (beyond the boundaries of vegetation types), as well as massive resource movements such as seed dispersion and runoff, results in the overlapping of terrestrial habitats.

Although one could legitimately look at many levels of ecological organization for important patterns of integration between organisms and their environment, the watershed is a particularly fundamental unit. The hydrologic integrity of a watershed provides a fairly stable template around which interconnected habitats can become organized into an ecosystem. Background geology, soils, and latitude of the watershed strongly influence the plants and animals that inhabit the drainage basin. These "habitats" in turn influence soil development, erosion, and solution of the substrate, and consequently affect the physical and chemical nature of other habitats within the basin. The net structure and function of these terrestrial and freshwater habitats influence the delivery rates and loadings of water and chemical energy to the downstream estuary. Here too, geology and long-term patterns of hydrologic input serve as evolutionary guidelines around which species can organize into habitats.

1.4 CONCEPTUAL MODEL OF REGIONAL ECOLOGICAL PROCESSES

In this section, we apply the above concepts to the development of a "model" of the lower Everglades, Florida Bay, and Florida Keys watershed. Through this model we present a simplified flow diagram of how the various components of the watershed (its meteorological setting, its hydrologic cycle, its soils, and its biological resources) interact to create and maintain a living unit.

In some respects, the conceptual model is similar to a painting of a coastal marsh: if one concentrates on a blade of grass, the detail is lost, and the blade, or what appears to be the blade, becomes no more than a stroke of paint. The artist's intention is not to accurately portray every blade of grass but to catch the essence of the marsh as a whole. This approach underlies the perspective sought in a conceptual model; that is, to sacrifice the minutiae, in order to identify the overriding controls, forces, sinks, and pathways of the system. It is hoped that through this perspective the viewer may see the forest in spite of the trees.

Symbols used throughout this section in constructing the conceptual model of energy and materials flow are presented in Table 1. A brief explanation of the meaning and general use of each of these symbols is also given.

Figure 2 presents a conceptual model of energy and materials flow through a selected ecological system (i.e., a number of closely related habitats). The Florida Keys ecosystem is chosen for illustration. Within Figure 2, an attempt is made to ground-truth each of the symbols and the lines interconnecting them with an explanation. Not all the possible connections and lines are presented since this unduly complicates the visualization process and eventually compromises the simplifying purpose of the model. Only the major forcing functions and internal metabolic processes are explicitly diagrammed. To the right of the model, a dashed line leads off to an abbreviated list of the overlapping habitats which this ecosystem encompasses.

In addition to the forcing functions listed as "Incoming Energies", the Florida Keys ecosystem is intricately linked to a series of additional "ecosystems", such as Florida Bay, the estuarine and saltwater wetlands of the mainland, the shallow coastal and continental shelf of the Gulf of Mexico, and the blue-water Straits of Florida. These interconnections are symbolized in the general model as double directional arrows between the Keys and the respective ecosystems, signifying that energy and matter flow in both directions.

In keeping with the initial purpose of this document, it is essential that we also incorporate man's role in watershed metabolism. As agriculture, industry, and

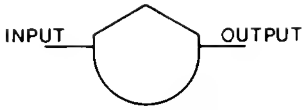
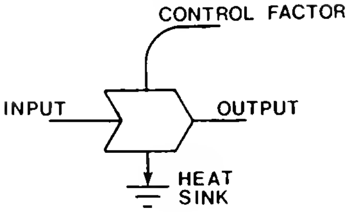
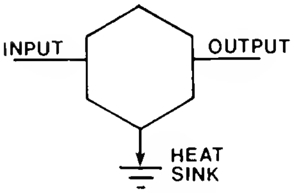
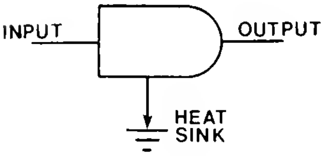
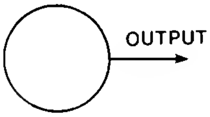
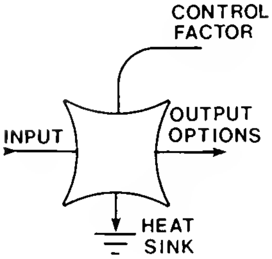
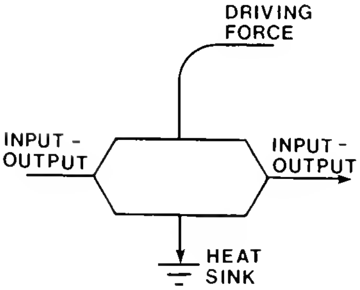
SYMBOL	EXPLANATION
	a. Passive Storage The passive storage symbol shows the location in a system for passive storage such as moving potatoes into a grocery store or fuel into a tank. No new potential energy is generated and some work must be done in the process of moving the potential energy in and out of the storage by some other unit. It is used to represent the storage of materials or biomass in systems.
	b. Workgate The workgate module indicates a flow of energy (control factor) which makes possible another flow of energy (input-output). It is used to show the multiplier inter-action of two system components.
	c. Self-maintaining consumer population The self-maintaining consumer population symbol represents a combination of "active storage" and a "multiplier by which potential energy stored in one or more sites in a subsystem is fed back to do work on the successful processing and work of that unit.
	d. Primary producer The primary producer symbol is a combination of a "consumer unit" and a "pure energy receptor". Energy captured by a cycling receptor unit is passed to a self-maintaining unit that also keeps the cycling receptor machinery working, and returns necessary materials to it. The green plant is an example.
	e. Energy source The energy source symbol represents a source of energy such as the sun, fossil fuel, or the water from a reservoir. A full description of this source would require supplementary description indicating if the source were constant force, constant flux, or programmed in a particular sequence.
	f. Logic Switch The logic switch signifies that the distribution of an energy flow is controlled at some point(s) within the ecosystem by a decision criteria. Where or when or how much of the energy flow is taking a given output pathway is determined by a logic control function. Examples include the control of pumping schedules and directions in response to water supply. The cost of maintaining and operating the combination of control structures and decision making pathways also follows the second law of thermodynamics.
	g. Two-way workgate The two-way workgate or forced diffusion module represents the movement of materials in two directions as in the vertical movement of minerals and plankton in the sea. The movement is in proportion to a concentration gradient or a casual force shown operating the gate. The heat sink shows the action to follow the second law of thermodynamics.

Table 1. Explanation of energy circuit language symbols utilized in the conceptual models (adapted from Snedaker and Lugo 1974).

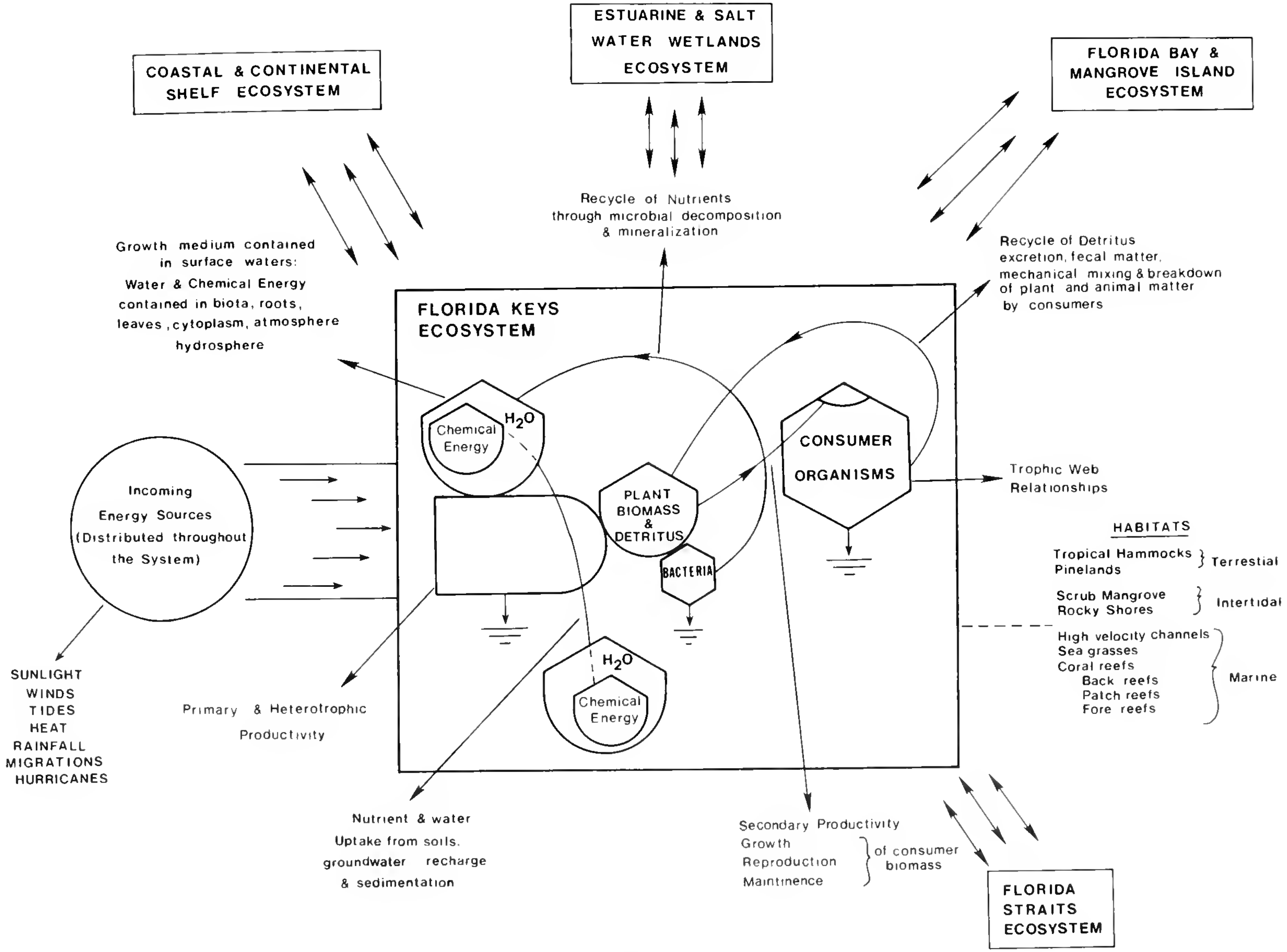


Figure 2. Conceptual model of keys ecosystem.

government expand, their management functions increasingly become nature's management functions as well. The private control of vast acreages of land for timber or agricultural production, the designation and management of public lands for parks, wildlife refuges, and conservation areas, and the spread of urban and suburban development, are not only competing interests within man's economy; they are also competing with, and dependent upon, nature's ability to self-regulate. To accurately perceive the relationships between man and nature in southwestern Florida it is essential to understand that man himself is a function of natural processes rather than a force separate from them.

With this in mind, the general model in Figure 3 is constructed to include the activities of man as an integral part of watershed metabolism. Curiously enough, man's activities do not bring any new principles to bear upon energy and material flow through natural ecosystems. Rather, his major impacts are:

(1) The selected conversion of natural lands into agricultural and timber production; and
(2) The funneling of natural and manufactured resources into the production and support of complex cultural structures (e.g., buildings, roads, and industrial goods).

A total conceptual model of the present study area is presented in Figure 4. This model identifies the primary ecological zonations of the watershed, namely:

(1) The terrestrial and freshwater wetlands ecosystem;
(2) The saltwater wetlands and estuarine ecosystem;
(3) The Florida Bay and mangrove island ecosystem; and
(4) The Florida Keys ecosystem.

For each of these zones or "ecosystems", the habitats which they incorporate are listed in Table 2. Major forcing functions are shown entering the model from the left side of the figure. Chemical and physical energy inputs are augmented by imported goods and services which support the activities of man, particularly in the Florida Keys and in the East Everglades Agricultural Area. Energy and materials are exported from the watershed via (1) evapotranspiration, (2) the emigration of species, (3) fisheries industries, (4) tidal flushing and runoff of chemical energy and sediment, and (5) export of agricultural and manufactured goods. Within each ecosystem the work of the plants and animals is symbolized by the combination of symbols presented in Figure 2. Two major oceanic ecosystems associated with the Florida Straits and the southeastern Gulf of Mexico, regularly influence the watershed. They are also shown in the model. The double-headed arrows that run between major ecosystem zones signify that energy and matter flow between the respective subsystems. These connections may take the form of physical/chemical energy transfers such as those effected by runoff, hurricanes, or tidal mixing; or biological energy transfers such as those effected through the active migrations of organisms.

Man's role in watershed metabolism is represented by three somewhat distinct consumer, or management, functions:

(1) Urban/industrial structure, primarily located on the eastern margin of the Everglades and in the Keys. This includes the activities of agriculture, commercial and sport fishing industries,

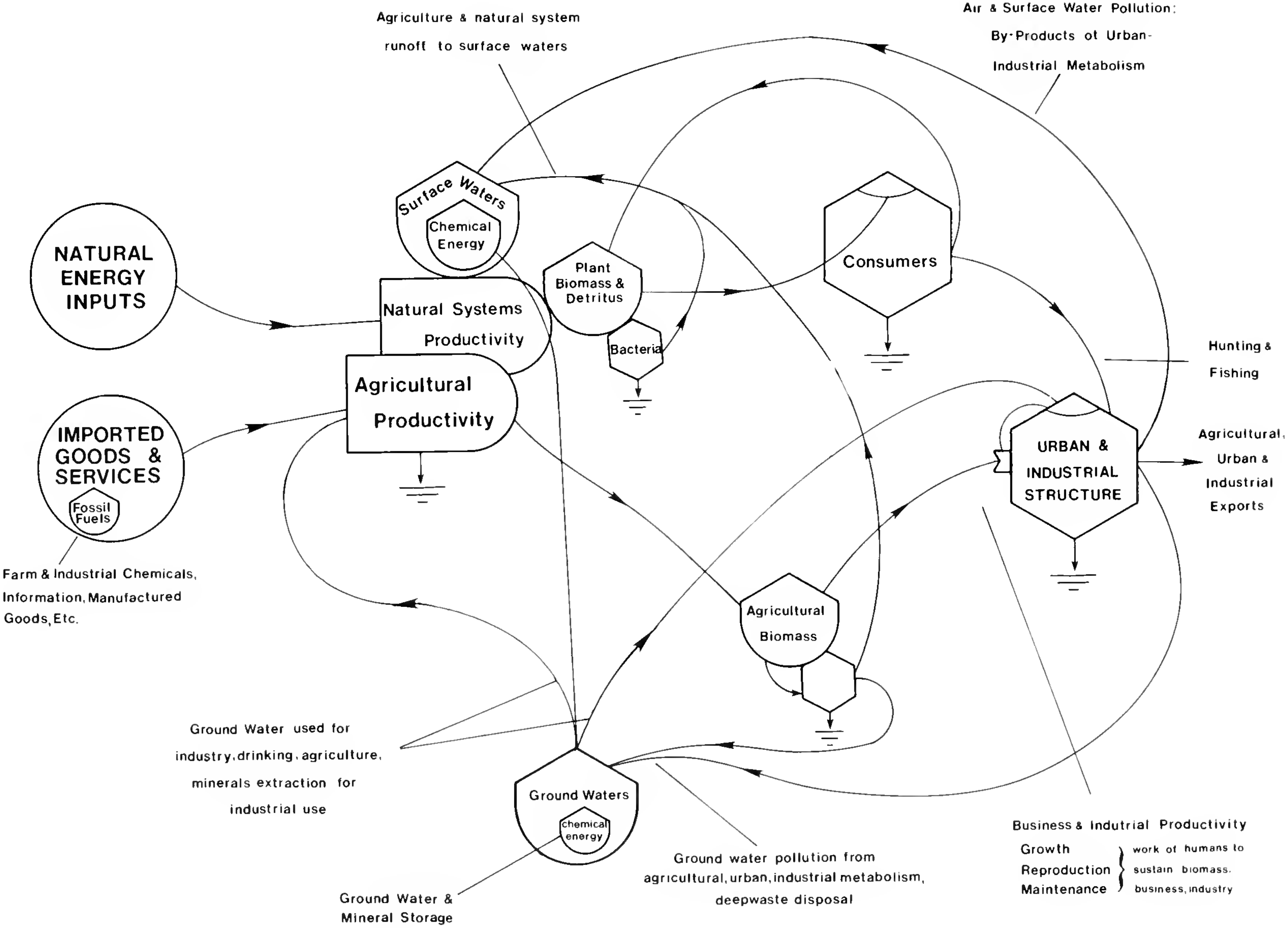


Figure 3. Conceptual model of ecosystem influenced by man.

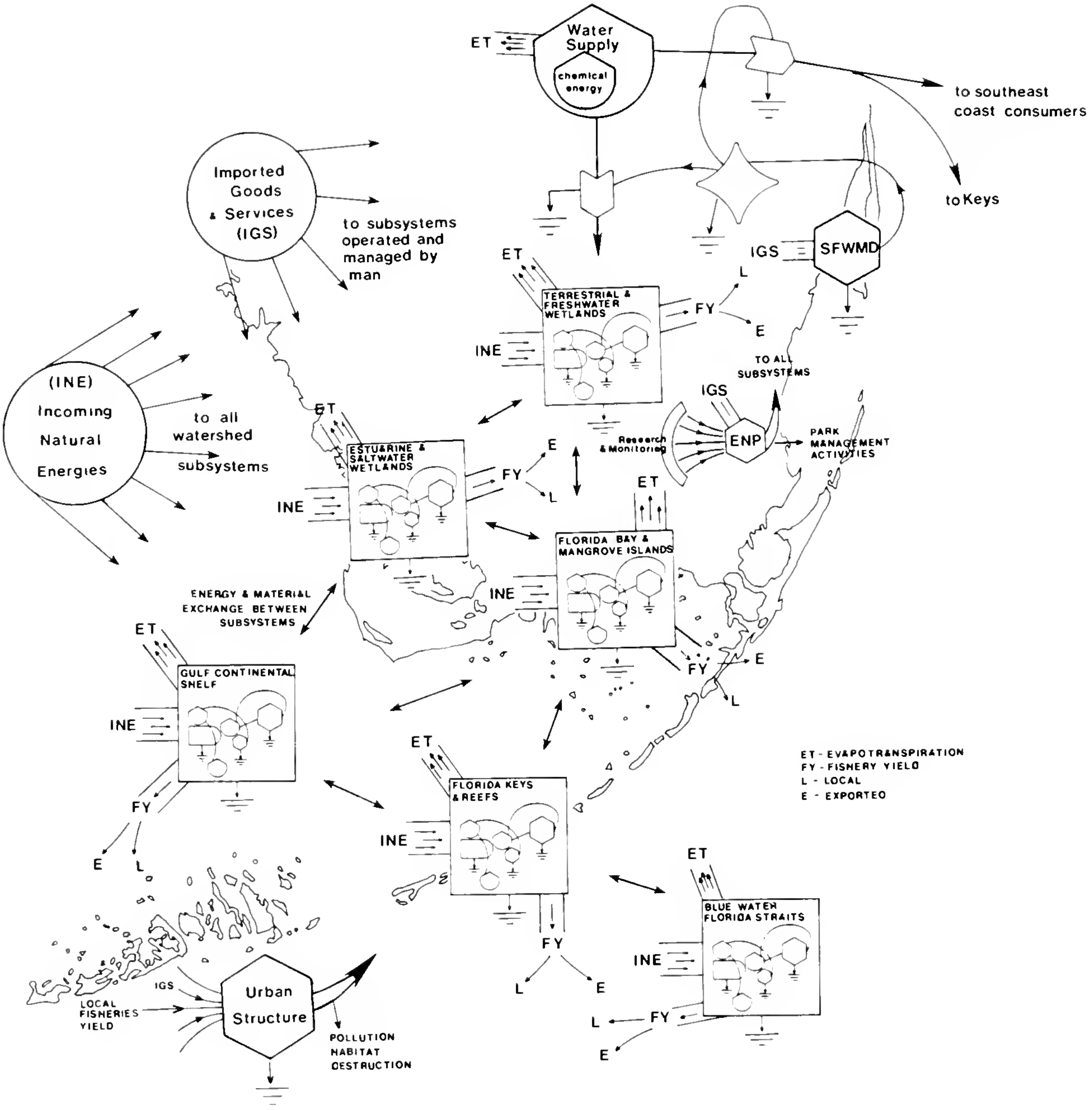


Figure 4. Conceptual model of lower Everglades/Florida Bay and the Florida Keys.

tourism, residents, and various cultural and economic support facilities;

(2) The Everglades National Park Service (ENP) which monitors (and to some extent controls) the vast majority of the study area;

(3) The South Florida Water Management District (SFWMD) which essentially controls the upstream watershed and is responsible for distributing water throughout south Florida.

Terrestrial & Freshwater Wetlands	Estuarine & Saltwater Wetlands	Florida Bay & Mangrove Islands	Florida Keys & Reefs
1. Pinelands	1. Salt marshes	1. Seagrasses	1. Tropical hammocks
2. Hammocks	2. Salt prairies	2. Intertidal shoals	2. Pinelands
3. Prairies	3. Beaches & dunes	3. "Lakes"	3. Disturbed habitats
4. Cypress	4. Mangrove forests	4. Mangrove islands & blue green algal mats	4. Rocky shores
5. Thickets	5. Oscillating salinity open waters a) Mangrove ponds b) Tidal streams c) Estuarine bays d) Oceanic bays		5. Mangroves
6. Marshes			6. Canals
7. Ponds			7. High velocity channels
8. Disturbed habitats			8. Seagrasses
			9. Coral reefs a) Back reefs b) Patch reefs c) Fore reefs

Table 2. Habitats corresponding to conceptual model zonations.

The remainder of this document is devoted to a detailed discussion of the ecological characteristics of the lower Everglades, Florida Bay, and Florida Keys. We hope that as the details of watershed metabolism unfold, the reader will be able to visualize where the information presented may be "plugged-in" to the conceptual model. We also hope that in so doing, the reader will gain some useful insights into the mechanisms that govern the quiet, persistent evolution of this fascinating ecosystem.

CHAPTER 2
PHYSIOGRAPHY

2.1 THE LOWER EVERGLADES

Figure 5 presents a map of the major physiographic delineations within the lower Everglades drainage basin. These delineations, as well as those in subsequent sections for Taylor Slough/Florida Bay and the Florida Keys, are based upon previously published accounts (e.g., Davis 1943, Puri and Vernon 1964, White 1970, Craighead 1971), as well as biological and hydrological factors such as dominant vegetation types, hydroperiod, surface drainage, and circulation. The term hydroperiod refers to that portion of the year when the water table is at or above the land surface.

The lower Everglades subunit can be further broken down into six distinct physiographic areas:

(1) Shark River Slough
(2) Rocky Glades
(3) Broad River/Lostmans River Drainage
(4) Coastal Swamps and Lagoons
(5) Cape Sable

Shark River Slough

The Shark River Slough refers to that portion of the Everglades that is more or less synonymous with Douglas' (1947) "river of grass". Within the present study area the slough is a broad southwesterly trending arc of continuous wetland, dotted throughout with numerous tree islands. It is distinguished on its northwestern and southeastern boundaries by expansive transitional areas of slightly higher bedrock elevation, and a consequently shorter hydroperiod. The slough occupies the center of the Everglades trough, a wide, slightly concave depression in the underlying limestone (White 1970).

Rocky Glades

To the south of Shark River Slough lies a transitional area known as the Rocky Glades or Rocklands (Davis 1943, DERM 1980). The name "Rocky Glades" is derived from the character of the limestone rock that lies exposed at the surface of this area. The limestone, which is often called pinnacle rock, occurs in craggy masses made of rock hardened bryozoan colonies. These colonies were laid down when the area lay beneath sea level during the late Pleistocene.

The Rocky Glades form a thin transitional area between the Shark and Taylor Sloughs. Geologically, the Fort Thompson Formation underlies the Everglades trough as a surface bedrock feature, while the back slope of the Atlantic Coastal Ridge (Miami Limestone) forms the surface rock for the areas farther east. Consequently, these bedrock features also make the Rocky Glades a hydrologic transition zone between the Shark River Slough drainage to the southeast and the Taylor Slough drainage to the south.

Broad River/Lostmans River Drainage

To the northwest of Shark River Slough the bedrock of the Everglades trough again rises gradually in elevation toward the Big Cypress Spur, which is a southerly extension of the Immokalee Rise, and the southwestern slope (Puri and Vernon 1964, White 1970). These latter features more or less define the Big Cypress Basin. The freshwater wetland and upland area between the Everglades trough and the Big Cypress Basin is labeled the Broad River/Lostmans River Drainage.

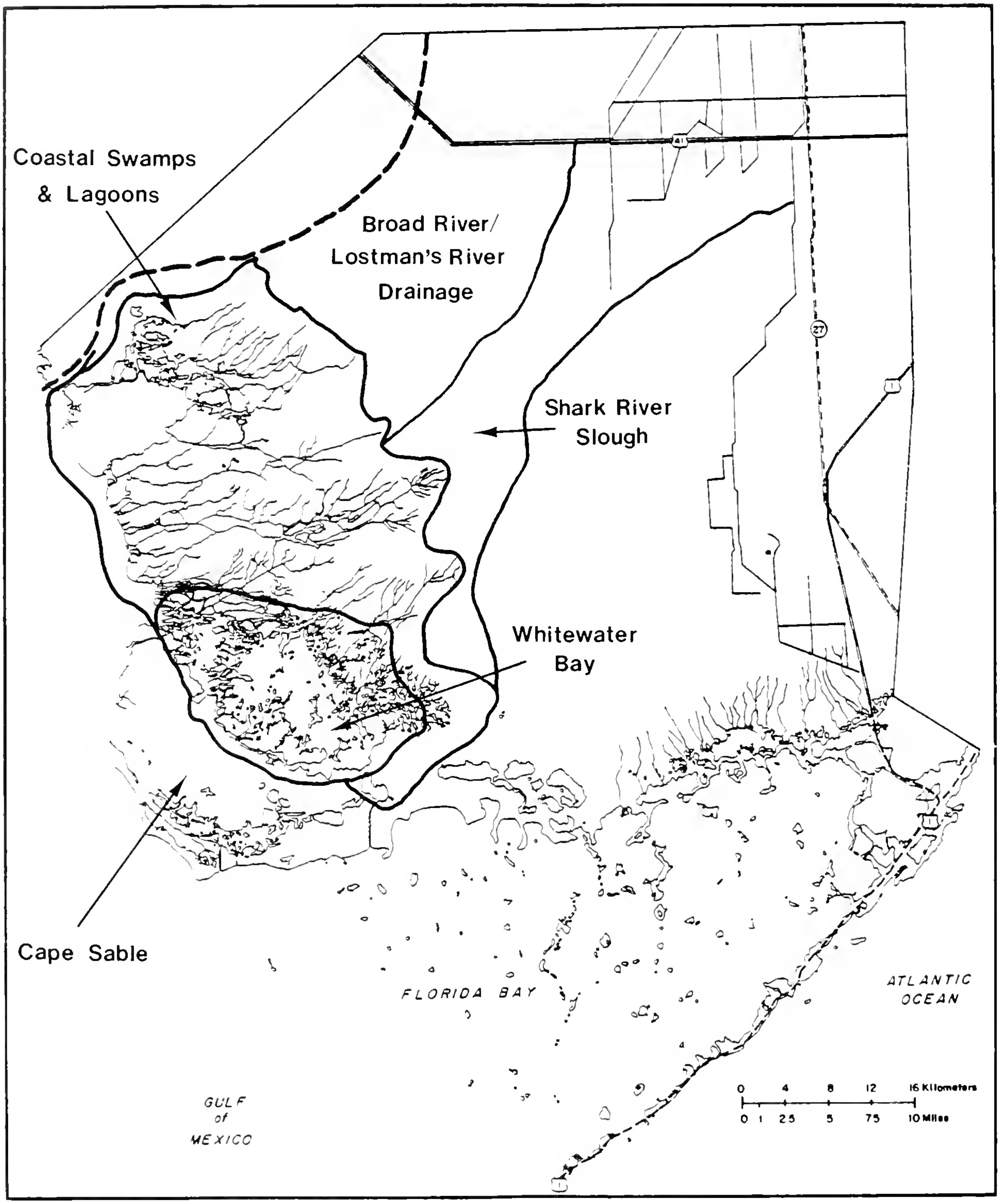


Figure 5. Map of lower Everglades physiographic zones (adapted from USDI 1979).

Like the Rocky Glades, this area is distinguished from Shark River Slough by subtle differences in hydrology (hydroperiod) and geology. In this area the Miami Limestone all but disappears while the Fort Thompson Formation, a bedrock feature of the Everglades trough, is gradually encroached upon by a thin veneer of Pamlico sands of late Pleistocene age (Cooke 1945). Farther northwest, the dissected Tamiami formation of the earlier Miocene age lies exposed at the surface, only thinly covered by more recent strata (Schroeder and Klein 1954, McCoy 1962).

Coastal Swamps and Lagoons

To the southwest of these three areas lies the low mangrove and salt marsh dominated zone referred to by Puri and Vernon (1964) as the reticulate coastal swamps. These coastal swamps and lagoons extend from the upland limit of periodic saltwater influence to the Gulf of Mexico, a distance of about 16 to 40 km (10 to 25 mi). Prominent features that delineate the area are:

1. the salt marshes which lie relatively upland;
2. the mangrove forests which grow in vast wetland expanses and along the shorelines; and
3. the "back bays" or lagoons. The back bays represent a distinct physiographic feature of the area which becomes more prominent as one moves north along the coast.

The coastal swamps and lagoons receive the major bulk of surface runoff from the Everglades. When sea level was lower, prior to the recent Flandrian sea level rise of the Holocene epoch, the area inundated by freshwater was relatively larger than it is today. As surface waters flowed over this area, differential solution of the less resistant bedrock limestone resulted in the formation of freshwater channels. The freshwater runoff also influenced the relative preponderance of various peat and/or marl forming environments.

As sea level subsequently rose to its present level, the more susceptible areas of underlying peat eroded and oxidized leaving anastomosing lagoons and "back bays" (Spackman et al. 1964, White 1970). The area is now characterized by fluctuating fresh and saltwater conditions.

The largest and most conspicuous of these lagoons is Whitewater Bay. Along its northern boundary the drainage pattern into Whitewater Bay distinctly follows numerous southeasterly trending channels such as the Watson River, North River, and Robertson River. Throughout the bay are numerous islands whose southwest/northeast orientation suggest historical erosion of their underlying marl along relict freshwater channels. To the southeast the bay is confined by a degenerate extension of the Atlantic Coastal Ridge that terminates in the "Cape Sable High" (White 1970). Prior to construction of the Buttonwood Canal, which directly connects Whitewater Bay with Florida Bay, flushing was toward the northwest. The Joe River, which runs parallel to the axis of the bay on its southwestern boundary, reflects this recent drainage pattern. Both Whitewater Bay and the Shark River Slough flush to the Gulf of Mexico in the vicinity of Ponce de Leon Bay.

Where the main thrust of the lower Everglades drainage enters the gulf, conditions are less favorable for the formation of lagoons or back bays (White 1970). Consequently, there is a wide area of coastline north of Whitewater Bay in which only one small lagoon-like body of water appears, i.e., Tarpon Bay in the Harney River. Farther north, however, beginning at Lostmans River, back bays become a prominent feature of the landscape. This feature continues and expands to the north within the Big Cypress drainage basin culminating in the Ten Thousand Islands area south of Cape Romano.

Cape Sable

One of the most distinctive features of the southwestern tip of Florida is Cape Sable. White (1970) claims that the cape overlies a degenerate westerly extension of Miami Limestone of the Atlantic Coastal Ridge. He refers to the terminal end of this extension as the "Cape Sable High". The forefront of the cape actually exhibits three distinct capes: the Northwest Cape and the Middle Cape, which are quartz sand covered capes; and the East Cape, which contains relatively more marl (Craighead 1971).

The present beaches are surface exposures of buried coquinoid ridges which constitute a major portion of the underlying strata of the seaward cape. Behind these beaches and beach ridges, the cape is separated from the nearest surface bedrock by a broad expanse of marl and peat, and Whitewater Bay. These marl and peat areas are vegetated with salt marshes, mangroves, salt prairies, and tropical hardwood hammocks (Craighead 1971, Browder et al. 1973).

It is believed that the beaches at Cape Sable first formed as a result of a shallow submarine scarp cut into the bedrock (White 1970). This wave-cut notch allowed localized wave breaking long enough for a bar to be built and a barrier to be formed. The subsequent growth of shellfish offshore continued to feed the beach with shell and sand, particularly during hurricanes (Craighead 1971).

The coastal prairies behind the beaches of Cape Sable are composed of a succession of troughs and low dunes (Craighead and Gilbert 1962). On the upland side of these prairies, the highest elevations support a continuous ridge of hammocks (Craighead 1971, Browder et al. 1973). A series of shallow ponds, the largest of which is Lake Ingraham, extend from the north of the Middle Cape east to Flamingo. Craighead considers these ponds to be remmants of former open waters that have not been completely filled by surrounding marl and peat. Water, when present in these troughs, can be either fresh or saline depending on local hydrologic conditions. White (1970) characterizes inland Cape Sable as an isolated pocosin sloping gradually down from a peat dome toward the Joe River and Whitewater Bay.

North of the Northwest Cape, beach sand is less apparent owing to the more gradually sloping submarine topography and the increased influence of freshwater glades runoff. Craighead (1971) singles out Big Sable Creek as an area where the creek delta and beach are actively receding with rising sea level. The erosion forces which are believed to be at work in forming the Big Sable Creek coastline environment are as follows:

(1) Shoreline mangroves are killed by deposits of hurricane mud;
(2) Storm tides gradually erode unconsolidated sediment;
(3) Trees are toppled and carried back to sea by hurricane backwash.

The types of shorelines that border the lower Everglades coast and their approximate geographic extent are summarized in Figure 6 (Spackman et al. 1964).

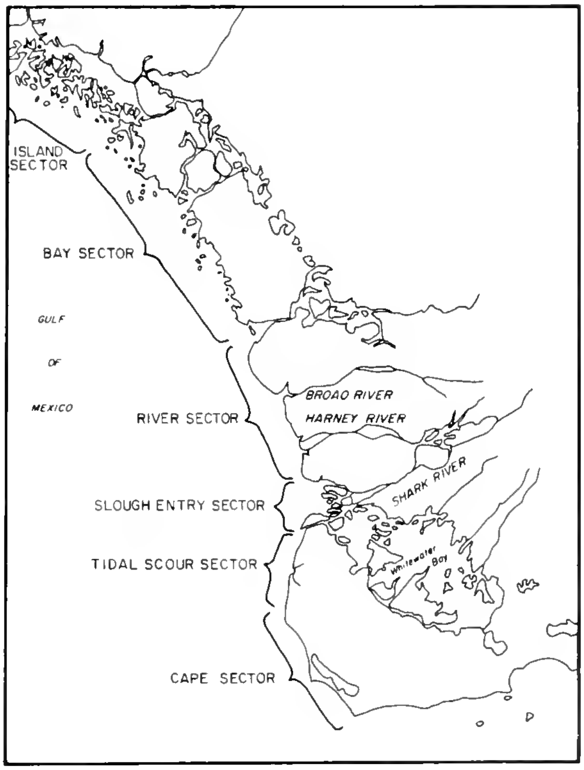


Figure 6. Coastline types of the lower Everglades (adapted from Spackman et al. 1964).

2.2 TAYLOR SLOUGH/FLORIDA BAY

Figure 7 presents a stylized map of the major physiographic delineations of the Taylor Slough/Florida Bay drainage basin. For our purposes the area is further broken down into a total of 8 physiographic subzones as follows:

(1) Taylor Slough Headwaters
(2) Upper, Middle, & Lower Taylor Slough
(3) Taylor Slough Coastal Drainage
(4) Coastal Swamps & Lagoons
(5) Florida Bay
    Northern Subenvironment
    Interior Subenvironment
    Gulf Subenvironment
    Atlantic Subenvironment

Taylor Slough Headwaters

The central component of the Florida Bay drainage basin is Taylor Slough. It occupies a more or less distinct surface drainage area formed by an extension of the Miami Coastal Ridge south and a southwest/northeast trending offshoot of this ridge known as Long Pine Key. Puri and Vernon (1964) show this as a continuous connection which forms the upper boundary of what they refer to as the "southern slope", while Davis (1943) refers to these areas as the "Southern Coast and Islands".

Nonetheless, a hydrologic bridge does exist at the confluence of the Miami Rock Ridge and the Everglades Keys (Davis 1943) connecting the southern slope and the area to the north. This northern area is known as the Taylor Slough headwaters (Waller 1979). It lies partially within the boundaries of Everglades National Park. Most of its approximately 250 km^2 (97 mi^2) area lies within a privately owned tract of land known as the East Everglades (DERM 1980). Land use in this area reflects the growing pressure of urban and agricultural interest.

The headwaters of Taylor Slough are separated from the Shark River Slough on the north by a narrow strip of land, the Rocky Glades, which is considered to be in the main stem of the Everglades sheet flow from Lake Okeechobee south to Whitewater Bay (Parker et al. 1955, McPherson et al. 1976, DERM 1980). Surface relief in the Taylor Slough headwaters is extremely limited. The area is perched at an elevation of approximately 2.3 m (7 ft) above mean sea level. Both Shark River Slough to the north and Taylor Slough to the south are slightly lower in elevation.

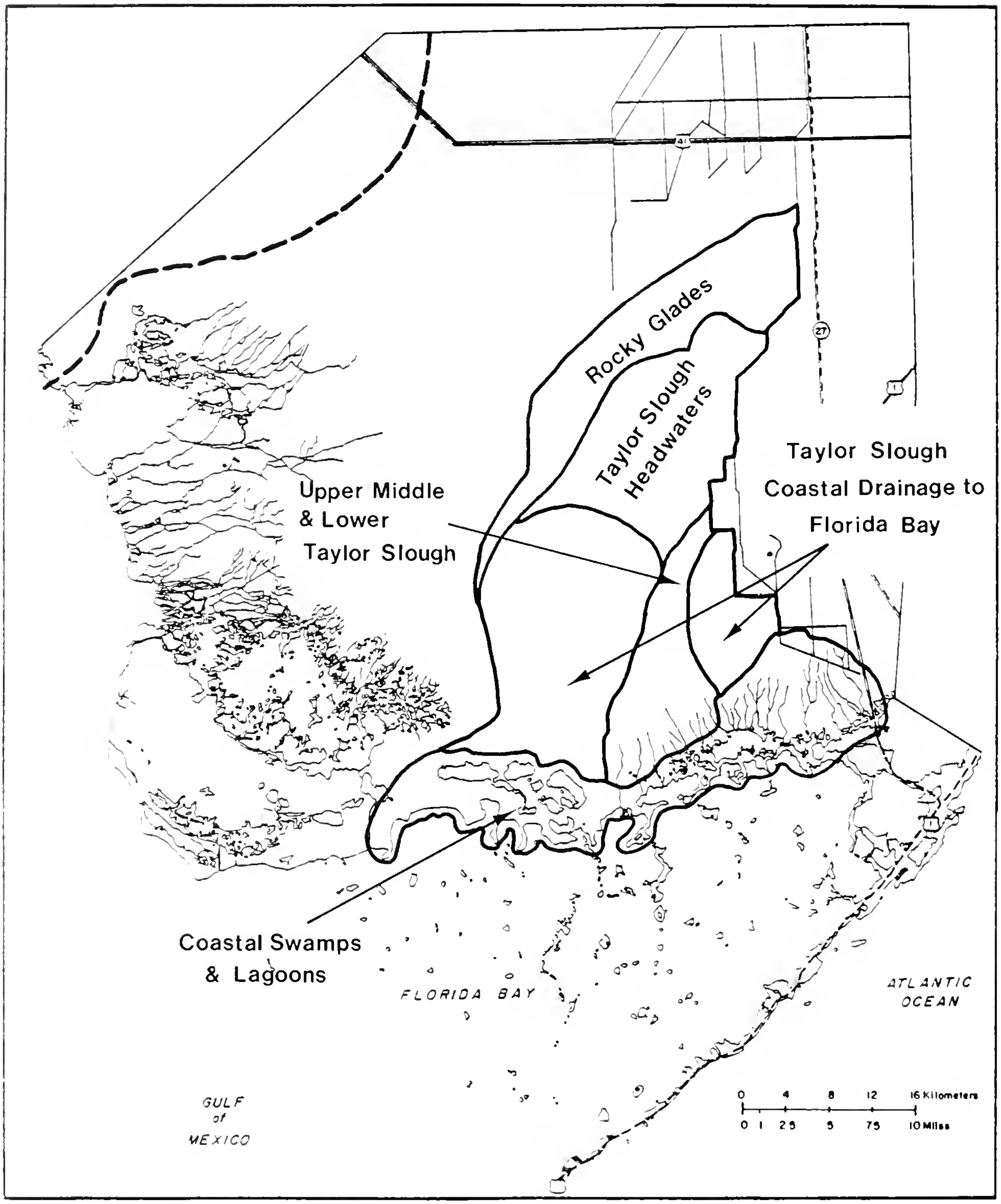


Figure 7. Map of Taylor Slough/Florida Bay physiographic zones (adapted from USDI 1979).

Historically, sheet flow from Lake Okeechobee through the Everglades has followed a south by southwest curve as outlined by the arc of Shark River Slough. Some of this sheet flow, however, has been transverse to the main axis of the Miami Rock Ridge, the Everglades Keys, and the Rocky Glades. This causes erosion of the thin layer of overlying marl soils and solution of the underlying Miami oolite, leading to a solution riddled topography. These erosional surfaces cut across the limestone toward Taylor Slough and the southern slope. This natural evolution of morphology is complicated by vegetational patterns, peat deposition, marl formation, and rock plowing for agricultural purposes. (Rock plowing refers to an agricultural practice in which marl soils are dug up and crushed to facilitate planting and drainage).

Upper, Middle, and Lower Taylor Slough

The northern boundary of this segment is located where SFWMD Canal 31-W intersects the main channel of Taylor Slough (Olmstead et al. 1980). This area is referred to by Olmstead et al. (1980) as upper Taylor Slough, a rather well defined, 5.5 km (3.4 mi) long segment running from the intersection of the slough and the canal levee structure L-31 W south to State Road 27, Anhinga Trail. Middle Taylor Slough refers to that segment of the slough from State Road 27 south 7 km (4 mi) (Olmsted et al. 1980). The slough is joined in this segment by a large arm from the east. Lower Taylor Slough refers to the segment lying south of this point to Florida Bay.

The bedrock of Taylor Slough is broadly concave with the central portion averaging only 90 to 120 cm (3 to 4 feet) lower than the margins. The center of this broad depression in the Miami oolite varies from 0.2 to 2.0 m (8 in. to 6.5 ft) below the margins. However, marl soils and peat deposits tend to obscure and smooth over the underlying variations in bedrock.

The slough itself is characterized by comparatively dry areas in the north that are dominated by muhly prairies (*Muhlenbergia filipes*) (Hilsenbeck et al. 1979). Interspersed in the upper part of the slough are limestone outcroppings (the Everglades Keys), which are colonized by pines and tropical hardwoods. A small but significant portion of the land is former agricultural land, now in the hands of Everglades National Park. The central portion of the upper slough is a relatively wetter area dominated by sawgrass (*Cladium jamaicensis*) and spike rush (*Eleocharis cellulosa*) marshes.

Farther south, middle Taylor Slough broadens and becomes vegetationally dominated by sawgrass, spike rush, and willow (*Salix caroliniana*) marshes (Olmstead et al. 1980). Toward Florida Bay the freshwater slough vegetation is gradually replaced by buttonwood (*Conocarpus erecta*), mangrove forests, salt barrens, and tropical hardwood hammocks.

Southeast Coastal Glades

Lying to the east and south of the main stem of Taylor Slough is another band of what Puri and Vernon (1964) refer to as gulf coastal lagoons. Upland of this band are freshwater marl prairies referred to in Figure 7 as the coastal drainage region, which serves as the only source of fresh water outside of direct rainfall to extreme upper Florida Bay. Farther east and north these marl prairies drain into the series of sounds that separate Florida Bay from Biscayne Bay.

This area roughly corresponds to what some call the southeast saline Everglades (Egler 1952, DERM 1980). A considerable chunk of this area (approximately 30%) lies within the privately owned East Everglades Agricultural Area. For our purposes, the northeast and eastern boundaries of this province correspond to SFWMD Canal 111 (C-111), also known as the Aerojet Canal, which runs from just east of the park entrance southeast to U.S. Highway 1 and then south to Florida Bay. This is considered to be the extent of the southeast coastal glades drainage system that directly affects Florida Bay. The remainder of the southeast coastal glades drains into Long, Barnes, and Card Sounds to the northeast.

Taylor Slough Coastal Drainage System

That portion of the southern slope north of the coastal swamps and lagoons, and west of Taylor Slough is referred to as the Taylor Slough Coastal Drainage. To the north, the area extends to include Long Pine Key and the Everglades Keys. To the west, the area is bounded by State Road 27 (Anhinga Trail).

The elevated limestone ridges that run west/southwest from the upper Taylor Slough (Long Pine Key and the Everglades Keys) form a barrier inhibiting sheet flow from Shark River and the lower Rocky Glades, as outlined in Figure 1. As such they represent the northern boundary of the drainage basin from which surface waters flow south either into Taylor Slough or directly into Florida Bay. The Park Highway is chosen as the western boundary of this province though some surface drainage does occur, especially in the wet season, through culverts underneath the road.

South of the Everglades Keys this segment is largely dominated by muhly prairies. Almost directly in the middle of the area is a large oblong area of scattered dwarf cypress, known as "hatrack" cypress. Although most of the segment is clearly dominated by natural communities, a significant area of former agricultural lands is also present on the southeastern fringe of Long Pine Key. This area, which was recently acquired by the National Park, is referred to as the Hole-in-the-Donut.

Coastal Swamps and Lagoons

To the west of Taylor Slough, Puri and Vernon (1964) distinguish two physiographic provinces, aside from the southern slope, lying within the Taylor Slough drainage basin. The first of these, the gulf coastal lagoons, refers to the series of lagoons from Seven Palm Lake to West Lake. A broad continuous strip of land covered by coastal prairie occupies the area north of these lagoons, running southeast to the mangroves bordering Madiera Bay. The northern border of the gulf coastal lagoons roughly corresponds to a partial barrier between fresh and saline waters known as the Buttonwood Embankment (Craighead 1971). A distinct band of pioneer red mangrove (Rhizophora mangle) occurs 3 to 8 km (2 to 5 mi) inland of this barrier. The second province distinguished by Puri and Vernon (1964) in this region is the reticulate coastal swamps which correspond to the more saline black mangrove (Avicennia germinans) and white mangrove (Laguncularia racemosa) communities which occupy the area south of the gulf coastal lagoons to Florida Bay.

To the west of lower Taylor Slough the coastal swamps and lagoons are characterized by a series of lakes (or lagoons) fringed by mangroves and some tropical hardwoods toward the eastern end. South of these lagoons toward Florida Bay the area is dominated by buttonwood, and red, black, and white mangroves, and prairies of salt tolerant (halophytic) herbaceous vegetation (Russell et al. 1980). On the eastern side of lower Taylor Slough the coastal lagoons are conspicuously absent, and surface drainage is better defined. This hydrologic structuring leads to a vegetation and land form pattern that generally follows and radiates out from the surface drainage pattern. Also less prevalent on the eastern side of Taylor Slough are the broad plains of buttonwood and halophytes.

Florida Bay

Florida Bay is a triangularly shaped body of water extending from about U.S. Highway 1 on the northeast to Long Key on the extreme southwest to East Cape Sable, lying north and west of Long Key. For purposes of this report the northeastern boundary of the bay follows U.S. Highway 1 down to Key Largo. The progressively restricted circulation and exchange of water in Card Sound and Barnes Sound act as a barrier inhibiting hydrologic and ecologic exchange between Biscayne and Florida Bays (Tabb et al. 1962, Lee and Rooth 1972). As such the sounds collectively represent a distinct physiographic transition zone between the two bay systems.

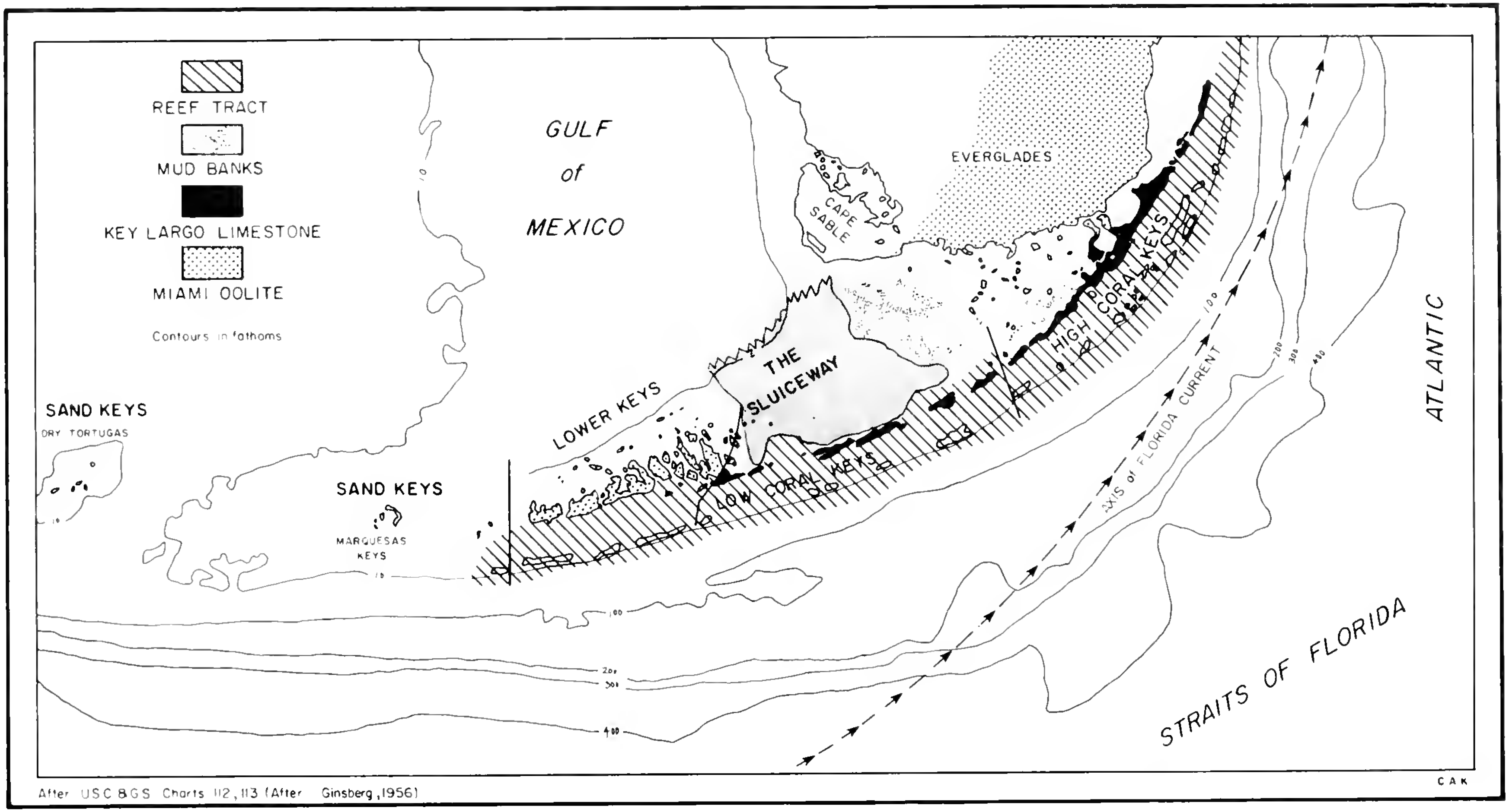
Florida Bay is characterized by numerous mangrove covered islands that represent the above-water pinnacles of a nearly continuous series of shoals. Fleece (1962) comments that these shoals often seem to occur at roughly right angles to one another. Many of the shoals surround areas of deeper water (> 2 m or 7 ft) which are locally referred to as "lakes".

The complex topography of the bay system is an important factor in determining the distribution of physical and chemical conditions, and thus subenvironments. As mentioned earlier, the upper most part of the bay is actually a series of semienclosed sounds which are fairly well isolated from one another hydrologically. Beginning just southwest of Blackwater and Little Blackwater Sounds, the mud shoals and islands are not as numerous or continuous, and the area is uniformly shallow (0 to 2 m or 0 to 7 ft). Moving toward the Gulf of Mexico on the mainland side, the width and length of the mud banks increases, though the number of islands and their area above water does not. Toward the Keys side, the mud banks are thinner and tend to encircle deeper "lake" areas.

Turney and Perkins (1972) divide the bay into four distinct subenvironments based on dominant molluskan faunas and physical/chemical factors. The northern subenvironment lies along the northern shoreline toward the Gulf of Mexico. The interior subenviroment is the broad central expanse of the bay which these and other authors (Ginsburg 1956, Gorsline 1963) believe is subject to little or no regular tidal flushing. The Gulf and Atlantic subenvironments correspond to those areas influenced by tidal exchange with the Gulf of Mexico and the Florida Keys area, respectively.

2.3 FLORIDA KEYS

Figure 8 presents a map of the major physiographic features of the Florida Keys. Extensive exposed and sheltered mangrove shorelines dominate the surface vegetation of the Keys, particularly on the Gulf of Mexico and Florida Bay side, and on the peripheral keys (e.g., Rodriguez



After USC&GS Charts 112, 113 (After Ginsberg, 1956)

Figure 8. Map of physiographic zones of the Florida Keys (adapted from Ginsburg 1956).

Key, Johnson Keys). Over the past 50 to 70 years, development through dredge and fill activities has converted many of these mangrove community areas into more habitable environments for man, as evidenced by changes in shoreline habitats (Griswold 1965). The new shorelines are generally characterized by riprap/gravel beaches, mixed sand and gravel beaches, and exposed and sheltered rocky shores and seawalls (Getter et al. 1981). Natural sand beaches are remarkably few and limited in size. Inland, the mangrove communities give way to tropical hardwood hammocks (primarily on the northern Keys and Big Pine Key), and Caribbean slash pine stands (Pinus eliottii var. densa) on islands surrounding and including Big Pine Key (Alexander and Dickson 1972, CZM 1974).

As evidenced by the extent of mangrove vegetation on the islands, much of the Florida Keys land area lies only .6 to 1 m (2 to 3 ft) above high tide. At only two locations in the island chain (both in the upper Keys) does the elevation reach or exceed 5 m (18 ft) (Hoffmeister and Multer 1968). Where these maximum elevations occur, the island's shape departs from the typically flat character of the majority of the Keys, exhibiting a slightly raised, centrally-elongated axis with the southeast and northwest sides sloping gradually to the Atlantic Ocean and Florida Bay, respectively. Beyond the shorelines, intertidal flats border both sides of the islands. These are generally shallow water areas, barely covered at low tide, which gently slope into the deeper water of the surrounding platform. In some places the flats are exposed at low tide and are covered by soft laminated algal crusts (Multer 1977). Florida Bay lies beyond the flats to the northwest of the upper Keys.

Farther southwest of Florida Bay, a great expanse of carbonate sediments exist under a shallow sea with a depth rarely exceeding 18 km (60 ft). This platform bounds the lower and middle Keys to the gulf side and is built upon the southwestern submarine extension of the Floridan Plateau (Brooks 1973). Stockman et al. (1967) labeled this current-swept region "The Sluiceway" as it exhibits a scoured seascape with only a thin veneer of recent carbonate sediments a few centimeters thick.

Seaward toward the Straits of Florida and paralleling the Keys is an arcuate band of living reefs, linear shoals and depressions described as the Florida Reef Tract by Vaughn (1916). Living reefs that locally reach to the low water mark are concentrated on the seaward side of this band to form a discontinuous barrier (see Figure 8), e.g., American Shoal, Carysfort Reef, Alligator Reef. These are also referred to as the Outer reefs (Ginsburg 1956) or Bank reefs (Shinn 1963). The area between them and the Keys is 4.8 to 11 km (3 to 7 mi) wide, and is referred to as the back reef (Ginsburg 1956) or inner shelf (Enos 1977). The back reef is characterized by patch reefs (Ginsburg 1956) or reef knolls (Turmel and Swanson 1976), (e.g., Hen and Chickens Keys, Mosquito Bank), linear shoals, (e.g., White Bank, Washer Woman Shoal) and areas of deeper water, exceeding 5.5 m (18 ft) (e.g., Hawk Channel) ranging in depth from 5.5 to 9 m (18 to 30 ft) off Key Largo to 6 to 15 m (20 to 50 ft) off Key West (USDC 1962, USGS 1971, Enos 1977).

The Florida Keys are divided into at least three physiographic zones distinguished by differences in their shape, orientation and lithology. These are, as illustrated in Figure 8, the upper Keys (Soldier

Key southwest to New Found Harbor Keys), the lower Keys (East Bahia Honda Key to Key West), and the distal atolls, including the Boca Grande Key Group, the Marquesas Keys, and the Dry Tortugas (White 1970).

The northernmost zone, the upper Keys, is characterized by long narrow islands, elongated in a northeast to southwest direction that roughly parallels the reef tract described earlier. Based on the slope and orientation to the reef tract, the origin and composition of the upper Keys is easily understood. Named and described by Sanford (1909), the Key Largo Limestone is a typical organic reef composed of wave resistant elements, the most important of which are hermatypic corals. These form the framework of the structure and are responsible for trapping large amounts of calcarenite in which they are now embedded (Krawiec 1977).

The lower Keys form a roughly triangular group of islands which generally elongate at right angles to the northeast-southwesterly orientation of the upper Keys. The exposed rock formation here is an extension of the Miami Limestone Formation, oolitic facies, upon which Miami and other southeastern Florida cities have been built (Hoffmeister and Multer 1968). The northwest-southeast elongation of the lower Keys is caused primarily by the direction of movement of the tidal scour produced by differences in time and height of the tides in the Gulf of Mexico and the Straits of Florida.

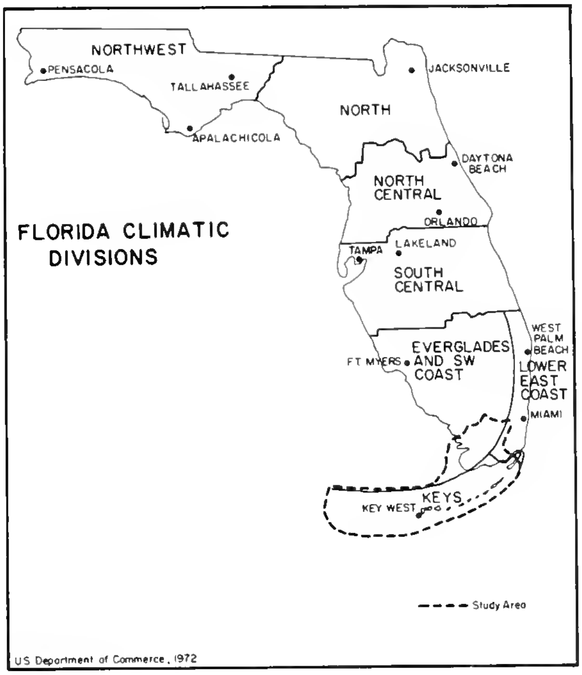
The distal atolls form the third physiographic region of the Florida Keys (Puri and Vernon 1964, White 1970). This designation is based, it appears, on little more than the isolated nature of the islands west of Key West, and their general shape. Davis (1942) referred to these "atolls" and the scattered islands to the west of Key West as the Sand Keys after an earlier description by Millspaugh (1907). The thirty islands of the Sand Keys fall into three primary groups: two atoll-like groups, the Marquesas and Dry Tortugas Keys, and a loose cluster of small islands just west of Key West, referred to by Millspaugh (1907) as the Boca Grande group. All of these islands fall within an area extending 112 km (70 mi) east and west, and 14.4 km (9 mi) north and south. The Boca Grande group of 14 islands extends 17.6 km (11 mi) west of Key West; the elliptical shaped Marquesas Keys lie 27.2 to 32 km (17 to 20 mi) west of Key West; and, the Dry Tortugas are clustered between 104 to 112 km (65 to 70 mi) west of Key West. Davis (1942) concluded that the coarse calcareous sand found in the three island groups are an accumulated matrix of unconsolidated detrital material of various origins including calcareous algae, mollusks, foraminifera, echinoids, nullipores (coralline algae - Shrock and Twenhofel 1953) and coral reef rubble (Dry Tortugas only). The two more easterly groups, the Marquesas Keys and the Boca Grande group, are built up from oolitic limestone banks of the Miami formation and are dominated vegetatively by mangrove and beach dune strand communities (Davis 1942). Their nearshore marine environment is distinguished by flat bare and grass covered calcareous sand bottoms, with a notable absence of coral reefs. Seaward of the Boca Grande group's southernmost islands, the Florida Keys reef tract terminates. The Dry Tortugas exhibit primarily beach-dune strand communities with the mangroves representing a very small man-introduced percentage of the land cover. Rockbottoms, shoals, and reefs characterize the nearshore and lagoonal waters (Multer 1977).

CHAPTER 3
CLIMATOLOGY

3.1 INTRODUCTION

A classification system devised by the National Weather Service divides Florida into seven climatic divisions, three of which influence the study area (Figure 9). Each zone encompasses an area within which basic climatic variables, primarily temperature and rainfall, are generally consistent when averaged over extended periods of record. The boundary lines between climatic divisions approximate lines of change and do not depict radical changes in climatic patterns. Likewise, station to station differences occur within any one division, especially where coastal boundary influences are significant. In spite of these limitations, the climatic divisions offer a ready means of organizing statewide and basin-wide descriptions, and will be used in much of the discussion to follow.

Many meteorological measurements are available from the three first-order weather stations operated by the National Weather Service that triangulate the study area (Ft. Myers, Key West, and Miami). An additional, more limited selection is available from numerous other government agencies. These measurements are collected for a variety of applications, agriculture and aviation being two of the more important. Detailed meteorological information is restricted to a few of the available stations in the basin, including Key West (International Airport), Homestead AFB, and the Key West Naval Air Station (NAS). In addition to the Key West station, two additional, primary NOAA weather stations (Miami and Ft. Myers) are included to complete the measurement of the basin. For a more in-depth discussion of weather stations adjacent to and within the study areas see Parker et al. (1955), Thomas (1970), Bradley (1972), Thomas (1974), and MacVicar (1981).



US Department of Commerce, 1972

Figure 9. Florida climatic divisions (adapted from USDC 1972).

3.2 RAINFALL

The Everglades/Bay/Keys basin has a tropical savanna climate characterized by a relatively long and severe dry season, and a wet season (Hela 1952). The dry season, lasting from November to April (Riebsame et al. 1974), generates between 18% to 33% of the annual rainfall (Thomas 1974), primarily from large scale (synoptic) winter frontal storms (Echternacht 1975). Table 3 shows the relationship between wet season, dry season, and total annual rainfall. The table illustrates two important qualities of rainfall distribution which are related to latitude and maritime influence (Thomas 1974). First, there is a noticeable decrease of annual precipitation from north to south. Second, the wet-dry season differences in precipitation become less pronounced from north (mainland) to south (lower Keys). Two of the 14 stations (denoted by asterisks) report data based on six or less years of record. These values probably do not represent the actual or "true" annual averages because of the brief recording period. The questionable validity of these two stations is further supported by a five year cyclic pattern observed by both Thomas (1970, 1974) and Sass (1967) for the eastern coastal ridge and the Florida Keys region. With the stations in these two areas removed from the data set, the two trends described previously become more pronounced. The probable cause for the differences in these two areas is the geographical placement of the Keys and coastal islands in relation to the prevailing easterlies, and the consequent effect on the land-seabreeze convective process. MacVicar (1981) reports that the predominance of convective type rainfall in south Florida during the wet season results in much higher rainfall totals on the mainland than along the shore or on the coastal islands. The distance of 1.6 km (1 mi) inland from the coast can mean a difference of 15% to 25% of the wet season and annual rainfall values. For example, the cooperative station on Miami Beach, at the water's edge, has a normal annual rainfall of about 117 cm (46 inches). Seventeen (17) kilometers (9 mi) inland, at the National Weather Service Office, the annual average rainfall is 150 cm (59 inches) (USDC 1981a). The decrease of convective influenced rainfall decreases annual average rainfall, and increases the percentage of dry season precipitation (see Table 3) to total precipitation.

Synoptic processes (cold fronts) dominate the basin's dry season (Echternacht 1975). They occur in the area an average of once every seven days (Warzeski 1976), although the frequency decreases equatorially (Thomas 1970). Rainfall related to these events has a characteristic distribution pattern distinct from that observed in convective-type thundershowers. Synoptic rains typically fall over a more uniform area of the front and are dependent only on the temporary passage of the system (Echternacht 1975). Data reported during its passage would be expected to come from a number of meteorological stations simultaneously (Gruber 1969) and would be independent of diurnal cycles reported for convective storms (Asplidin 1967).

Wet season daily rainfall patterns, which are dominated by convective storms, exhibit large differences in precipitation from station to station (Bradley 1972, Woodley et al. 1974, Echternacht 1975). Woodley (1970) estimates the natural variability of rainfall from a single cumulonimbus cloud in south Florida to range from 200 to 2000 acre-feet; 90% of the 60 to 80 thunderstorms occurring annually in the basin occur during the wet season (Bradley 1972). These storms are brief and usually intense, with some strong winds. Day-long wet season storms occur infrequently and are associated with tropical disturbances (Bradley 1972). The short duration, high intensity

	Station Location	Years Record	Dry Season PPTN(a)	(%)	Wet Season PPTN(a)	(%)	Annual PPTN(a)
Main-land	Tamiami Trail 40 mi	26	10.1	18%	47.0	82%	57.1
	Everglades	43	10.3	19%	44.6	81%	54.9
	Homestead Exp. Stat.	55	12.5	20%	50.2	80%	62.7
	Royal Palm Rang. Stat.	20	11.0	19%	46.4	81%	57.4
	Flamingo	20	9.7	20%	40.0	80%	49.7
Upper Keys	Tavernier	32	12.5	26%	35.5	74%	48.0
	Lignumvitae Key	4	8.9	24%	28.0	70%	36.9*
	Long Key	20	10.3	24%	33.5	76%	43.8
	Marathon Shores	19	11.3	27%	30.6	73%	41.9
Lower Keys	Big Pine Key	6	9.3	24%	29.0	76%	38.3*
	Key West WSD	127	10.7	28%	27.9	72%	38.6
	Key West Airp.	27	12.1	30%	27.6	70%	39.7
	Dry Tortugas	17	11.3	32%	24.2	68%	35.5
	Sand Key	11	9.6	33%	19.1	67%	28.7

*N < 10, see text
(a) measurements given in inches

Table 3. Wet season, dry season, and total annual precipitation for the Everglades/Bay/Keys basin (adapted from Thomas 1974).

thundershowers are related to cyclic land-seabreeze convection patterns and result in the majority of rain occurring during the mid to late afternoon hours, or when the peak convergence is observed (Gruber 1969, Echternacht 1975). A temporal shift in these diurnal patterns has been noted along the eastern shore and the coastal islands, including the Florida Keys. Here, where the convective activity is initiated prior to moving inland, the daily rainfall occurs during the early morning hours (USDC 1981a, 1981b).

Distribution of rainfall over southern Florida during the wet season follows a bimodal pattern shown in Figure 10. The first of two peaks occurs in May or June and the second during September and October (Thomas 1974). This bimodal seasonal distribution of rainfall is associated with an upper air trough which extends southwards from the middle latitudes centering itself over southern Florida during June. It is displaced westwards into the Gulf of Mexico during July and August and returns again in September/October (Gruber 1969, Thomas 1970). Periods of heaviest rainfall occur when this trough is overhead (Riehl 1954). Although this bimodal quality is characteristic of all the basin stations, the late spring/early summer peak is less pronounced in the Keys (Thomas 1970).

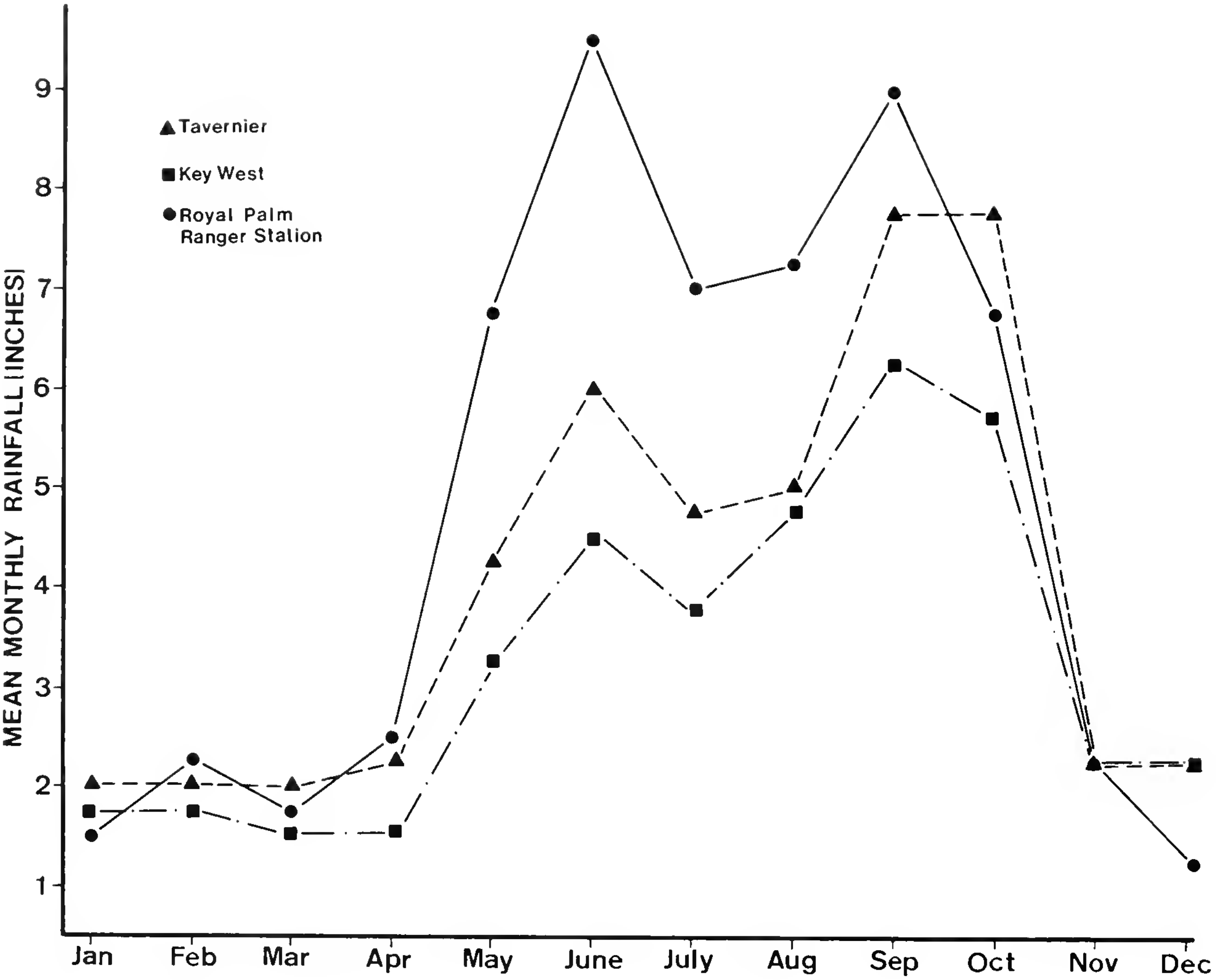


Figure 10. Average monthly rainfall for three representative stations in the study area (adapted from USDC 1981a, 1981b, 1981c).

Thomas' (1970, 1974) analysis of the average annual rainfall distribution for the Everglades/Bay/Keys basin is presented in Figure 11a. Annual (and monthly) rainfall varies considerably from year to year; ranges in excess of 102 cm (40 in) for an individual station are commonplace. For example, Key West reported 160 cm (62.92 in) during 1969 and 51 cm (19.99 in) in 1974 (USDC 1981b). Figures 11b and 11c illustrate the mean total wet season and dry season rainfall, respectively, for the study area. These two figures highlight the differences between the mainland and the keys' annual rainfalls.

A precipitation characteristic commonly reported and of interest for air pollution and ecological work is the number of days on which certain size classes of rainfall occur, i.e., rainfall greater than or equal to .254 cm (0.10 in). Table 4 presents a summary of mean number of days per month with rainfall

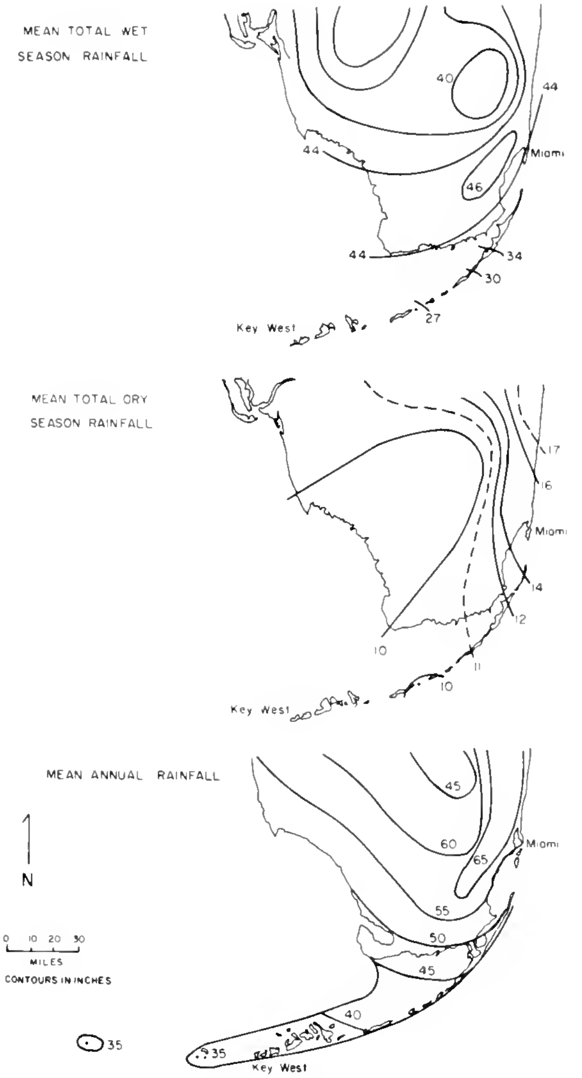


Figure 11. Annual mean, total wet season, and total dry season rainfall patterns in the study area (adapted from Thomas 1974, MacVicar 1981).

greater than or equal to .0254 cm (0.01 in), for first order stations, and .254 cm (0.10 in), for second-order stations, within or adjacent to the Everglades/Bay/Keys basin. The distribution of rainfall frequency displays a fairly uniform pattern both monthly and seasonally. The lower east coast exhibits a greater number of high rainfall days over the summer/wet season than either the Keys or the southwest coast. The mean annual rainfall amounts, and number of days with rainfall greater than or equal to 1.27 and 2.54 cm (0.5 and 1.0 in) for the climatic divisions covering the Everglades/Bay/Keys basin also support the trends mentioned above.

Comparing the rainfall size classes presented for these events yields a ratio of 7:5:2:1; that is, there are roughly 7 times more days recording rainfall greater than or equal to .0254 cm (0.01 in) than .254 cm (1.0 in). Also, the majority of the rainfall events (75%) in the basin contribute less than 1.27 cm (0.50 in).

The SFWMD has recently completed the first phase of a project which provides an important addition to the rainfall data base. MacVicar (1981) has produced a series of rainfall-frequency maps summarizing the predicted maximum precipitation for durations ranging from one to five days, and wet, dry, and annual series for 1, 3, 5, 10, 25, 50, and 100 year return periods. Figure 12 presents his results for average annual maximum for 1 day rainfall. These rainfall-frequency maps cover the entire south Florida region, considering data from all rainfall gages with at least 20 years of daily records available. The Flamingo Ranger Station at the southwest corner of the mainland, near Cape Sable, was omitted from consideration even though more than 20 years of records exist (Thomas 1974). This omission seriously hampers the contours' accuracy in much of the southwestern mainland area of the Everglades/Bay/Keys basin. This should be kept in mind when comparing mean annual and seasonal contours between Thomas (1970, 1974) and MacVicar (1981).

a.) MEAN NUMBER OF DAYS PER MONTH WITH RAINFALL ≥0.01 INCH (.0254 cm)

DIVISION Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Everglades and SW Coast													
Fort Myers	5	6	5	5	8	15	18	18	16	8	4	5	113
Lower East Coast													
Miami	7	6	6	6	10	15	16	17	18	15	8	6	129
Keys													
Key West	7	6	5	4	8	13	13	15	16	12	7	7	112

Source: U.S. Department of Commerce, 1975.
Period of Record: Variable (Minimum length of record, 11 years. Length of record at all but two stations greater than 25 years.)

b.) MEAN NUMBER OF DAYS PER MONTH WITH RAINFALL ≥0.10 INCH (.254 cm)

DIVISION Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Everglades and Sw Coast													
Belle Glade	4	4	4	4	6	12	12	12	12	8	3	3	84
Naples	3	3	3	3	6	10	13	12	12	6	2	3	76
Lower East Coast													
Homestead	3	4	4	4	8	12	12	13	13	10	4	3	90
Keys													
Tavernier	3	3	2	3	5	9	8	8	11	9	3	3	67

Source: U.S. Department of Commerce, August 1976.
Period of Record: 1951-1974.

Table 4. (adapted from Dames and Moore 1978).

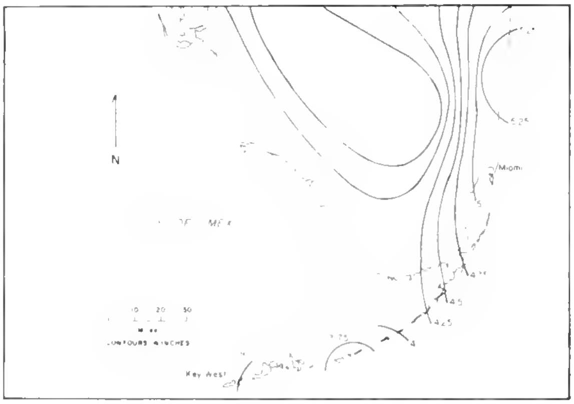


Figure 12. Average annual maximum for one day rainfall (adapted from MacVicar 1981).

Drought is occasionally experienced even during the "wet" season (Bradley 1972). The effect of drought is aggravated or ameliorated by variations of temperature which affect transpiration, evaporation, and soil moisture. One of the more noteworthy studies in this regard is that of Gannon (1978). In attempting to model the daily sea breeze circulation over the south Florida peninsula, Gannon (1978) concludes that developments on the land surface such as urbanization and wetland drainage inadvertently modify weather patterns by redistributing rainfall via changes in the overall daily heat budget. Soil moisture and surface albedo (the ratio of reflected radiation to total radiation) are the two most important factors influencing the strength of the daily sea breeze circulation in Gannon's model. Surface albedo in turn is inversely related to soil moisture; thus wetland drainage may exert something of a self-accelerating effect on the daily hydrologic cycle through: (1) lowering soil moisture which itself changes the heat budget and provides less moisture for evapotranspiration; and (2) increasing surface albedo which even further increases daytime heating. The total removal of wetlands from the weather cycle through paving and other urban development further amplifies the shift toward higher temperatures.

The insidious implications of this situation for fish and wildlife, as well as for the human population of south Florida, have recently been noted by Arthur Marshall (Boyle and Mechum 1982). His hypothesis is that development and drainage have slowly replaced Florida's wet season "rain machine" with a relatively drier "heat machine" during summer months. Thus wet season rains which are so vital to south Florida's ecosystems occur less frequently due to massive changes in the daily heat budget.

3.3 WINDS

Wind patterns in south Florida are determined by the interaction of prevailing easterly tradewinds and localized diurnal factors produced by land-sea convection patterns (during the wet season), or synoptic scale cold fronts (during the dry season) (Echternacht 1975). In a comprehensive examination of seasonal differences in the large scale wind fields for the Florida peninsula, Gruber (1969) described the seasonal streamlines at three vertical levels: 950 millibars (mb) occurring at 0 to 610 m (0 to 2000 ft); 500 mb, occurring at 5,486 to 6,096 m (18,000 to 20,000 ft); and 200 mb, occurring at approximately 12,192 m (40,000 ft). His work was summarized by Echternacht (1975) in an attempt to apply the wind field patterns to potential air pollution problems affecting south Florida. Figure 13 illustrates the four seasonal wind field patterns adapted by Echternacht (1975) at the 950 mb level (i.e., for low-level winds). For the Everglades/Bay/Keys basin Figure 13 shows a dominant easterly influence varying from due east in fall and winter seasons, to east southeast in spring and summer.

This prevailing easterly flow interacts with the two seasonal wind patterns described previously. During the wet season (May to October), convective scale winds initiated by thermal gradients at the land-sea interface find support from the prevailing southeasterly winds (Pielke 1973). The heating of the land surface promotes seabreeze circulation during the day resulting in the convergence of warm moist air over the peninsula (Dames and Moore 1978, Gannon 1978). At night the process reverses, the land cools faster than the ocean, and air tends to diverge away from the peninsula. The recurrent wind cycle and maritime influence is significant to the area's wet season climate due to the flat terrain and proximity to the water (< 40 m or 25 mi) (Bradley 1972, Echternacht 1975). Frank et al. (1967) monitored the daily changes in divergence over the Florida peninsula for the summer months of June through August. As illustrated in Figure 14, a pronounced diurnal pattern was recorded showing very strong convergence (i.e., negative divergence) during the day (peaking around 12:00 to 2:00 E.S.T.). Therefore, the convective scale is the fundamental scale of motion during the basin's wet season (Echternacht 1975).

In the dry season (November to April) the convective influence diminishes as the sun's angle of incidence decreases, reducing the radiant heating of the land's surface during the day and thus minimizing the thermal gradient between the land-sea surfaces (Blair and Fite 1965). During this time the wind patterns are influenced by synoptic scale systems or winter

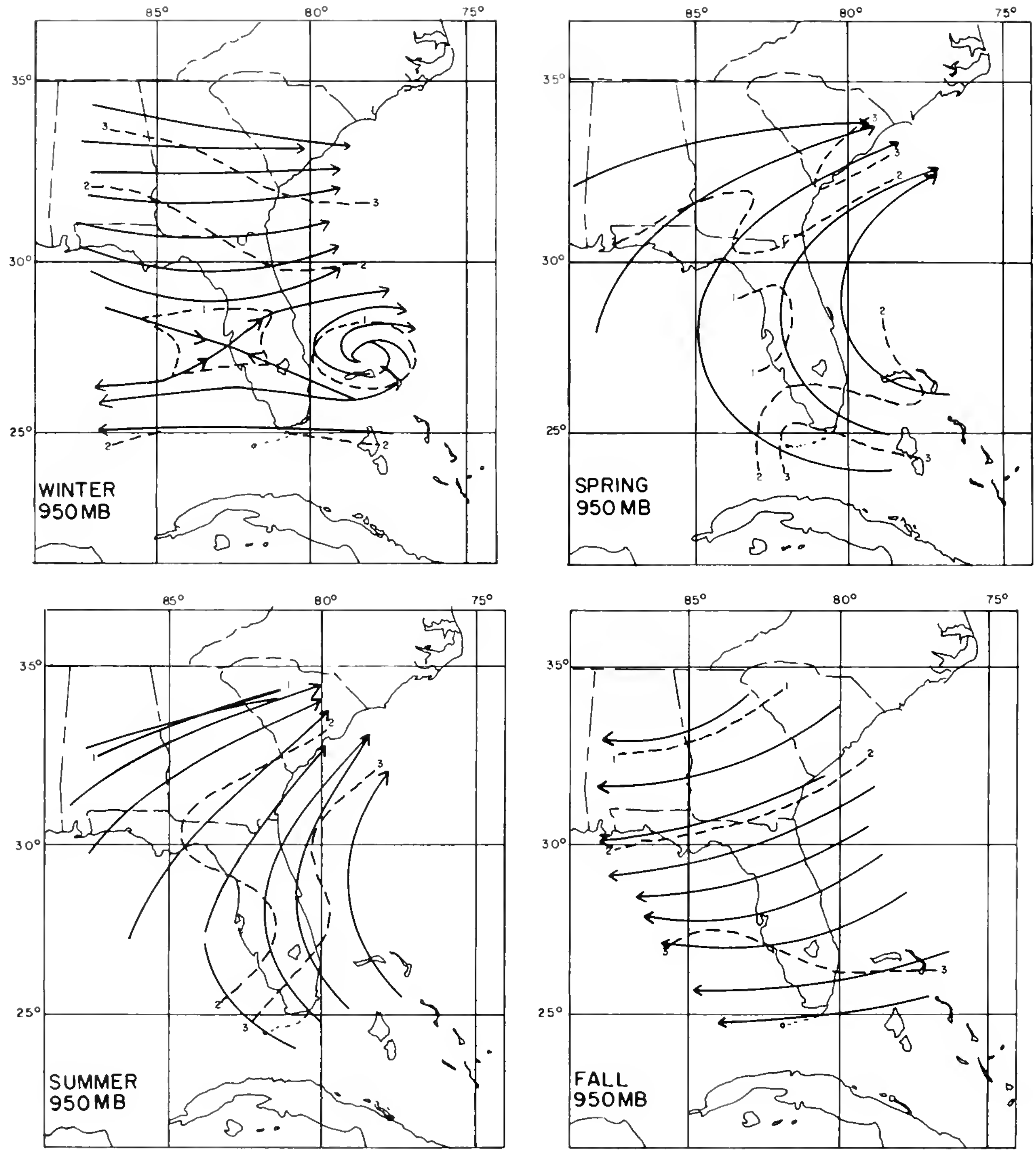


Figure 13. Streamlines and isotachs at the 950 mb sublevel for 1957 to 1965 (adapted from Echternacht 1975).

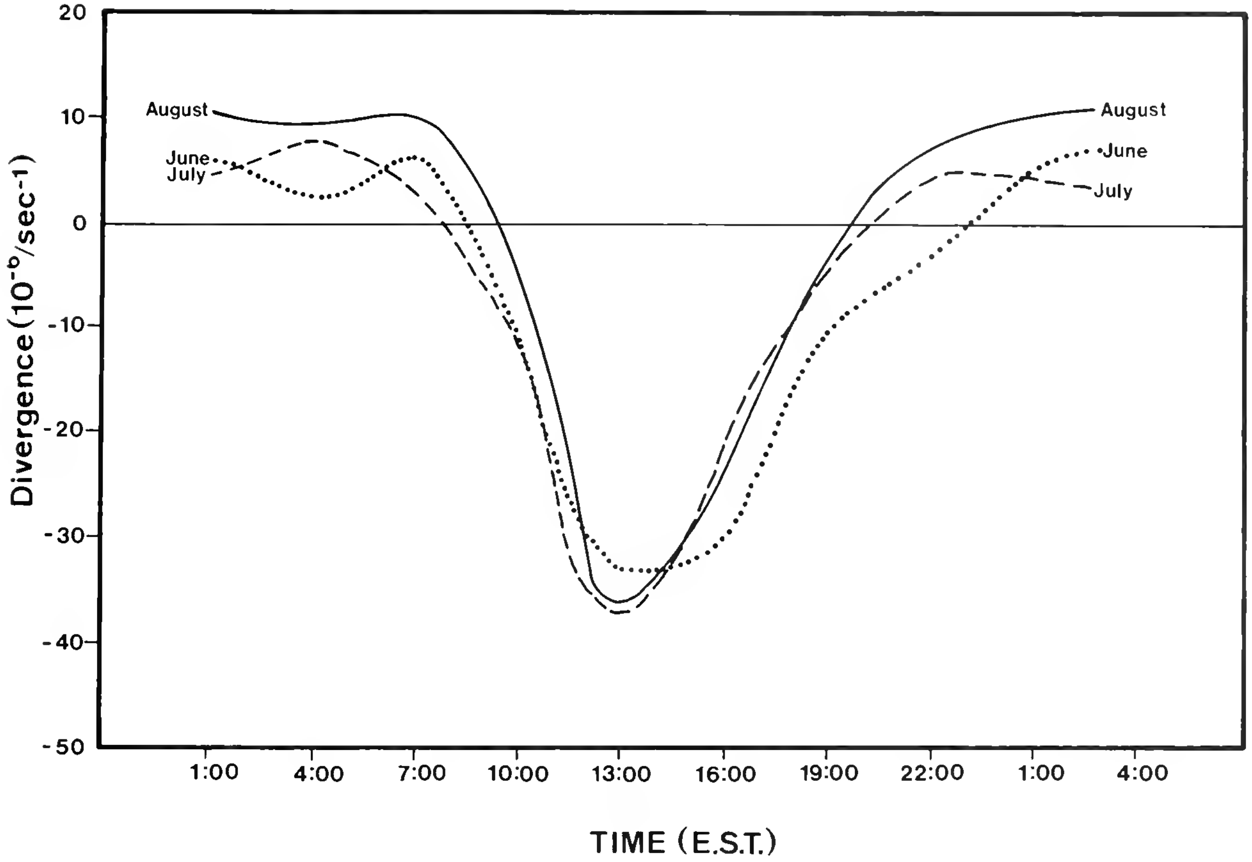


Figure 14. Mean monthly divergence curves for June through August 1963 over the Florida peninsula (adapted from Frank et al. 1967).

frontals moving cold air masses southward. Although the south Florida basin lies far enough to the south to remain under the influence of the easterlies year round (see Figure 13; winter), a northerly component, related to the synoptic scale systems, affects the daily weather patterns (Echternacht 1975). Winter cold fronts pass over the basin approximately once a week during this dry season (Warzeski 1976). Warzeski (1976) describes the cold front in the Biscayne Bay region as follows:

"An average cold front affects wind patterns in the Biscayne Bay region for 4 to 5 days, involving a slow 360° clockwise rotation of wind direction (direction from which the wind is blowing). Winds rise above ambient throughout this period, reaching maxima roughly half a day before and after passage of the front itself. Maximum winds ahead of the front are from the southwest and reach 8 m/sec. Maximum winds during an exceptional cold front can reach 20 to 26 m/sec."

Monthly wind speed and direction for the three first-order weather stations triangulating the basin (Ft. Myers, Miami, Key West) are presented in Table 5 (USDC 1981a, 1981b, 1981c). The reported wind directions are those most frequently occurring during each month. This method of comparison does not give an adequate depiction of diurnal shifts in wind direction and speed resulting from the differential heating of air and water surfaces or the passage of individual winter frontal systems. It does, however, indicate the predominance of different seasonal factors controlling wind. On a seasonal basis, highest average wind speeds tend to occur in late winter and early spring, and lowest speeds during the summer. High localized winds of short duration occur occasionally in connection with summer thundershowers and with cold fronts moving across the state during other seasons (Bradley 1972). Wind speeds associated with convective systems follow a diurnal pattern. On a typical day, wind speeds are lowest in the nightime, increase during the daylight hours to a peak in the afternoon, and then decrease again in the evening (Dames and Moore 1978).

Synoptic scale influences are associated with the passage of the front, as previously described, rather than with diurnal patterns (Warzeski 1977). The influence of synoptic scale systems on prevailing wind direction is evidenced by the northerly component of the prevailing wind directions for the months of October through January in Table 5.

Wind direction and speed tend to vary with height above the ground. The variation of wind direction with height is not always uniform, but wind speed generally increases with height over the flat terrain of the Everglades/Bay/Keys basin (Dames and Moore 1978). Seasonal variations of wind speed and direction at the 950 mb level (0 to 610 m or 0 to 2000 ft) are presented in Figure 13. Dames and Moore (1978) examined the low-level wind patterns at 150m, 300m, and 500m (492, 984, and 1640 ft) at Miami. They concluded that:

"During both the morning and evening at all three levels, winds are predominantly from the east and southeast. Furthermore, the mean wind speeds of the prevalent wind directions are greater than at Tampa and Jacksonville. Certainly this is not the case on each day of the year, but it appears to be the most common situation".

	Ft. Myers Internat. Airport		Key West Internat. Airport		Miami Internat. Airport	
Month	Wind (mph) Speed	Prevail. Direct.	Wind (mph) Speed	Prevail. Direct.	Wind (mph) Speed	Prevail. Direct.
J	(8.5) 8.6	E	(12.1) 12.2	NE	(9.5) 9.4	NNW
F	(9.1) 9.2	E	(12.2) 12.3	SE	10.1	ESE
M	(9.4) 9.6	SW	12.6	SE	(10.5) 10.3	SE
A	(9.0) 8.9	E	(12.8) 12.7	ESE	(10.7) 10.4	ESE
M	8.2	E	(10.8) 11.1	ESE	(9.6) 9.4	ESE
J	7.4	E	(9.7) 9.9	SE	(8.2) 8.1	SE
J	(6.8) 6.9	ESE	(9.9) 10.1	ESE	(7.9) 7.8	SE
A	(6.8) 6.9	E	(9.6) 9.4	ESE	(7.9) 7.6	SE
S	(7.7) 7.9	E	(10.1) 10.3	ESE	8.2	ESE
O	8.5	NE	(11.3) 11.4	ENE	(9.3) 9.1	ENE
N	8.3	NE	(12.1) 12.0	ENE	(9.6) 9.2	N
D	(8.2) 8.3	NE	(12.1) 12.0	NE	(9.2) 8.8	N
YR	8.2	E	11.3	ESE	(9.2) 9.0	ESE

Table 5. Most common wind direction and speed by month for selected first order weather stations (adapted from USDC 1981a, 1981b, 1981c).

3.4 TEMPERATURE

The southern latitude and maritime influences are the primary controls on the temperature regime in the Everglades/Bay/Keys basin. The climate is basically subtropical/ marine characterized by a long, warm summer followed by a mild, dry winter (Bradley 1972).

Illustrated in Figure 15 are isotherms developed for south Florida (Thomas 1970) describing mean annual temperature (Figure 15a), and the mean monthly temperature for the coolest month (January, Figure 15b) and the warmest month (August, Figure 15c). Differences between coastal/keys areas and inland regions are highlighted by the fact that the isotherm contours follow the coastline (Figure 15). The coastal/keys areas reflect a maritime influence, exhibiting low daily ranges of temperature and rapid warming of cold air masses which pass to the east of the state (USDC 1981a, 1981b). Inland locations generally display a greater range of temperatures due to the more rapid heating and cooling of ground surfaces (Gerrish 1973, Dames and Moore 1978). For example, the average daily range of temperature is 5.5°C (10°F) at Miami Beach and Key West, while well inland in the Everglades the average daily range is near 10°C (18°F) (USDC 1981a, 1981b). Another example of this temperature differential between coastal and inland areas appears in the annual number of days with temperatures reaching 32°C (90°F) or above. Miami Beach reports less than 15 days per year as compared to inland stations reporting approximately 60 days per year (USDC 1981a). The minimum temperatures reported for coastal/keys and inland sites repeat this trend.

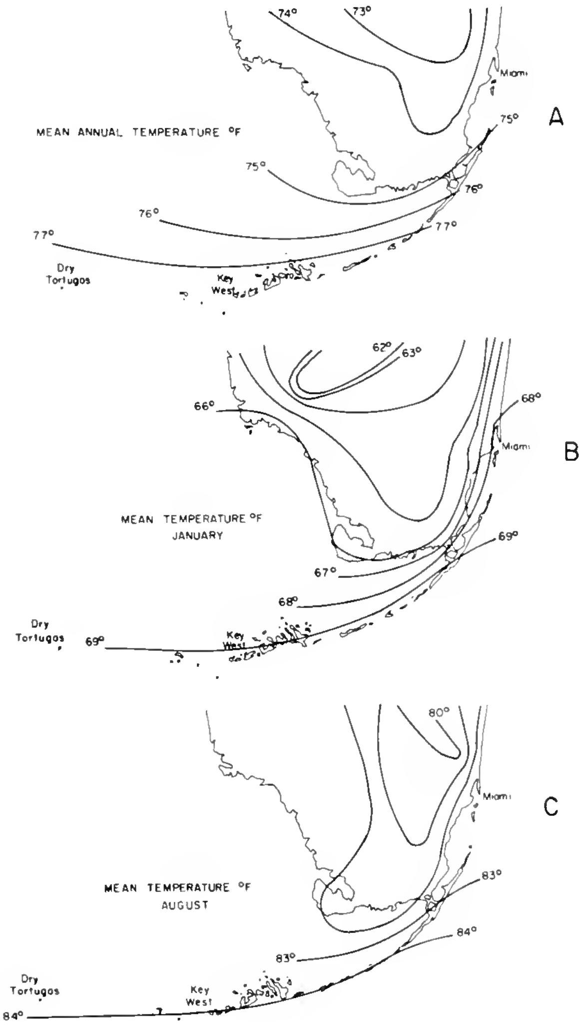


Figure 15. Isotherms for study area annually, and in January and August (adapted from Thomas 1970).

3.5 RELATIVE HUMIDITY

A simple statistical representation of relative humidity is difficult for many locations because of large diurnal and seasonal variations (USDC 1981a, 1981b, 1981c). In Florida, and more so in south Florida, the situation is less complex because of the abundance of moisture throughout the year (Dames and Moore 1978). Table 6 summarizes the mean monthly relative humidity for 0100, 0700, 1300, 1900 hours at the Miami, Ft. Myers, and Key West first-order weather stations.

Combining all hours of the day and all months into a single average, the mean annual relative humidity is quite uniform throughout the basin, averaging about 75% (USDC 1981a, 1981b, 1981c). Relative humidities are generally highest during the early morning hours,

	Key West Airport (N=32)					Miami Intern. Airport (N=16)					Ft. Myers, Page Field (N=20)				
Month	0100	0700	1300	1900	x	0100	0700	1300	1900	x	0100	0700	1300	1900	x
JAN	81	82	69	77	77	81	84	60	69	74	86	88	58	73	76
FEB	78	80	67	75	75	79	83	57	66	71	84	88	55	70	76
MAR	77	79	66	73	74	78	82	57	65	71	84	89	52	68	73
APR	76	77	64	71	72	75	79	55	64	68	84	88	48	65	71
MAY	77	77	65	72	73	80	82	61	70	73	85	88	51	67	73
JUN	78	78	68	73	74	84	86	67	75	78	88	88	59	74	77
JUL	77	76	66	71	73	82	86	64	72	76	88	88	60	75	78
AUG	78	78	67	73	74	83	87	66	74	78	88	89	61	77	79
SEP	79	81	70	76	77	85	89	68	78	80	88	90	62	78	80
OCT	80	82	69	76	77	83	87	65	74	77	86	88	57	73	76
NOV	80	83	69	76	77	81	85	62	71	75	87	89	56	74	77
DEC	81	83	70	78	78	79	84	59	70	73	87	89	56	75	77
YEAR	78	80	68	74	75	81	84	62	71	75	86	89	56	72	76

Table 6. Mean monthly relative humidities (%) for 0100, 0700, 1300, 1900 hours, and 24 hour average from south Florida first order weather stations (adapted from USDC 1981a, 1981b, 1981c).

typically on the order of 75% to 90%, and generally lowest in the afternoon hours, averaging from 50% to 70%. On a seasonal basis, mean relative humidities tend to be lowest in the spring months (April) and highest in the summer and fall months, although seasonal differences are not great. The Florida Keys, reflecting a dominant maritime influence, show even less daily and seasonal variation. Also, the seasonal peak for the Keys appears more in the fall as opposed to the summer as observed in Miami (USDC 1981a, 1981b). Figure 16 illustrates the more stable relative humidity exhibited in the Keys compared to mainland stations.

3.6 SOLAR RADIATION

Throughout the year, incoming solar radiation varies little within the latitudinal constraints of the Everglades/Bay/Keys basin (Dames and Moore 1978). What does vary are factors such as cloud cover, air pollution (particulate load or dustiness), and relative humidity, which modify the transmission, absorption and reflection of solar energy (Blair and Fite 1965, Bamburg 1980). These factors result in temporal and spatial variations in the amount of solar radiation reaching the land and water surfaces.

Miami is the only first-order weather station to collect solar radiation data in or near the study area (Bradley 1972). From 20 years of records, the average daily solar radiation reported is 447 langleys (gm-cal/cm^2). Monthly variation ranges from 319 langleys in December to 572 langleys in April (Bradley 1972). The higher values are reported during middle to late spring rather than during the summer

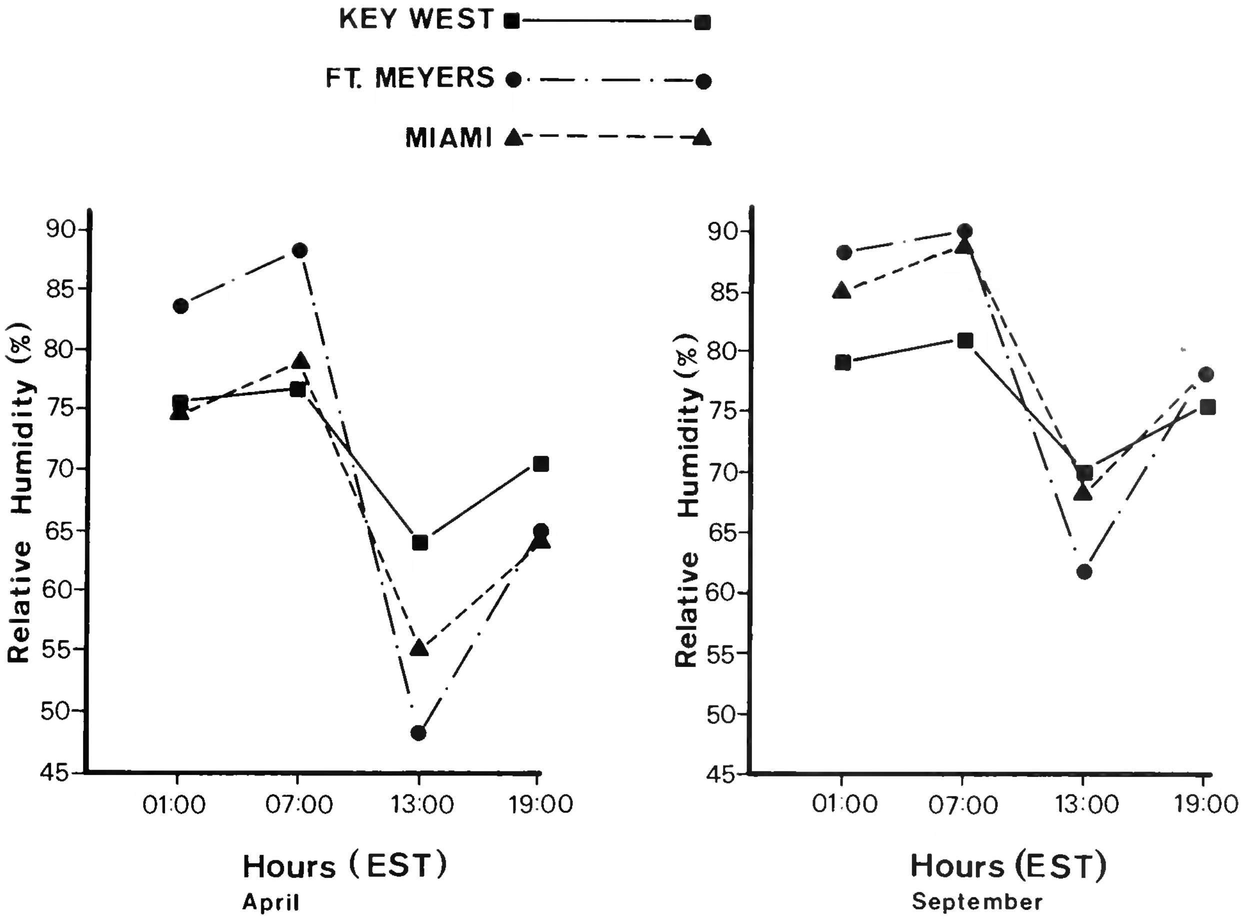


Figure 16. Diurnal patterns in relative humidity over south Florida in April and September (adapted from USDC 1981a, 1981b, 1981c).

solstice (when the angle of incidence is least) because of increased precipitation and cloud cover associated with the beginning of south Florida's wet season.

As stated previously, the potential incoming solar radiation is approximately the same throughout the basin. However, the insolation (radiation reaching the ground/water surface) varies in relation to local atmospheric differences (Bamburg 1980). Table 7 shows climatic data collected at Ft. Myers, Miami, and Key West first-order stations. This data represents either a direct measurement of incoming solar radiation or observations which measure the factors affecting the solar energy's passage through the atmosphere (Bradley 1972, USDC 1981a, 1981b, 1981c). The Miami Station is located some 15 km (9 mi) inland, thus it is assumed that this station represents the characteristics of the study area's more inland environment (USDC 1981a). It is also assumed that Ft. Myers and Key West represent the coastal and island environments, respectively, of the basin. The coastal/island areas within the basin exhibit less cloud cover and more clear days than

	Key West Internat. Airport						Miami Internat. Airport							Ft. Myers Page Field					
Month	(1)	(2)	(3)	(4)	(5)	(6)	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(1) N/A	(2)	(3)	(4)	(5)	(6)
JAN	73	5.1	11	12	8	0	61	5.3	10	12	9	1	334		5.0	11	12	8	5
FEB	76	4.7	11	10	7	0	61	5.3	9	11	8	1	397		4.9	11	10	7	3
MAR	83	4.6	13	12	6	0	78	5.4	8	15	8	1	475		4.9	12	11	8	3
APR	84	4.5	13	12	5	0	80	5.4	8	15	7	1	572		4.6	11	13	6	2
MAY	81	5.2	9	14	8	0	66	6.0	6	15	10	*	540		5.0	9	15	7	1
JUN	74	6.2	4	16	10	0	76	6.8	3	14	13	0	506		6.1	5	15	10	*
JUL	77	6.3	3	18	10	0	78	6.6	2	17	12	*	539		6.5	2	18	11	*
AUG	77	6.3	3	18	10	0	74	6.6	2	18	11	*	510		6.3	3	18	10	*
SEP	71	6.6	3	15	12	0	73	6.8	2	15	13	*	440		6.2	4	15	11	*
OCT	70	5.7	8	13	10	0	70	6.0	6	14	11	*	387		5.0	11	12	8	1
NOV	71	5.1	10	12	8	0	63	5.4	8	14	8	1	350		4.7	12	11	7	2
DEC	72	5.1	11	12	8	0	60	5.3	9	13	9	1	319		4.9	12	11	8	4
YEAR	76	5.5	99	164	102	1	70	5.9	73	173	119	9	447		5.3	103	151	101	21

(1) Percent of possible sunshine
(2) Mean sky cover sunrise to sunset (tenths)
(3) Mean number of days, sunrise to sunset to be clear
(4) Mean number of days, sunrise to sunset to be partly cloudy
(5) Mean number of days, sunrise to sunset to be cloudy
(6) Mean number of days with heavy fog (* = trace)
(7) Average daily solar radiation in langleys

Table 7. Solar radiation and related climatological data for Key West, Miami, and Ft. Myers first order weather stations (adapted from USDC 1981a, 1981b, 1981c).

inland areas. This quality is most apparent in the dry season months (November through April), during which the highest number of clear days are reported for all three stations. The number of days of heavy fog increases from south to north, and from east to west. During the dry season the fog is usually an early morning or late night phenomenon which generally dissipates or thins soon after sunrise (USDC 1981a, 1981b, 1981c). Heavy daytime fog is seldom observed in south Florida (Bradley 1972). The mean annual total hours of sunshine for the basin ranges from approximately 3000 hours inland to nearly 3300 hours at Key West (Dames and Moore 1978).

3.7 HURRICANES

Warzeski (1976) divides the climatic conditions of south Florida into three energy levels or intensities. These are: (1) prevailing mild southeast and east winds; (2) winter cold fronts; and (3) tropical storms and hurricanes. The first two were previously discussed in the sections on wind and rainfall.

Tropical storms and hurricanes, because of their infrequent occurrence, significance as an ecological force, and unique climatic characteristics, are treated here as a separate climatic element.

In summer and fall, occasional low-pressure areas are observed which originate in the warm, moist air of the equatorial trough. The winds are light and usually drift from east to west. Then an atmospheric wave appears in the easterly flow and proceeds westward at 16 to 24 km per hr (10 to 15 mph) (Blair and Fite 1965). These easterly waves usually form between 5° and 20° north of the equator. From this point the easterly wave development may go through one or all four stages of a tropical cyclone as described by Riehl (1954):

(1) Formative stage. Winds usually remain below hurricane force with the strongest winds generally occurring in one quadrant, poleward and east of the center of a deepening of the barometric trough. Areas of weak wind circulation (less than 61 km per hr or 38 mph) are referred to as "tropical depressions" or "tropical disturbances". These disturbances move in a very rough counterclockwise direction and may travel great distances organized as such (Gentry 1974).

(2) Immature stage. If the shallow depressions intensify with winds exceeding 61 km per hour (38 mph) the "tropical depression" has become a "tropical storm" characterized by barometric pressures dropping to 1000 mb and below, and winds forming tighter concentric bands around the center or eye. The cloud and rain patterns also change from disorganized squalls to narrow organized bands spiraling inward (Riehl 1954). If the winds intensify to 119 km per hr (74 mph) or more, a tropical cyclone or hurricane is born (Gentry 1974). Still only a relatively small area is involved, i.e., hurricane force wind radius of 32 to 48 km (20 to 30 mi) (Riehl 1954).

(3) Mature stage. The surface pressure at the center is no longer falling and the maximum wind speed no longer increases (Riehl 1954). Instead, the circulation expands, extending the radius of hurricane force winds.

(4) Decaying stage. Tropical cyclones, both mature and immature, generally move westward in the prevailing westward drift of the easterlies. They enter the decaying stage as they recurve from the tropics and enter the belt of westerlies, usually decreasing in size (Riehl 1954, Blair and Fite 1965).

During the immature and mature stages the general westward movement ranges from 16 to 48 km per hr (10 to 30 mph). The typical path is parabolic, although the actual path of any given storm is governed by the winds existing above it, resulting in a multitude of speed and directional changes (Blair and Fite 1965). Blair and Fite (1965) provide a concise description of the passage of a hurricane over the Everglades/Bay/Keys basin:

"As such a storm approaches, the barometer beings falling, slowly at first and then more and more rapidly, while the wind increases from a gentle breeze to hurricane force,

and the clouds thicken from cirrus and cirrostratus to dense cumulonimbus, attended by thunder and lightning and excessive rain. These conditions continue for several hours, spreading destruction in their course. Then suddenly the eye of the storm arrives, the wind and the rain cease, the sky clears, or partly so, and the pressure no longer falls but remains at its lowest. This phase may last thirty minutes or longer, and then the storm begins again in all its severity, as before, except that the wind is from the opposite direction and the pressure is rising rapidly. As this continues, the wind gradually decreases in violence until the tempest is passed and the tropical oceans resume their normal repose. The violent portion of the storm may last from twelve to twenty-four hours."

South Florida has the dubious honor of being visited more often by hurricanes and tropical storms than any other equal-sized area of the United States (Gentry 1974). The Everglades/Bay/Keys basin is exposed to both Atlantic and Carribean hurricanes. Tropical cyclones generally strike the east coast of south Florida from an ESE direction--a predominant direction for Atlantic hurricanes before recurvature (Jordan 1973, Ho et al. 1975). The west coast of south Florida is vulnerable to late-season tropical cyclones moving in a northeastward direction after recurvature (Cry 1965, Bradley 1972). Figure 17 illustrates the frequency of hurricane occurrences along the Atlantic coastline for five of 58 coastal segments delineated by Simpson and Lawrence (1971). Points-of-entry in south Florida of tropical storms and hurricanes also appear in Figure 17. Major hurricane tracks passing through the Dry Tortugas appear in Figure 18. The average forward speed for hurricanes affecting the basin is 10 knots with a radius of maximum winds extending an average of 20 nautical miles from the center (Ho et al. 1975). Detailed descriptions of the passage of specific hurricanes and tropical storms through the basin exist in literature such as the U. S. Department of Commerce's "Monthly Weather Review". This journal summarizes all meteorological data associated with the passage of tropical waves, disturbances, storms, and hurricanes for each year's hurricane season.

The three primary forces associated with the passage of a hurricane are wind, storm surge, and rain. As discussed previously, sustained winds greater than 119 km per hr (74 mph) must exist prior to a tropical storm's graduation to hurricane status. Sustained winds over 200 km per hr (125 mph) must be present for a hurricane to be classified a "Great Hurricane". Ball et al. (1967), Pray (1966), and Perkins and Enos (1968) describe the passages of two "Great Hurricanes", Donna (Sept. 1960) and Betsy (Sept. 1965), through the Florida Keys. Winds over 200 km per hour (125 mph) have occurred in the study area on several occasions during the last century (Sugg et al. 1971, see Figure 17). The most notable was the "Labor Day" hurricane in 1935 which passed over Long Key with winds estimated between 322 to 402 km per hr (200 to 250 mph) (Bradley 1972).

One can best appreciate the ecological significance of hurricanes when it is understood that the wind force increases by the square of the wind speed. In other words, a 150 km per hr (93 mph) wind exerts four times as much force as a 75 km per hr (47 mph) wind. When hurricane winds exceed 400 km per hr (249 mph, as was estimated for the "Labor Day" hurricane by Gentry 1974) their strength becomes almost inconceivable.

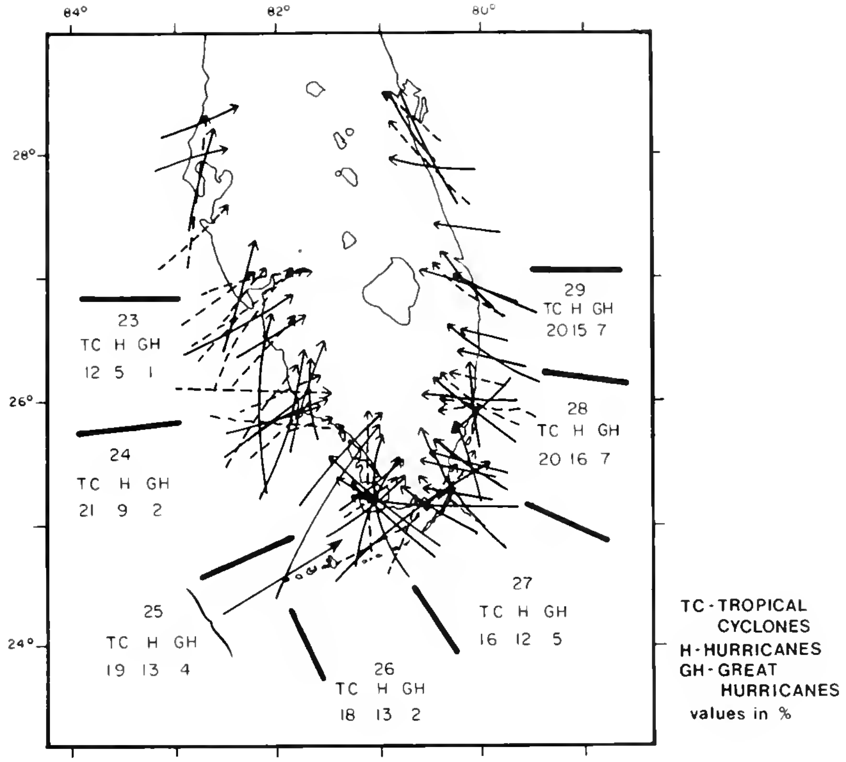


Figure 17. Points of entry and probabilities of hurricanes at selected coastal locations (adapted from Jordan 1973).

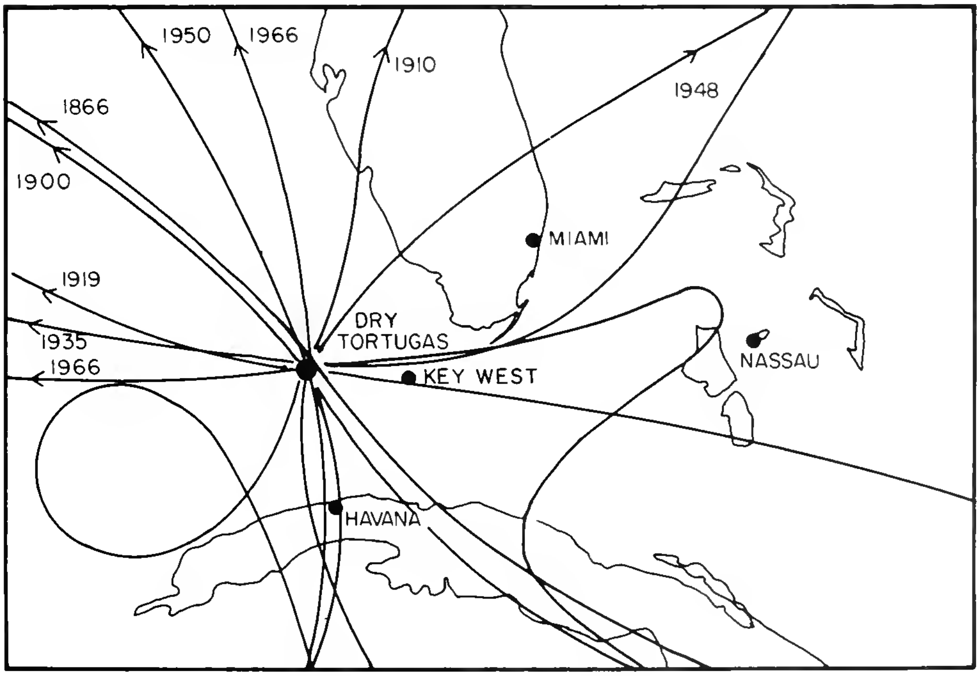


Figure 18. Tracks of major hurricanes passing over the Dry Tortugas since 1871 (adapted from Jordan 1973).

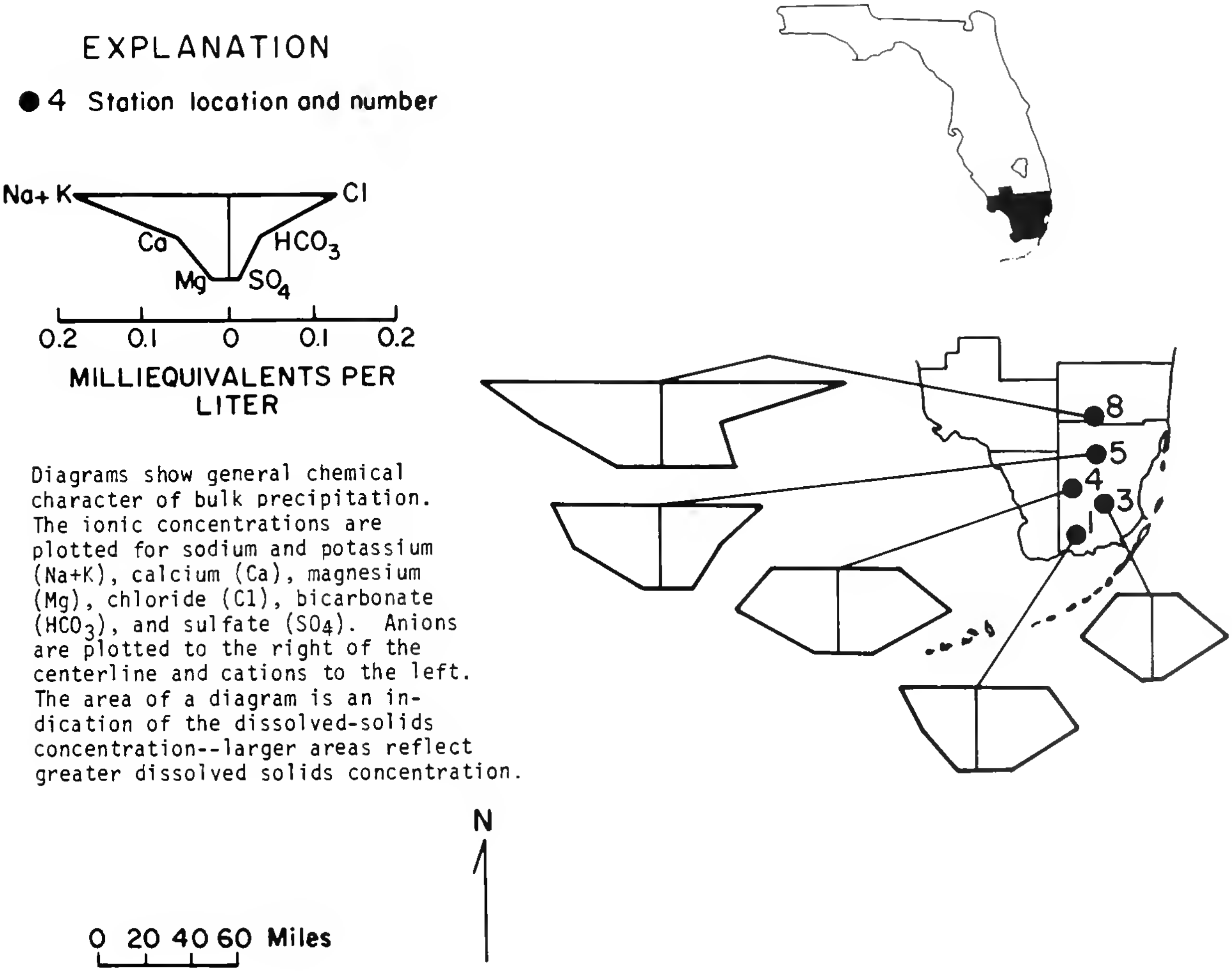
Storm surge, resulting in an increase in high tides and rough seas, is caused by a complex interaction of storm wind, minimum pressure, and the slope of the bottom topography of waters adjacent to the land (Gentry 1974). The effects are of course more pronounced when the storm moves onshore, as opposed to moving along the coastline. Since 1873, 8 hurricanes have caused record storm tides in south Florida, 2 of them within the study area (Simpson et al. 1969). There appears to be no discernible pattern in the occurence of these great storms - all areas of the coast have been equally affected. Record storm surge tides range between 2.9 and 5.5 meters (9.5 and 18 feet) above undisturbed or still water levels (Simpson et al. 1969). In addition, coastal areas are also subject to strong wave action which causes waters to reach even further inland than indicated by tide heights alone (Gentry 1974).

The amount of rainfall associated with tropical storms varies greatly depending on several factors, the more obvious ones being the intensity of rainfall, the forward movement, and the size of the storm (Gentry 1974). Because of the violent nature of the storm, the error in the rainfall measurements may be as high as 50%. Usually 12.5 to 25 centimeters (5 to 10 inches) of rain are recorded during the passage of a tropical storm (Gentry 1974).

3.8 AIR POLLUTION

Three general types of atmospheric contaminants (related to both natural and man-made sources) affect the south Florida environment (Echternacht 1975). These are: (1) sources for small particulate matter that can form condensation nuclei, (2) sources for particulate matter suspended in the air that can be scavenged by falling raindrops, and (3) sources of solutes which are dissolved in condensation particles (cloud droplets). The sources for all three and their geographic distributions are dependent on the basin weather patterns. For the Everglades/Bay/Keys basin this means the wet-dry season variation. Passage of large scale synoptic systems during the dry season (November-April) may contain pollutants from sources far removed from the state (Echternacht 1975), in addition to localized sources (Holle 1971). Wet season convective systems exhibit diurnal activity related to land-sea breeze interactions. These systems convey atmospheric contaminants primarily from local sources, i.e., automobile emissions, stack gases, fertilizer and pesticide dusts, and ash from burned marsh grasses and sugar cane residue (Holle 1971, Echternacht 1975).

Two mechanisms are involved in the movement of air-borne contaminants from the atmosphere to the land and water surfaces. The material, inorganic and organic, is transported either by (1) wet or (2) dry fallout (Irwin and Kirkland 1980). Material associated with dry fallout is in a continuous flux of suspension and deposition, e.g., wind generated dust, car emissions. Those materials deposited during wet fallout or rainfall, either in a dissolved or particulate form, are affected by two processes referred to as rainout and washout (Echternacht 1975). Semonim and Adams (1971) describe rainout as the removal of aerosols in the rainmaking process and washout as the process of falling rain scavenging air-borne particulates. For instance, in south Florida Echternacht (1975) concluded that with nutrient fallout total phosphate (TPO_4) in the particulate form is subject to the washout process, i.e., scavenging of particulate TPO_4 by falling rain and as dry fallout year round. In contrast, nitrogen as NO_x occurs primarily in the solute form and is therefore removed in the rainout process. Total atmospheric fallout, wet plus dry, is commonly reported as bulk precipitation. It consists of three fractions: (1) dissolved materials in aqueous precipitation, (2) the water-soluble component of dry precipitation, and (3) the water-insoluble component of either wet or dry precipitation (Irwin and Kirkland 1980). Irwin and Kirkland (1980) summarized qualitative rainfall characteristics at selected USGS study sites in Florida including six sites within or adjacent to the Everglades/Bay/Keys basin. Figure 19 illustrates the mean chemical composition of the more common inorganic ions in rainfall. Within the basin, particularily at stations 3 and 4, calcium (Ca) and bicarbonate (HCO_3) are dominant ions while magnesium (Mg) and sulfate (SO_4) are least significant. At Station 5 (40 Mile Bend Tamiami Trail) sodium plus potassium (Na + K) and chloride (Cl) dominate and continue to do so up to Lake Okeechobee. Waller and Earle (1975) suggest that the elevated sodium and chloride concentrations are a function of the proximity of ocean waters, although a decrease observed in stations within



Diagrams show general chemical character of bulk precipitation. The ionic concentrations are plotted for sodium and potassium (Na+K), calcium (Ca), magnesium (Mg), chloride (Cl), bicarbonate (HCO_3), and sulfate (SO_4). Anions are plotted to the right of the centerline and cations to the left. The area of a diagram is an indication of the dissolved-solids concentration--larger areas reflect greater dissolved solids concentration.

Figure 19. Location of precipitation sampling sites in study area, and average chemical concentrations (adapted from Irwin and Kirland 1980).

the Everglades National Park (1, 3, 4) further south and closer to the coast do not support this supposition. Higher calcium/bicarbonate levels observed in this basin (sites 1, 3, 4) are believed to be derived from fine rock and marl soils (Waller and Earle 1975).

Waller (1975) reports that bulk precipitation comprises as much as 78% of the total annual input of nitrogen and 90% of the input of phosphorus to the conservation areas north of the Everglades National Park. The majority of the total loading occurs during the wet season due to the increased quantity of rainfall. Concentrations in dry fallout, however, tend to increase during the dry season (Echternacht 1975, Waller and Earle 1975). Echternacht (1975), reviewing the South Florida Water Management District's rainwater data, illustrated this seasonal difference of nitrogen and phosphorus concentrations. Peak concentrations occur during spring months, which are characterized by high winds and low rainfall and, therefore, high dry fallout conditions (Table 8). Summer months, during peak rainfall and maximum dilution, show the lowest concentrations. Dilution, soil drying, increased wind activity, and contamination of collecting devices by animals are believed to be the primary causes of the obscured seasonality. Fire is also believed to be a factor in enhancing the concentration of dry fallout in the dry season (Holle 1971, Waller and Earle 1975).

The mean nutrient values for total nitrogen as "N" are fairly uniform for all sites; however, phosphorus as "P" reported at sites 1 and 3 are the highest recorded in the state's USGS monitoring network (Irwin and Kirkland 1980; see Figure 19). These two sites are monitored monthly and are located close to "natural" settings at the Everglades National Park Research Center and at Grossman Hammock in Shark River Slough. Therefore it is suggested that local biota, such as birds and frogs, may be contaminating the samples (Waller and Earle 1975, Irwin and Kirkland 1980). Bulk precipitation data collected by the South Florida Water Management District support the idea of contamination at sites 1 and 3 (Echternacht 1975). Davis and Wisniewski (1975) reported nitrogen as "NO_x" and phosphorus (ortho as "P") at sites in Homestead, Tamiami Trail (40 Mile Bend), and the Everglades. The values reported are much lower than reported at sites 1 and 3 by Irwin and Kirkland (1980).

	Ammonium	Nitrate	Nitrite	Orthophosphate	Total Phosphate
	NH+	NO_3	NO_2	OP	TP
	ppm	ppm	ppm	ppm	ppm
Summer	0.30	0.28	0.01	0.03	0.04
Fall	0.61	0.26	0.02	0.06	0.07
Winter	1.91	0.27	0.02	0.08	0.09
Spring	2.30	0.49	0.06	0.13	0.30

Table 8. Seasonal averages of nutrient species contained in rainwater at Tamiami Trail 40 mile bend (adapted from Echternacht 1975).

Most trace metals in bulk precipitation are derived from dry soils and fine rock material wafted into the air by winds. Mercury and arsenic, however, are believed related to pesticide use on nearby agricultural operations (Waller and Earle 1975). Lead and iron are attributed to motor vehicle activity (Irwin and Kirkland 1980). Site 4 (Tamiami Trail, 40 Mile Bend) is the only site in the basin monitored for trace metals in bulk precipitation. Of all trace metals, cadmium and zinc show up in the most potentially hazardous concentrations; however, these concentrations are believed to result from contamination by nearby galvanized metals (Waller and Earle 1975). All trace metal sampling sites are located near highways and/or located with the objective of measuring some local phenomena, and thus very likely do not portray regional conditions (Irwin and Kirkland 1980).

The pH of rainfall reported at sites 1, 3, 4, and 5 within the basin ranged from pH 5.2 to pH 8.7 (Irwin and Kirkland 1980). This data should be viewed as only approximate due to the holding times imposed.

Data on selected pesticides and industrial compounds monitored are rather limited for the basin. Trace amounts of PCB were reported at sites 1 and 3, and malathion and diazinon were just detectable at site 4. Site 2 monitored at a campground near Florida City just south of Homestead reported the presence of a variety of pesticides, highest of which were diazinon (mean concentration = 0.26 ppb) and malathion (mean = 0.47 ppb). The sampling site is located to the east of the Everglades National Park and sandwiched in between two major farming areas dealing mainly in truck crops, i.e., vegetables. Application of pesticides in this area is usually done by aerial sprayers, providing ample opportunity for atmospheric contamination over the sampling site. The values reported should be considered conservative because of the rapid breakdown of the organophosphate compounds reported in highest concentrations, such as malathion.

Dames and Moore (1978) studied sulfur dioxides in the state of Florida, concentrating their efforts in Hillsborough, Duval, and Escambia Counties. The results were applied to other counties including Dade and Monroe. Their review of historical data for Miami and Homestead showed very low values, with most readings below the official detection threshold of 0.01 ppm. Dade County's projected 1980 rate of emissions (1,164 grams/sec.) was the highest of any south Florida county and ranked ninth in the state. Dames and Moore (1978) concluded, however, that the 24-hour maximum concentrations of SO_2 are presently, and will continue to be, far below Florida and national air quality standards, even at locations where the maximum combined effects are expected.

Inversions occur when warm air becomes caught below colder air, resulting in the trapping of a stable air column and thereby preventing mixing or dilution of air pollutants immediately above the ground. By monitoring towers in and adjacent to the basin, Gerrish (1973) concluded that inland inversions form almost every night, are much stronger than those on the coast of south Florida, and are strongest in the dry season. Because of the diurnal nature of the inversions, significant atmospheric pollutant buildup seldom occurs; the daily inversions are quickly dispersed by the dynamic wind and rain patterns that exist over the basin (Dames and Moore 1978).

CHAPTER 4
GEOLOGY

4.1 STRUCTURE AND GEOLOGIC SETTING

The Floridan Plateau (Figure 20), originally named by Vaughan (1910), represents the great projection of the North American continent that separates the Gulf of Mexico from the Atlantic Ocean. It includes not only the state of Florida, but an equal area beneath water less than 50 fathoms (91.4 m or 300 ft) deep. The plateau underlies all of the Everglades, Florida Bay, and the Florida Keys, as well as a large area of the Gulf of Mexico. In the gulf, the plateau's bottom slopes gently away from the west coast of Florida, but it drops off sharply just south of the Keys into the Straits of Florida. The median axis of the plateau passes through Key West, Bradenton, Sarasota, Cedar Key, and Madison, Florida (Cooke 1945).

Table 9 is a reference chart for the ensuing discussion of geologic structure and stratigraphy. More detailed tables correlating specific rock formations and facies in Florida with geologic periods may be found in Cooke (1945) and Puri and Vernon (1964).

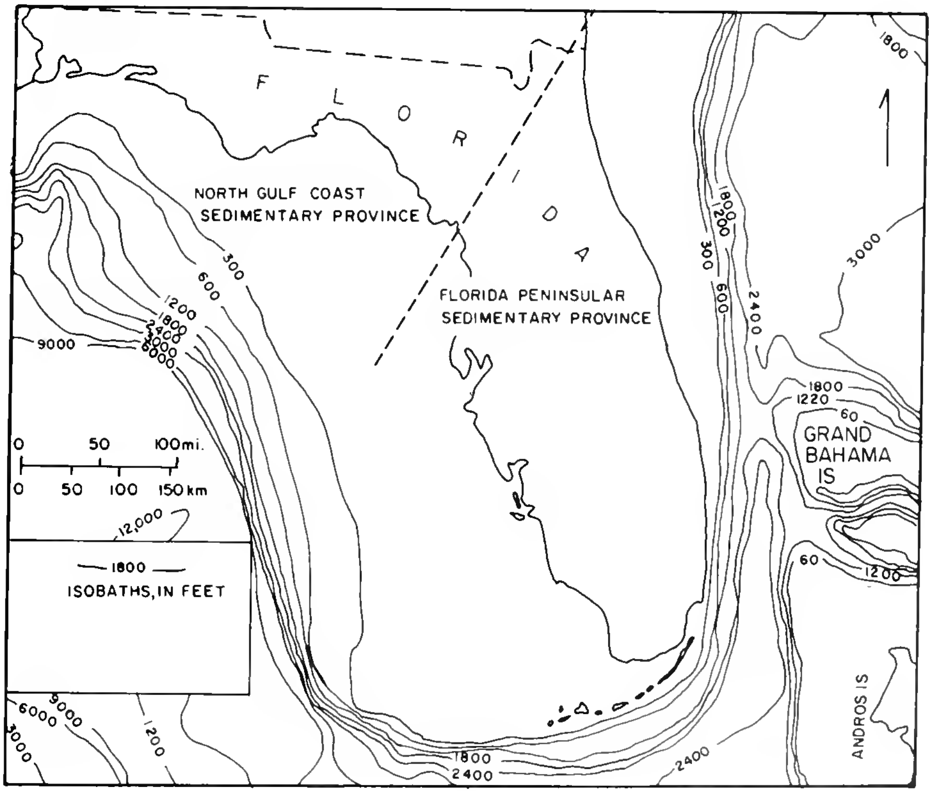


Figure 20. The Floridan Plateau (adapted from Perkins and Enos 1968).

GEOLOGIC TIME AND FORMATIONS

ERAS	PERIODS AND SYSTEMS	EPOCHS AND SERIES	APPROXIMATE NUMBER OF YEARS AGO	EARLIEST RECORD OF ANIMALS	PLANTS
CENOZIC	QUATERNARY	Holocene (recent) Pleistocene (glacial)		mankind	
	TERTIARY	Pliocene Miocene Oligocene Eocene Paleocene	70,000,000	placental mammals	
MESOZOIC	CRETACEOUS	Upper			grasses and cereals
		Lower		birds	
	JURASSIC		160,000,000	mammals	flowering plants
	TRIASSIC				ginkgoes
PALEOZOIC	PERMIAN		230,000,000		cycads and conifers
	PENNSYLVANIAN			insects	
	MISSISSIPPIAN			reptiles	primitive gymnosperms
	DEVONIAN			amphibians	
	SILURIAN		390,000,000		vascular plants: lycopodiums equisetums ferns,etc.
	ORDOVICIAN		500,000,000	fishes	mosses
	CAMBRIAN		620,000,000		
PROTEROZOIC	NOT DIVIDED INTO PERIODS		1,420,000,000	invertebrates	spores of uncertain relationship marine algae
ARCHEOZOIC			2,300,000,000		

Table 9. Reference chart for discussion of geology.

Structurally, the area under consideration in this report lies within what Pressler (1947) refers to as the Florida peninsula sedimentary province. The peninsula sedimentary province is characterized by nonclastic (chemically or biologically produced as opposed to erosion produced) sediments, primarily carbonates and anhydrites. Of particular significance to the present study area are two structural features of the peninsula. The first is the south Florida embayment of the Gulf of Mexico, whose center of deposition passes through Florida Bay and the Keys, paralleling the lower southwest coast (Puri and Vernon 1964). The second is the south Florida shelf, a term applied by Applin and Applin (1964) to a shallow shelf generally paralleling and leeward of the south Florida embayment.

Pressler (1947) believes that anticlinal folds are the most prevalent type of structures within the south Florida embayment. Although probably occurring as secondary structural features, faults should also be prevalent within this area. Based on the configuration of the surface of the submerged areas, Pressler and others believe the Florida peninsula is bounded on the south and east by major fault zones. These faults are probably due to continental movements in addition to settling, compacting, and continuous downwarping of the sedimentary fill. The latter factors are also likely to contribute localized structural features significant to the accumulation of oil.

According to Applin and Applin (1964), the floor of the coastal plain in the Florida peninsula is the truncated surface of a variety of igneous and sedimentary rocks that are chiefly Precambrian and early Paleozoic in age. Unfortunately, most of the work conducted on underlying Pre-Mesozoic rocks in Florida is restricted to north and central portions of the peninsula. One of the primary reasons for this is the volume of sedimentary fill overlying the coastal plain floor in southern Florida. A number of investigators (Pressler 1947, Antoine and Harding 1963, Applin and Applin 1964) place the Pre-Mesozoic floor at 3,658 to 6,096 m (12,000 to 20,000 ft) below mean sea level. Figure 21 (from Puri and Vernon 1964), summarizes the stratigraphic relationships of the Pre-Cenozoic Florida peninsula.

4.2 TERTIARY STRATIGRAPHY

The oldest rock layer of the Tertiary beneath the Everglades, Taylor Slough, and Florida Keys is the Avon Park Limestone, a cream colored chalky limestone of marine origin belonging to the Clairborne group of the Eocene series (Cooke 1945). Above this, the Crystal River Formation thins from east to west beneath Taylor Slough headwaters, and remains thinly represented farther south. Suwannee Limestone (Cooke and Mansfield 1936), of late Oligocene age, and the Hawthorn facies, of the Alum Bluff stage of the Miocene series, overlie these older strata. Pliocene rocks underlying the Everglades, Florida Bay, and the Florida Keys are represented by the contemporaneous Caloosahatchee and Tamiami Formations (Parker and Cooke 1944). To the north, toward the Big Cypress, the dissected Tamiami Formation is thinly covered by Pleistocene sands and occasionally even outcrops at the surface.

4.3 PLEISTOCENE SEDIMENTS

The cessation of the deformation that warped the Citronelle Formation to the north of the present study area is a convenient beginning

					PANHANDLE			PENINSULA	
					WEST	EAST	NORTH	CENTRAL	SOUTH
MESOZOIC	CRETACEOUS	GULF	Navarro Age	SELMA	BEDS OF NAVARRO AGE (?) (ABSENT IN PART)............			LAWSON LIMESTONE.........................	
			Taylor Age		BEDS OF TAYLOR AGE................................			BEDS OF TAYLOR AGE......................	
			Austin Age		BEDS OF AUSTIN AGE................................			BEDS OF AUSTIN AGE......................	
			EAGLE FORD AGE	EUTAW	EUTAW		ATKINSON FORMATION	BEDS OF EAGLE FORD AGE..................	
				TUSCALOOSA	UPPER	MILLER SAND			
			WOODBINE AGE		MARINE			BEDS OF WOODBINE AGE.....................	
						MOYE (PILOT) SAND			
					LOWER				
		COMANCHE OR GULF						THIN CONTACT GREEN SHALE	
		COMANCHE				UNDIFFERENTIATED	UNDIFFERENTIATED	BEDS OF WASHITA AGE........... BEDS OF FREDRICKSBURG AGE...... BEDS OF TRINITY AGE........... Punta Gorda Anhydrite Sunniland Limestone	
	JURASSIC OR CRETACEOUS	UPPER JURASSIC OR LOWER CRETACEOUS						FT. PIERCE FORMATION	
	JURASSIC					UNDIFFERENTIATED (I Well)			
	TRIASSIC [?]	UPPER TRIASSIC		NEWARK GROUP	RED AND VARICOLORED CLASTIC ROCKS CONTAINING, IN SOME WELLS, INTRUSIONS OF DIABASE AND BASALT.		DIABASE INTRUSIONS AND/OR FLOWS		
PALEOZOIC	DEVONIAN	MIDDLE [?]			TERRESTRIAL DEPOSITS (I WELL)				
	SILURIAN						BLACK SHALE		
	ORDOVICIAN	MIDDLE					BLACK SHALE		
		LOWER					QUARTZITIC SANDSTONE AND SOME DARK SHALE		
PRE-CAMBRIAN OR LOWER PALEOZOIC					PORPHYRITIC RHYOLITE (I WELL)		RHYOLITIC LAVA AND PYROCLASTIC ROCKS		
PRE-CAMBRIAN ?								GRANITE AND DIORITE	
AGE UNKNOWN								HIGHLY ALTERED IGNEOUS ROCK (I WELL)	

Figure 21. Stratigraphic nomenclature of Pre-Cenozoic strata in the Florida peninsula (adapted from Puri and Vernon 1964).

date for the Pleistocene epoch in Florida (Cooke 1945). Subsequent oscillations of sea level in response to glacial formation and melting are primary factors in determining Pleistocene rock formations underneath the Everglades, Taylor Slough, and Florida Bay. Much of the area is underlain by marine sedimentary sequences punctuated by fresh water limestones and subaerial exposure surfaces (Perkins 1977). The wedge of overlying Pleistocene sediment, which attains a thickness of approximately 61 meters (200 ft) in the lower Keys, pinches out northward against topographically higher Miocene and Pliocene sediments, such as the Tamiami and Caloosahatchee Formations mentioned earlier (Perkins 1977).

Sea level prior to the initial Pleistocene glacial melt lay at approximately 82.3 meters (270 ft) above the present shore line. Dry land on the Floridan Plateau was restricted to a few small islands lying in what is now Polk County, and another group in the vicinity of the Trail Ridge area near Jacksonville. Subsequent sea level fluctuations gradually left more and more of the Floridan Plateau exposed. As Cooke (1945) explains, this successive dampening of sea level rise is probably the result of sea floor spreading which concurrently increased the global volume of the oceans. Table 10 lists the names of recognizable sea level fluctuations of the Pleistocene in Florida and the respective heights to which they extended above present day sea level.

Name	Height Above Present Sea Level (ft)
Brandywine	270
Coharie	215
Sunderland	170
Wicomico	100
Penholoway	70
Talbot	42
Pamlico	25
Silver Bluff (tentative)	5

Table 10. Recognized sea level fluctuations of the Pleistocene in Florida (adapted from Cooke 1945).

The most ancient of the Pleistocene rock layers in south Florida is the Fort Thompson Formation. Sellards (1919) first applied this name to the formation, which consists of beds of fresh water marl and limestone alternating with beds of marine shell marl, in the vicinity of Fort Thompson on the Caloosahatchee River (Cooke 1945). The Fort Thompson includes three separate and distinct marine shell beds, the youngest of which is the Coffee Mill Hammock marl. The three marine beds are separated by two thin beds of soft marl containing shells of fresh water snails. The tops of the fresh water beds have been hardened into brittle limestone, but are perforated by solution holes which are filled with marine shells from succeeding strata. The Fort Thompson Formation is of special importance to the human population of the southeast coast for it forms part of what is commonly referred to as the Biscayne Aquifer, the sole drinking water source for much of the southeast coast. Figure 22 from Dubar (1974) shows the Fort Thompson Formation in relation to more recent Pleistocene strata in south Florida. Toward the east coast the formation is relatively thicker than toward the west coast, where it thins out about half way across the peninsula.

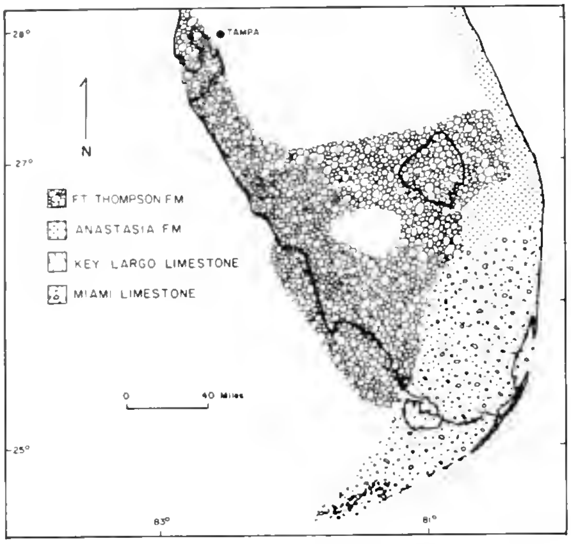


Figure 22. Distribution of surface exposed Pleistocene formations (adapted from Dubar 1974).

Of the major formations laid down during the Pleistocene, the Miami Limestone is by far the most prominent surface exposed formation within the lower Everglades, Florida Bay, and to some extent the Keys. Miami Limestone, first named Miami Oolite by Sanford (1909), refers to the generally soft white limestone that extends over much of the southern tip of Florida and the terminal Keys. To the northeast the formation gradually increases in sand content until it merges, in the vicinity of Palm Beach, with the sandy Anastasia Formation also of the Pleistocene Epoch (Cooke 1945). In the lower Keys the formation again gradually increases in sand content, a fact which led Sanford (1909) to name the formation the "Key West Oolite" in the vicinity of the Keys. However, more current research on the origins and relationships within the Miami Limestone have led to general abandonment of the term "Key West Oolite".

Hoffmeister et al. (1967) describe the "Miami Limestone" as composed of two distinguishable facies, an upper oolitic facies and a lower bryozoan facies. The upper oolite facies began forming in the late Pleistocene epoch when sea level conditions favored the formation of unstable oolite sand belts just back from the outer edge of the Florida platform. The constituent particles of the oolitic facies are ooids, pellets, and skeletal sand. Ooids are concentrically laminated, spherical to subspherical grains which formed as a result of the unique physical and chemical conditions which occurred on shallow sand belts along the southeast coast. The nuclei of ooids may be composed of any type of rock fragment, such as calcite, shell, or quartz sand. As deep water from the Gulf Stream rushed over the shallow bank, the temperature and salinity of the water increased, thus decreasing the solubility of calcium carbonate. The water became increasingly turbulent and agitated, causing excess carbon dioxide to be driven off, further reducing the calcium carbonate solubility. Together these actions resulted in the precipitation of calcium carbonate around tiny rock fragments leading to the formation of typical ooids (Hoffmeister 1974). As would be expected on a relict oolite sand belt, ooids comprise the major rock type found in the Atlantic Coastal Ridge. West and northwest of the ridge (into the Everglades and Taylor Slough headwaters) ooids decrease to approximately 10% of the rock. The pelletal component of the oolite refers to grains which are ellipsoidal in shape and carry no implication of their origin, while the skeletal sand component originates from the remains of numerous shallow water mollusks and bryozoans.

The oolite facies contains localized layers of calcite which generally increase in crystalline structure with depth (Ginsburg 1954). As one proceeds down in the oolite, many of the aragonitic ooids and pellets have been entirely or partially replaced by calcite. In the lower levels beneath the water table, many of the ooids and pellets have themselves been completely dissolved, leaving only cavities in the calcitic cement. Hoffmeister et al. (1967) refer to the character of this cavity ridden limestone rock as oomoldic.

In physical appearance the oolitic facies may often be crossbedded, i.e., exhibit longitudinal ridges oriented at varying angles to one another. These are more prominent on the seaward side than on the Everglades side of the Atlantic Coastal Ridge. The crossbeds are believed to have formed as a result of the complex tidal and wave action to which the ridge was exposed.

On the western side of the coastal ridge the oolitic facies slopes gradually down toward the Everglades, slowly decreasing in thickness over the distance of a few miles. In its place the underlying bryozoan facies of the Miami Limestone is exposed at the surface (Figure 23).

The bryozoan facies, which averages 3 m (10 ft) in thickness, consists of large numbers of massive tubular cheilostome bryozoan compound colonies, primarily Schizoporella floridana. Many of these colonies are 30 cm (1 ft) or more in diameter. As outlined in Figure 23, the bryozoan facies underlies the oolitic facies beneath all but the southern tip of Taylor Slough. Here and southward to the upper Keys the oolite appears to be continuous down to, or contemporaneous with, the Key Largo Limestone. A fair number of fossil corals, especially branching Porites sp., are found along this strip in place of the bryozoans.

Hoffmeister et al. (1974) describe the occurrence of two main growth forms of bryozoan colonies:

(1) those that are rough irregular masses with knobby subcylindrical projections that vary greatly in size; these are the more numerous group as well as generally larger in size; and

(2) a smaller size form, 10 to 13 cm (4 to 5 in) at most, also irregular with crooked branches emanating from a bumpy base. The tubes have a tendency to flange out near the tops.

In their present environment, bryozoans in Florida Bay are often found encrusting around gorgonians, blades of sea grasses, and green algae. This same growth form is evident in the geologic record of the "Miami Limestone".

As the shallow seas slowly retreated, the submerged oolitic bar (now the Atlantic Coastal Ridge) gradually emerged as dry land. During this slow retreat tidal channels were cut through the unstable oolite, connecting the shallow sea that lay over the present Everglades with the Atlantic Ocean to the east. These tidal channels can be seen today in the Atlantic Coastal Ridge as complete or partial transverse cuts and valleys often called "Transverse Glades" (Davis 1943). Some of these contain major fresh water streams and canals, while others are overlain by sand or shell deposits. One of the larger of these relict tidal channels connects Taylor Slough head waters with upper Taylor Slough.

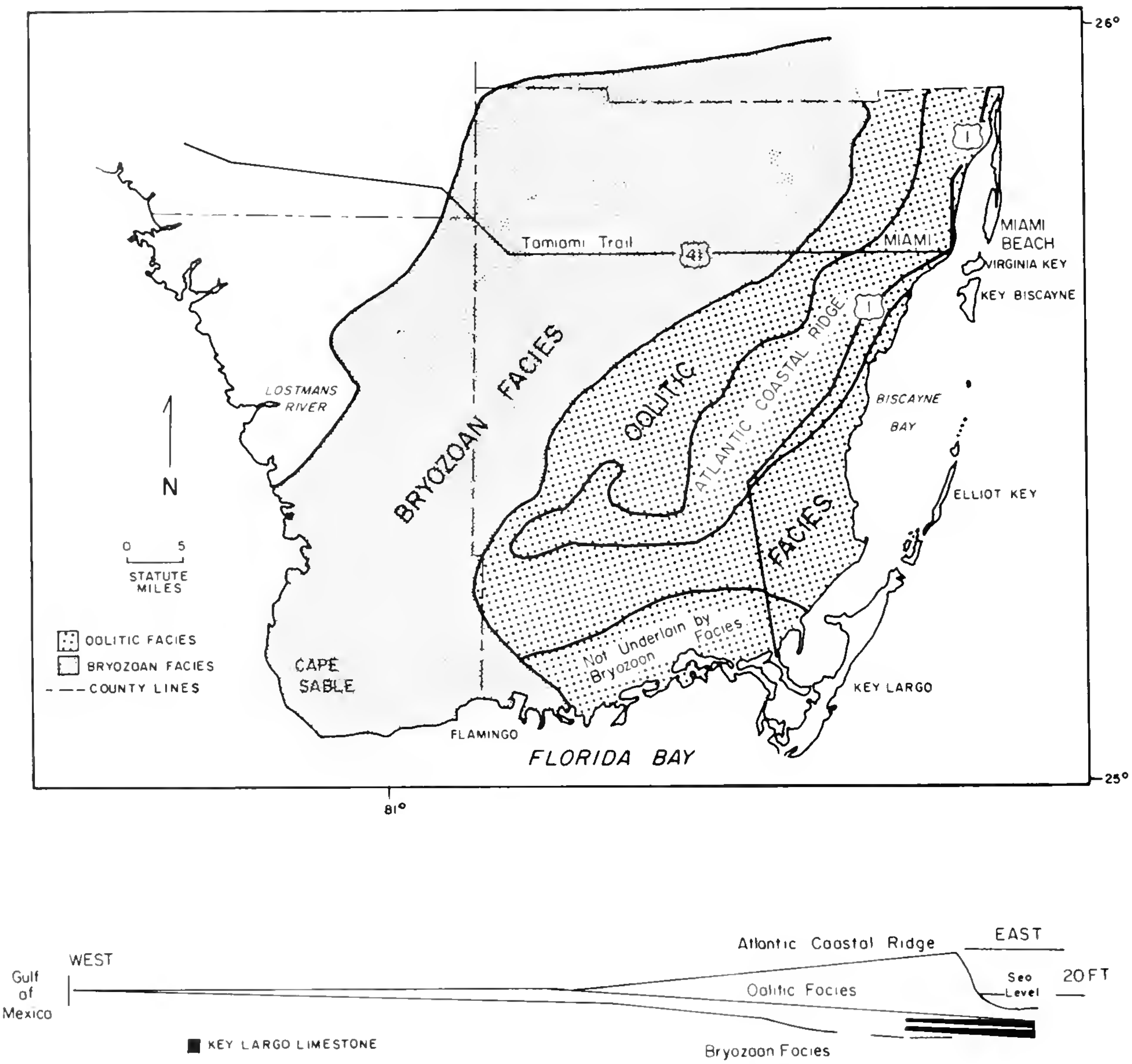


Figure 23. Distribution of the Miami Limestone (adapted from Hoffmeister et al. 1964).

According to Hoffmeister et al. (1967), ecologic conditions behind the coastal ridge during periods of the Pleistocene were ideal for the encrusting bryozoan Schizoporella floridana to flourish. Some polychaetes and mollusks such as Strombus sp., also found the shallow sea environment relatively hospitable. On the southeast facing forefront of the ridge, tidal flushing of a migrating sand shoal/patch reef complex made it possible for corals to encroach upon the bryozoan community (Perkins 1977). This accounts for the lack of underlying bryozoans at the southern tip of Taylor Slough and beneath Florida Bay, and their relative replacement there with Porites corals and Key Largo Limestone.

Key Largo Limestone, first named and described by Sanford (1909), represents a typical organic reef composed of in situ, wave resistant elements, the most important of which are hermatypic corals. These form the framework of the structure and are responsible for the trapping of large amounts of calcarenite in which they are now embedded (Multer 1977). Hoffmeister and Multer (1964) summarize the spatial distribution, community composition, chemical composition, and additional qualities of the Key Largo Limestone as follows:

"The Key Largo is an elevated coral reef of Pleistocene age. Its horizontal extent is now fairly well known by aerial examination and core borings. It underlies Miami Beach in the north, comes to the surface at Soldier Key and is again submerged beneath the Miami Oolite from Big Pine through Key West. In addition it has recently been found a few feet beneath sea level along the eastern shore of the Florida mainland from Miami southward for at least 40 miles.

"It varies considerably in thickness throughout. At Key West and Big Pine Key it is at least 180 feet thick, at Grassy Key 170 feet, at middle Key Largo 70 feet, and at the northern tip of Key Largo 145 feet. Wherever its base has been located it rests on an unconsolidated quartz and calcareous sand.

"Its composition is that of a typical coral reef with large, massive coral heads, many in place, surrounded by smaller coral colonies, shells and shell fragments of all sizes of common marine organisms. Reef building corals are found from top to near the bottom of the formation, but, in general, are more prolific in the upper two-thirds than in the lower third. An indurated calcarenite of varied organic components is probably the most important rock by volume.

"Probably the dominant coral species of the formation are Montastrea annularis, Diploria clivosa, D. Strigosa, D. labrinthiformis and several species of Porites. In addition Acropora cervicornis is prolific at several localities. Practically all the coral species found living today on the Florida reef tract can be recognized in the Key Largo. One notable exception is Acropora palmata. This species, commonly known as the Elkhorn coral, is one of the most prolific in the living reefs and as yet has never been located in the Key Largo.

"...The great bulk of the Key Largo Limestone is greatly altered and recrystallized. Some excellent specimens of well-preserved corals can be found here. From these it has been determined, on the basis of the Thorium-Uranium ratio that the apparent age of the upper part of the Key Largo Formation is about 100,000 years.

"One of the most interesting types of lithology of the Key Largo is what has been called for want of a better name "holey limestone". This rock displays an unusual framework structure in which numerous large and irregularly shaped holes, which comprise 40 to 60 percent of the total volume, are present. The rock is found chiefly a few feet below sea level and is brought to the surface in large quantities by dredges engaged in making cuts for boat slips and canals.

"The origin of this rock has posed a difficult problem. Although it is believed to have been formed in more than one way, it is now

known that the accumulation of tremendous amounts of fragments of a thin branched Porites accounts for much of it.

"The stratigraphic relation between the Key Largo Limestone and Miami Oolite can be seen at a contact at the southeastern point of Big Pine Key. Here the Miami Oolite gently overlaps the old coral reef in a southern direction. The contact appears to be of a transitional character. No other surface contact has been seen in the lower Keys. However it is known that the oolite cover of these Keys is relatively thin, particularly along their southern borders. For example at Boca Chica and Stock Island it has a thickness of only 3 to 6 feet. The oolite cover appears to thicken gradually to the north; at the center of Key West is reaches 20 feet."

Multer (1977), with more recent coring data, reports an expanded range of the Key Largo Limestone to occupy an area up to or exceeding a 20 km (12.4 ft) width (extending both seaward and into the Florida Bay) and extending at least 376 km (235 miles) in a continuous band from North Miami Beach to the Dry Tortugas (Multer and Hoffmeister 1968). The interface of the Key Largo Limestone with the Miami Limestone Formation on the southeast Atlantic Coastal Ridge is illustrated in Figure 23. The Key Largo Limestone intermingles with the bryozoan facies of the Miami Limestone Formation, tapering off in a westerly and northerly direction. The maximum elevation for the formation is +5.5 m (18 ft) on Windley Key in the upper Florida Keys (Dubar 1974). The core borings, besides establishing the formation range, led Multer and Hoffmeister (1968) to divide it petrologically into three major facies:

"(1) an outer reef facies (2 to 4 miles seaward of the present Keys) containing 4 common rock types, including encrustate Acropora palmata boundstone, (2) a back-reef facies (2 miles seaward and approximately 1 mile lagoonward of the Keys) containing 6 common rock types, and (3) a lagoonal facies in the approximate site of modern Florida Bay containing five common rock types.

"Vertical persistence of major facies and similarity of each with overlying Holocene sediments indicate a general continuity of environments for at least the last 100,000 years."

4.4 HOLOCENE SEDIMENTS

Holocene sediments in the lower Everglades and Taylor Slough are the result of a seasonal abundance of rainfall and a warm subtropical climate which have, over the last 5,000 years, stimulated both luxuriant plant growth and case hardening of periodically exposed limestone rock. The case hardening has, in time, made surface penetration of the Everglades trough caprock difficult, thus promoting retention of water and the growth of wetland vegetation. Together these conditions lead to an ideal setting for the production of alternating layers of organic peat and calcitic mud in recent sediments. Holocene sediments in the Keys reflect a much more pervasive marine influence.

4.41 THE EVERGLADES AND SOUTHWEST COAST

Gleason et al. (1974) consider all Holocene sediments and soils of the south Florida mainland to be of the Lake Flirt Formation. Sellards (1919) first named this formation the Lake Flirt Marl based on geologic cross sections exposed in old Lake Flirt to the west of Lake

Okeechobee. However, Brooks (1968) later renamed it the Lake Flirt Formation to include muck layers sandwiched in between the distinct marl beds. Due to the low relief of the area and its recent emergence from the sea, erosional soils are generally non-existent or poorly developed (Davis 1943).

It is generally agreed (Davis 1943, Parker and Cooke 1944, Davis 1946, Gleason et al. 1974) that the distribution of surface sediments and soils in south Florida closely follows bedrock geology and hydrology. Underlying bedrock topography is characterized by two troughs corresponding to Shark River and Taylor Sloughs. In contrast, these distinctive features of the bedrock topography are nearly obliterated in the surface topography. Due to peat accumulation and/or the deposition of fresh or brackish water calcium carbonates, surface relief tends to become flattened out.

Within the lower Everglades and Taylor Slough study area, there are two major divisions of Holocene sedimentary sequences:

(1) that area in which cores to Pleistocene bedrock reveal no brackish water sequences of marl or peat and

(2) that area in which cores indicate (primarily through the presence of Rhizophora peat) an inundation by brackish, marine conditions at some time in the recent past.

The Everglades are characteristically dominated by herb covered marshes and forested swamps. Sawgrass (Cladium jaimaicenis), a sedge, generally prevails over the majority of the landscape, often to the apparent exclusion of all else. Interrupting this river of grass are numerous, relatively small forested areas that may be elliptical, round, or tear-dropped in shape. These are variously referred to as tree islands, heads, keys, cones, or hammocks (Craighead 1971). The shape of individual islands is believed to be a function of surface hydrology (Davis 1943, Loveless 1959). Elliptical islands are prominent in the relatively fast flowing Shark River Slough, while rounder islands are more characteristic of the drier areas north of Florida Bay. The "tails" of tree islands are often found to be growing in furrows of the bedrock (Craighead 1971).

There are different types of islands, and many are successionally related to one another. Some originate on bedrock highs where the slight elevation difference allows colonization by true terrestrial vegetation. Subsequent deposition and trapping of organic matter retains this initial elevation advantage. Other islands such as the "bay head" are usually found in bedrock depressions which are built up to a low mound of organic soils above the surrounding marsh. Still others, such as the cypress and willow heads, exhibit little or no peat buildup above average high water. Spackman et al. (1964) describe a sequence of events whereby cypress initially colonizes a wet area and gradually succeeds into a bayhead. Figure 24 presents cross sectional profiles of these two types of tree islands.

In the cypress island, the underlying veneer of fresh water marl suggests that the area was once a spikerush (Eleocharis dominated) marsh where deposition of calcium carbonate by the marl producing algal mat was once very active. Note that the marl appears perforated by the peat, a characteristic

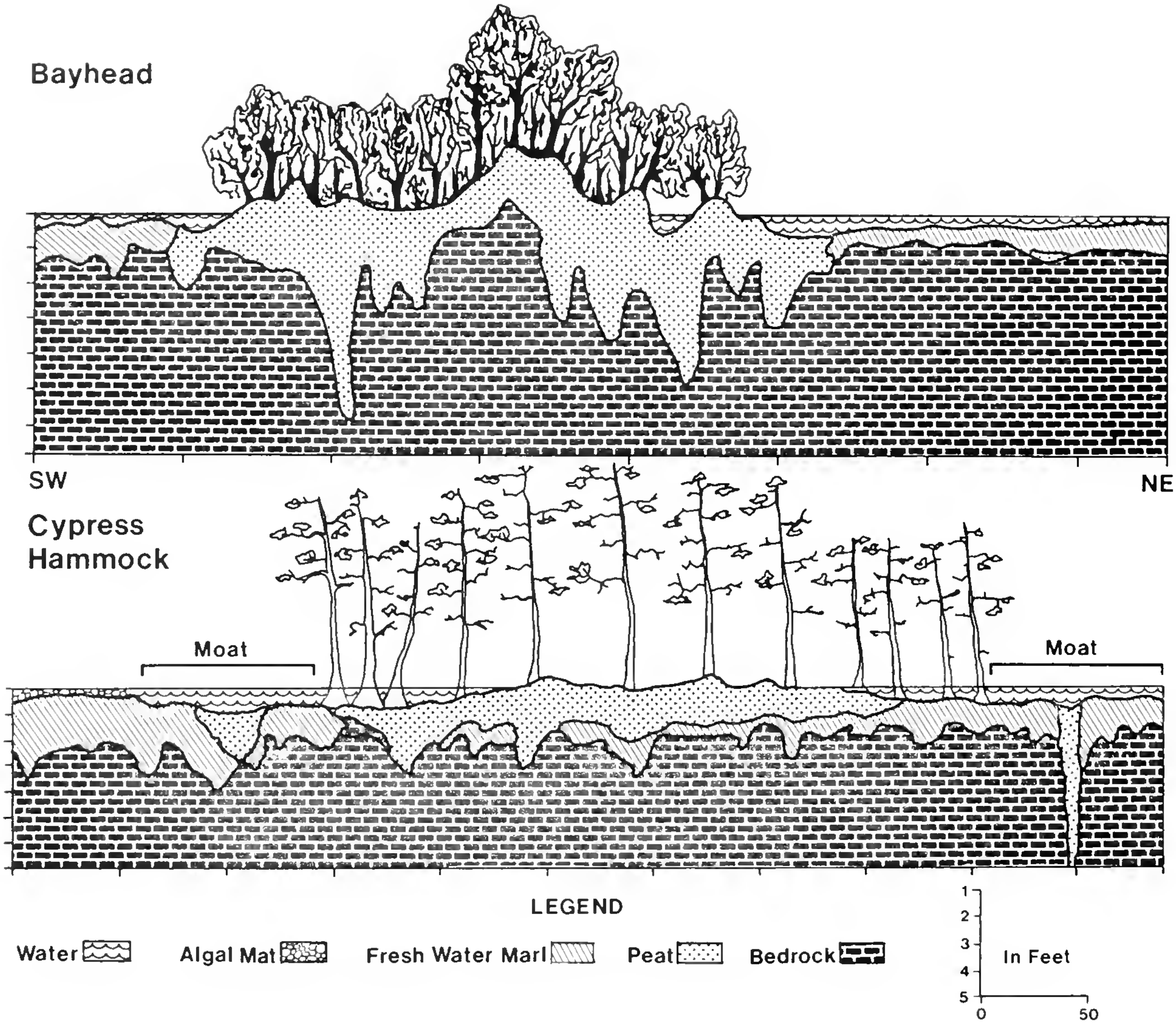


Figure 24. Cypress head/bay head sedimentary profiles (adapted from Spackman et al. 1964).

which suggests to Craighead (1971) that peat accumulation may actually "dissolve" the underlying limestone and thus contribute to the maintenance of the islands. In the bayhead, freshwater marl beneath the island is absent, elevation above the water level is higher, and the characteristic moat of the cypress head is much less conspicuous.

As the last glacial ice sheets of the Pleistocene retreated, sea level gradually rose to the vicinity of where it now stands. However, oscillations of sea level did not stop with the passing of the Ice Age; rather they became relatively smaller and more frequent. Fairbridge (1974) presents a general model of recent sea level changes (Table 11) but warns that the south Florida sequence is not well documented.

(1)	(2)	(3)		(4)
200 - 0	-------	-----	20th C. Submergence	Modern
600 - 200	-1°C	-0.5m	Paria Emergence	Medieval
1,000 - 600	+0.5°C	+0.3m	Gotland Emergence	Viking (Dunkerquian III)
1,200 - 1,000	-0.5°C	-0.5m	--------	"Dark Ages"
1,600 - 1,200	+1°C	+0.6m	Rottnest Submergence	Carolingian (Dunkerquian II)
2,000 - 1,600	-0.5°C	-2m	Florida Emergence	Roman
2,800 - 2,000	+1°C	+2m	Abrolhos Submergence	Iron Age (Dunkerquian II)
3,400 - 2,800	-1°C	-1m	Pelham Bay Emergence	Bronze Age
4,300 - 3,400	+2°C	+3m	Younger Peron Submergence	Neolithic (Calaisian II)
4,700 - 4,300	-0.5°C	-1m	Bahama Emergence	--------
6,000 - 4,700	+2.5°C	+4m	Older Peron Submergence	Mesolithic (Calaisian I)

(1) Years expressed B.P., "before present" (A.D. 1950) in uncorrected radiocarbon years (6,000 B.P. = approximately 6,900 B.P. sidereal years).

(2) Temperature, world average departures for mid-latitudes, at peak stage.

(3) Maximum sea level departure from present M.S.L. (extreme departures probably lasted only a few centuries or less; note that changing tidal characteristics may considerably vary these figures).

(4) Cultural labels are, for general interest, those of northern Europe, with chronostratigraphic terms from the Flandrian area.

Table 11. Mean sea level oscillations during the last 6,000 years (presented in stratigraphic order from top to bottom; to perceive the historic sequence, read table from bottom to top) (adapted from Fairbridge 1974).

Concurrent with sea level fluctuations, climatic conditions (i.e. temperature and rainfall) also oscillated. These latter oscillations in turn exerted rather dramatic effects on surface and ground water tables, salt water intrusion, hydroperiods, and consequently on sedimentary environments and rates in southern Florida. Some of the record of these fluctuations lies buried beneath the swamps, while the rest is either totally eroded or less conspicuously preserved beneath the continental shelf.

Early opinions (Davis 1940) that the growth of the southwest Florida shoreline was regressive, i.e. sea level was receding, due to sediment accumulation and land building by mangroves, were at least partially founded on an error in the assigning of a marine origin to the basal carbonate sediment (Gleason et al. 1974). From historical accounts of red mangroves growing inland from their present distribution, it was suggested by Davis (1940) that the mangrove forest might be moving seaward. Today it is generally agreed that mangroves may well act as sediment traps and shoreline stabilizers; however, major shifts in shoreline features are more likely dominated by sea level fluctuations, longshore drifts of sediment, tidal scouring, erosion, and fluctuations in climate and water table. Figure 6 identifies the shoreline types occurring along the mangrove coast of the Everglades. These are particularly important zones to remember since they more or less define the forces that shape the southwest coast environment.

In the cape sector of Figure 6 the Holocene record is dominated by interfingering beach, marl, and peat. Behind the aggrading barrier beach on the forefront of the cape are hardwood hammocks, salt marshes, salt barrens, and shallow lakes which in places overlie a continuous peat layer as much as 2.7 to 4 m (9 to 13 ft) thick (Spackman et al. 1964, Smith 1968). To the north of the cape sector lies a dissected section of coastline known as the tidal scour sector. As mentioned earlier, the mangrove forest and underlying peat in this section of the coast are being actively eroded and swept out to sea.

Recent sediments within Whitewater Bay itself are gradational in a northeast to southwest direction going from predominantly fresh water to predominantly brackish (Spackman et al. 1964). Bedrock contours in Whitewater Bay reveal a slight ridge (2 m or 6 ft contour) just behind the mouth of the slough entry sector. Islands in Whitewater Bay, which vary from a few square yards to many hectares in area, are generally steep, two-sided sequences of peat overlying a thin veneer of freshwater marl. Within the open water of Whitewater Bay and especially in the mangrove ponds to the northeast, a sediment called "liver mud" (Davis 1940) abounds. This jellolike sediment is believed to result from the mixing of eroded peat with freshwater marl brought in by surface runoff.

To the south of Whitewater Bay toward Flamingo, recent sediments form a slightly elevated bank of marine marl known as the Flamingo Marl (Davis 1943). This bank is believed to have been heaped upon the shoreline by storm waves (Craighead and Gilbert 1962). Figure 25 presents a general profile of recent sediments from Florida Bay at Flamingo, north through Whitewater Bay.

The slough entry sector of Figure 6 refers to the area where Shark River Slough and Whitewater Bay enter the Gulf of Mexico. Numerous steeply sloping islands, often covered with straight boled red mangroves 15 to 23 m (50 to 75 ft) tall, dominate the coastline. The islands, like those of Whitewater Bay, are essentially blocks of peat resting on bedrock or thin marl. Occasionally, the upper half of the block may be composed of carbonaceous mud. Island surfaces are commonly higher on their gulf or tidal channel exposed sides, thus forming a sort of marl levee. Sediments of the levee are composed of calcareous and siliceous muds which have been heaped up by storms. Some of the mud carries over the island margins and mixes with the accumulating organic matter to form the upper carbonaceous mud layer of the peat blocks.

To the north of the slough entry sector the coastline is relatively smooth, and black mangroves (Avicennia germinans) may extend all the way to the shore. This is known as the river sector portion of the coast. Cross sections from cores at the mouth of the Harney River show a buried peat layer extending nearly 3.2 km (2 mi) out into the gulf beneath surface marine sediments. These cores provide very convincing evidence of a transgressing sea (Spackman et al. 1964).

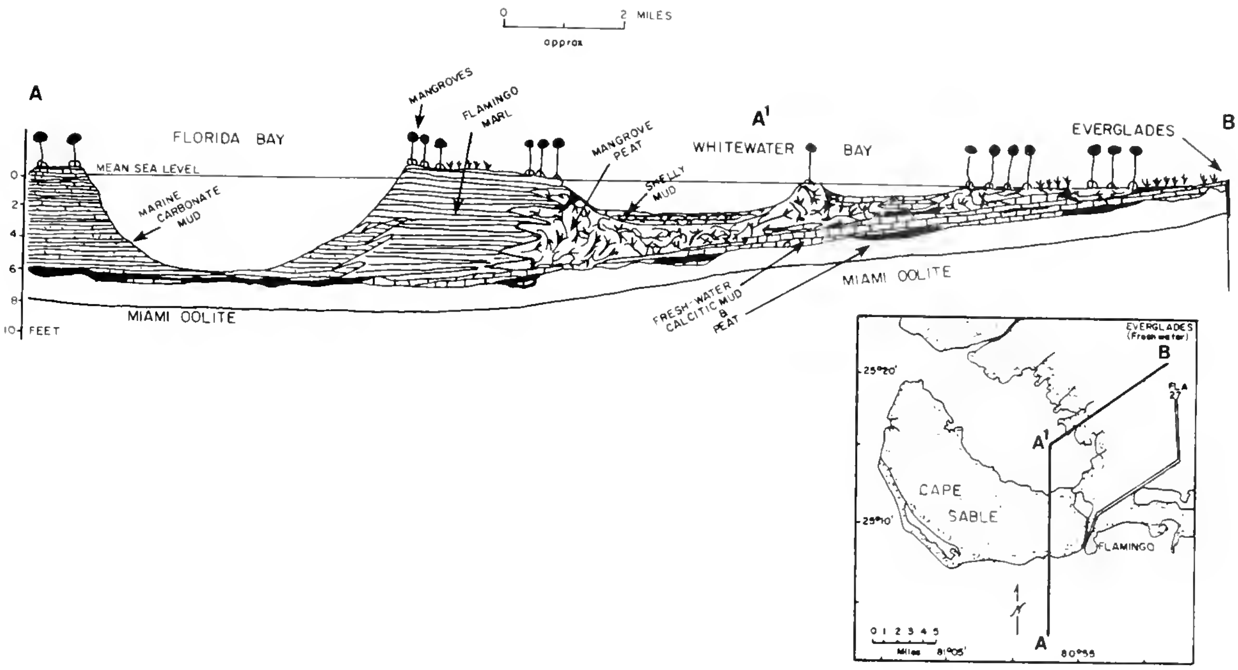


Figure 25. Sectional profile through Florida Bay, Flamingo, Whitewater Bay, and the Everglades (adapted from Spackman et al. 1964).

For a detailed account of recent sedimentary sequences and a general historical picture of the fresh to saltwater transition zones of the southwest coast during the Holocene, the reader should consult Smith (1968) and Cohen (1968). These authors outline the sedimentary patterns of marl and peat along the lower Everglades from Flamingo and Cape Sable to just north of Lostman's River.

4.42 TAYLOR SLOUGH AND FLORIDA BAY

The most extensive work on the distribution, origin, and stratigraphic relationships of Holocene sediments in the southern Everglades (particularly Taylor Slough) is presented by Gleason (1972), and summarized by Gleason et al. (1974). Representative cores of six distinct stratigraphic groups and a map of their distribution in Taylor Slough appear in Figure 26.

Group A, located in the deepest central portion of the slough, is composed exclusively of peat. Alternating layers of water lily (Nymphaea odorata) and sawgrass peats reflect changes in the surface environment due to climatic and sea level fluctuations. Gleason et al. (1974) believe the entire central depression of Taylor Slough is probably underlain by this continuous peat substrate down to the oolitic bedrock. The alternating but continuous record of peat suggests that this portion of the slough has always been wet, variations have occurred in mean depth and hydroperiod due to Holocene climatic fluctuations.

Group B, located on both the western and eastern margins of the slough, is composed entirely of calcite. The calcite is produced through the action of the blue green algal mat that extends over much of the exposed limestone and is common

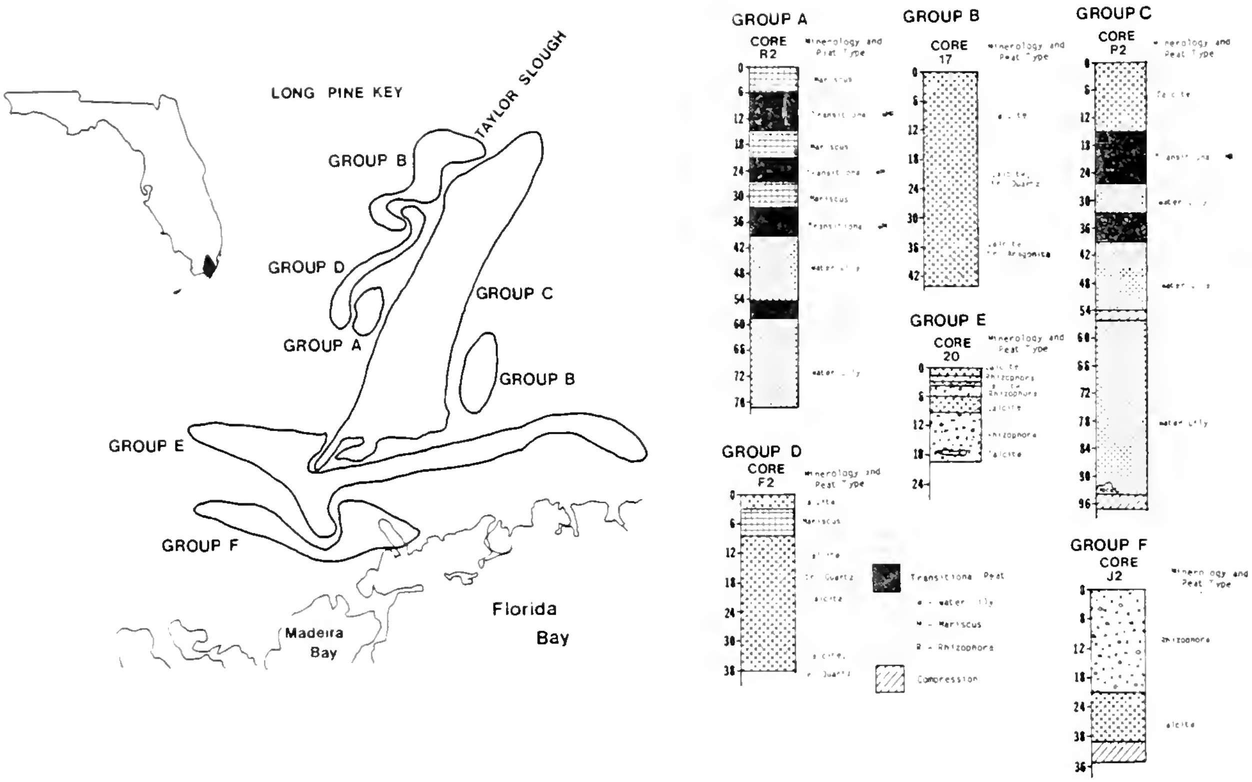


Figure 26. Taylor Slough sedimentary zones and core types (adapted from Gleason et al. 1974).

in the "marl prairie" communities to the east and west of Taylor Slough. This ongoing deposition of calcite is believed analogous of the conditions which produced the strata of the Lake Flirt Formation. The continuous calcite strata in these cores suggests the recent environment has remained fairly constant in these vicinities.

Group C, located on the eastern margin of the slough and running parallel to its axis, consists of an upper layer of calcite underlain by alternating layers of peat. Gleason et al. (1974) interpret this structure as a "filling up" of the basin with sediments. Deep water peats gradually build up, then transitional peats, and finally, as the hydroperiod shortens, calcareous periphyton begin depositing a calcitic mud layer.

Group D, located on the western margin of the upper slough, consists of a peat layer sandwiched in between two calcite layers. Gleason interprets this structure to represent an historical shift in hydroperiod allowing peat to build up in a relatively wetter area. A subsequent drop in water level forced the return of a calcite producing, relatively drier environment.

Group E, located along the upper fringe zone between Taylor Slough and Florida Bay, represents a transitional environment reflecting the oscillations of Holocene sea level. The many alternating layers of red mangrove peat and calcitic mud indicate that neither marine nor freshwater conditions have dominated during recent time.

Group F, located along the southern lip of the slough consists of red mangrove peat overlying a layer of calcitic mud. This arrangement supports the theory of a general transgression of the sea over south and southwestern Florida (Scholl et al. 1969).

In Florida Bay, Holocene sediments range in thickness from 15 cm (6 in) in the lake areas to 3 to 3.7 m (10 to 12 ft) near Cape Sable. Radiocarbon dating indicates that deposition of these largely unconsolidated, fine grained calcareous muds began about 4,000 years ago (Scholl 1966), during the Flandrian transgression (rise in sea level) that accompanied the melting of the last continental ice sheets.

Prior to this time, the bedrock of Florida Bay had been invaded by wetland and terrestial vegetation similar to that of the present day Everglades. The surface was also exposed to the same forces of erosion and solution from freshwater rains and runoff. As sea level rose, the gradually encroaching marine waters encountered conditions that were similar to those now existing in the southern Everglades. Scholl (1966) believes that bank formation (the keys of Florida Bay) began early in the bay's history, presumably where slack water conditions existed due to converging currents. Hoffmeister (1974) believes the keys and shoals provide a rough tracing of former freshwater drainage patterns that have been greatly altered by current action, especially near the Coral Keys and the open gulf. Sediment trapping and further vegetational stabilization from mangroves and sea grasses as sea level continued to rise resulted in the present day configuration of mangrove keys. Ball et al. (1967) demonstrate that the exposed keys and submerged banks may in fact increase in area due to sediments heaped up during hurricanes.

Figure 27 presents a cross section of cores from Cross Bank in Florida Bay (near Upper Matecumbe Key). These cores outline the three major strata of the Holocene sedimentary record that occur in Florida Bay: (1) the very few or no shells layer (corresponding to the carbonate mud of Fleece 1962); (2) the slightly and moderately shelly layer (corresponding to the shelly sand of Fleece 1962); and (3) the peat layer. Peat layering is reported from cores beneath keys (Fleece 1962) and shoals (Turney and Perkins 1972), but is not found elsewhere in Florida Bay away from these structures.

The carbonate mud layer arises primarily from the action of encrusting green algae such as Halimeda sp., Udotea sp., and Penicillus sp., which secrete fragile skeletons of tiny aragonite crystals (Stockman et al. 1967). These same authors estimate that the Penicillus population alone could account for one third of the lime mud production in Florida Bay. Numerous other species of calcareous algae are believed to make up the difference, in addition to some import from the gulf (Hoffmeister 1974).

Ginsburg (1956) reports that 51% of the sediments by weight in Florida Bay have a mean grain size greater than 1/8 mm as opposed to 83% in the nearby Florida Key reef tract. Of this relatively smaller proportion, 87% is of molluskan (76%) and foraminiferan (11%) origin. In contrast to these bay sediments, the shelly sands near the keys contain a considerably greater amount of algal and coral remains.

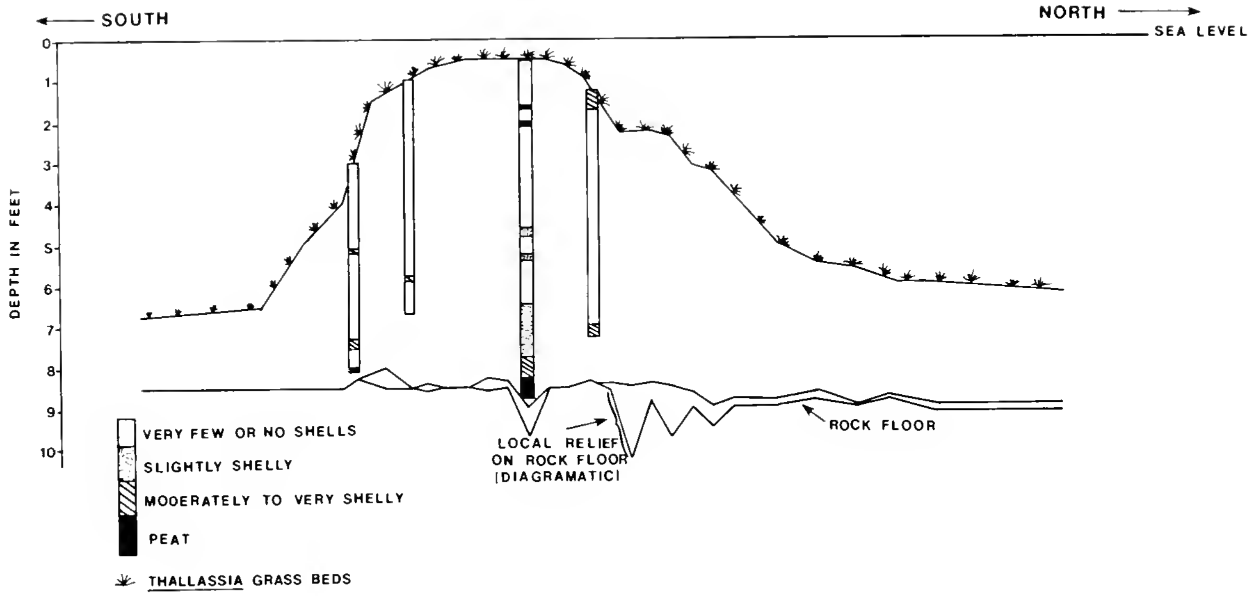


Figure 27. Cross section of Cross Bank in Florida Bay (adapted from Turney and Perkins 1972).

4.43 FLORIDA KEYS

Our discussion of Holocene sediments in the Florida Keys is presented in two sections: (1) sediments of the marine environment; and (2) sediments of the terrestrial and freshwater enviroment. Based on surface area alone, it is obvious that the former of the two dominates in sediment contribution to the area.

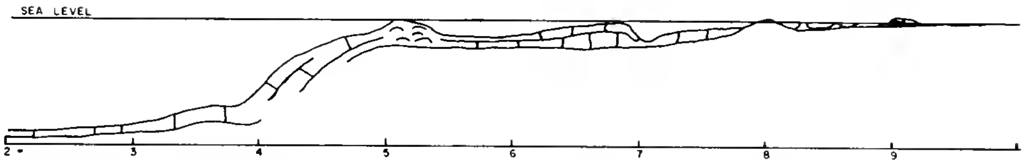
Recent marine sediments of the Keys are produced in what amounts to a vast, multifaceted carbonate factory (Enos 1977). These bioclastic sediments are produced by organisms restricted geographically by bottom morphology, circulation, and most importantly by the very substrate the organisms themselves have produced. Figure 28 illustrates and summarizes the Holocene sediments of the south Florida shelf margin in the vicinity of the lower Keys.

Enos (1977) describes three natural subdivisions of the seaward shelf off of the lower Keys:

(1) the slightly restricted inner shelf margin;
(2) the outer shelf margin where circulation and turbulence are maximum; and
(3) the shallow slope seaward of the shelf break.

The primary controls on sediment distribution patterns are skeletal productivity, mechanical redistribution, pre-existing rock topography, and contemporary sediment topography.

Sediment accumulations in the inner shelf margin are generally less thick and muddier than those on the outer margin. Wedges of sediment piled against the Pleistocene rock of the Keys reach more than 5 m (15 ft) in thickness. These wedges are elongate parallel to the shelf edge. Patch-reef banks of the inner



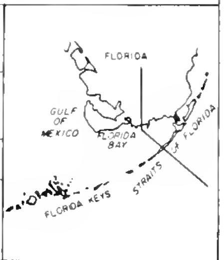
FACIES NUMBER & THICKNESS FACIES	THICKNESS UNKNOWN OPEN MARINE, NERITIC	MAY BE 1500 FEET TOE OF SLOPE CARBONATES	5 TO 40 FEET FOREREEF SLOPE A. MUDDY SKELETAL SAND BLANKET	10 TO 45 FEET ORGANIC REEF A. CORAL-ALGAL REEFS B. SKELETAL SAND	15 TO 35 FEET SHELF EDGE SANDS A. SHOAL SKELETAL SANDS B. BLANKET SKELETAL SANDS C. PATCH REEF SANDS	5 TO 20 Feet OPEN SHELF (INNER SHELF MARGIN) A. MUDDY SAND BLANKET B. PATCH REEF BLANKET C. MUDDY SHOALS	1 TO 12 FEET RESTRICTED SHELF A. MOLLUSKAN MUD BANKS B. MOLLUSK-SHELL BASAL SHEET SAND C. PELLETED SUPRATIDAL MUD D. QUARTZ SAND BLANKET AND BEACHES (E & W FLORIDA COAST	1 TO 8 FEET TERRESTRIAL DEPOSITS A. FRESHWATER LIME MUDS B. PEAT
LITHOLOGY	"LIMESTONE"	"LIMESTONE"	PURE "LIMESTONE"	PURE "LIMESTONE"	PURE "LIMESTONE"	"LIMESTONE" ARENACEOUS "LIMESTONE" AND QUARTZ SAND TO NE	"LIMESTONE" ARENACEOUS "LIMESTONE" AND QUARTZ SAND TO NE AND NW	"LIMESTONE" AND PEAT
COLOR	LIGHT GRAY			WHITE	WHITE	LIGHT GRAY	MEDIUM GRAY	CREAMY WHITE, BLACK
GRAIN TYPE AND DEPOSITIONAL TEXTURE	SKELETAL WACKESTONE SKELETAL PACKSTONE IN STRONG CURRENTS (GULF STREAM)	SKELETAL PACKSTONE?	SKELETAL PACKSTONE, GENERALLY MUDDIER WITH INCREASING WATER DEPTH	COARSE SKELETAL GRAINSTONE, BOUNDSTONE	SKELETAL GRAINSTONE, WELL SORTED, ROUNDED	SKELETAL LIME PACKSTONE, (SOME VERY FINE GRAINED); SKELETAL LIME WACKESTONE	MOLLUSKAN PELLETAL LIME WACKESTONE AND PACKSTONE. PELLETAL-FORAM LIME WACKESTONE AND MUDSTONE.	LIME MUDSTONE
BEDDING AND SEDIMENTARY STRUCTURES	UNKNOWN, SOME BURROWING	UNIFORM THICK BEDS	UNKNOWN, SOME BURROWING	MASSIVE ORGANIC FRAMEWORK WITH INTERNAL CAVITIES, RIPPLES IN GRAINSTONE	RIPPLES, CROSS BEDDING LINED BURROWS	MASSIVE BEDDING, EXTENSIVE BURROWING (BIOTURBATE)	EXTENSIVE BURROWING (BIOTURBATE) LOCAL SETTLE-OUT LAMINATION STROMATOLITES AND BIRDS-EYE VUGS	NONE
TERRIGENOUS CLASTICS ADMIXED OR INTERBEDDED	NONE	NONE	NONE	NONE	NONE	GRADUALLY SANDIER TO NE	ADMIXTURE OF QUARTZ SAND, (<10%), DETRITAL DOLOMITE, DARKENED SKELETAL GRAINS.	SLIGHT QUARTZ SAND ADMIXTURE
A. GENERAL DESCRIPTION	PELAGIC FORMS, LOCALLY SHALLOW WATER BENTHONIC ADMIXTURE	PROBABLY PELAGIC WITH SHALLOW BENTHONIC ADMIXTURE	SHALLOW WATER FORAMS, PELAGIC FORAMS INCREASE WITH WATER DEPTH	ALGAL PLATES & CORAL FRAGMENTS BRANCHING & HEAD CORALS ENCRUSTING CORALLINE ALGAE	ABRADED SKELETONS OF SHELF BREAK FAUNA FEW INDIGENOUS FORMS	SEMIRESTRICTED FAUNA & FLORA, VARIED FINGER CORALS FRINGE SHOALS	SEMIRESTRICTED TO RESTRICTED FAUNA, LARGELY MOLLUSKAN	FRESH-WATER FAUNA
B. ORGANISMS DOMINANT	FORAMINIFERA (PELAGIC) GASTROPODS (PTEREPODS)		FORAMINIFERA (PELAGIC) CORALLINE ALGAE HALIMEDA PLATES CORALS MOLLUSKS ECHINOIDS	HALIMEDA PLATES CORALS CORALLINE ALGAE PELECYPODS FORAMINIFERA, INCL. HOMOTREMA ECHINOIDS (LONG SPINES)	HALIMEDA PLATES CORALS, GASTROPODS PELECYPODS, FORAMINIFERA (PENEROPLIDS), CORALLINE ALGAE, ECHINOIDS (FRAGMENTS)	HALIMEDA PLATES GASTROPODS, PELECYPODS, FORAMINIFERA, (PENEROPLIDS, MILIOLIDS), CORALS (FINGER CORALS, HEAD CORALS)	GASTROPODS, PELECYPODS, FORAMINIFERA (MILIOLIDS) OSTRACODS, BRYOZOANS	GASTROPODS, OSTRACODS
GEOCHEMICAL DATA				75-95% ARAGONITE 5-25% Mg CALCITE	80-96% ARAGONITE, 5-30% Mg CALCITE	55-90" 16 ARAGONITE, 35 TO 10% Mg CALCITE, 0 TO 10% CALCITE	50-65% ARAGONITE, 20-45% Mg CALCITE, 10-15% CALCITE, 1-1% ORGANIC CARBON	100% CALCITE MUD 40 % ORGANIC CARBON IN PEAT
DIAGENETIC FEATURES				BORING PELECYPODS, WORMS, ETC. MANY ENCRUSTERS	MICRITIZATION			
POROSITY DEVELOPMENT				INTRA-& INTERGRANULAR POROSITY EXCELLENT POTENTIAL	EXCELLENT POTENTIAL, INTRA-INTERGRANULAR, POROSITY	LOW POTENTIAL, DESPITE BUILDUPS	LOW POTENTIAL	
RECORDED VELOCITIES					5400 FT/SEC	5400 FT/SEC		
RESERVOIR DATA				POROSITY 47% PERMEABILITY 33,000 Md	POROSITY 44-57%, PERMEABILITY 5,400 TO 34,000 Md	POROSITY 65%, PERMEABILITY 60 TO 325 Md	POROSITY 60-75%, PERMEABILITY 0.9-80 Md (>2000 Md IN SUPRATIDAL MUD)	

Figure 28. Summary of Holocene sediments of the south Florida shelf margin (adapted from Enos 1977).

shelf margin also tend to be elongate parallel to the shelf edge, but most are small, less than 2 km (1.2 mi) long. Tidal deltas, oriented perpendicular to the shelf edge, develop where passes between rockfloor highs enter restricted basins of the inner shelf. Most of the sediment in tidal deltas is generally less than 5 m (15 ft) thick.

Changes in sediment thickness and total volume along the lower Keys are most closely tied to the amount of tidal exchange with the restricted shelf. Where water from the inner shelf and the broad Gulf of Mexico shelf flows across the shelf margin, sediment acumulation is reduced, probably owing to decreased productivity. Tidal deltas and inner shelf-margin sediment wedges are lacking here, too, because they are dependent on current constriction by the Florida Keys.

The outer margin, (> 3 km or 2 mi) is the site of the thickest (typically 8 m (26 ft) or more) and most permeable (up to 35 darcys) sediments in the Holocene package. The thickest sediment accumulations lie in belts parallel to the shelf edge. The trends of these belts are quite predictable, but the sediment thickness and physical properties vary along the axis of the coast. The outer reef belt is the most nearly continuous and the thickest. It is 1 to 2 km (about 1 mi) wide and located immediately behind the shelf break.

The shallow-slope sediment blanket is thickest within a kilometer of the shelf break at a water depth of about 30 m (100 ft). Shelf-edge sands form prisms of thick sediment 1 to 2 km (.6 to 1.2 mi) wide, 2 to 3 km (1.2 to 1.9 mi) behind the slope break. The largest sand shoal is 40 km (25 mi) long and as much as 9 m (30 ft) thick. Where sand shoals are lacking, a belt of discontinuous patch-reef banks may occupy the same position. The patch-reef belt is also 1 to 2 km (.6 to 1.2 ft) wide, trends parallel to the shelf, and may be more than 8 m (25 ft) thick, but continuity is poor and the sediments are generally muddy. A bed-rock depression with a thin layer of muddy sediment isolates the patch reef belt of the lower Keys from the outer reef belt.

Enos (1977) states that the Holocene sedimentary sequence differs from the Pleistocene in that it contains little quartz or nonskeletal carbonate, and the distribution of grainstone is less widespread. He attributes these differences to the relatively small degree of submergence in recent time and the low supply of terrigeosus material from the Florida mainland. Table 12 summarizes the existing sediment producing communities off the lower Keys and their relative productivity.

1. Rock or dead reef
   a. open marine--mainly encrusting and boring organisms
   b. restricted circulation--mainly encrusters and borers
2. Mud
   a. grass covered--turtle grass (*Thalassia*), green algae (*Halimeda*, *Penicillus*) miliolid foraminifera, browsing gastropods, burrowing pelecypods and shrimp (*Calianassa*)
   b. bare--a few green algae, foraminifera
3. Sand
   a. grass covered--*Thalassia*, *Halimeda*, peneroplid foraminifera, browsing gastropods, burrowing pelecypods
   b. bare--burrowing echinoids
4. Patch reef--head corals
5. Outer reef--corals (*Acropora*, *Montastrea*, *Diploria*, *Porites*), *Millepora*, *Halimeda opuntia*
6. Forereef muddy sand--pelagic foraminifera
7. Shoal fringe, restricted--finger coral (*Porites*), red algae (*Goniolithon*), *Halimeda opuntia*
8. Reef rubble--few organisms

Relative skeletal productivity by the habitat communities is estimated as

5 > 4 > 7 >> 2a >> 3a > 1a > 1b > 6 >> 2b > 3b > 8.

Table 12. Mappable habitat communities of the south Florida reef and shelf (adapted from Enos 1977).

Jindrich (1969) and Basan (1973) provide more specific discussion of the Holocene sediment environments in the lower Keys gulf side, an area only briefly discussed by Enos (1977). Figure 29 illustrates the depositional environments outlined by Jindrich (1969). The majority of carbonate sediment accumulation is due to the sediment-trapping effects of the marine grass *Thalassia testudinum* and the calcareous green alga *Halimeda opuntia*. The sediment consists primarily of *Halimeda*, mollusks, foraminifera, and Pleistocene limestone rock fragments (Jindrich 1969). In the Barracuda Keys, to the ENE of Jindrich's study area and still to the gulf side of the lower Keys, Basan (1973) identified a similar pattern of carbonate sedimentation containing the same four major components described by Jindrich (1969) and in the same relative abundance. Studies by Landon (1975) and Kissling (1977) contain more recent and supplemental research on carbonate sediments in the lower Keys' seaward region, out to and including the shallow slope.

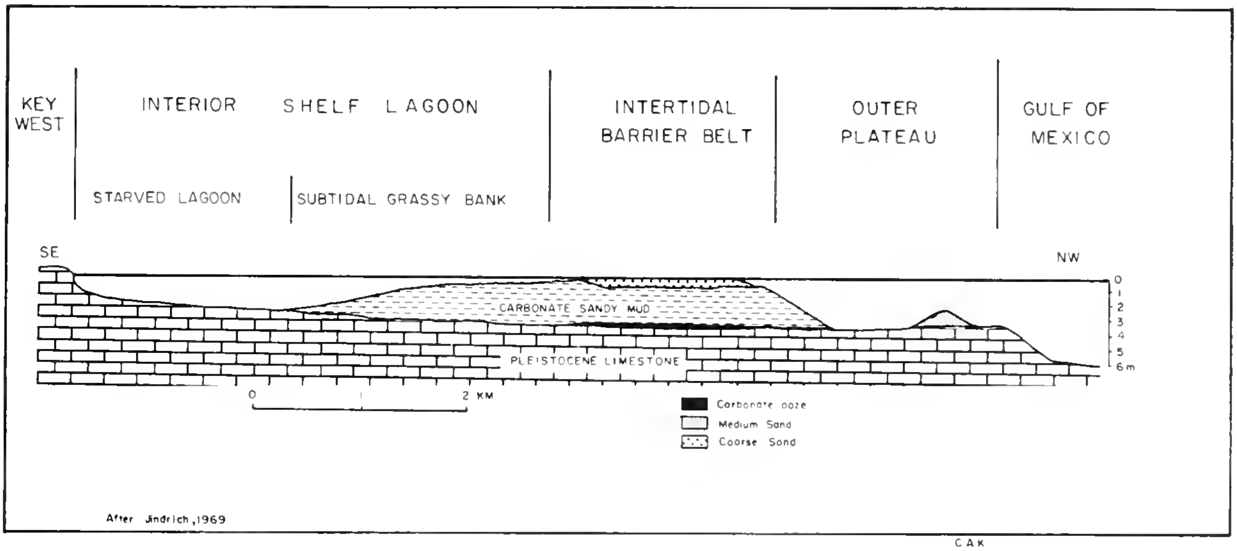


Figure 29. Depositional environments in the lower Keys (adapted from Jindrich 1969).

Holocene sediment investigations in the distal island groups west of Key West (Boca Grande Group, Marquesas Keys, and Dry Tortugas) are rather scarce. For the area including the Marquesas and Boca Grande groups the only study found which addresses recent sediments was Davis' (1942) work describing the general topography of the Sand Keys (name attributed to all three distal island groups). Davis (1942) describes these two island groups as low, calcareous sand and marl ridges emerging from a shallow limestone bank representing an extension of the lower Keys oolitic facies of the Miami Limestone. The composition of the calcareous sediment is similar to banks on the lower Keys' gulf side, as previously discussed (Jindrich 1969, Basan 1973).

Compared to the Marquesas Keys, corals play a much more significant role in the composition of recent sediments in the Dry Tortugas. The Dry Tortugas represent a drowned Pleistocene platform 17 to 21 m (56 to 69 ft) below sea level which is comprised of three biogenic buildups (facies): (1) detrital lagoonal bank, (2) *Montastrea* reef bank, and (3) *Acropora palmata* reef (Jindrich 1972). These facies lie adjacent to one another and are also present in vertical succession as individual growth stages that vary in thickness and lateral extent. A zone of *Acropora cervicornis* develops as a transition between the *Montastrea* and *A. palmata* growth stages. The present reef assemblages and bottom topography have been strongly influenced by cumulative storm effects that are linked to the slow sea level rise over the past several millenia (Jindrich 1972).

Storm degradation is manifested by (1) continuous removal of *A. palmata* and its replacement by storm-resistant coralline algae and *Millepora* sp. to produce truncated rocky surfaces, (2) abundant reef rubble, (3) erosion of spur-grooves, and (4) development of intertidal rubbly reef flats.

Noncoralline sediments range in size from cobble-sized algae to foraminifera. Variations in texture and particle composition are mainly a result of sediment transport and grain shape. In general, three modes of sediment transport produce three characteristic assemblages of constituent particles:

(1) a gravel sized population;
(2) a sand sized population; and
(3) a fine sand to silt sized population.

Strong mixing occurs between the gravel and sand population on the storm degraded shoals, and between the sand and silt population on the lagoon bottom. Sands generally flank the reefs and reef banks and show minimum mixing. Lagoonal bank sediments, stabilized by seagrass and coral growth, are composed of an incongruous mixture of the in-place fraction and varying proportions of transported sediments.

During a low sea-level stand created by a period of Pleistocene glaciation, organic acid solutions created numerous pits or holes in the surface of the Keys' limestone (Krawiec 1963). These pits (geologically referred to as breccias) became, and still act as, storage tanks for coral debris, organic soils from mangrove swamps and hardwood hammocks, and loose material of all available types generated by the hurricanes and lesser tropical storms. These result today in an exposed karst topography over the Florida Keys (Kissling 1968, Seimers and Dodd 1969, Dodd and Seimers 1971, Multer 1977), Florida Bay (Gray 1974), and the seaward lagoonal environment (Turmel and Swanson 1964). The karst topography affects the localized drainage and concentration of soils on the Keys. This concentration in turn influences the terrestrial floral and faunal distribution (Multer 1977). Immediately over the bedrock in the Keys are laminated crusts which are either exposed, covered by thin soils, or covered, in the case of solution holes, by thicker miscellaneous debris described above. Multer and Hoffmeister (1968) describe three types of indurated crusts coating the Florida Keys: (1) porous laminated crust characterized by horizontal root tubes; (2) dense laminated crust, smoother and less permeable than the porous crust and marked by the absence of root tubes; and (3) microcrystalline rind, a thin, dense, tan microcrystaline calcite mosaic. Figure 30 illustrates the mechanisms responsible for forming subaerial crusts formed on the Florida Keys.

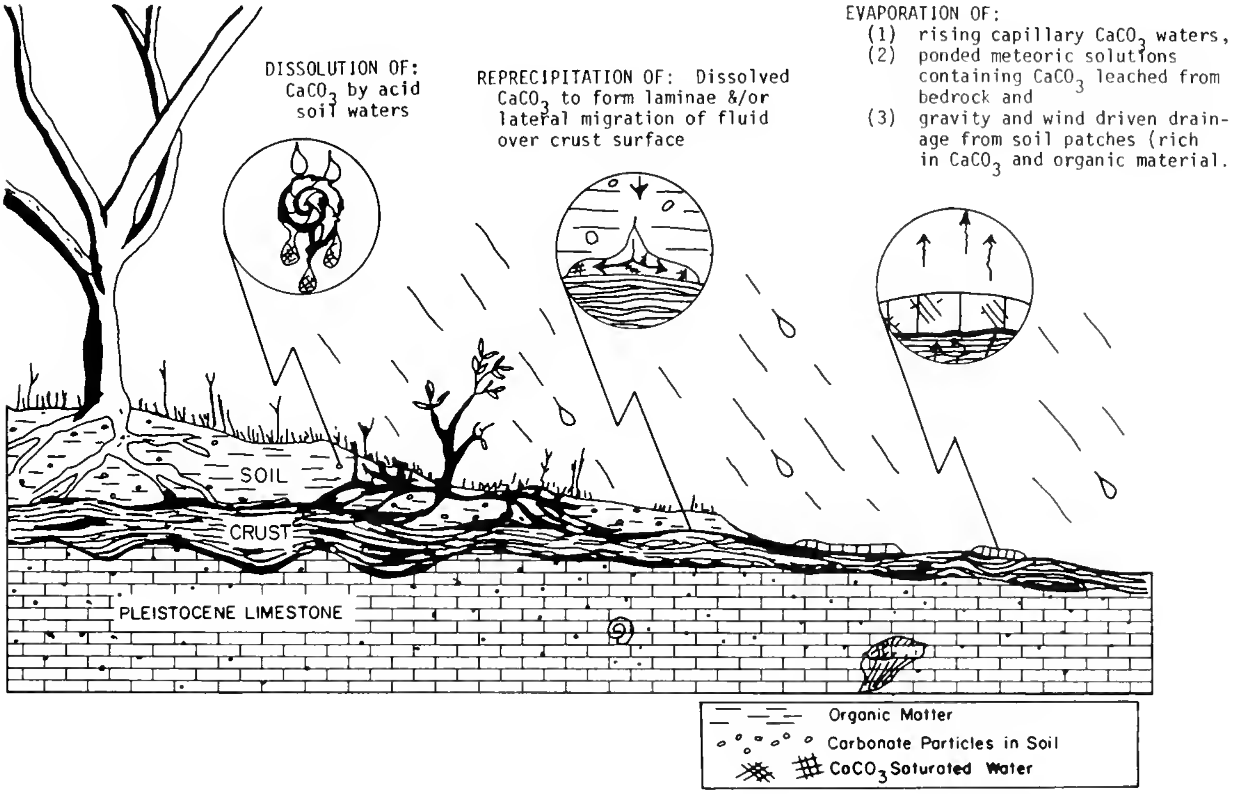


Figure 30. Schematic drawing of mechanisms involved in forming subaerial crusts in the Florida Keys (adapted from Multer and Hoffmeister 1968).

No studies have been found describing the origin and formation of existing freshwater marl areas observed by Alexander and Dickson (1970, 1972) in the Key Deer Wildlife Refuge. Whether these are of marine or freshwater origin is unknown. Davis (1940) describes the succession of mangrove species to climax coastal hammock forests as an accumulation of mangrove and other humus with a marl clay, of marine origin, until it becomes granular and loamy and supports the vegetation of the hammock forests. Observations on the soils associated with the Caribbean pine and hardwood hammock communities included in more recent studies concur with Davis (1940) (Alexander 1953, Alexander and Dickson 1970, 1972).

CHAPTER 5
SURFACE HYDROLOGY AND WATER QUALITY

5.1 HISTORICAL PERSPECTIVE

The quantity, distribution, and quality of freshwater within the Everglades, more than any other environmental characteristic, influences the capacity of this area to support its unique fish and wildlife resources. Before man's influence, the terminal Everglades received a seasonal pulse of surface sheetflow. It began in June or July, spread slowly toward the coast, and reached peak flow and stage around October. As Lake Okeechobee filled with fresh water from direct rainfall and Kissimmee River runoff, it eventually spilled over at points in its southern boundary and began filling the 64.4 km (40 mi) wide river of grass. As the lake continued to rise due to heavy summer rainfall, the entire southern lip of the lake would gradually become obscured by a continuous connection between the open water to the north and the sawgrass plains to the south.

Water levels in the pre-drainage Everglades were on the average much higher than today, occasionally leading early investigators to refer to it as a "lake" (Parker 1974). The Atlantic Coastal Ridge acted as a partial dam on the Everglades eastern boundary. Water periodically spilled over this dam through the lower transverse glades, through falls eroded in the porous limestone, or over the top of the ridge when waters were especially high. The relative hydraulic head (approximately 3 m or 10 ft during low water) resulted in numerous artesian springs in downstream Biscayne Bay; apparently outflow occurred through subterranean solution channels. Toward the southwest the predrainage river of grass flowed slowly in a southwesterly trending arc through luxuriant sawgrass marshes, open water sloughs, and mangrove covered shorelines.

Beginning in the early 1900's this pattern of water abundance began to change significantly. In 1882 the construction of the Caloosahatchee Canal signified the beginnings of a physical alteration process in the hydrologic regime that continues today. The period 1905 to 1913 saw the North New River and Miami Canals completed and placed into operation. By 1921 the Hillsboro and West Palm Beach Canals were added. At the same time (1916-1924), the St. Lucie Canal was dug in order to provide drainage for Lake Okeechobee. However, a hurricane in 1926 set back the usefulness of the St. Lucie Canal for this purpose by overloading it with sediment. In 1935 redigging of the canal restored it to its original design conditions. Several other major canals in the Miami area, mainly the Tamiami, were also constructed during the 1920's.

Also in the 1920's, construction of a levee, the Hoover Dike, around the south and east of Lake Okeechobee was begun. Continual expansion of this structure for flood purposes has resulted in a levee some 136.8 km (85 mi) long around the entire southeast portion of the lake, beginning north of the Caloosahatchee Canal. Most of these major structures were in place by the mid to late 1930's.

Beginning in the late 30's it became apparent that the uncontrolled drainage of the Everglades opened up the potential problem of salt water intrusion along the southeast coast. The drought of 1943 through 1945 amplified the potential for this problem and started the search for a long term solution.

In 1949 the Florida Legislature authorized the formation of the Central and Southern Florida Flood Control District (CSFFCD). The purpose of this agency was to develop a comprehensive, coordinated means by which to regulate both flood waters and salt water intrusion.

By 1953 the CSFFCD had constructed a system of levees along the eastern boundary of the Everglades to retain freshwater runoff during the dry season. By 1960 the levees had been expanded to enclose what are now referred to as Conservation Areas 1 and 2 in the northern Everglades. By 1962 a levee running parallel to the Tamiami Canal was completed, giving partial enclosure to Conservation Area 3. By 1967 all but a 11.4 km (7.1 mi) gap along the latter's western boundary was completed, thus allowing regulation of flow to the present study area.

In 1967 canal C-111 was constructed along the southeastern boundary of the study area as part of CSFFCD's South Dade County Area Plan of Improvement (Barnes et al. 1968). The canal, an extension of canal-levee L-31W along the Atlantic Coastal Ridge, was intended to provide flood control, drainage, and navigation benefits for the area from Florida Bay on the south to Tamiami Trail on the north. This area is now known as the East Everglades. A salinity barrier (S-197 of CSFFCD) was constructed and became operational near the confluence of the canal with U.S. Highway 1 in 1968 (Meyer and Hull 1969).

Working from our initial conceptual model of regional ecological processes, Figure 31 presents a modified version which emphasizes and summarizes the major pathways of the hydrologic cycle as it occurs within the study area. Each of the storages in Figure 31, or groups of closely associated storages, is discussed somewhat in sequence with the natural flow of water, and the chemical energy contained within it. Some of these pathways have been discussed in the section on climatic factors. In this section we focus primarily on patterns in the ground related pathways of the hydrologic cycle, such as spatial and temporal variations in flow through and storage of water, and fresh and saltwater fluctuations.

5.2 CONSERVATION AREA 3

Conservation Area 3 is divided into two areas, 3A and 3B, having surface areas of 2,037.2 and 331.2 km^2 (786.6 and 127.9 mi^2) respectively (Figure 32). Regulation of the area varies from 2.9 to 3.2 m (9.5 to 10.5 ft) providing a maximum total storage capacity of 380,000 acre-feet. Due to the sloping topography (4 m or 13 ft on the north to 2.1 m or 7 ft on the south), most of the storage is at the lower end. High evapotranspiration losses due to dense vegetation cover tend to restrict the area's utility as a storage reservoir. In addition to receiving input from upstream pumpage (Canal 123) and direct rainfall, Conservation Area 3A also receives some runoff from the Big Cypress Basin via the L-28 tieback canal (SFWMD 1977).

Prior to the construction of the levees on the south of Conservation Area 3, flow out of the area occurred via numerous bridges beneath Tamiami Trail. In general, the flow was then intercepted and

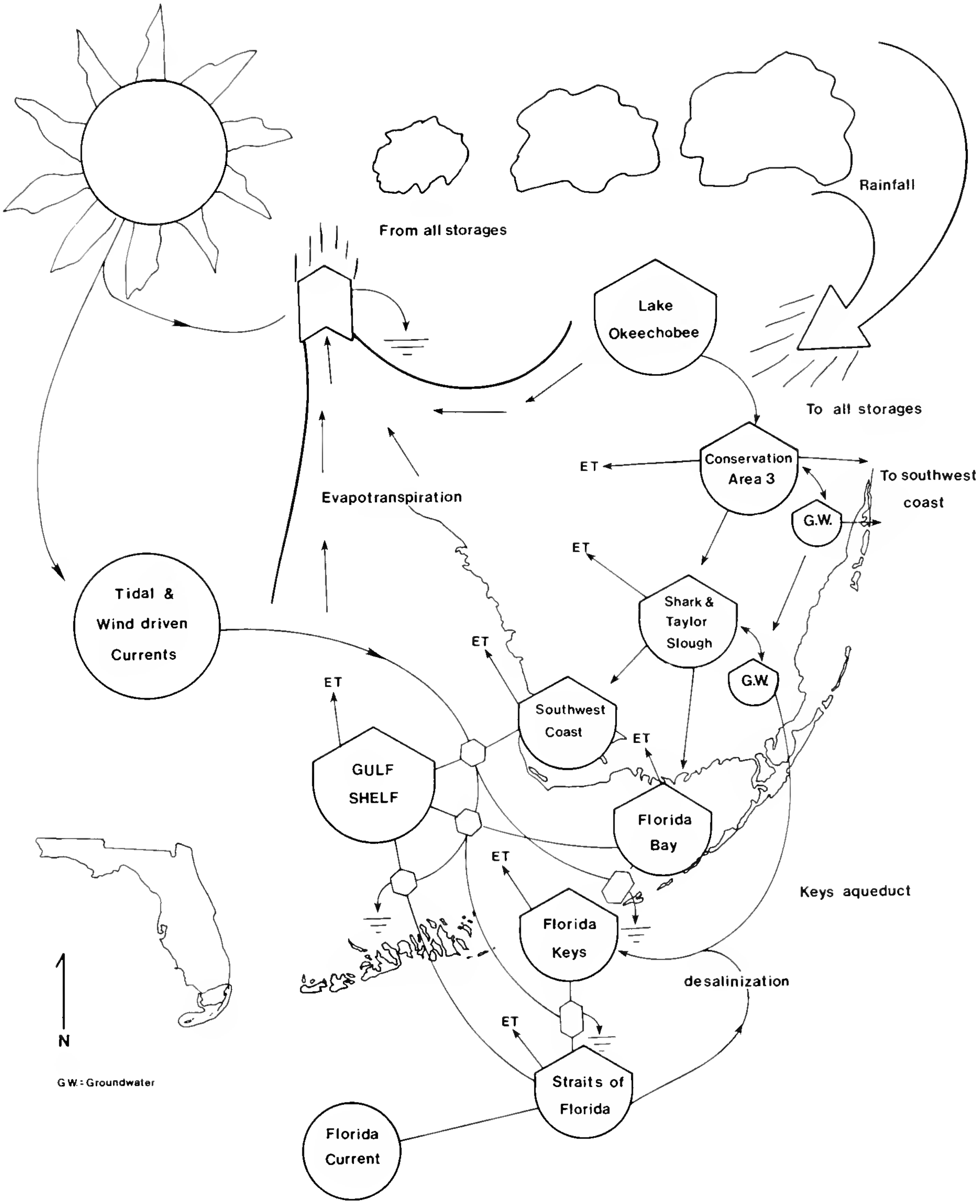


Figure 31. Hydrologic cycle model modified from Figure 4 conceptual model of regional ecological processes.

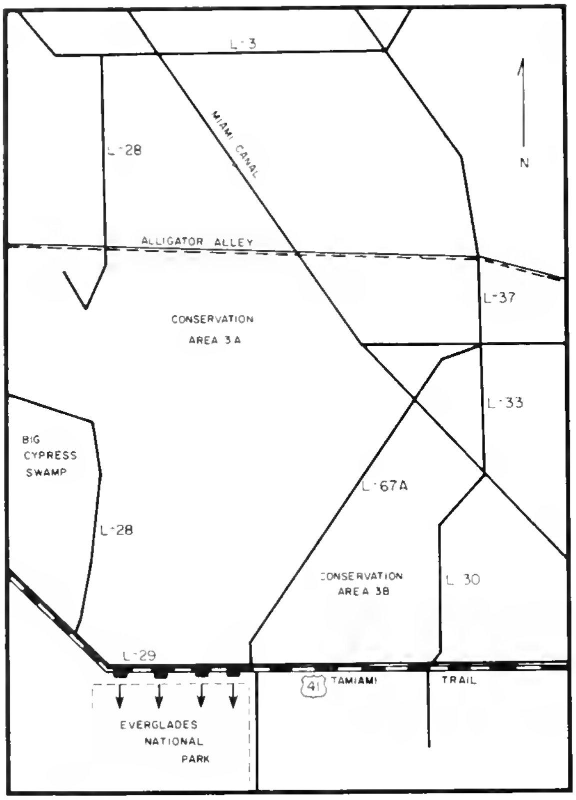


Figure 32. Map of Conservation Area 3 and control structures (adapted from SFWMD 1977).

redistributed by Tamiami Canal southward through numerous stub canals into Everglades National Park (ENP) and the East Everglades (Parker et al. 1955). When levees 29 and 67A were constructed in 1962 and 1963 the pattern and magnitudes of flow delivered to ENP on the south changed dramatically (Leach et al. 1972). Figure 32 outlines the structures and flow patterns involved in the transmission of waters through the Tamiami Canal south to ENP and the East Everglades. Flow patterns across the canal are divided into 3 sections, the western section from Monroe to 40-mile bend, the middle section from 40-mile bend to L-67A, and the eastern section between L67A and L-30.

In the westernmost section beyond Conservation Area 3, Leach et al. (1972) found that flow continued in much the same pattern after levee construction as prior to construction. In the middle section flow was routed through four spillways (S-12, A-D) and down the Levee 67A extension canal, while in the easternmost section flow was restricted to seepage across and under levee L-29. Prior to construction of L-29 the eastern section provided considerably more water to the south Dade, East Everglades area than it does today. Peak flows to the south were highest in the eastern section before levee 67-A directed water to the middle section and levee 29 acted to retain most of the water within Conservation Area 3B. In the middle section peak flows have been augmented due to storage and diversion. In summary, Leach et al. (1972) identify two major changes that have occurred in terms of water input to lower Shark River Slough over the past 40 years:

(1) A general increase in the flow of water to the Everglades resulting from the deflection of water south by levee 30 along the coastal ridge; and

(2) redistribution of the majority of flow through the spillways below area 3A away from the East Everglades due to construction of levee 67-A and levee 29.

Because hydroperiod plays such as important role in the ecology of the Everglades, considerable attention has been fixed on determining a minimum water input requirement for Everglades National Park. This input is to be delivered and regulated by SFWMD, the regional water management agency. Dealing strictly with the runoff component of this input, Leopold et al. (1969) estimated an annual minimum requirement of

315,000 acre-feet, including input from the Big Cypress, to maintain the Everglades National Park. Of this total, 260,000 acre-feet was considered to be the average annual flow required from Conservation Area 3A. This was just slightly less than the 273,000 acre-feet estimate of Van V. Dunn (1961). The latter's estimate was a median value rather than an absolute minimum (Tabb 1963).

Klein et al. (1975) calculates that the total annual inflow to the park prior to conservation area construction (1941-1962) was 947,000 acre-feet. Bear in mind that this estimate includes rainfall and runoff, and it reflects a relatively low water condition compared to the pre-drainage Everglades. As of 1941 Lake Okeechobee was diked and much of what used to be Everglades sheet flow was being bled off through major drainage canals to the east and west. After conservation area construction (1963-1970) Klein estimates average annual inflows to the park at 1,384,000 acre-feet. Of the 437,000 acre-feet increase, approximately 250,000 was due to the water control structures and the rest to increased rainfall.

Since 1972, the U.S. Geological Survey (USGS) has been monitoring the quality of surface waters and sediment within the conservation areas to the north of Tamiami Canal. Moving south through the conservation areas, water quality characteristics change significantly. In particular, specific conductance, a measure of the total ionic content of water, decreases in a southerly direction (Waller and Earle 1975, Goolsby et al. 1976). A distinct gradient of increasing specific conductance also exists in the direction of the urbanized east coast within Conservation Area 3 (Waller and Earle 1975).

Mineralization of Everglades surface waters is due primarily to the closeness of highly soluble calcium carbonate rock and leaching from organic soils. Additionally, groundwater to the south of Lake Okeechobee is highly mineralized due to contact with connate (entrapped) seawater from ancient marine sediments (Parker et al. 1955). As rainfall and runoff oscillate seasonally, concentrations of major inorganic ions respond accordingly. Wet season concentrations are generally lower than dry season concentrations, due to relative dilution (Table 13).

Notable exceptions to the general seasonal trend are color and sulfate in both groups of stations and calcium at the marsh sites. All of these increase in concentration with increased rainfall/runoff. Excess color in the marshes arises from washout of organic tannins and lignins, which are higher in concentration during the wet season than during the dry season. Sulfate concentrations decrease during the dry season presumably because of anaerobic reduction to sulfide (Waller and Earle 1975). Calcium concentrations decrease during the wet season probably because of enhanced precipitation under pH conditions greater than 8.3.

In contrast to the general seasonal pattern, Lutz (1977) reports no particular seasonal trends in the major individual inorganic ions in the Tamiami Canal to the east of the study area; however, specific conductance does show an increasing trend during the dry season as well as a slight increase with depth.

Nitrogen, phosphorous, and organic carbon are fairly high in the conservation areas due to the highly organic soils and productive marsh environment. As with the

	Season	(PCS)1/	Ca	Mg	Na	K	HCO_3	SO_4	Cl	DS2/	H3/
Marsh sites	D	85	41	20	130	7.0	218	4.5	200	520	180
	W	72	43	10	48	2.3	166	12	67	270	120
Southern canal sites	D	49	74	12	52	3.0	270	1.8	80	370	230
	W	56	57	5.8	27	1.7	190	3.1	44	240	155

Dry season samplings - April 1973 and 1974.

Wet season samplings - October 1972 and 1973.

1/ Platinum - cobalt standard.

2/ Dissolved solids.

3/ Hardness.

Table 13. Average concentrations of major inorganic ions and color for wet and dry seasons in Conservation Area 3 (in milligrams per liter except where noted) (adapted from Waller and Earle 1975).

major inorganic ions, nutrient concentrations tend to decrease toward the south as agricultural runoff is assimilated or trapped within the marshes. Median total nitrogen values range between 0.6 and 1.8 mg/l toward the south end of Conservation Area 3. Total phosphorous is fairly low throughout Conservation Area 3 and in Tamiami Canal ranging between 0.00 and 0.02 mg/l (Waller and Earle 1975). Nitrogen at the marsh sites in the lower end of WCA 3 tends to increase toward the end of the dry season as water levels drop and ponding concentrates remaining nutrients. In Tamiami Canal little seasonality is evident in total nitrogen concentrations. Phosphorous concentrations show little seasonal variation in both the canal and at the marsh sites.

Trace metal concentrations at marsh stations and in Tamiami Canal are presented in Table 14. Of all the trace metals only iron occasionally exceeds water quality standards, but this is typical of the soils in this area. No particular seasonal or spatial trends are obvious in trace metal occurrence and distribution.

Organic pesticides and their breakdown products seldom remain in detectable concentrations within the surface waters of the conservation areas, although they are detected in 71% of rainfall samples at concentrations of 0.01 mg/l to 0.9 mg/l (Waller and Earle 1975). Concentrations were lowest at the northern boundary of ENP, probably because of its distance from agricultural lands to the north.

Due to their physical, chemical, and biological properties, many pesticides (as well as trace metals and nutrients) tend to accumulate in organic sediments. Consequently, sediments generally exhibit higher concentrations of these materials than the waters above them. The building of organic peat soils by

		As			Cd			Co			Cr			Cu			Fe		
		Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max
Marsh Sites	Total	1	10	17	0	1	9	0	1	6	0	1	10	0	2	10	10	220	1400
	Dissolved	0	10	17	0	1	8	0	1	5	0	1	10	0	2	10	10	80	180
Southern Canal Sites	Total	0	12	40	0	2	10	0	1	5	0	3	30	0	6	130	50	250	950
	Dissolved	0	6	14	0	2	7	0	1	4	0	3	10	0	5	10	20	10	310

		Pb			Mn			Zn			Hg			Sr		
		Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max
Marsh Sites	Total	0	5	22	0	36	300	0	28	150	0.0	0.1	0.8			
	Dissolved	0	5	22	0	26	280	0	46	40				30	780	2500
Southern Canal Sites	Total	0	6	25	0	14	30	0	34	250	0.0	0.1	1.0			
	Dissolved	0	3	25	0	9	25	0	20	40				90	740	1400

Table 14. Average, minimum, and maximum concentrations of trace metals in surface waters of Conservation Area 3 (in micrograms per liter) (adapted from Waller and Earle 1975).

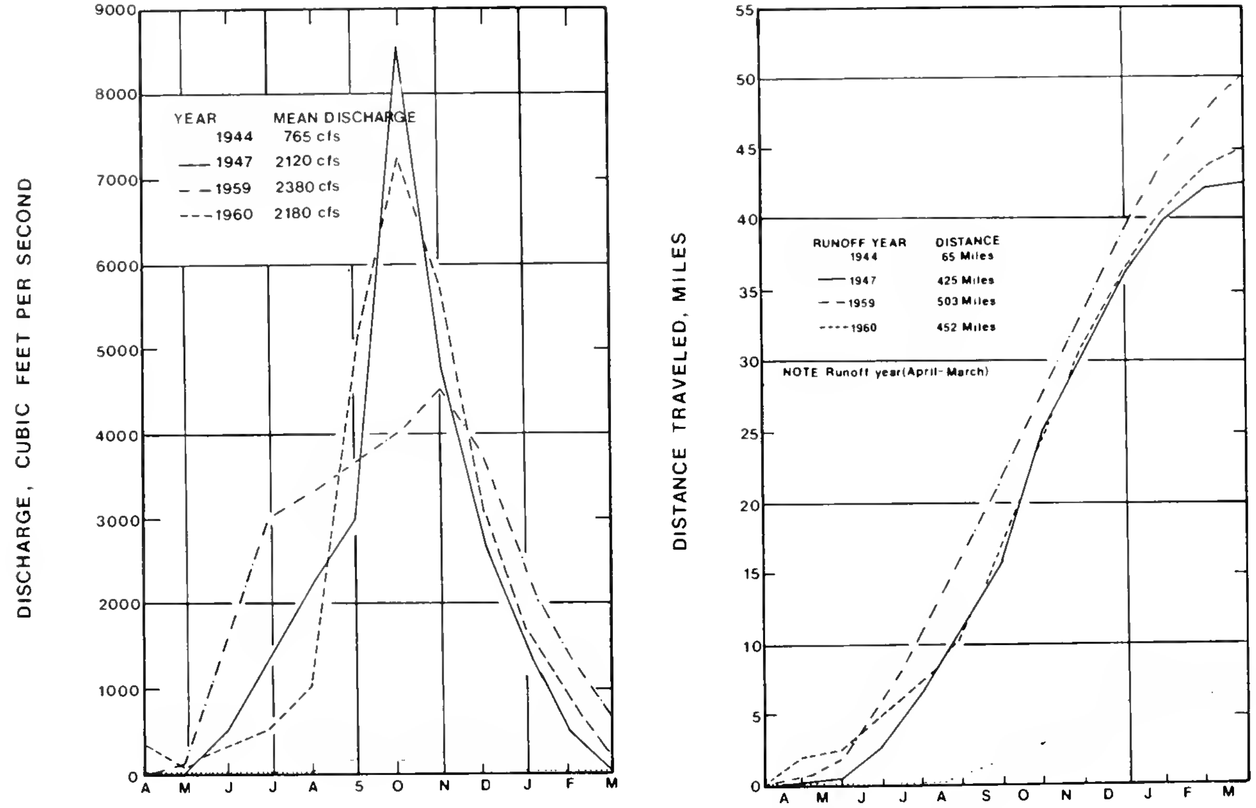
sawgrass, wet prairies, and other Everglades communities indicates that the sediments act as a sink for these materials entering the system either in solution or in particulate form. As water, sediment, and detritus move through the glades, some of this material may be recycled.

In general, canals which cut through and drain the organic soils disrupt their function as a nutrient and pesticide sink. Lowering water levels exposes the soils to oxidation causing the release of bound nutrients, organic moities, inorganic ions, and trace metals which remained tied up under the reducing conditions necessary for peat accumulation. Waller and Earle (1975) report relatively higher concentrations of nutrients in the marsh soils than in the canal sediments; and higher concentrations of trace metals in canal sediments than in marsh soils. Pesticide concentrations in all sediments declined with distance away from agricultural operations. Apparently the canals serve as a mechanism for hastening the export of trace metals and organic matter, as well as water, from the conservation areas. Unfortunately, they are exported to urbanized areas and estuaries where they are not necessarily wanted.

5.3 SHARK RIVER SLOUGH AND ASSOCIATED ESTUARIES

Flow through the Tamiami Canal spillways generally peaks in October due to the corresponding peak in rainfall (Leach et al. 1972), while minimum flows occur in April and May just prior to the onset of the wet season. Considerable variation in this general pattern occurs from year to year, however, as evidenced in Figure 33a of monthly average flows from a variety of years.

As expected, water movement through Shark River Slough, in any



A

B

Figure 33.

Hydrograph of monthly mean discharge through Tamiami Trail (adapted from Leach et al. 1972).

Monthly distance traveled by sheet flows under varying conditions (adapted from Leach et al. 1972).

year or sequence of years, depends on the timing, duration, and magnitude of flood and drought conditions. Once inside the park, water flows slowly southward as a broad sheet. Under high flow conditions the rate of sheetflow migration may reach 426.7 to 487.7 m (1,400 to 1,600 ft) per day or about 80.5 km (50 mi) per year. Under low flow, rates may drop to zero as the water table falls below ground level (Figure 33b). Superimposed onto this slow movement of sheetflow, the constant background forces of evaporation and transpiration act to remove as much as 85% of the average total input of rainfall (Parker 1974, Parker et al. 1955).

Thus the picture emerges, not so much of a continuous "river of grass" flowing from Tamiami Canal to Whitewater Bay, Florida Bay, and the Gulf of Mexico, but rather of a series of sheetflow pulses, each from a different runoff year. These are connected to one another to form a continuous but oscillating gradient of flow through the Shark River Slough. Seasonal pulses from Tamiami Canal are augmented by local rainfall and diminished by evapotranspiration. As the seasonal pulse of rainfall/runoff recedes and the rate of flow decreases, so too do losses to transpiration and evaporation. The pulse may travel as little as 8 to 10 km (5 to 6 mi) in a year or as much as 32 km (20 mi) depending on specific conditions. Then, as the subsequent year's pulse begins, what remains of the previous year's pulse (usually below ground by then) becomes replenished with local rainfall and upstream drainage. Increased upstream flow from the current year's pulse pushes last year's even farther downstream, eventually into the estuarine zone.

The open water estuarine zone of the western Everglades National Park begins about 24 to 32 km (15 to 20 mi) southwest of the 40-Mile Bend in Tamiami Canal. Beginning with the numerous small creeks that form the headwaters of the Shark River estuary, the tidally affected brackish water zone extends southwesterly for approximately 32 km (20 mi) to Ponce de Leon Bay. To the south of the Shark River estuary, coastal drainage into Whitewater Bay occurs through a diffuse network of smaller rivers, most notably the Watson, North, and Roberts Rivers. To the north of Shark River estuary, drainage to the gulf through the Harney and Broad Rivers is not only local but in part derives from the Shark River Slough. North of the Broad River, Lostman's Bay signifies the beginnings of the "back bay" zone (White 1970) that extends northward along the coast eventually grading seaward into the Ten Thousand Islands. This area is characterized by a line of bays set back and separated from the coast by a 3 to 8 km (2 to 5 mi) wide strip of mangrove swamp. Drainage into Lostman's Bay and the Gulf of Mexico arises primarily from the drainage area north of Shark River Slough and adjacent to the Big Cypress Basin.

The upper end of Shark River estuary, known as Rookery Branch, exhibits wide seasonal fluctuations in water level and salinity. As local rainfall and upstream flow increase during June to October, water level rises and salinity falls. Seasonal salinity variation in the Shark River estuary is greatest at Rookery Branch and gradually decreases toward Ponce de Leon Bay. The relatively shallow depth, low channel slope, strong wind, and constant tidal flux results in a generally well-mixed, homogeneous water column in Shark River and nearby estuaries. Tidal velocities approaching 6.4 km per hr (4 mph) have been observed in the lower Shark River (McPherson 1971).

Kolipinski and Higer (1969) characterize Shark River Slough within the National Park as relatively unpolluted with respect to nitrate, sulfate, calcium, dissolved solids, and iron. Median values and ranges for these parameters from 65 samples collected between December 1959 and September 1967 appear in Table 15.

PARAMETER	SHARK RIVER SLOUGH CONCENTRATION	
	RANGE (mg/l)	MEDIAN (mg/l)
Nitrate	0-7.9	0.7
Sulfate	0-7.7	0.4
Calcium	40-173	54
Dissolved solids	24-1152	230
Iron	0-0.87	0.20

Table 15. Selected water quality parameter concentrations in Shark River Slough (adapted from Kolipinski and Higer 1969).

In the upper slough, still within the park, Kolipinski and Higer (1969) studied the dissolved oxygen dynamics of an alligator hole within a willowhead, and the surrounding sawgrass marsh. Under high water conditions, diurnal oxygen levels in the hole and marsh were very similar, ranging from about 3.0 mg/l in early morning to as much as 9.0 mg/l during early afternoon. As water levels dropped below ground level, respiration in the alligator hole increased. At low water levels diurnal fluctuations remained small, and concentrations seldom reached greater than 2.0 mg/l. Similar conditions were reported for the Tamiami Canal waters.

Pesticide concentrations in surface waters from both the upper Shark Slough and the lower estuary are reported to be uniformly low (Kolipinski and Higer 1969, McPherson 1971). Concentrations of DDT within sediments, however, are as much as 1000 times greater than in surface waters in the upper slough.

Recently Flora and Rosendahle (1981) documented an ominous but confusing change in the inorganic chemistry of Shark Slough surface waters. Prior to construction of L-29 on the north boundary of the park, specific conductance in the slough averaged 272 uohms/cm. The sodium to chloride ratio (Na:Cl) averaged 0.34 for the same period. After construction (1962 to present) specific conductance averages 652 uohms/cm and the Na:Cl ratio averages 0.88. This increased mineralization of surface waters is believed to be the result of increased drainage by canals, thereby removing the buffering action of marsh filtration. Rainfall in the area is much less mineralized and therefore tends to improve the water quality. This change is ominous because of its magnitude yet confusing because its effects on marsh productivity and ultimately the food web are not easily predicted.

McPherson (1971) reports an expected seaward increase in the concentration of inorganic ions toward the mouth of the Shark River estuary. Silica (SiO_2), tannins, and lignins occur in higher concentrations at the freshwater end of the estuary. Nutrients, trace metals, and pesticides vary widely, exhibiting no regular seasonal or spatial trends.

Information on changes in the long term, overall water quality of the Shark River estuaries are reported by Davis and Hilsenbeck (1974). These authors document the gradual inland migration of saline waters in response to upstream diversion and management activities. Their findings are particularly important in that they point out an insidious change in the availability of habitat for estuarine organisms, whose survival and growth depend on a certain timing and range of fluctuating salinity conditions.

5.4 WHITEWATER BAY

Previous discussions of geology and geomorphology have established that Whitewater Bay is an eroded depression lying just north of a southeasterly extending ridge of Miami Oolite. The relatively well defined drainage pattern to the northeast of the bay (the Watson, North, and Roberts Rivers) suggests that historical Shark Slough drainage at lower sea level conditions traversed its present boundaries and flowed directly into Whitewater Bay (White 1970). The general northeast/southwest orientation of the many islands within the bay strongly reinforces this conclusion (Spackman et al. 1964). Dominant molluskan fauna in recent sediments (Scholl 1963) also confirms that a definite fresh to brackish to marine environment has prevailed along this same axis in the bay over the past 5000 years.

As the bay was gradually submerging to form an open water estuary, inundation by tides, primarily through the Shark River Slough to the north, modified the historical drainage pattern. Thus a seasonally oscillating "double" gradient was established; one dominating during the wet season in the northeast/southwest direction representing the historical freshwater flow influence; the other dominating the dry season in the northwest/southeast direction representing the effect of tidal inundation and flushing.

In 1957 the situation was even further modified by the opening of the Buttonwood Canal which connected Whitewater Bay to Florida Bay by way of Coot Bay. Under the pre-canal conditions, Coot Bay and southeastern Whitewater Bay were extremely sensitive to the effects of wind, particularly along the southeast/northwest axis. With southeast winds, water was effectively drained through Tarpon Creek into Whitewater Bay, while during sustained northwest winds, water "piled up" in the small bay. It is significant to note also, that under both conditions daily tidal fluctuations were nearly obliterated by wind action.

After the Buttonwood Canal opened, the piling up of water in Coot Bay under northwest winds was all but eliminated. Flow constriction by Tarpon Creek continued to allow some build up in Whitewater Bay, but Coot Bay was essentially well flushed. The hydrologic connection between Coot Bay and Florida Bay disrupted the seasonal cycle of water supply to the small lakes south of Coot Bay. These had previously received input from the overflow of waters in Coot Bay (Tabb et al. 1962), especially during the dry season when northwest winds are most frequent. Presently the Buttonwood Canal is being closed in an effort to reestablish the historical conditions.

The timing of the wet and dry seasons in Whitewater Bay, as reflected in minimum and maximum salinities, has been shown to be approximately 3 months out of phase with flow from the Tamiami Canal to the north (Figure 34). As freshwater inflow peaks, the salinities line up in a distinct southwest-northeast gradient consistent with the orientation of the water supply (Figure 35). As freshwater inflow subsides, salinity gradients tend to reorient along the bay's southeast to northwest axis consistent with the main direction of tidal flows. Extreme losses to evapotranspiration often lead to salinities greater than in open sea water as evidenced in Figure 35. Especially intense localized conditions of rainfall or drought can, however, produce considerable variation in these general seasonal patterns (Clark 1971).

5.5 TAYLOR SLOUGH

Surface discharge from Taylor Slough arises from two sources:

(1) local rainfall; and
(2) overland sheetflow originating from Shark River overflow and Tamiami Canal between levees 30 and 67A.

As presented earlier, rainfall in Taylor Slough averages around 150 cm (59 in) annually, with a peak in September and a low in December (Earle and Hartwell 1973). Likewise,

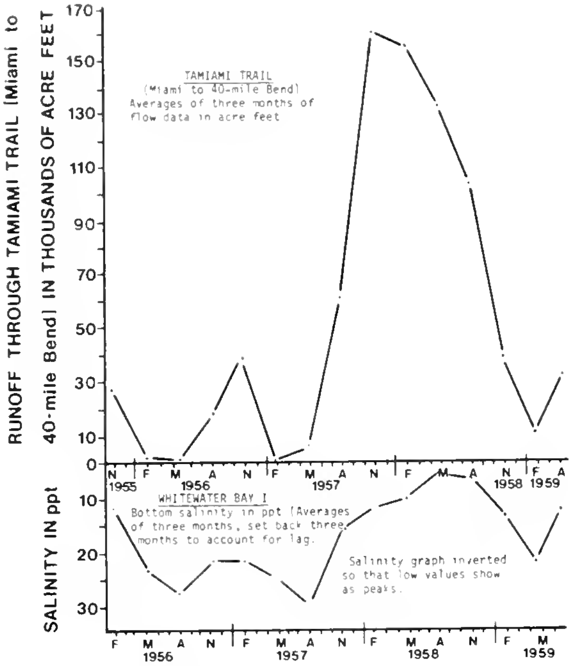


Figure 34. **Relationships between salinity in Whitewater Bay and freshwater runoff across Tamiami Trail (adapted from Tabb et al. 1962).**

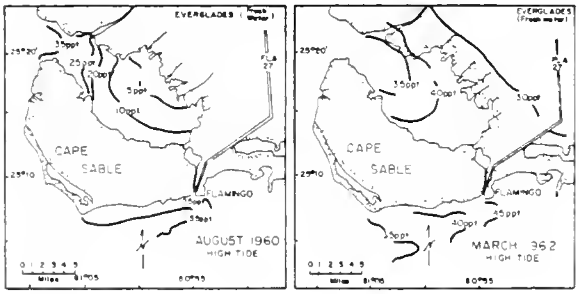


Figure 35. **Representative isohalines in Whitewater Bay during wet and dry seasons (adapted from Tabb et al. 1962).**

seepage discharge from the Tamiami Canal between levees 30 and 67A generally peaks in August through October and bottoms out in March or April. As mentioned in the discussion of Conservation Area 3A, a marked decrease in flow across this section of Tamiami Trail occurred after 1960 as the result of increased water retention behind levee 29 and diversion of flow to the west by levee 67A.

Schneider and Waller (1980) claim that surface water levels in the Taylor Slough headwaters display a relatively smaller range of fluctuation than in areas to the north (Shark River Slough) and south (canal C-111). Apparently, surface water levels in the Taylor Slough headwaters are less strongly impacted by drainage controls than are the other two areas.

However, groundwater records in the same area suggest that changes have occurred in the below ground water levels subsequent to the canal and levee construction of the 1960's. Specifically, groundwater tables exhibit less seasonal variability, with some indication that seasonal lows are now lower than prior to water level control. In the wells close to canal C-111 this is particularly obvious. Control structure S-18C on C-111 opens automatically when upstream stage reaches 0.6 meters (2 ft), effectively dampening the peak of "average" high water levels.

Surface flow from upper Taylor Slough is measured as it passes under a 12.1 km (7.5 mi) stretch of Context Road through no less than 80 culverts. Downstream, near Homestead, flow is again measured beneath a 4.8 km (3 mi) stretch of State Road 27. Schneider and Waller (1980) present flow duration curves for these two stations that show the upper slough effectively drying up for much of the average year. Differences in flow durations during different years are attributed to differences in the total rainfall during the two periods (Schneider and Waller 1980), rather than to an effect of drainage.

In 1979 the National Park Service and the U.S. Army Corps of Engineers agreed that 37,000 acre-feet of water per year would be supplied to upper Taylor Slough through pumping station S-332, to be installed on canal 31-W. It is expected that the new flow regime will result in significant changes in the hydrology and vegetation of the slough below this point. Additional information on hydrologic conditions, such as approximate hydroperiods, in the lower slough prior to flow augmentation are presented by Olmstead et al. (1980) in association with vegetation distributions.

Considerable effort has been expended in recent years to characterize the impact of land use and drainage activities on surface and groundwater quality in upper Taylor Slough (DERM 1980). With the exception of samples taken in a borrow canal which taps the saline Floridan Aquifer, concentrations of major inorganic ions and specific conductance are generally lower in Taylor Slough than in the Shark River Slough to the north. Background specific conductance in Shark River Slough is around 400 uohms/cm^2 while to the south, in Taylor Slough, values are slightly lower (Waller 1979). At the borrow canal station, distinct seasonality is apparent in specific conductance due to the relative diluting influence of Shark River overflow during the wet season.

Macronutrients at both canal and marsh sites within Taylor Slough are low. Organic carbon is relatively lower in Taylor Slough surface waters than in Shark River Slough, presumably because of the less organic marl soils in the former. As ponding occurs during the dry season there is a tendency for nutrients and inorganic ions to increase in concentration.

5.6 FLORIDA BAY

The freshwater drainage to Florida Bay is limited to runoff from Taylor Slough, runoff from the coastal wetlands south of the main Shark River Slough, and groundwater seepage from the mainland. Thomas (1974) has shown that the inverse relationship between the height of the groundwater table and salinity in northern Florida Bay is a fairly linear one.

Due to its restricted flushing, water levels in Florida Bay may fluctuate by as much as 53 cm (21 in) seasonally (Turney and Perkins 1972). During hurricanes, water depths have been observed to increase as much as 3.7 m (12 ft) in western Florida Bay and 1.2 to 1.5 m (4 to 5 ft) in the northern bay (Ball et al. 1967).

Based on the distribution of benthic mollusks, Turney and Perkins (1972) divide Florida Bay into four subenvironments (Figure 36):

(1) The northern subenvironment near the mangrove coast;
(2) The interior subenvironment, encompassing the northeastern half of the bay;
(3) The Atlantic subenvironment, beginning at the middle Keys and running along the back of of the reef tract; and
(4) The Gulf subenvironment, just inside the 1.8 m (6 ft) contour between Cape Sable and Fiesta Key.

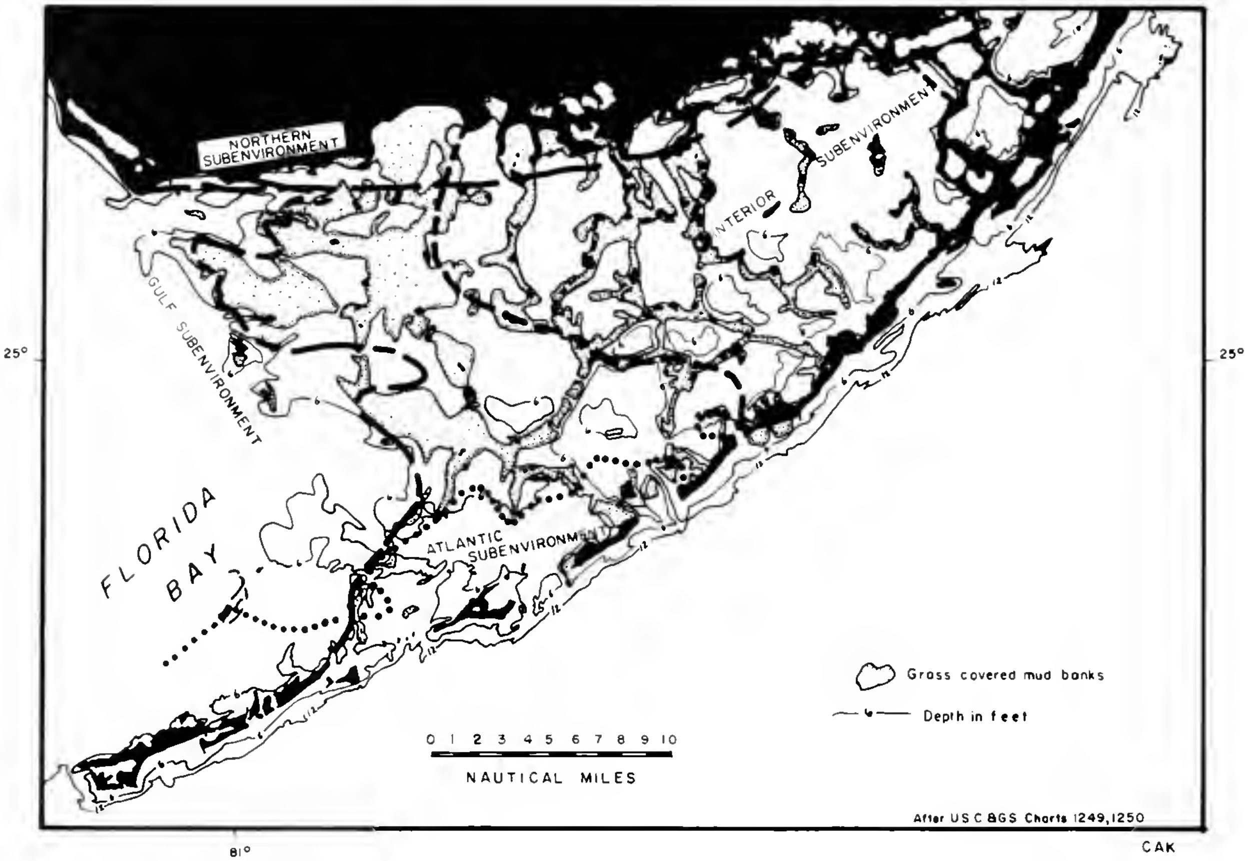


Figure 36. Distribution of subenvironments in Florida Bay defined by mollusks (adapted from Turney and Perkins 1972).

Ginsburg (1956) divides the bay into only two zones, an interior zone unaffected by tides and an outer, tidally influenced zone. The latter's interior zone encompasses Turney and Perkins' northern subenvironment starting from just east of Flamingo, as well as their interior subenvironment. The tidally influenced zone roughly corresponds to the Gulf and Atlantic subenvironments as defined above.

The four molluskan subenvironments are a convenient classification for hydrologic purposes as well. The barely submerged northern subenvironment lies within the zone influenced by seasonal freshwater runoff. Salinities range from 13-48 ppt, temperatures from 15 to 38°C (59 to 100°F). Only the western edge of this zone, from just east of Flamingo to the gulf, is subject to significant tidal flushing. Even here hypersaline conditions are commonly detected during the dry season (Tabb et al. 1962).

The interior subenvironment, which contains the most lakes, is characterized by widely fluctuating salinities (22-52 ppt) and very restricted circulation. Net seasonal deficits and excesses of runoff and rainfall are strongly reflected in this zone. Flushing is negligible except for occasional wind induced movement across the many enclosing mud banks and mangrove islands. Gorsline (1963) has detected very weak counterclockwise currents within some of the larger lakes.

The Atlantic subenvironment experiences near normal salinities (35-41 ppt) and more moderate temperatures ranging from 17 to 32°C (63 to 90°F). Beginning at the low coral keys Florida Bay exchanges waters with the Straits of Florida through numerous channels between islands. In addition, there are indications that some seepage occurs across the porous Key Largo Limestone. The inland extent of the flushing tends to increase southward toward the sluiceway and the Gulf of Mexico influence.

The Gulf subenvironment exchanges with gulf waters through tidal flux and long shore currents. The latter occur within what Marmer (1954) refers to as a current shadow, a sheltered section of the continental shelf. However, the lack of sediment accumulation tends to contradict this general hypothesis; apparently current spinoffs do traverse the area regularly forming what Stockman et al. (1967) refers to as the "sluiceway" across the low coral keys between Long and Big Pine Keys into the Florida Straits. Salinities in this subenvironment approach near-normal marine conditions.

The movement of water masses within the interior zone is related to: (1) mainland runoff; (2) seasonal rise in sea level; and (3) evaporation. The timing of the mainland runoff and sea level rise results in the delayed flow of freshwater into the central bay until the winter months. Lloyd (1964), tracking salinity changes during the summer, fall, and winter of 1958-59, demonstrates this postponed freshwater inflow effect as illustrated in Figure 37(a-c). The wet season, May through October (the wetter months being August through September and October), coincides with the period when sea level in this region rises (Marmer 1954) (from August to December, peaking in October). Figure 37a illustrates a time (August) when the freshwater runoff is pushing low salinity water out along the bay's northern border and extending a tongue of brackish water into the central bay. Concurrently, seasonally high temperatures and restricted circulation along the southern and western bay accelerates evaporation, creating a large region with salinities in excess of 36 ppt (shaded portion of Figure 37a). In November, the annual sea level rise acts to push the brackish, lower salinity waters back up into the northern edge of the bay (Figure 37b) resulting in near-marine salinities for the remainder of the bay. As the sea level falls (about 15 cm or 6 in), the January-February isohalines reflect a movement of the lower salinity waters of the mainland swamps into a major portion of the bay (Figure 37c). Ginsburg (1956) reports similar seasonal patterns. In addition to the seasonal salinity variation, a 5 to 7 year drought/flood cycle also affects the magnitude of any one year's salinity range (McCallum and Stockman 1964). The effects of these variations may be quite phenomenal on year to year salinity regimes. For example, August salinities in central Florida Bay may range from 15 ppt to 50 ppt in succeeding years depending on rainfall/runoff conditions.

Although sediment chemistry is fairly well studied in Florida Bay (Taft and Harbaugh 1964, Scholl 1966), surface water chemistry is

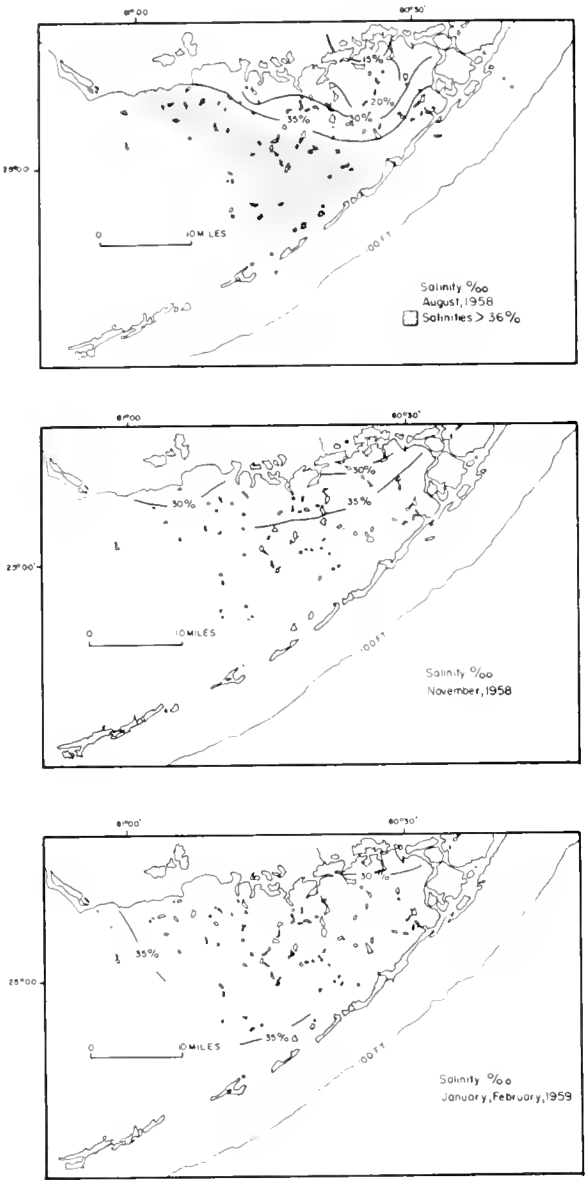


Figure 37. Isohalines in Florida Bay (adapted from Lloyd 1964).

not. Parameters most commonly reported are salinity and temperature (reported above) and turbidity (Schmidt and Davis 1978). In upper Florida Bay turbidity tends to be highly variable, ranging from 1-3 mg/l after sustained winds of 10 to 20 knots (Scholl 1966). Toward the Gulf of Mexico the winds are a less influential but nontheless important factor in turbidity concentrations. Here, however, the activities of bottom feeders (especially mullet) are commonly reported to cause "whitings" (i.e., high turbidities) as they feed in large schools on grass beds and over the lime mud sediments.

5.7 FLORIDA KEYS

The hydrologic cycle in the Florida Keys involves a complex array of transport mechanisms including oceanic currents, evaporative processes, tidal actions, winds, freshwater flow, and catastrophic events such as hurricanes. Of these, the tides, wind-driven currents, and oceanic currents and their associated spin-off eddies and counter-currents, dominate the overall movement of water in the system.

Tides in the Florida Keys generally exhibit two high and two low tides of uneven amplitude per tidal day (or lunar day, 24.85 hrs), as illustrated in Figure 38 (NOAA 1977). A semidiurnal tidal pattern exists in the area north of Key Largo while the mixed pattern occurs to the south (Figure 39). The semidiurnal tidal pattern is similar to the mixed, except the amplitudes of the two highs and two lows are approximately equal. Also, as shown in Table 16, the tidal range along the shallow slope break (outer reef) decreases from Fowey Rocks (ESE of Miami) to Sand Key (SW of Key West).

Although a similar decrease occurs nearshore, localized variables including winds, local bathymetry, and shoreline geomorphology markedly affects the inshore tidal amplitude and phase (Enos 1977, Hanson 1980). Hanson (1980) observes a tidal phase shift of as much as several hours between east (Bogie

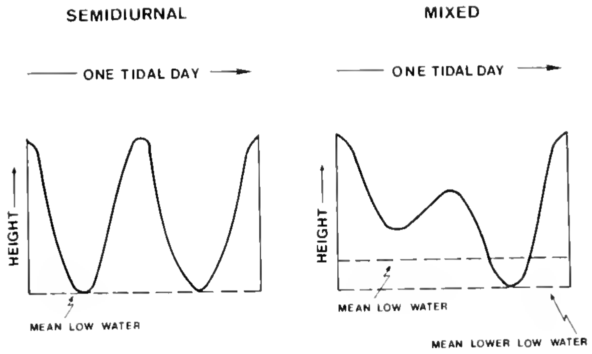


Figure 38. Schematic of mixed and semidiurnal tides (adapted from NOAA 1977).

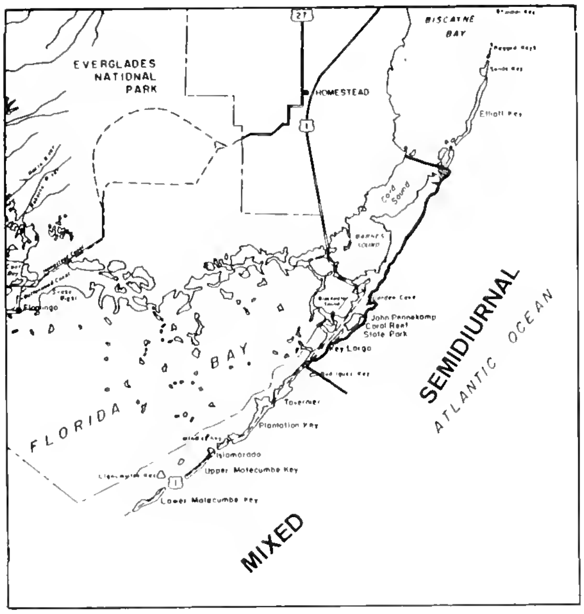


Figure 39. Delineation of tide types in the Florida Keys (adapted from NOAA 1977).

Tide Prediction	Distance* (km)	Phase Difference (min) High Tide	Phase Difference (min) Low Tide	Range (cm) Mean	Range (cm) Spring
Fowey Rocks†	..	..	..	73	88
Molasses Reef	72	13	09	67	79
Alligator Reef	85	10	24	61	73
Tennessee Reef	105	35	27	55	67
Sombrero Key	142	41§	70§	49	61
American Shoal	184	48§	64§	40	49
Sand Key†	222	58§	76§	37	46

* Distance from Fowey Rocks measured along the reef arc, approximately at the 18 m (60 ft) contour.

† Fowey Rocks is near Miami; Sand Key is near Key West. Times are minutes later than Fowey Rocks. Based on Tide Tables (ESSA 1967).

§ These times are predicted relative to Key West Tides which bear no simple relationship to Miami tides. They are referred to Miami times by estimating an average phase difference of 2 hr. between Miami and Key West tides. Actual daily differences vary between 1 and 3 hr.

Table 16. Tidal ranges along the shallow slope break (adapted from Enos 1977).

Channel) and west (Pine Channel) sides of Big Pine Key. According to Enos (1977) this phase difference in tide crests through the length of the reef tract, between Fowey Rocks and Sand Key (Table 16), is of equal or greater importance than the amplitude reduction. He observes that the "...theoretical delay in twice-daily tide crests between points separated by about 1°45' longitude would be 3 1/2 min. The actual delay of more than an hour is presumably caused by friction introduced by the topography of the Florida Plateau and must involve translation of water masses. This tide-induced water movement is suggested as a mechanism for a weak counter-current southwestward along the south Florida shelf margin".

The Keys' tidal pattern is made more complex by the effect of the upper Keys physical alignment which virtually blocks all direct interaction between Florida Bay and the seaward reef tract, creating two very distinct environments within a few miles of each other (Ginsburg 1956, Marszalek et al. 1977). In contrast to the tidal ranges reported along the outer reef (Table 16), the more restricted eastern part of

Florida Bay exhibits an average range of less than 15 cm (6 in). Table 17 provides tide range values from the shallow slope break to Florida Bay. This reduction occurs quite abruptly just inside the Keys (Enos 1977).

	Range (cm)	
Station	Mean	Spring
Profile A, open shelf, no large tidal passes		
1. Molasses Reef	67	79
2. Mosquito Bank	67	79
3. Tavernier	67	79
4. Eastern Florida Bay	<15	..
Profile B, narrow tidal passes		
1. Alligator Reef	61	73
2. Upper Matecumbe Key	61	76
3. Lignumvitae Key, Florida Bay	9	..
Profile C, wide tidal passes		
1. Tennessee Reef	55	67
2. Long Key	58	73
3. Arsenic Bank, Florida Bay	18	21

Table 17. Profiles of tidal ranges from the shallow slope break to the inner shelf (Florida Bay) (adapted from Enos 1977).

Jones et al. (1973) and Ross (1975) relate the Florida Bay and Atlantic tidal range differences to a tidal height gradient developing between the two environments resulting in a net water movement from southeast to northwest. Ross (1975) summarizes this dicotomy of reef tract and Florida Bay tidal regimes and their subsequent effect on the Keys' hydrology:

> *"Long waves (tides) generated by the passage of astronomical bodies at this latitude tend to lag the time of passage. Thus, high tide at Miami, Florida, high tide at the western extremities of the Gulf of Mexico, say Galveston, Texas, and low tide at the eastern extremities of the Gulf of St. Petersburg, Florida, all occur at approximately the same time. This occurs because the tidal wave generated in the Atlantic cannot move into the Gulf around the Keys, and the Gulf of Mexico gives rise to a new tidal wave which meets the Atlantic wave in the Key West area. The tidal wave which moves down the Atlantic side of the Keys has a normal range (height between higher high and lower low, NOAA 1977) of approximately 1.5 feet as does the normal tide in the Gulf of Mexico. Florida Bay because of its depth, has a limited response to the astronomical passage and derives its changes in water heights from flows from the Gulf of Mexico and the Atlantic. The result is a normal tidal range of approximately 0.5 feet, more in phase with Gulf tides than with Atlantic tides.*
>
> *"When tide heights on each side of the Keys are plotted for various locations, it can be seen that a considerable difference in water heights exists from east to west during portions of the tidal cycle. A lesser tidal height difference exists in the west to east portion of the tidal cycle because of the phasing of the tides. As a result, a net flow from east to west is expected through any openings in the northern section (upper keys) of the Florida Keys. The difference in water levels between the two sides of the Keys may be as much as one foot at times in the northern section, tapering to a fraction of an inch in the lower section, near Key West... .*
>
> *"In the southern portion of the Keys very small tide height differences exist. Flow through these bridges is predominantly the result of easterly wind and wave-driven water."*

In addition to spatial differences in the tidal structure of the Florida Keys, a temporal pattern also exists (Lloyd 1964). The daily tidal amplitude changes in accordance to well known lunar and solar cycles as well as` in response to short-term meterological events, i.e., winter cold fronts and tropical storms. The most dramatic change is the storm tide associated with the passage of hurricanes. A combination of the cyclonic motion, slope in the bottom topography, high winds and extremely low atmospheric pressures have resulted in tides 4.6 m (15 ft) above mean high water line (Gentry 1974).

A response unique to the Florida Keys is the tidally forced, cyclic flow of groundwater from one side of the islands to the other. This lateral subsurface flow occurs in response to: (1) the porous nature of the Miami and Key Largo Limestone Formations; (2) the solution-cavities characterizing the two formations; (3) the tidal gradients (in some cases) developed from one side to the next; and (4) the narrow physiography of the islands (Ginsburg 1956, Chesher 1974, Enos 1977). In a Key West firewell located near the center of the island and on one of its highest parts, the tidal amplitude is dampened but displays a time lag of only a few minutes (Parker et al. 1955). This indicates that water passes fairly quickly betwen the well and the marine recharge site. Similar results were observed on Big Pine Key, particularly during the dry season (Parker et al. 1955, Hanson 1980), and in a number of landlocked canals, limestone rock quarries, and solution formed ponds and holes throughout the Florida Keys (Chesher 1974). Keck (1969) and Chesher (1974) examined this tidal response of inland waters and observed a consistent relationship between the dampened amplitude (tidal range reduction) and the distance from its marine recharge source.

The shallow depths, and the open and exposed character of the waters surrounding and permeating the Florida Keys promote an environmental setting conducive to wind-driven currents. This relationship between currents and the winds have been well documented in the literature (Griffin 1974, Enos 1977). Currents on a shallow reef bank on the outer shelf margin have been observed to respond rapidly to the wind's direction and velocity over 3-day observation periods (Jones 1963). Chew (1954) reports that currents off Key West (seaward) correlate well with wind direction but not wind velocity. Enos (1977) observed strong notheast currents for several days near Molasses Reef moving approximately 45° downwind of the prevailing winds and suggests that bottom topography may have channeled the flow or that a spin-off eddy from the Florida Current may have been "blown onto the shelf".

Other studies that have examined the wind-driven currents in the Florida Keys include: (1) Koczy et al. (1960) and Rehrer et al. (1967) on the current patterns between the Tortugas and Cape Sable; (2) Ball et al. (1967), Perkins and Enos (1968), Gentry (1974), and Warzeski (1976) on the effects of tropical storm winds on the Keys' hydrology; (3) Chesher (1974) and USEPA (1975) on canal responses to winds; and (4) Ginsburg (1956, 1964) and Turney and Perkins (1972) on Florida Bay's response to seasonal winds. The winds driving these currents are primarily derived either singly or in combination from three types of wind force or energy levels characteristic of this geographical region: (1) prevailing easterlies; (2) winter cold fronts; and (3) tropical storms (Warzeski 1976). These energy levels (discussed in greater detail in the section on climate) provoke unique current responses of temporal and spatial variability discussed in the following sections.

The prevailing easterlies, characterized by a low energy level (low to moderate wind velocity) of a long term nature, originate as the name implies from the east (SE to NE) (Gruber 1968). These winds provide a "background condition" onto which the remaining two energy levels are superimposed. Winter cold fronts bring high winds of a sustained nature (3 to 4 days) that rotate the resultant wind vectors in a clockwise 360° manner and reach 3 m/sec (26 ft/sec). As the front passes, higher winds from the northwest reach 10 to 15 m/sec (33 to 49 ft/sec) and have been reported as high as 20 to 26 m/sec (66 to 85 ft/sec) (Multer 1977). The third energy wind level is produced by tropical storms which in the most intense form, hurricanes, produce winds ranging from 33 m/sec (108 ft/sec) to over 100 m/sec (328 ft/sec) (Gentry 1974). As the occurrence of a hurricane is rare (1 chance of occurring every seven years), the effect of these events on the current patterns will be treated separately in a later section.

Enos (1977) summarized in Table 18 the resultant wind vectors, constancy, and velocity for the Florida Keys area. These wind vectors represent the synergism of all winds on a seasonal basis, dominated usually by the first two energy levels (prevailing easterlies and synoptic-scale fronts). From September-November (fall) and December-February (winter) the influence of the cold fronts produces the northerly component to the resultant northeast winds as well as an increased mean wind velocity. The summer and spring months typically exhibit lower velocity winds coming from east and southeasterly directions. The response of currents to the winds reflects the temporal variability of the winds on a seasonal, monthly, and even daily basis (Hanson 1980).

Months	Resultant[1] Direction	Constancy[2]	Velocity(knots)
Dec-Feb	↙	30-50	12
Mar-May	←	35-50	9
June-Aug	↖	30-60	8
Sept-Nov	↙	4-60	10

[1] Resultant is a vector of frequency and average force, averaged for two (2) 5° areas over 3 months.

[2] Constancy is the percentage of time that wind blows from the quadrant containing the mean.

Table 18. Summary of wind data from the Florida Keys (adapted from Enos 1977).

Winds from the south and southeast, which are generally experienced in the summer months, approach a majority of the Keys at a right angle to the islands and the reef tract (Enos 1977, Marszalek et al. 1977). This wind assists the flood tide in pushing water masses in a northwest direction across the reef tract and through the passes and island channels into Florida Bay and the Gulf of Mexico (Ginsburg 1956). Because of the buffering action of the outer reefs and short distance to the islands, the wind-generated waves rarely exceed a moderate chop (Enos 1977). This wind tends to "pile" waters up on the seaward side of the Keys, accelerating the southeast to northwest lateral seepage of waters through the permeable limestone (Chesher 1974). Concurrently, the waters of Florida Bay tend to be pushed up toward the mainland (Ginsburg 1956, Turney and Perkins 1972).

A vivid demonstration of these summer winds occurred during an oil spill off the Marquesas Keys (Chan 1976). The spill occurred approximately 42 km (26 mi) south-southwest of these islands when an oil tanker discharged 1,500 to 3,000 barrels of a crude oil emulsion "clingage" into the western edge of the Florida Current. The spill moved northeast with the Florida Current and prevailing winds from the southeast, thus driving the oil slick ashore along a 48 km (30 mi) stretch of the lower Keys from Boca Chica Key to Little Pine Key (Chan 1976).

During spring and fall the resultant winds are from the east-northeast. At this time the arcuate nature of the islands and reefs becomes a particularly critical factor in localized currents. Relative to prevailing winds, the orientation of the islands and reef tract shifts from north-northeast at Key Largo to east-northeast at Key West. In the upper Keys the wind's approach is nearly perpendicular to the reef tract and generally onshore. Further down the Keys, in the middle Keys and particularly into the lower Keys, the predominant winds run nearly parallel to the islands. This alignment promotes a longer fetch along Hawk Channel, creating larger waves and more turbid waters due to resuspension of fine calcareous sediments (Griffin 1974, Enos 1977). The easterly component of these winds continues to supplement the flood tide flow in the middle and upper Key channels, while in the lower Keys the elongated shoals lying perpendicular to the resultant winds reduce the wind-driven flow through the islands (Hanson 1980). The effect on Florida Bay and the water on the gulf side of the middle and lower Keys is to push waters to the gulf or to the west-southwest (Koczy et al. 1960, Rehrer et al. 1967, and Turney and Perkins 1972). The distal islands of the Tortugas and Marquesas Keys experience west-southwest wind-driven currents supplementing the more southerly oceanic flow of the eastern edge of the Gulf Loop Current (Koczy et al. 1960, Rehrer et al. 1967, and Jones et al. 1973).

During the remainder of the year from December to February, and even the later fall months, synoptic-scale cold fronts pass through the area bringing winds of a variety of directions and speeds (Enos 1977, Marszalek et al. 1977). Northeast and north-northeast winds generally prevail. These prevailing winds run parallel to the upper Keys causing a similar resuspension of sediments which the middle and lower Keys experienced in the fall and spring seasons (Enos 1977). Florida Bay waters are pushed in two directions:

(1) west-southwest toward the lower Keys and distal island groups (Koczy et al. 1960, Rehrer et al. 1967); and (2) south-southwest supplementing the ebb flow and carrying sediments through the passes over the middle Keys reef tract and into the Straits of Florida (Turney and Perkins 1972, Marszalek et al. 1977). Farther removed from the turbid Florida Bay waters, the lower Keys and distal islands receive waters from the nearshore Florida shelf. These waters are of variable temperature and salinity and tend to supplement the south and southwesterly flow of the Gulf Loop Current's eastern edge (Jones et al. 1973, Marszalek et al. 1977). In addition to the winter's prevailing winds there are sustained strong winds from the southwest and northwest associated with passage of cold fronts (Multer 1977). The most obvious effect of these winds is to pile up Florida Bay waters on the northwest side of the upper Keys. This tends to assist the tidal movement of bay and gulf waters through the middle and upper Keys and into the straits of Florida (Ginsburg 1956, Chesher 1974, Marszalek et al. 1977).

The previous description of wind-driven currents in the Florida Keys summarizes the dominant or prevailing conditions. However, temporal variations of wind patterns often cause currents to behave in stark contrast to the norm, as illustrated in Figure 40. Here the effect of west winds on the water level changes in Florida Bay can be observed as a year round phenomenon not restricted to winter months (Ginsburg 1964). Although hurricanes are relatively rare, the intensity and duration produce the most severe wind currents observed in the Keys (Ball et al. 1967, Perkins and Enos 1968). The currents that result from the passage of a hurricane depend on the trajectory and point of landfall. Ball et al. (1967) provide an excellent description of the "Great" Hurricane Donna's passage over the middle and upper Keys as well as the ensuing geomorphic changes resulting from currents, tides, and the storm surge. Because of the cyclonic (counter clockwise) movement of winds about the hurricane's eye, the storm's passage may entail hurricane-force winds from totally opposite directions within the course of a few hours (Gentry 1974). In Donna's case this resulted in the "draining" and "flooding" of Florida Bay within a 24 hour period (Ball et al. 1967).

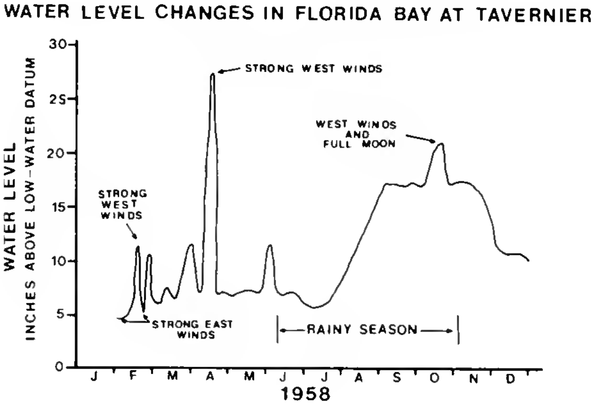


Figure 40. Water level fluctuations in Florida Bay at Tavernier (adapted from Ginsburg 1964).

Oceanic Currents

Two oceanic currents affect the Florida Keys hydrology; these are: (1) the Gulf Loop Current, north and west of the islands; and (2) the Florida Current, south and east of the Florida Keys. The precursor of both Florida currents, the Caribbean Current, is initially formed by the union of the Guana and Equatorial Currents to the northeast of South

America. From this union the current flows west-northwest paralleling the north coast of South America towards Central America. As it approaches the Central American coast it turns northward passing into the Yucatan Straits and is renamed, appropriately, the Yucatan Current. The Yucatan Current's life is relatively shortlived; as it moves north and northeast it develops into two distinct branches. One flows to the north into the Gulf of Mexico; the other flows directly towards the Florida Straits. The former branch of the Yucatan Current, called the Gulf Loop Current, flows in a clockwise direction in the gulf, returning to join the other branch of the Yucatan Current in the Florida Straits. The merger of these two branch currents give rise to the Florida Current which flows in an east-northeast direction along the eastern side of the Florida Keys outer shelf and then north along the Atlantic coastline. Within the Florida Current the two branches of the Yucatan Current retain their distinctiveness, segregated by differences in salinity and temperature (Wennekins 1959). The Gulf Loop Current forms the western core which lies closest to the Florida Keys and exhibits a greater temperature and salinity variability than the eastern core (Wennekins 1959).

The extent of the Gulf Loop Current's penetration into the Gulf of Mexico is extremely variable from year to year and seasonally. Its northward intrusion into the gulf extends, at times, as far as the Mississippi Delta, and, at other times, is restricted to an area south of 24°N latitude, parallel to the Florida Keys (Leipper 1970). Longitudinally the Loop Current and its spinoff eddies may extend eastward over Florida's western shelf, and westward as far as the Texas coastline. This current usually transports more than 25 million m^3/sec of water at speeds from 50 to 200 cm/sec (2 to 7 ft/sec) largely contained in a band 90 to 150 km (56 to 93 mi) wide (NOAA 1973).

Maul (1977) provides one of the most complete descriptions of the Gulf Loop Current available to date. He examines previous theories describing the current's movements in light of an additional 14 month survey of the 22°C (72° F) isotherm at 100 m (328 ft) depth conducted during a period from August 1972 to September 1973. Figure 41 illustrates the 22°C (72°F) isotherm pathlines at 100 m (328 ft) monitored during this 1972-73 period. This figure portrays the geographic relationship between the Florida Keys and the Gulf Loop Current's pathway. At times, as previously stated, the current impinges into an area over the Florida shelf. For example, during August 1972 the current was located tangentially to the Florida Platform near the Dry Tortugas. From September 27-28, 1972, the current flowed dirctly toward the west Florida shelf and, according to Maul (1977), "there was evidence of Loop Current water on the shelf, and the 22°C (72°F) isotherm apparently went aground well north of the Dry Tortugas. By early November, the current has reformed to its southernmost extent, and evidence of Florida Bay wter flowing south through the Keys was noted in both the ship track and a LANDSAT image". Maul (1977) reviewed previous 22°C (72°C) isotherm pathlines presented by Leipper (1970), Whitaker (1971), Robinson (1973), and his own work to illustrate the temporal and spatial variability of the Gulf Loop Current's flow from year to year.

Based on this variability, Maul (1977) questions the validity of the annual cycle and fixed seasonal aspects of the Loop Current as

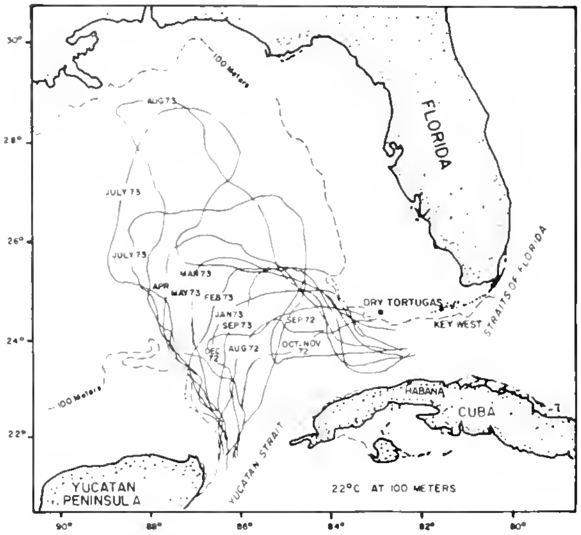


Figure 41. Pathlines of the 22° isotherm at 100 meters depth in the Gulf of Mexico from August 1972 to September 1973 (adapted from Maul 1977).

previously proposed (Leipper 1970). Maul (1977) instead suggests a possible relationship between the cycle of Gulf Loop Current penetration into the gulf, and cycles of: (1) surface drift velocity of the Florida Current; and (2) direct transport of the Florida Current. He also notes an inverse relationship between the penetration of the current into the Gulf of Mexico and the distance the current was found (22°C or 72°F isotherm at 100 m or 328 ft) from the Cosgrove Lighthouse located between the Dry Tortugas and Key West.

The Gulf Loop Current's effect on the nearshore waters of the Florida Keys is masked in many cases by tide and wind driven currents. Chew (1961) describes several cyclonic currents along the western coast of Florida powered by the kinetic energy from the adjacent Loop Current. These counterclockwise moving currents exist primarily north of Cape Romano but at times entrain Florida Bay waters, carrying it to the north: alternatively they may also "leak" waters along the western edge of Florida Bay and through the Keys to the Florida Straits. Florida Bay, for the most part, remains in a current shadow with the surface ocean currents of the Gulf of Mexico apparently having little effect on even the westernmost part of Florida Bay (Turney and Perkins 1972). The waters north of the lower Keys and west of Florida Bay at times are moved in a west-southwesterly direction pulled possibly by a venturi action of the Gulf Loop Current's south and southeasterly flow through the distal island groups (Koczy et al. 1960, Rehrer et al. 1967, Murphy et al. 1975, Maul 1977).

An interesting study following the "red tide" as a natural tracer of current patterns off south Florida is reported by Murphy et al. (1975). The occurrence of Gymnodinium breve and its associated fish kills were traced from Sanibel Island on the west coast to West Palm Beach on the Florida east coast. The red tide's movement from off Sanibel Island to the Tortugas fishing grounds suggested the involvement of the Gulf Loop Current which had been identified flowing south-southwest over the southwest Florida shelf (Maul 1977).

The axis of the Florida Current is still another factor in local hydrology. Within the Straits of Florida, the current's axis closes in on the Florida coastline as it progresses to the northeast. Off the Dry Tortugas the current lies 124 km (77 mi) to the south. As it approaches the waters adjacent to the upper Keys, the current is within 30 km (19 mi) of the islands.

Although the current does not usually enter the shelf, a strong northerly current is noticeable immediately seaward of the shelf break from Key Largo northward (Enos 1977). Surface velocities in the Florida Straits average about 150 cm/sec (5 ft/sec) (Brooks and Niiler 1975, Enos 1977, Jaap 1982). Thorp (1935) and Vaughan (1935) postulate that a countercurrent exists shoreward of the Florida Current over the shallow shelf. Although reference elsewhere in the literature has also been made to this countercurrent (Davis 1940, 1942, Ginsburg 1956, NOAA 1973), Enos (1977) points to a lack of adequate documentation to justify this suppositon. He does concede however, that a slight westward component exists in addition to the dominant tidal and wind-driven currents. As discussed previously (wind-driven currents), Enos (1977) has observed strong northeasterly currents near Molasses Reef for several days seemingly independent of tidal action and approximately 45° from the downwind direction of the seabreeze. He concludes that the current was either the result of "channelized" wind-driven currents or a spin-off eddy of the Florida Current blown over the Florida Shelf. Lee (1975) observe these spin-off eddies in the waters adjacent to Miami. These eddies vary seasonally and monthly in their speed and direction (e.g., the July mean speed was 20 cm/sec or 39 ft/min; March and April means were 7 cm/sec or 14 ft/min). Enos (1977) suggests that long term southwestern "countercurrents" may also be an artifact of altered nearshore tide phase changes formed from the northeast to southwest or from Miami to Key West (discussed in greater detail in the section on tides). Finally Brooks and Niiler (1975), in studying the Florida Current off Key West during the early summer of 1972, observe a counterflow traveling at less than 25 cm/sec along the northern edge of the Florida Straits whereas the Florida Current was observed to be traveling in the opposite direction (to the ENE) at less than or equal to 145 cm/sec (49 ft/min). Although described as a countercurrent extending from the shore out 7 km (4 mi), the nearshore data are based on only one station located 25 km (16 mi) seaward of Key West.

Freshwater

Freshwater reaches the Florida Keys in one of two major ways: (1) indirectly through fluctuating freshwater discharges from drainage basins bordering the eastern Gulf of Mexico; and (2) directly through rainfall. Seasonal inflow from the drainage basins reduce the salinity of the Gulf Loop Current and Florida Bay, in turn affecting the waters of the middle and lower Keys (Wennekins 1959, Marszalek et al. 1977). Marszalek et al. (1977) relate the more restricted coral growth on the distal islands (Dry Tortugas and Marquesas Keys) and lower Keys to the greater variability of salinity and temperature of the Gulf Loop Current. In contrast, these authors point to the more luxurient coral growth in the upper Keys reef tract as a result of the more stable Florida Current salinity and temperature regime which affects that area's reef water.

Rainfall in the Florida keys, as previously discussed in the Climate section, is the lowest reported for Florida averaging from 89 to 114 cm (35 to 45 in) annually and with 80% to 90% falling from May to October (Hanson 1980). Most of this rainfall, because of the slight geographic relief and the pervious nature of the Key Largo and Miami oolite rock formations, infiltrates to the shallow groundwater table forming freshwater lenses (Parker et al. 1955, Klein 1970, Chesher 1974, and Hanson 1980). Figure 42 shows a vertical profile of the freshwater lens on Big Pine Key during March 1977 (Hanson 1980). The size of freshwater lens is controlled by at least six factors as outlined by Hanson (1980) and Klein (1970): (1) freshwater recharge (rainfall); (2) freshwater discharge (seepage, pumpage, runoff, and evapotranspiration); (3) response to tidal fluctuations; (4) proximity to saltwater bodies; (5) permeability of the subsurface materials; and (6) elevation of the island above sea level. As expected, the dimensions of the freshwater lenses increase and decrease in response to precipitation and therefore wet and dry season conditons (Klein 1970, Hanson 1980). Parker et al. (1955) described freshwater lenses on Key West and Big Pine Keys as increasing in thickness during the rainy season. During the dry season, even without pumpage, the freshwater tends to disappear quickly by seepage to the sea and by evapotranspiration processes. As mentioned earlier, the Florida Keys groundwater is intricately linked to the sea; thus the water table of each key undulates with the tides (Parker et al. 1955, Klein 1970, Chesher 1974, Hanson 1980), accelerating the lateral seepage of freshwater to the sea.

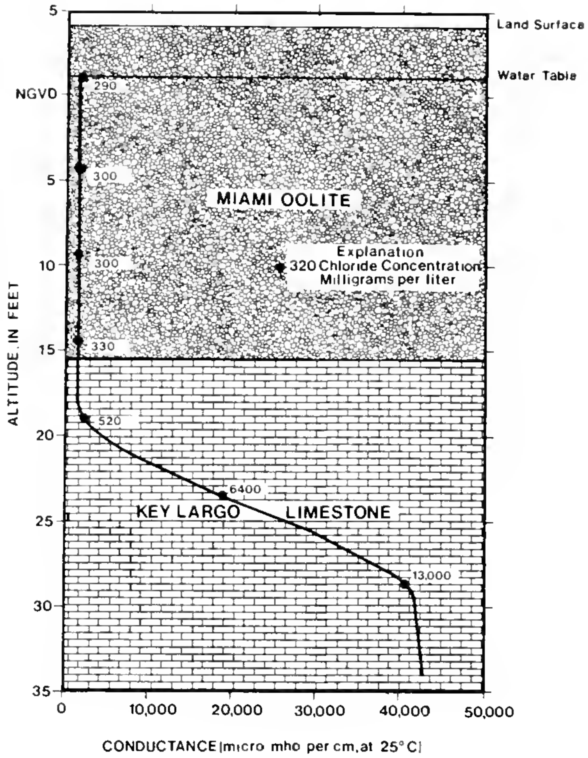


Figure 42. Conductivity and chloride concentration in relation to geology on Big Pine Key, Florida (adapted from Hanson 1980).

The development of canals for housing (Chesher 1974), mosquito control (Alexander and Dickson 1972, Hanson 1980), and ports (Chesher 1974) has short-circuited the previous residence times of the island's freshwater supplies. Alexander and Dickson (1972) report that a ditching program on Big Pine Key for mosquito control had within two years (1964 and 1965) ditched 4,976 acres of the 6,000 acres available. These ditches are approximately 4.9 m (16 ft) wide, vertical-sided, and are "deep enough to allow tidewater to flow in them from the nearby open sea". Consequently such ditches tend to accelerate runoff, increase saltwater intrusion, and thus decrease the freshwater lens on the island.

Evaporation/Transpiration

Of the two processes of evaporation and transpiration, the former is far more influential in the Florida Keys hydrologic budget. Transpiration tends to be localized and confined to individual islands, where it exerts some control of freshwater lenses (Hanson 1980). Evaporation, on the other hand, exerts an important effect on the hydrologic budget of the Florida Keys, especially where the circulation is restricted. Such restricted environments include: (1) the large, complex, and subdivided lagoonal environment of Florida Bay; (2) small, complex lagoonal environments bordering the Keys and the mainland, e.g., Blackwater Sound and Barnes Sound; (3) small sea island lagoonal environments of the Keys, e.g., Coupon Bight, Upper Sugarloaf Sound, Buttonwood Sound; and (4) intertidal and supratidal areas, e.g., Crane Key tidal flats, supratidal mud flats on Sugarloaf Key (Multer 1977). The restricted circulation of these areas in combination with strong seasonal winds, clear skies, extended dry season, and relatively high temperatures promotes evaporative processes resulting in seasonal salinity variations of as much as 50 parts per thousand (Ginsburg 1956).

Evaporation usually peaks in late spring and early summer, when maximum winds, negligible rainfall, and clear skies prevail (Lloyd 1964). During drought years such as those experienced during the summer of 1956, the peak shifts more to the middle or late summer months (Chew 1961). Chew (1961) also suggests that the proximity of a station to nearshore currents may significantly influence evaporation. Stations located only short distances from one another, one in open water, the other apparently within the "current shadow" described by Marmer (1954), exhibit radical differences in salinity over relatively short time intervals.

Water Quality

The water quality of the Florida Bay side of the Florida Keys was addressed, in part, in the section on Florida Bay hydrology and water quality. As stated in that section, water quality data in this region is fairly limited (Schmidt and Davis 1978), restricted basically to data on salinity, temperature, and to a lesser extent, turbidity. Some additional data omitted in the earlier section and of a more site specific nature regarding the nearshore bay environment of the upper Keys follows.

Lynts (1966) and Evink (1981) report on seasonal changes in the interior bay zone, specifically of Buttonwood and Blackwater Sounds, respectively. Evink (1981) observes salinity ranges between 30 ppt and 40 ppt near Snake Point in northeastern Blackwater Sound over a 14 month period. The maximum and minimum salinities follow the delayed seasonal response previously discussed, resulting in low salinities in winter and high salinities in summer. Lynts' (1966) investigation of Buttonwood Sound suggests a pattern more directly responsive to the wet and dry periods. August values range from 25.3‰ to 28.9‰ responding to the wet season precipitation. The February data show increases in salinity from 37.9‰ to 40.8‰ in response to the dry season water deficit. It appears that Buttonwood Sound is hydrologically disconnected from Florida Bay, responding primarily to the localized precipitation/evaporation regime and the tidal interflow across Key Largo (Lee and Rooth 1972).

Lynts (1966) also monitored temperature, pH, and Eh of the sediment water interface. He concludes that temperature, like salinity, varies in response to climatic changes. In addition to seasonal changes, temperature is responsive to diurnal variation in the surface air temperature. Ginsburg (1956), Lloyd (1964), and Turney and Perkins (1972) also note the sensitive nature of temperature changes which not only vary on a short-term temporal level but spatially as well. Lloyd (1964) observes temperatures on the same day as much as 2°C (3.6°F) higher over shallow calcareous mud-bank shoals or 2°C (3.6°F) lower in nearby "lakes" as compared to the mean water temperature. This spatial quality is also reflected in the annual temperature range. Ginsburg (1956) reports water temperatures of shallower areas ranging from 19° to 38°C (66° to 100°F) annually while deeper waters around mud banks ranged from 20° to 30° (68° to 90°F).

Variation of pH and Eh is tied to organic activity and temperature, and therefore varies in a similar pattern as described for temperature (Lynts 1966, Multer and Hoffmeister 1968). Diurnal pH changes in the Key's littoral marine environment range from a pH of 7.4 to 9.2, and in the freshwater environment from a pH of 6.5 to 10.0. This daily fluctuation is related to photosynthesis and respiration (P/R) processes which control the uptake (photosynthesis) and release (respiration) of CO^2. These processes attenuate the $CaCO_3$ (calcium carbonate) equilibrium which modifies the water's alkalinity and therefore its pH.

Turbidity varies a great deal in the nearshore bay environment of the upper Keys. Important variables controlling the level of turbidity include: (1) water body axis and orientation; (2) bottom morphology (depth); (3) sediment type; and (4) wind direction, duration, and speed (Chesher 1974, Griffin 1974, Manker 1975). Manker (1975), monitoring turbidity at several nearshore locations on the bay side of Plantation Key and Key Largo, found suspended particulate concentration (turbidity) to be 2 to 3 times greater in lagoonal environments than in the reef tract areas. Within the bay side environment, stations sheltered from the prevailing winds by mangrove capped mud banks exhibit turbidities ranging from 0.38 mg/l to 1.95 mg/l. Exposed or open stations monitored on the same day with similar wind direction and speed exhibit turbidities ranging from 2.95 mg/l to 7.30 mg/l.

The only study reviewed that examines water quality bayward of the Florida Keys, outside the realm of the basic physiochemical parameters previously discussed, is Manker's (1975) examination of heavy metals in the suspended particulates and bottom sediments. In general, the heavy metals lead (Pb), mercury (Hg), chromium (Cr), cobalt (Co), and zinc (Zn) are found to be equally concentrated in the fine suspended particulates and the fine (four micron) fraction of the bottom sediments, and much less concentrated in bulk sediment. Manker (1975) notes that the fines are very susceptable to resuspension and, because of the greater concentration of heavy metals, provide a potential mechanism for conveying these substances out of the area and onto the reef tract. The greatest values reported correlate with areas of increased human activity (boating and vehicular) and population density. In additon to the routine sampling program, an additional bottom sediment sample was taken from the bay side of Tavierner Key from a stormwater pipe providing drainage for U.S. Highway 1. This sample exhibited extremely high levels of metal contamination; concentrations of chromium and cobalt were 1.5 to 2.0 times concentrations reported at all other stations, 5 times greater for mercury, 10 times greater for lead, and 50 times greater for zinc.

Water quality on the seaward side of the Florida Keys exhibits two basic spatial patterns. Along the northeast-southwest axis (Key Largo to Dry Tortugas), changes in water quality are related to the physiography of the islands and the nearby ocean currents. Along the southeast-northwest axis, from the outer shelf break to the island's shoreline, changes in depth, circulation, and sediment size largely control variation of the water quality.

From Key Largo to the Dry Tortugas, water variations are related to three of the area's physiographic characteristics: (1) the continuity of the islands; (2) the proximity of the Gulf Loop Current; and (3) the proximity of the Florida Current (Marszalek et al. 1977). The upper Keys, including Plantation, Tavernier, Upper and Lower Matecumbe Keys, and Key Largo, form a nearly continuous barrier of islands effectively isolating the seaward reef tract from the highly variable water quality of Florida Bay (Ginsburg 1956, Marszalek et al. 1977). For the middle Keys (Long Key to Newfound Harbor Keys), and to a lesser extent the lower Keys, the island barrier is broken up by numerous channels and passes which allow wind-driven and tidal mixing of bay and reef tract waters (Stockman et al. 1967, Marszalek et al. 1977). The Gulf Loop Current's entrainment of continental edge waters from the eastern gulf, like the Florida Bay water, creates a more varied water quality regime than normally observed in oceanic waters (Wennekins 1959, Marszalek et al. 1977).

This relatively more variable current dominates the lower Keys' seaward environment as it wraps around the distal islands and joins the Florida Current. In contrast, the Florida Current provides a more stabilizing influence on the Keys' seaward waters. In addition, the axis of the current produces spinoff eddies as it converges on the Keys. This sends tropical waters of oceanic salinity into the seaward environment of the upper Keys. The lower Keys and distal islands are comparatively less influenced by the spinoffs.

The net result of these three physiographic factors is: (1) a stable water quality regime seaward of the upper Keys; (2) a great deal of variability in the middle Keys' marine environment; and (3) an environment in the lower Keys and distal islands that is more moderate than (2) and less stable than (1). Additional confirmation of the influence of these three factors on reef tract water quality comes from Vaughan's (1918) extensive study of reef tract temperatures. Vaughn (1918) shows that Carysfort Reef (Key Largo) has the narrowest temperature range observed. The reduced temperature range infers a more stable environment, reflecting the close proximity of the Florida Current and the spatial separation from the Gulf Loop Current and Florida Bay waters. Maximum mean monthly temperatures for the reef tract occur in the late summer ranging from 28.7°C (84°F) at Fowey Rocks to 31.1°C (88°F) at Sand Key (Key West). Minimum mean monthly temperatures occur during January and range from 21.8° to 22.5°C (71° to 73°F). There is a critical difference between low temperatures from one reef to another that is not evident in mean monthly values. Vaughan (1918) examines the coldest ten-day periods and reports that Fowey Rocks, the northern-most reef station, characterized by limited reef growth, exhibits the coldest ten-day period; 2.3°C (8°F) colder than the next lowest value, reported at Sand Key. Enos (1977) and others (Shinn 1966, Antonius 1977, Marszalek et al. 1977) suggest that such short-term temperature drops serve more to limit a coral's geographical range and affect its yearly viability than long-term temperature averages (monthly mean) typically reported.

Spatial variation of salinity along the longitudinal axis of the reef tract is less than observed for temperature; however, the data base reviewed is also more sporadic. Davis (1940) reports salinity data for the area's water for the years 1936 to 1938, and although the data base is severely limited in scope and duration it provides an interesting perspective on temporal and spatial changes in response to 'wet' (1936) and 'dry' (1937-38) years. As shown in Table 19, the Straits of Florida and the Dry Tortugas stations exhibit salinities intermediate (36%) to those observed in the Gulf (33%) and the Atlantic (37%).

	No.	Salinity (ppt)			
Location	Samples	1936	1937	1938	Average
Atlantic Ocean	5	37.0	36.8	37.1	37.0
Straits of Florida	16	35.7	36.2	37.8	36.2
Tortugas	12	35.8	35.7	36.1	35.9
Gulf of Mexico	10	31.7	33.1	32.5	32.6

Table 19. Average salinity of open sea nearshore waters associated with the Florida Keys (adapted from Davis 1940).

Table 20 summarizes salinity data from studies more specific to the outer reef tract. Salinity generally ranges between 36 ppt and 38 ppt, particularly off the upper and lower reef systems. The more northern locations, Fowey Rocks and Triumph Reef (Elliott Key) exhibit lower salinities in response to inflow from Biscayne Bay. The Dry Tortugas, like the northern reefs, exhibit lower salinities, responding in this case to the Gulf Loop Current's entrained continental shelf waters (Wennekins 1959). The Gulf Loop Current's waters occassionally expose the lower Keys' reef system to sudden drops in salinity, as observed by Jaap and Wheaton (1975) on East and West Sambo Reefs. Monitored from March 1973 to August 1974, the salinity remained at a constant 37 ppt except during August 1973, when the salinity dropped to 33 ppt.

Location	Salinity Range (ppt)	Source
Fowey Rocks	34.2 - 38.6	Dole & Chambers 1918
Triumph Reef	35.3 - 36.5	Smith et al. 1950
Margot Fish Shoal	36.8 - 37.3	Jones 1963
Key Largo-Outer Reefs	36.6 - 36.9	Manker 1975
Lower Keys-Outer Reefs	36.0 - 38.0	Kissling 1977
W & E. Sambo Reef	37.0 - (33)*	Jaap & Wheaton 1975
Key West-Fore Reef	36.0 - 37.0	Chew 1954
Dry Tortugas	35.2 - 36.1	Dole 1914, Davis 1940

*see text

Table 20. Salinities reported for the Florida reef tract and vicinity.

Turbidity along the Florida Keys seaward environment is, like temperature and salinity, dependent on the degree of mixing with the Florida Bay and Gulf Loop Current water masses (Ginsburg 1956). Waters in the upper Keys, sheltered from the bay and cleansed with Florida Current waters, are least turbid. The middle Keys, at times, are very turbid in response to movement of bay waters over the reef tract and into the Straits of Florida (Ball et al. 1967, Stockman et al. 1967). Turbidity in the lower Keys and distal islands falls somewhere in between, being additionally influenced by the Gulf Loop Current (Marszalek et al. 1977).

Certain water quality variations are best understood in relationship to transects running from the islands offshore to the outer reef tract. Figure 43 is a summary of the physical properties associated with various habitats commonly found between the Florida Keys' outer shelf and the islands. Habitats are those listed in Table 12. This figure serves to point out the variety and complexity of environmental conditions existing from reef to shore, particularly when compared to the variation exhibited along the elongated axis of the Florida Keys. In general, turbidity, temperature variation, and salinity variation increase from the shelf break to the nearshore environment.

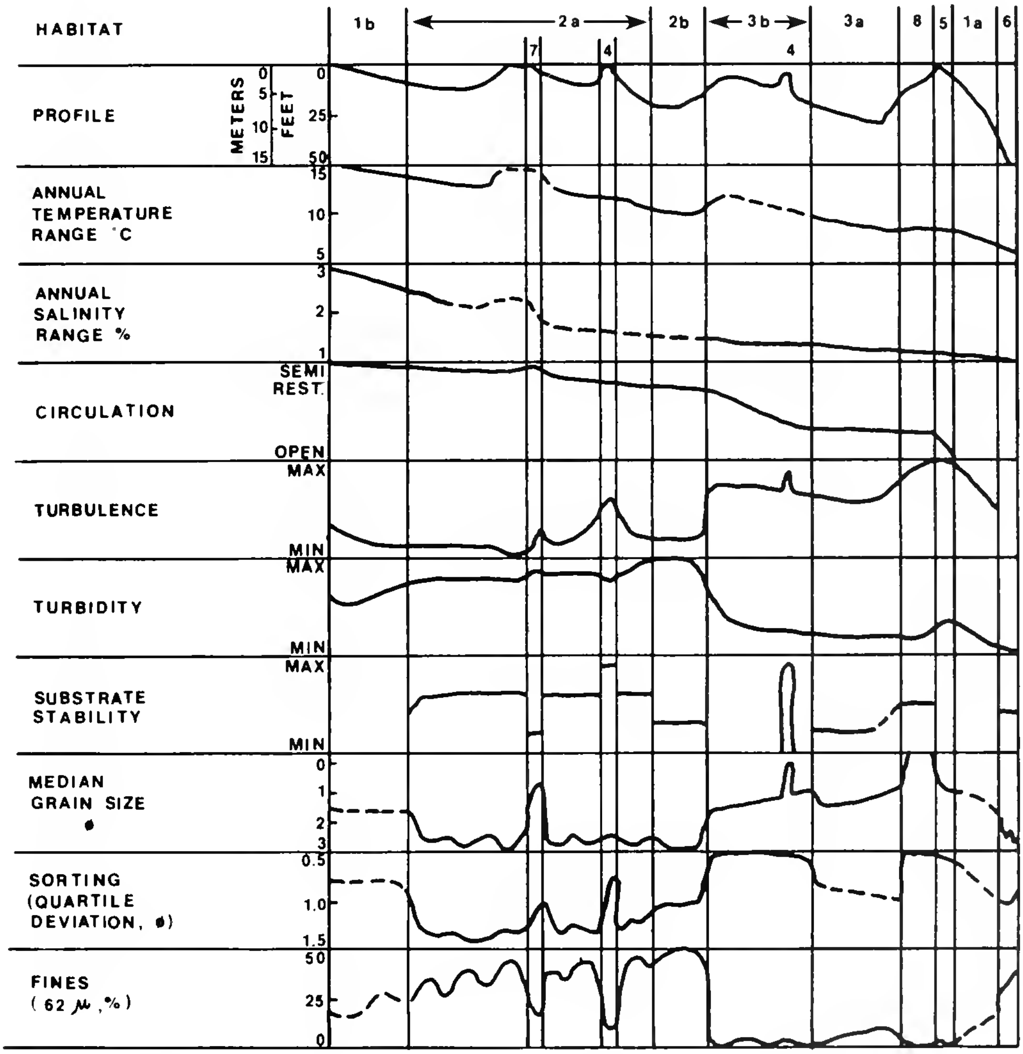


Figure 43. Summary of physical/chemical conditions along the south Florida shelf margin in the Florida Keys (adapted from Enos 1977).

Temperature variation is primarily controlled by depth and circulation. In the nearshore shallow waters adjacent to the islands, a diurnal pattern follows daily changes in air temperature. Along the shelf break a seasonal pattern characteristic of the Florida Current is prevalent. Shinn (1966) reports that both mean monthly and annual temperature ranges along a transect from Key Largo Dry Rocks to Key Largo increase moving shoreward. Temperatures during the 1961-1962 monitoring program range from 20° to 30.5° (68° to 87°F) at the outer shelf margin; 17.2° to 32.8°C (63° to 91°F) at an inner shelf margin patch reef; and 13.2° to 33.8°C (56° to 93°F) at a Key Largo nearshore area. Jones (1963) observes as much as a 6°C (11°F) daily variation over a patch reef in the upper Keys. In shallower waters the diurnal response increases, resulting in rapid temperature changes as great as 8°C (14°F), dropping as low as 10°C (50°F) during the passage of synoptic cold air masses (Zischke 1973, Multer 1977, Little and Milano 1980, Zieman 1982).

Salinity variation, like temperature, is controlled by depth and circulation which affect the volume of water and the surface area. In shallow areas, temperature is affected as the volume is reduced thereby providing a smaller mass to heat. With an increase in the surface area to volume ratio, heating and cooling are facilitated. With salinity, the reduced volume and increased surface area to volume ratios produce an analagous result. The smaller the volume of water, the greater the influence of rainfall on decreasing the salinity, and the greater the influence of evaporation on the increasing salinity. A greater surface area promotes rapid mixing of precipitation, while at the same time promoting evaporation; temperature increases and increased wind/surface contact tends to replace "wet" air with "dry" air. The salinity increases gradually from reef to shore, as illustrated in Figure 43 and, like temperature, salinity exhibits a pulse over the inner reef's shoal fringe where circulation is restricted and shallow depths exist (Enos 1977). Chew (1954) observed salinity in the fore reef area ranging from 36%-37% and in the back reef or inner shelf from 33%-37%. Additional salinity data from the Keys nearshore environment falls within a range similar to Chew's (1954) back reef data, averaging from 33.8% to 40.4% (Springer and McErlean 1962, Little and Milano 1980).

Within the channels and passes of the lower Keys, and the sounds, lagoons, bights, coves, and salt ponds on the islands themselves, depth and circulation are further reduced with concurrent increases in salinity and temperature variation (Bock 1967, Howard and Faulk 1968, Howard et al. 1970). Annual temperature and salinity ranges appear to be inversely proportional to depth within Pine Channel (lower Keys). At a depth of 15 cm (6 in) the mean monthly salinity range was 12 ppt for a 12 month monitoring program. At 90 cm (35 in) the mean monthly range decreased to around 9.8 ppt. At depths from 1.35 to 1.95 m (4.4 to 6.4 ft) the range of mean monthly values decreased to 6.0 ppt. Variation at each site was related to local rainfall, evaporation, and in shallow depths, to tides (Bock 1967).

Turbidity is controlled by depth, sediment type, vegetative cover, bottom geography, and circulation. In general, turbidity along transects from reef to nearshore areas is greatest in the bare mud bottom areas of the inner shelf in Hawk Channel. Ginsburg (1956) observes white water within the channel during periods of sustained winds of 24 km/hr (15 mph) or greater, as does Chew (1954) off Key West. Griffin's (1974) extensive study of temporal and spatial variation of turbidity associated with dredging activities off Key Largo reports a similar pattern. Along the inner shelf (Hawk Channel), turbidities peak most intensively during the winter months when prevailing northeasterly winds blow down the channel instead of across it. Griffin (1974) reports mean suspended sediment concentrations increasing from the shelf break (0.50 optical mg/l) through the outer reefs (0.80 optical mg/l) to the inner reefs (4.4 optical mg/l). Turbidities resulting from "hard-rock dredging" off Key Largo and measured adjacent to the dredging activity range from 18 mg/l (0.7 m or 2.4 ft outside a functioning turbidity diaper) to 212 mg/l (over the edge of the diaper at a leak). Down current from the diaper, turbidities ranged from 22 mg/l to greater than 40 mg/l. Apparently the containment procedure, even when malfunctioning, substantially reduces the peak turbidity levels (Griffin 1974). Plume direction is, as expected, sensitive to prevailing currents and rarely exceeds the limits of an area extending 0.3 nautical miles alongshore and 0.33 nautical miles offshore. No detectable impact is noted on a patch reef 0.48 nautical miles to the NNE of the dredging activity.

Variation of dissolved oxygen across the reef tract is controlled by temperature, salinity, turbulence, and bio-chemical processes. As illustrated in Figure 43, turbulence generally decreases while temperature and salinity variation and the concentration of bio-chemical processes per unit volume increases with decreasing depth (Enos 1977). The net effect is generally to increase dissolved oxygen variation from the reef to shore.

Dissolved oxygen in the upper 50 m (164 ft) of the Straits of Florida ranges from 3.7 mg/l to 5.4 mg/l with an annual mean value of 4.6 mg/l (USDC 1974). Jaap and Wheaton (1975) report surface dissolved oxygen values ranging from 5.4 mg/l to 8.2 mg/l over East and West Sambo reefs (outer reefs off Key West). A wider range 4.2 mg/l to 8.6 mg/l is observed near the bottom. Manker (1975) reports a more restricted range of 6.2 mg/l to 8.6 mg/l, averaging 6.3 mg/l over the outer reefs off the upper Keys. Farther shoreward over the patch reefs, dissolved oxygen variation increases (Jones 1963). In a patch reef environment seaward of Elliott Key, dissolved oxygen ranges from 3.8 mg/l to 5.9 mg/l. Diurnal dissolved oxygen on the patch reef varies seasonally, resulting in a daily fluctuation of 0.08 mg/l in winter (95% to 120% saturation) and a 1.6 mg/l daily range during the summer (90% to 125%). The maximum daily values occur from 1400 to 1600; the minimum values occur between 0300 and 0800 (Jones 1963). A similar trend of slight supersaturation during the day and slight undersaturation at night occurs in the shallow reef waters of the Dry Tortugas (McClendon 1918). Jones (1963 notes that minimum oxygen values, observed in the early morning hours, reach a seasonal minimum during late summer and early fall when water temperatures and community respiration are highest. The opposite response takes place during winter months. Manker (1975) reports a range of 6.2 mg/l to 8.6

mg/l of dissolved oxygen over the reef tract off Key Largo, Plantation, Tavernier, and Elliott Keys. All values were measured from 0900 to 1800, during the summer months, and therefore represent the higher end of the diurnal and seasonal range of dissolved oxygen values. The majority of oxygen concentrations fall below 6.0 mg/l with less than 20% exceeding 7.0 mg/l. From the nearshore stations, monitored concurrently, a wider range (0.9 mg/1 to 9.5 mg/l) was reported with 25% of the values below 6.0 mg/l and less than 20% exceeding 7.0 mg/l. Other authors (Howard and Faulk 1968, Howard et al. 1970, Chesher 1974) have observed similar wide ranges of dissolved oxygen in the nearshore and lagoonal environments. Howard et al. (1970) report that dissolved oxygen varies from 3.9 mg/l to 11.7 mg/l in Coupon Bight, between Newfound Harbor Keys and Big Pine Key. There the diurnal pattern, which varies within several subenvironments of the bight, characteristically peaks at approximately 1500 and is most pronounced (0.7 mg/l/hr) within the seagrass (Thalassia testudium) sub-environment. The lowest (3.9 mg/l) and highest values (11.7 mg/l) are associated with areas where circulation is more restricted. Narrower diurnal ranges are related to environments with better tidal-flushing (channel, open bay, and open-rock shore environments). In mangrove channels and tributaries of the lower Keys (Channel, Boca Chica, Mud, O'Hara, and Sugarloaf Keys) and the upper Keys (Key Largo), dissolved oxygen varies from 2.7 mg/l (North Creek, Key Largo) to 8.0 mg/l (O'Hara Key) (Chesher 1974). Very little oxygen stratification exists in these fairly shallow natural channels ranging from an average of 5.15 mg/l at the surface to 4.97 mg/l at the bottom. These rather uniform depth profiles of oxygen concentration are in stark contrast with vertical stratification that is evident in man-made canals. In the upper Keys, values range from 5.92 mg/l at the surface to 2.63 mg/l at the bottom; in the middle Keys, 5.58 mg/l to 4.27 mg/l; and in the lower Keys, 6.03 mg/l to 4.74 mg/l (Chesher 1974).

Phosphorus in the surface waters (upper 50 m or 164 ft) of the Florida Straits range from undetectable to 1.22 microgram (ug) atoms per liter as P, averaging 0.07 ug atoms per liter (USDC 1974). Inside the reef tract off Elliott Key, total and inorganic phosphorus ranges from 0.15 to 0.25 ug atoms/l, and undetectable to 0.1 ug atoms/l, respectively (Jones 1963). No discernible diurnal pattern exists, and no constant ratio between total and inorganic phosphorus is apparent.

Like phosphorus, nitrate-nitrite is present in very low concentrations throughout the year. Nitrate as N and nitrite as N ranged from 2.0 to 9.0 ug atoms/l and 0.05 to 0.25 ug atoms/l, respectively (Jones 1963).

A similar trend of low nutrient levels is indicated for the mangrove channels and tributaries in the lower Keys and Key Largo (Chesher 1974). Orthophosphate as P averaged 0.05 ppm, ranging from 0.02 ppm to 0.15 ppm. A general decrease in concentration occurs from surface to bottom. Nitrate as N ranges from 0.05 ppm to 0.15 ppm. Both nitrogen and phosphorus data from this study are based on few measurements within a restricted temporal and spatial framework and therefore may not represent a true picture of the nutrient patterns along the Florida Keys nearshore environment.

Heavy metal concentrations (Pb, Hg, Cr, Co, and Zn) to the seaward side of the upper Keys follow the same pattern as described for the upper Keys lagoonal (bayward) environment (Manker 1975). Metal concentrations are similar in both suspended particulates and the four-micron fraction of the bottom sediments. Concentrations in both fractions greatly exceed the concentrations in the bulk sediment. Areas of higher heavy metal concentration correlate with high population density, automotive and boat traffic, and improperly monitored and maintained sewage disposal systems (Manker 1975). In all cases, a boat basin/marina located in the John Pennekamp State Park exhibited the highest heavy metal concentration observed in bulk sediment. Manker (1975) attributes this to gas combustion by-products, improper waste disposal (boats), and stormwater runoff. For the bulk sediment samples taken from the seaward side of the upper Keys (excluding the boat basin/marina), chromium (Cr), cobalt (Co), and zinc (Zn) did not exceed background levels except for a small nearshore area adjacent to where U.S. Highway 1 joins the Florida Keys.

Lead (Pb) and mercury (Hg) exhibit high concentrations (exceeding background levels of 19 ppm and 0.2 ppm, respectively) at four general areas: (1) nearshore of Plantation and Tavernier Keys; (2) Biscayne Bay to the reef tract; (3) where U.S. Highway 1 joins the Keys; and (4) in the John Pennekamp boat basin/marina. Concentration of all heavy metals in the marina are three to seven times the observed background levels. Table 21 shows heavy metal concentrations in live and dead corals from several reefs (Hen and Chickens Reef) along the upper reef tract. Based on this data, Manker (1975) speculates that: (1) reef damage in the upper Florida Keys and Biscayne Bay area is caused by the influx of chilled waters associated with cold frontal passage, and secondarily to toxic metals; and (2) depauperate macrophytic communities in the John Pennekamp State Park boat basin/marina "may" be a result of toxic metal contamination.

Location (North to South)	Hg	Cr	Co	Zn
Fowey Rocks	549	361	882	1343
Triumph Reef	77	482	124	1285
Pacific Reef	52	678	84	929
Carysfort Reef	36	1381	58	1153
Elbow Reef	104	1272	168	891
Molasses Reef	46	496	73	2329
Hen & Chickens (Live Corals)	37	767	60	2949
Hen & Chickens (Dead Corals)	114	694	183	4767

Table 21. Concentration (ppb) of heavy metals mercury, chromium, cobalt, and zinc in corals from the upper Keys reef tract (adapted from Manker 1975).

Chesher (1974) reports concentrations of lead, mercury, and chromium in natural mangrove channels in the lower Keys (Mud Key and O'Hara Key) to be at or below the background conditions established by Manker (1975). Copper levels, ranging from 5.0 to 2.6 ppm dry weight are also at background levels. Zinc concentrations ranging from 10 to 26.1 ppm dry weight, are much greater than those reported by Manker (1975), but are at the lower end of the scale of the values reported by Chesher (1974) from elsewhere in the Keys. No explanation is given to explain the discrepancy.

Several chlorinated hydrocarbons are found in the natural mangrove channels of the lower Keys (Chesher 1974). Although in most cases the values are at or below those measured in man-made canals, p,p'DDT at Mud Key is greater than or equal to concentrations in many of the man-made canals. This chlorinated hydrocarbon was commonly used to control mosquitos in the Keys until 1968. Because of Mud Key's relatively remote location along the northern outer banks of the lower Keys, the presence of this chemical indicates wide spread geographical contamination and long term persistence.

Inland and coastal canals represent one of the more dramatic signatures of man's presence in the Florida Keys. From Key West to Key Largo more than 320 canals permeate the islands. Water quality within the canals, most critically dissolved oxygen, is controlled by the canal's orientation, dimensions, canal walls slope, entrance depth, number of entrances, adjacent land use, and substrate (Chesher 1974). Of these, the canal's orientation and substrate appear to be the most important.

Substrate in the Florida Keys canals may be: (1) mangrove peat or fine calcareous muds; or (2) Miami Oolite or Key Largo Limestone. Organic material and turbidity (resulting from resuspension of fines) often result in the vertical dissolved oxygen stratification in mangrove peat/mud canals exceeding 2 m (6 ft) in depth (FDPC 1973, Chesher 1974, USEPA 1975). This stratification promotes the isolation of the lower layer of water from tide and wind forced flushing of the canal waters. Indigenous (mangrove peat) and imported (seagrasses, runoff) organic material accumulate in the stagnant bottom layer contributing more, via decomposition, to the oxygen demand and deficit. Canals with rock substrate (Miami Oolite or Key Largo Limestone) do not exhibit anoxic layers until the canal depths exceed around 3 m (10 ft) or greater (Chesher 1974).

Second in importance to bottom substrate as a control of the canal's water quality is the canal's orientation to the prevailing winds and tides. Elongation parallel to the prevailing wind direction (E-W or NW-SE) maximizes wind forced movement of water. If the canal's mouth is downwind more effective flushing occurs, whereas openings upwind can result in debris build-up and horizontal stratification of water quality from the canal's end to the mouth (FDPC 1973). Multiple openings create a pass-through situation promoting flushing (USEPA 1975).

Salinities range from 27 ppt to 41 ppt, and may exhibit vertical increases averaging as much as 2 ppt from surface to bottom. Sombrero Marina (Vaca Key), receiving runoff from residential, commercial, and transportation (U.S. Highway 1) areas, shows a surface to bottom salinity difference of 8 ppt during August 1973, although temperature varied less than 0.5°C (0.9°F). This form of stratification commonly occurs following a large influx of freshwater runoff, forming a freshwater lens in the canal. The sudden isolation of the more saline waters by the density gradient creates an anoxic environment, possibly resulting in fish kills (FDPC 1973, Chesher 1974).

The relatively deep and sheltered nature of the canal waters leads to a more moderate temperature range than observed in the Keys' nearshore environment. Temperatures range from 23° to 32.6°C (73° to 91°F) although measurements are sparse, particularly for the colder, winter months. Generally temperatures decrease with depth due to differential heating. Where inversion of this trend occurs, stratification of the higher temperature waters is usually associated with low dissolved oxygen.

A by-product of the passage of freshwater runoff over and through the oolitic and coralline limestone formations is the introduction of $CaCO_3$ (calcium carbonate) and a consequent increase in pH. This process is reflected in canal pH values ranging from 7.2 to 9.3 (FDPC 1973, Chesher 1974). In canals where stratification is prevalent, pH can decrease as much as one unit from surface to bottom (FDPC 1973).

The macronutrients nitrogen and phosphorus are generally low in man-made canals. Dissolved inorganic phosphorus as P averages between 0.040 to 0.082 ppm (FDPC 1973, Chesher 1974). USEPA (1975) reports total phosphorus as P ranging from 0.01 ppm to 0.06 ppm. Nitrate and total kjeldahl nitrogen as N range from undetectable to 0.33 ppm and from 0.19 ppm to 1.48 ppm, respectively. Higher nutrient levels are found in canals with increased human activity (marinas, commercial and transportation land use), mangrove peat and mud substrate, and poor circulation (FDPC 1973, Chesher 1974, USEPA 1975).

A distinctly diurnal dissolved oxygen patten is prevalent in man-made canals in the Florida Keys (Chesher 1974, USEPA 1975). Lowest values are generally found shortly after dawn and highest values in mid afternoon. Vertical and horizontal variations in oxygen can result from biological production, restricted flushing, and resuspended organic matter. Variations may also be affected by the interactions of these factors with circulation patterns, canal geometry, and anoxic layering (FDPC 1973, Chesher 1974, USEPA 1975). A depth profile resulting from this interaction typically resembles a bell shaped curve with lowest oxygen values at the surface and bottom, and highest values at mid-depth. Figure 44 illustrates the combined effect of these actions bringing aerated waters in with the tide floating over the anoxic layer, but under a wind-driven layer derived from the oxygen depleted water at the canal's dead end (FDRC 1973).

Of the heavy metals monitored, copper, lead, and zinc appear in greatest concentration associated with boat basins/marine and urban stormwater conveyance systems (FDPC 1973, Chesher 1974, USEPA 1975).

Table 22 summarizes the most complete survey of pesticides in Florida Key canal sediments (Chesher 1974). Mangrove channels and tributaries on Mud and O'Hara Keys provide an approximation of background

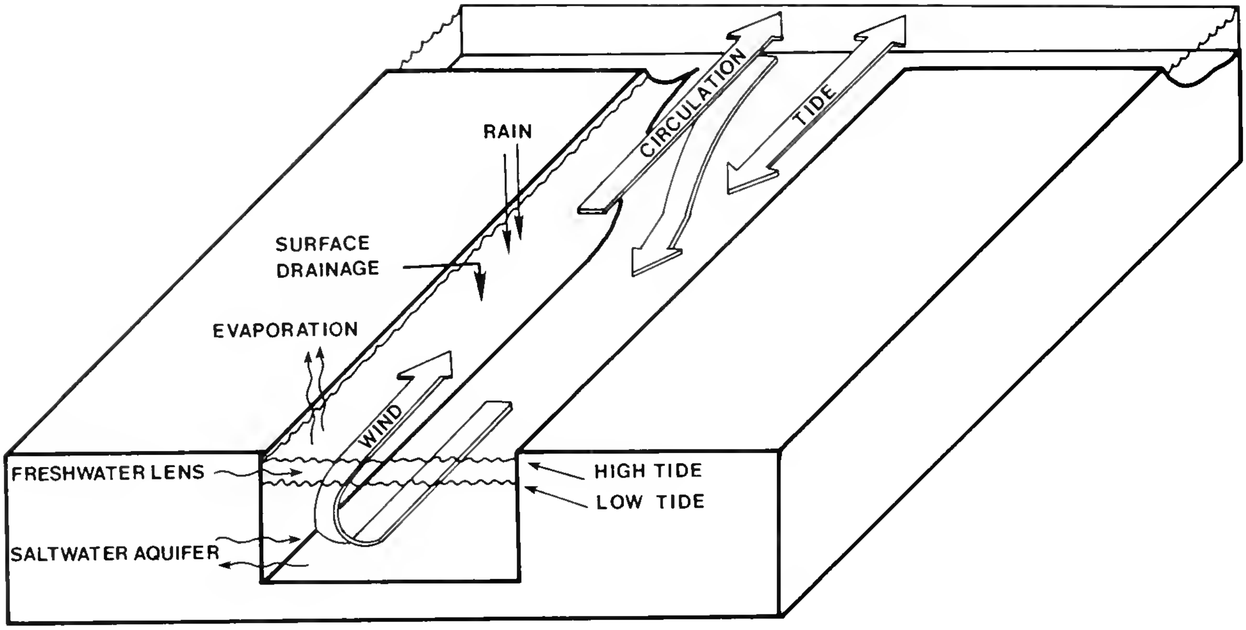


Figure 44. Schematic diagram of water budget in canals of the Florida Keys (adapted from Chesher 1974 and Bailey et al. 1970).

levels. High levels of p,p'DDT are attributed to the pre-1968 mosquito control spraying program. Pesticides used for households, golf courses, plant nurseries, and marinas may be the reason for the other elevated levels of pesticides (exceeding Mud and O'Hara Key levels), but the specific sources were not identified (Chesher 1974).

Groundwater in the Florida Keys is restricted to: (1) the shallow groundwater regime consisting of freshwater lenses interfacing with brackish and marine groundwater (Hanson 1980); and (2) deeper Floridan Aquifer waters (Beaven and Meyer 1978). Groundwater nutrient concentrations are very similar to canal waters (Doctor's Arm) monitored by FDPC (1973), Chesher (1974), and USEPA (1975). Floridan Aquifer wells in the Florida Keys contain water with concentrations of 1,600 to 20,000 mg/l of chloride and 3,430 to 37,500 mg/l of dissolved solids from samples taken at depths ranging from 248 to 610 m (812 to 2,000 ft). Total nitrogen and phosphorus concentrations are similar to the shallow aquifer and freshwater lens reported on Big Pine Key (Hanson 1980).

Sample	Aldrin	Heptachlor Epoxide	Dieldrin	o,p'DDE	p,p'DDE	o,p'DDD	p,p'DDD	o,p'DDT	p,p'DDT
Mud Key (8)	9.9	10.1	16.9	16.2	33.4	-	-	6.1	25.4
O'Hara Key (9)	[illegible]	7.9	4.5	13.5	24.3	-	-	T	T
Riviera ([illegible])	18.0	21.1	5.6	-	[illegible]	-	-	T	[illegible]
Key Haven ([illegible])	20.9	10.7	23.5	-	[illegible]	-	-	21.8	27.8
Sombrero Marina (21)	13.6	19.7	[illegible]	-	60.1	-	30.1	21.1	46.9
Sea Air (23)	20.5*	[illegible]	14.6	[illegible]	[illegible]	-	T	[illegible]	15.8
Port Antigua ([illegible])	35.7	[illegible]	15.4	[illegible]	51.7	-	-	10.9	8.8
Ocean Drive (37)	[illegible]	16.3	20.1	[illegible]	43.7	-	-	9.8	T
Garden Cove (49)	14.5	[illegible]	39.8	[illegible]	43.7	-	T	9.6	[illegible]
Port Largo ([illegible])	21.4	9.8	17.8	14.8	31.5	-	T	11.7	93.6
Sexton Cove ([illegible])	44.5	13.5	11.5	-	15.5		-	[illegible]	[illegible]
Sexton Cove ([illegible])	[illegible]	16.8	11.1	[illegible]	[illegible]	-	-	20.4	328.2

* = trace amount of endrin

T = trace amounts

Table 22. Concentrations of pesticides (ppb, dry weight) in canal sediments from the Florida Keys (adapted from Chesher 1974).

CHAPTER 6
TERRESTRIAL AND FRESHWATER WETLANDS

6.1 HABITAT ZONATION

Figure 45, adopted from Browder et al. (1973), presents a very general but useful map of the distribution of terrestrial and freshwater wetlands within the present study area as of 1973. Because the scale of the map is large, much of the subtle ecotonal variation that exists within and between habitats cannot be shown. Restricting themselves to just the privately owned East Everglades portion of this ecosystem, Hilsenbeck et al. (1979) delineate no less than 40 types of terrestrial and freshwater wetland vegetation associations. In upper and middle Taylor Slough, Olmstead et al. (1980) delineate a total of 10 vegetation communities, 4 in which graminoids (grasses) dominate and 6 in which trees dominate. Based on fish and wildlife distributions, the South Florida Research Center (SFRC) (1980), distinguishes only 7 terrestrial and freshwater wetland habitats for the same area encompassed by Hilsenbeck et al. (1979).

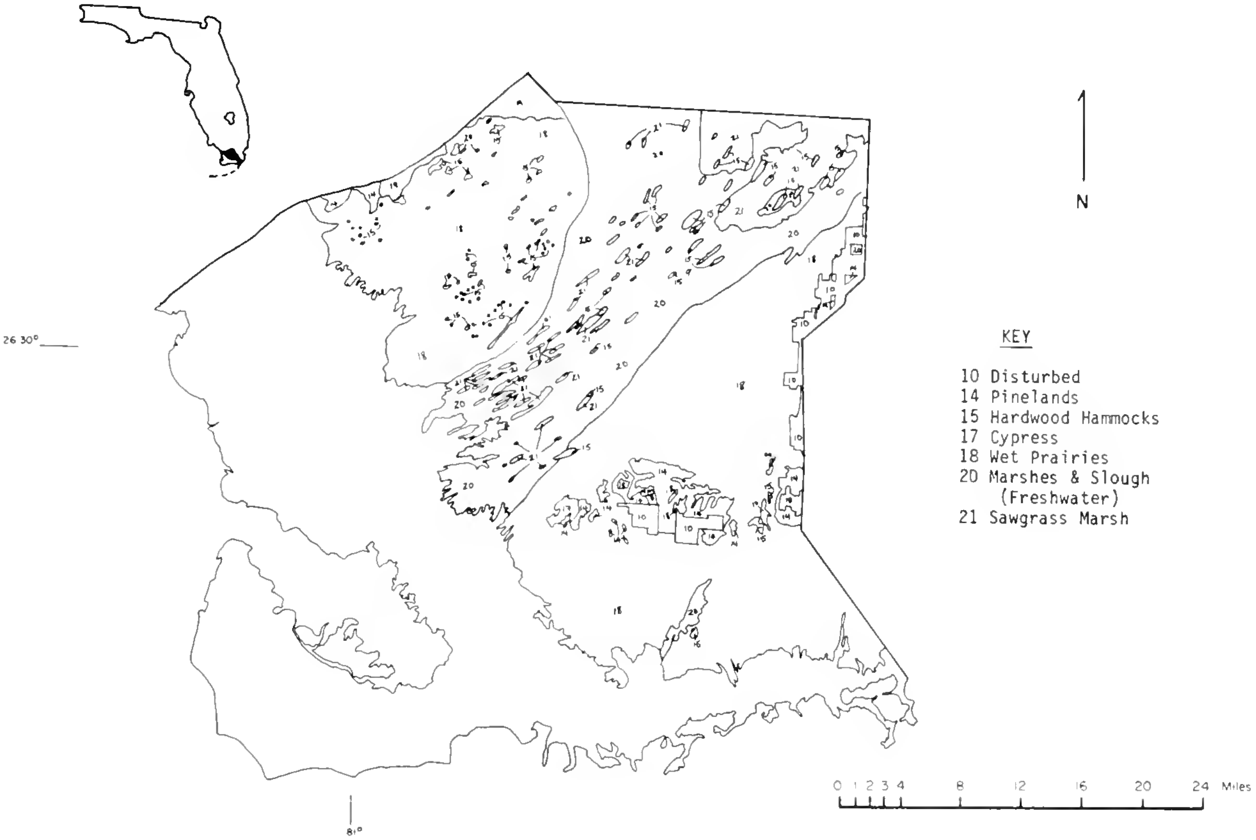


Figure 45. Terrestrial and freshwater wetlands in the lower Everglades and Taylor Slough (adapted from Browder et al. 1973).

Using these latter delineations, which correspond to those outlined in our conceptual model (Figure 4), Table 23 is generated. This table outlines the hiearchical relationship that exists between habitats, vegetation associations, and hydroperiod. It should be noted that within each habitat category, the order of listing of vegetation communities bears no hard and fast relationship to increasing hydroperiod. At this level, many other factors such as soils, proximity to disturbances, type and timing of disturbances, associations with nearby habitats, and so forth exert a plethora of effects on plant distributions.

Hydroperiod (months)	Pinelands	Hammocks	Prairies	Cypress	Thickets	Marshes	Ponds	Disturbed
0-2	Slash Pine Saw Palmetto	Oak Climax Bayhead/ Tropical Midden Forests						Rock Plowed Exotics in Forests Brazilian Pepper Monocultures Braz. Pepper/ Guava Groves Exotics in Prairies Saltbush/ Braz. Pepper
2-3			Narrow Beardgrass Muhly with Sawgrass Muhly on Marl Muhly with Cypress					
3-4				Hatrack Cypress Cypress Domes Cypress Heads Cypress Strands	Pond Apple/ Willows Wax Myrtle/ Saltbush Willow/Pond Apple Wax Myrtle Willow Thicket Cocoplum Heads			
4-5						Maidencaine Flats Sawgrass Marsh Spike Rush/ Beak Rush Flag/Pickerel Weed Cattail Marsh		Melaleuca/ Sawgrass
5-6								Cypress Fire Recovery
6-7								
7-8								
8-9								Canal Banks
9-10							Ponds with Cypress Ponds with Marshes Ponds with Thickets	Canals
>10								

Table 23. Vegetation communities by habitat types.

A number of excellent and extensive summaries of vegetation communities and factors influencing their composition and succession exist for the south Florida region. Davis (1943) was the first to deal with communities on a regional scale. More recently Loveless (1959), Craighead (1971), Hofstetter (1973), Alexander and Crook (1974), Hilsenbeck et al. (1979), and McCoy (1982) have presented an ongoing regional analysis of vegetation community structure and change.

Figure 46 presents a generalized scheme of plant community successional relationships in the study area. Common and scientific names of flora discussed throughout this paper are based on the comprehensive treatise by Long and Lakela (1971).

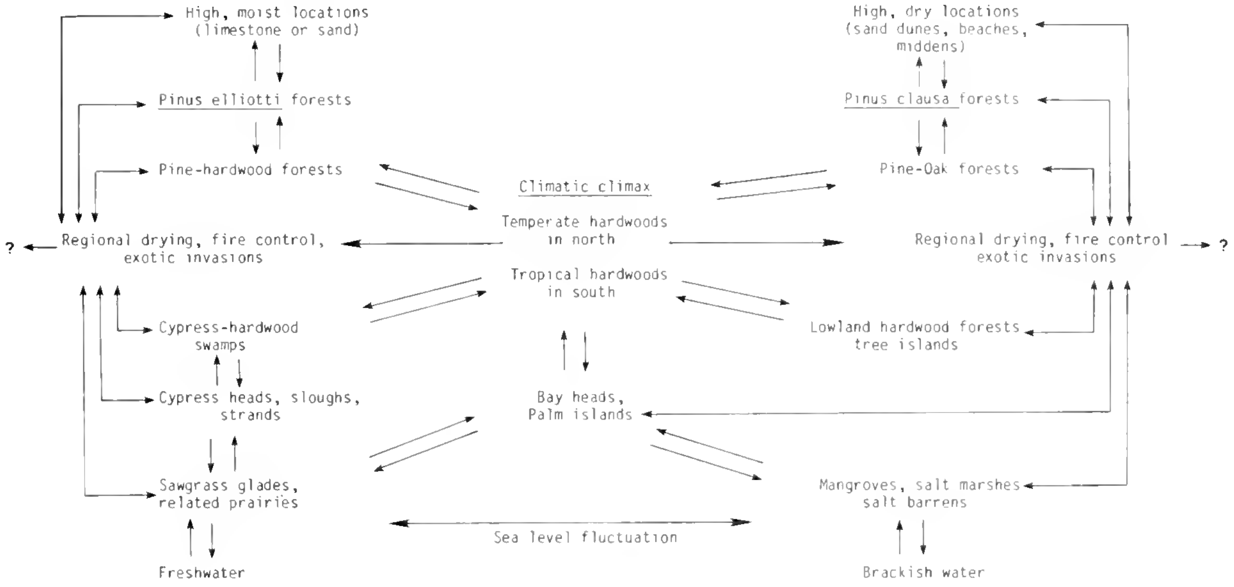


Figure 46. Summary diagram of successional relationships among south Florida vegetation communities (adapted from Alexander and Crook 1973).

6.11 PINELANDS

The pinelands of the study area are conspicuously associated with outcroppings of the Atlantic Coastal Ridge. Soil development here is extremely poor. The substrate is the solution riddled oolitic facies of the Miami Limestone. The dominant species is Caribbean slash pine (Pinus elliottii var. densa). Saw palmetto (Serenoa repens), wax myrtle (Myrica cerifera), varnish leaf (Dodonaea viscosa), and velvetseed (Guettarda elliptica) are common in the understory (Olmstead et al. 1980).

Pinelands are a fire arrested climax community. Without periodic fire, the pines are gradually out-competed by tropical hardwood species. The relatively open understory, the accumulation of pinestraw, and the open canopy of the pines encourages the initiation and spread of fire. Slash pine seedlings require stimulation by fire in order to germinate, while the thick, moist bark of maturing trees often protects them from consumption by milder fires. Seedlings and saplings of encroaching hardwoods tend to be destroyed or at least held in check by fire.

Without fire, however, the competitive edge tips in favor of tropical hardwood hammocks. Mature slash pine are highly susceptible to disease and without the germinating stimulus of fire, young saplings do not replace them. The relatively closed canopy of the tropical hardwood hammock tends to conserve more moisture and quickly recycle forest floor litter, thus discouraging further fires.

6.12 HAMMOCKS

Hilsenbeck et al. (1979) list five (5) types of hammocks (or forests) in the east Everglades study area:

(1) Shark River Slough bayhead forests;
(2) Taylor Slough bayhead forests;
(3) Bayhead-tropical hardwood forests;
(4) Tropical hammock forests; and
(5) Midden forests.

Shark River Slough bayhead forests typically exhibit 3 strata: a canopy layer between 4 and 10 m, (13 and 33 ft) a shrub layer between 0.6 and 3 m (2 and 10 ft), and a ground layer up to 0.6 m (3 ft) (Hilsenbeck et al. 1979). The canopy layer generally consists of strangler fig (Ficus aurea), red bay (Persea borbonia), willow (Salix caroliniana), and wax myrtle (Myrica cerifera). The shrub layer contains elderberry (Sambucus simpsonii), myrsine (Myrsine guianensis), wild coffee (Psychotria sulzneri), and dicliptera (Dicliptera assurgens). The ground layer is typically composed of sawgrass (Mariscus jamaicensis), leather fern (Acrostichum danaeaefolium), swamp fern (Blechnum serrulatum), Boston fern (Nephrolepis exaltata), shield fern (Thelypteris kunthii), bloodberry (Rivina humilis), creeping orchid (Habenaria nivea), and melonette (Melothria pendula).

Taylor Slough bayheads tend to be better developed than Shark Slough bayheads with regard to canopy closure, species richness, and stratal organization. Also, many of the canopy trees are larger, both in height and diameter. Floristically Taylor Slough bayheads differ from those of Shark Slough in that bald cypress (Taxodium distichum), poisonwood (Metopium toxiferum), cabbage palm (Sabal palmetto), and even red mangrove (Rhizophora mangle) and buttonwood (Conocarpus erecta) may be present in the canopy layer. The shrub layer contains numerous tropical hardwoods such as white stopper (Eugenia axillaris), antswood (Bumelia reclinata var. reclinata), and spanish stopper (Eugenia myrtoides). In the ground layer the unusual species Apteria aphylla (or nodding nixie) is very common.

Tropical hammock forests represent the upland climax community for the study area and for southern Florida in general. This community develops on organic soils that are sufficiently elevated so that the effective hydroperiod is less than 1 month in duration. The best developed stands with the tallest and largest trees have no effective hydroperiod except during extremes of flooding, such as associated with hurricanes. The hammock forest canopy is generally closed, usually excluding more than 85% of ambient sunlight. The forests are floristically very diverse both with respect to canopy and understory vegetation. The average height of the vegetation is from 2.8 to 10 m (9 to 33 ft).

The structure of the hammock forests is generally 2 stratal: a canopy stratum 4.5 to 12 m (15 to 40 ft) high, and an understory and ground stratum from ground level to 2 m (7 ft). The canopy layer includes: live oak (Quercus virginiana var. virginiana), strangler fig (Ficus aurea), willow bustic (Dipholis salicifolia), wild mastic (Mastichodendron foetidissimum), pigeon plum or tie tongue (Coccoloba diversifolia), wild tamarind (Lysiloma latisiliqua), gumbolimbo (Bursera simaruba), paradise tree (Simarouba glauca), lancewood (Nectandra coriacea), and poisonwood (Metopium toxiferum). Understory species include: white stopper (Eugenia axillaris), Simpson's stopper (Myrcianthes fragrans var. simponsii), whitewood (Schoepfia schreberi), marlberry (Ardisia escallonioides), tetrazygia (Tetrazygia bicolor), wild coffee (Psychotria undata), bloodberry (Rivina humilis), Boston fern (Nephrolepsis exaltata), wood fern (Thelypteris augescens), hammock panic grass (Panicum commutatum), and strap fern (Campyloneurum phyllitidis).

Tropical hammock forests have a very stable microclimate beneath the canopy layer, and consequently support a rich and diverse epiphytic flora. The most common and abundant species include: stiff-leaved wild pine (Tillandsia fasciculata), giant wild pine (T. utriculata), reflexed wild pine (T. balbisiana), soft-leaved wild pine (T. valenzuelana), and needle-leaved wild pine (T. setacea) (Hilsenbeck et al. 1979).

Forests that occupy Indian middens differ only slightly from typical hardwood hammocks. Because of the unusually high elevations provided by the midden itself, these forests have essentially no hydroperiod and often support large trees. The canopy vegetation usually has fewer species than other hammock sites. Dominant species include: wild mastic (Masticodendron foetidissimum), live oak (Quercus virginiana var. virginiana), hackberry (Celtis laeigata), willow bustic (Dipholis salicifolia), mulberry (Morus rubra), and strangler fig (Ficus aurea). Characteristic species of the understory are: satinleaf (Chrysophyllum oliviforme), banana (Musa paradisiaca), and sugar cane (Saccharum officinarum).

6.13 PRAIRIES

Wet prairies make up a sizeable portion of what might be called the background vegetation of the terrestrial/freshwater zone, particularly on either side of Shark River Slough. Hilsenbeck et al. (1979) identify three types of wet prairies:

(1) Muhlenberghia prairies;
(2) Muhlenberghia with narrow beardgrass prairies;
(3) Narrow beardgrass/three-awn grass/love grass prairies on oolite outcrops.

Olmstead et al. (1980) lump all prairies in Taylor Slough into one category, Muhlenberghia prairies.

The pure muhly grass prairies occur on sites with a hydroperiod of anywhere from 2 to 7 months and marl soils from 2 cm to 1 m (1 in to 3 ft) in depth. Muhlenberghia filipes is the dominant species in terms of cover and intensity, but it is often associated with several other graminoids, namely sawgrass (Mariscus jamaicensis), black rush (Schoenus nigricans), narrow beardgrass (Schizachyrium sp.), Elliott's beardgrass (Andropogon elliotti), nodding beak rush (Rhynchospora microcarpa), and erect panic grass (Panicum erectifolium).

The muhly/beardgrass prairie represents a muhly prairie that is undergoing successional changes toward a more mesic (dry) condition. These changes consist of: (1) the gradual replacement of muhly associated graminoids by beardgrass (Andropogon glomeratus) and plume sawgrass (Erianthus giganteus) and (2) the local invasion of the community by native and exotic trees and shrubs. These changes, though to some extent natural, are being augmented by regional drainage activities. They may also be becoming less reversible due to the spread of highly competitive environmental generalists such as Australian pine (Casuarina sp.), cajeput (Melaleuca quinquenervia), and Brazilian pepper (Schinus terebinthifolius).

The narrow beardgrass/three-awn-grass/love grass prairie is a unique assemblage that is closely related to the muhly prairie. It differs in that it occupies elevated mesas, or outcroppings of oolite rock that may have a thin covering of marl soil. These prairies are never very extensive but are locally abundant as small patches in the rocky glades. Three species of grasses, narrow beardgrass (Schizachyrium rhizomatum), arrow feather (Aristida tenuispica), and Elliot's beardgrass (Andropogon elliotti) are usually present.

6.14 CYPRESS

Hilsenbeck et al. (1979) identify three types of cypress communities:

(1) Open canopy (hatrack) cypress forests;
(2) Cypress strands; and
(3) Cypress domes.

Olmstead et al. (1980) list a fourth category, cypress heads, in their study of Taylor Slough vegetation.

The open canopy hatrack cypress (Taxodium distichum) forest is actually a combination cypress and prairie since it occurs in such close association with muhly grass and sawgrass, on thin marl soils, and at the lower end of the cypress hydroperiod range in Table 23 (4 to 7 months). The name for this particular community derives from the stunted growth form assumed by the trees, which vaguely resembles a bunch of hatracks. The hatrack cypress typically provide less than 5% of canopy closure making the understory vegetation quite important in overall community structure.

Cypress strands are elongated areas having a hydroperiod of 4 to 10 months, in which cypress dominates the canopy with red bay (Persea borbonia) and strangler fig (Ficus aurea) occassionally present. Soil composition beneath the strands varies from peaty marls to peats and some mucks. In general, cypress strands are confined to the eastern margin of Taylor Slough, although some are found on the margins of Shark River Slough as well.

Cypress dome forests are also generally limited to the eastern margin of Taylor Slough. They develop on peat soils with an 8 to 12 month hydroperiod. The structural geometry of the dome forest is such that the largest trees are located in the interior of the strand on deeper organic soils and around the central pond, and the shorter trees with smaller diameters are situated at the periphery of the stand. This relative positioning results in the dome or bell-shaped curvation that is characteristic of this kind of forest.

The canopy dominant is bald cypress (Taxodium distichum), with a typical height between 9 and 15 m (30 to 50 ft). Canopy closure is rather complete, producing a densely shaded interior beneath it. The understory vegetation is not diverse, except around the margins of the forest and the edges of the central pond. Epiphytes are common, occurring particularly in the branches and on the trunks of the smaller peripheral trees.

6.15 THICKETS

Wax myrtle/saltbush thickets in the East Everglades are situated on slightly elevated oolitic outcrops that vary in area from several square meters to well over a hectare. The oolite is present as a table-like formation that is much like an island, being surrounded by less elevated pinnacle rock and associated muhly prairie vegetation. This community type designation is a more advanced successional stage, and is typically more extensive spatially than transitional prairies.

Wax myrtle (Myrica cerifera) and saltbush (Baccharis halimifolia) are the dominant species, and they usually account for more than 50% of the aerial cover of the community. The remaining fraction of the cover is composed of a large number of broad-leaved trees, shrubs, herbs, and an occassional slash pine (Pinus elliottii). The floristic composition of this remaining fraction varies greatly from site to site, but several tree species are usually present. These include: myrsine (Myrsine guianensis), Florida trema (Trema micrantha), poisonwood (Metopium toxiferum), blolly (Pisonia discolor), strangler fig (Ficus aurea), willow bustic (Dipholis salicifolia), dahoon holly (Ilex cassine), and indigo berry (Randia aculeata). Willow thickets are very widespread in the East Everglades agricultural area and appear to be increasing in size and abundance. Willow thicket vegetation is generally restricted to marshlands, but are occassionally present in seasonal muhly prairies and in close association with various broad-leaved tree islands that are located in either marshes or prairies. Willow thickets occupy deep soils of muck, peats, or peaty marls and reach the most vigorous development in areas with a hydroperiod of more than 5 months. This vegetation type often forms the margins of seasonal ponds, alligator holes, and other depressions in the Everglades.

Structurally, willow thickets are somewhat dome-shaped when present singly in the open marsh, but many willow thickets are circular, roughly rectilinear, or trapezoidal in outline when associated with other arboreal vegetation, or when senescence, fire damage, or extensive flooding has occurred. Salix caroliniana is the dominant species with regard to cover, density, and above-ground biomass, and this community is essentially a monoculture. The height of the willow is usually between 1.8 and 4 m (6 to 13 ft) above the soil surface. Very often, some of the larger trunks of Salix are oriented parallel to the substrate and extend several meters under water. These individuals give rise to many vertical coppices (stems) that later take root and become new individual trees.

Willow thickets are ecologically important because they serve as feeding, nesting, and roosting habitat for many of the herons, egrets, and other wading birds. Gallinules feed heavily on willow catkins. Additionally, they provide a general habitat for the alligator and most of the aquatic vertebrate fauna in the Everglades marsh ecosystem.

Coco plum (Chrysobalanus icaco) form thickets that are prominent tree island features along the eastern margins of the Shark River Slough and are especially well-developed in the Taylor Slough region of the East Everglades. As a rule, these islands are less than 0.5 hectares (1.2 acres) in extent and inhabit peat soils that overlie slightly elevated patches of oolitic rock. This community rarely develops on deep peats without a slight rock elevation present. The soil surface is often submerged for 2 months in the peak of the wet season and has an effective hydroperiod of 4 or 5 months. These communities are most common within spikerush/beakrush flats suggesting that only there are they likely to escape destruction by fire. Coco plum is also very cold sensitive. The dominant species typically accounts for 70% to 80% of the canopy composition and over 80% of the density. Frequently, several large multi-branched coco plum plants constitute most of the vegetational cover. This is because of their sprawling growth habit in which many lateral branches are produced parallel to the ground. These laterals consolidate outward along the periphery of the tree island and give the visual impression of a rank growth of many individual plants. The height of the vegetation in coco plum thickets ranges from 2.5 to 6 m (8 to 20 ft).

Coco plum thickets are variable both in terms of structural geometry and floristic composition. On the average, these thickets possess a circular or ovate outline, but frequently are elliptical where surface drainage gradients are steep. Although coco plum is the community dominant, several other species are typically present, and epiphytes are located in the densely shaded understory where surface fire has been absent for several decades. Among the species commonly associated with coco plum are: cypress (Taxodium distichum), red bay (Persea borbonia), sweet bay (Magnolia virginiana), pond apple (Annona glabra), swamp fern (Blechnum serrulatum), myrsine (Myrsine guianensis), giant wild pine (Tillandsia utriculata), stiff-leaved wild pine (Tillandsia fasciculata), reflexed wild pine (Tillandsia balbisiana), and creeping orchid (Habeneria nivea).

Willow/pond apple/wax myrtle thickets are very common in middle and eastern Shark River Slough. They are characterized by a very dense and consolidated growth of willow (Salix), pond apple (Annona glabra), and wax myrtle (Myrica cerifera), ranging in height from 1.5 to 5 m (5 to 16 ft). This community develops most frequently along the margins and elongated tails of the broad-leaved tree island in the central Shark Slough. In the local vernacular, they are referred to as "hell-holes" or "hell-nests", terms which aptly describe their impenetrability. An important successional relationship appears to be one going from willow thickets to willow/pond apple/wax myrtle thickets to coco plum and then to bayhead forests. The willow/pond apple/wax myrtle formation also appears to develop on a bayhead-dominated site following a very severe fire or series of fires that destroy several centimeters of organic soil, thereby reducing the relative elevation of the site. This same shift from the bayhead community to the present one probably results from an increase in the duration of the hydroperiod at the site as well.

Many vertebrate species utilize the willow/pond apple/wax myrtle community as a feeding or nesting habitat. Notable among these are the whitetailed deer, the bobcat, the Florida indigo snake, the black racer snake, the phoebe, the yellow-billed cockoo, and the alligator.

Pond apple/willow thickets develop in and around open ponds that typically contain some surface water all year. The soils associated with the pond apple/willow forest community are deep, often well decomposed peats (i.e., muck). These forests are very limited in area, being usually associated with hardwood hammocks, and particularly with Indian midden sites.

The dominant vegetative component is pond apple (Annona glabra), which accounts for 80% to 90% of the canopy cover. Willow (Salix caroliniana) is the remaining proportion of the canopy. Epiphytes, particularly giant wild pine (Tillandsia utriculata), stiff-leaved wild pine (T. fasciculata), and soft wild pine (T. valenzuelana) are common throughout the forests. A characteristic understory flora of emergent and submerged hydrophytes is generally present. Some of these species include: alligator grass (Paspalidium paludivagum), milkweed vine (Sarcostemma clausa), pickerelweed (Pontederia lanceolata), flag (Sagittaria lancifolia), swamp mermaid weed (Proserpinaca palustris), loosestrife (Lythrum caroliniana), matter figwort (Bacopa monnieri), and hemp vine (Mikania batatifolia).

This particular forest community does not constitute a large proportion of the overall study area, but it is of special ecological importance because it functions as nesting, feeding and roosting habitat for many of the Everglades wading birds and also as habitat for alligators and the general Everglades aquatic vertebrate community.

6.16 MARSHES

Five (5) types of vegetation communities are included in the marsh category (Hilsenbeck et al. 1979) as follows:

(1) Sawgrass marsh;
(2) Spike rush-beak rush flats;
(3) Maidencane flats;
(4) Flag-pickerelweed communities; and
(5) Cattail marshes.

Sawgrass marsh

As with wet prairie, sawgrass marsh represents one of the most extensive and definitive background vegetation communities of the freshwater Everglades. Sawgrass marshes, dominated by sawgrass (Cladium jamaicensis), are found on relatively deep organic soils with a hydroperiod of 5 to 10 months. Sawgrass is generally of fairly uniform height (1.0 to 2.5 m or 3 to 8 ft) and highly variable density. This differential density lends a patchy character to the sawgrass. Some areas will have densely stocked culms while others will be devoid of vegetation. Periphyton and algal mat are usually present throughout this community type, but are best developed in communities of lower graminoid density.

A large number of submerged and emergent hydrophytes that are usually associated with sawgrass on an annual or seaonal basis include: water hyssop (Bacopa caroliniana), matter figwort (B. monnieri), ludwigia (Ludwigia repens), sprangle top (Leptochloa fascicularis), bladderwort (Utricularia biflora), flag (Sagittaria lancifolia), pickerelweed (Pontederia lanceolata), and spike rush (Eleocharis cellulosa).

Spike rush/Beak rush Flats

The dominant vegetation of this community is a highly variable mixture of spike rush (Eleocharis cellulosa) and beak rush (Rhynchospora tracyi) in association with R. corniculata, spider lily (Hymenocallis latifolia), string lily (Crinum americanum), water hyssop (Bacopa caroliniana), bladderwort (Utricularia biflora), and several other seasonally abundant species.

These flats, with a hydroperiod of 6 to 10 months are generally adjacent to and intergrade with sawgrass marshes. In contrast to sawgrass marshes, they have a decidedly open aspect to them, caused primarily by a reduced density of emergent stems (both living and dead) and substantially reduced average vegetation height. Typically, spikerush/beakrush flats have a large proportion of open water, and most if not all of this open marsh community supports a thick layer of algal mat. Periphyton are also abundant on the submerged stems.

Maidencane Flats

Maidencane flats intergrade with sawgrass marsh vegetation and spike rush/beak rush flats producing a patchwork vegetation mosaic that is characteristic of natural Everglades marshes. Floristically, maidencane flat vegetation is rather uniform, consisting of maidencane (Panicum hemitomon), sawgrass (Cladium jamaicensis), flag (Sagittaria lancifolia), willow (Salix caroliniana), spatterdock (Nuphar luteum), white water-lily (Nymphaea odorata), alligator grass (Paspalidium paludivagum), and cattail (Typha angustifolia).

Flag/Pickerelweed Communities

Flag/pickerelweed ponds and sloughs occupy the marsh areas with the longest hydroperiod (i.e., between 8 and 12 months) and deep soils composed of organic materials (mucks and various peats). These communities are generally present as an open central pond or slough with a marginal belt of vegetation composed of a distinctive assemblage of marsh species. Chief species are: pickerelweed (Pontederia lanceolata), fire flag (Thalia geniculata), flag (Sagittaria lancifolia), alligator grass (Paspalidium paludivagum), swamp mermaid weed (Proserpinaca palustris), water hyssop (Bacopa caroliniana), and bladderwort (Utricularia biflora). Most often, flag/pickerelweed communities are situated at the margins of tree islands in the open marsh, but occasionally they occur in the open marsh where there is a depression in the bedrock resulting from fire or alligator activity. These communities are important because they represent the ecological refuge for aquatic animals, both vertebrates and invertebrates, during droughts and seasonal dry-downs. The most conspicuous of these animals is the American alligator.

6.17 DISTURBED HABITATS

Disturbed habitats range over all hydroperiods from plowed tomato fields (an analog of the muhly prairies) to canals and canal banks (an analog of the marshes and ponds). The vegetation of individual disturbed habitats depends not only on hydroperiod but also on the nature of the disturbance, its intensity, and its proximity to other habitats and disturbances. Actively cultivated tomato fields are obviously dominated by tomatos. Abandoned fields however, are open to competitive invasion by a host of native as well as exotic species.

In general, disturbed habitats are much more common in the privately owned East Everglades area, as a result of intensive agriculture and drainage. Within Everglades National Park these habitats are most commonly found in the Hole-in-the-Donut area (see Section 2.1).

Hilsenbeck et al. (1979) divide these disturbances into three major categories: (1) fire related recovery vegetation; (2) exotic species in natural secondary successions; and (3) agriculturally induced successions. To this can be added a fourth category including dredged canals and canal banks.

Fire Related Recovery Vegetation

Fire related recovery vegetations include three (3) types of communities within the east

Everglades (Hilsenbeck et al. 1979): (1) Bayhead recoveries; (2) Cypress dome recoveries; and (3) Hammock forest recoveries.

Bayhead forests are not a typical fire maintained plant community. Although fire related disturbance of natural bayhead vegetation, like that of tropical hammock forests, is a natural phenomenon, it appears that this type of alteration is considerably more frequent today than it was prior to the 1900s. Coupled to this increased frequency of disturbance is the expansion of exotic species throughout the southern Florida ecosystem. These concomitant events are correlated, because fire altered upland forest communities are rapidly colonized by exotic tree species if a colonizing source is nearby and the site is opened when propagules are available for dispersal.

In bayhead recoveries not subjected to invasion by exotics, vegetation is characterized by a rank growth of bracken fern (Pteridium aquilinum), willow (Salix caroliniana), saltbush (Baccharis halimifolia), elderberry (Sambucus simpsonii), wax myrtle (Myrica cerifera), and bushy beadgrass (Andropogon glomeratus). This dense vegetation is usually overlain and entwined with several vines, including sweet briar (Smilax auriculata), moon vine (Ipomoea tuba), Virginia creeper (Parthenocissus quinquefolia), chicken grape (Vitis rotundifolia), and hemp vine (Mikania batatifolia).

The degree of organic soil removal by the fire varies over the full range of possibilities, from complete loss to very limited surficial litter removal. Commonly over half of the peat soil is removed to pinnacle rock and the remainder varies from patches of slight damage to a loss of 10 to 25 cm (4 to 10 in) of soil. Complete burnouts may lack any discerable vegetational feature aside from a rank growth of sawgrass and a few scattered willows, elderberry plants, and saltbushes. Downwood and charred root remnants, however, are usually present somewhere within the burn site.

The time required for the community to return to the pre-burn condition is a matter of speculation. It appears that well over a century may be required before the community structure and floristic composition would converge on the pre-burn condition of the bayhead forest vegetation (Hilsenbeck et al. 1979).

Cypress dome recovery formations are not particularly common within their study area, being located in the vicinity of the Aerojet property south of Fla S.R. 27 on the eastern margin of Taylor Slough. Cypress dome burnouts are of significant ecological interest because they are not a fire-adapted nor fire-maintained community, and as a result, are seriously disturbed by any degree of fire presence within the limits of the community. The most obvious types of fire damage are to the vegetation and to the soil layer beneath the community.

Direct damage to the vegetation is quite variable in degree, running from the complete obliteration of all of the cypress to the partial removal of understory vegetation, and the seedling and sapling age classes of cypress. On the average, the damage involves the destruction of some of the mature trees and some proportion of the juveniles, in addition to limited destruction of other canopy and understory vegetation. The result of this effect is the production of a multiphasic vegetational mosaic that has several ages of vegetation within the recovery community. In all cases, except for the least severe, many epiphytes are destroyed, particularly those that are close to the ground.

Cypress dome recovery vegetation is characterized by a very dense growth of bracken fern (*Pteridium aquilinium*), willow (*Salix caroliniana*), saltbush (*Baccharis halimifolia*), elderberry (*Sambucus simpsonii*), bushy beardgrass (*Andropogon glomeratus*), primrose willow (*Ludwigia peruviana*), fleabane (*Pluchea purpurescens*), and sawgrass (*Mariscus jamaicensis*). Frequently this vegetation develops among the remaining erect trunks and the heavy cover of cypress downwood scattered throughout the community. This recovery vegetation is typically overlain with many vines, including catbrier (*Smilax auriculata*), vine milkweed (*Sarcostemma clausa*), poison ivy (*Toxicodendron radicans*), and moon vine (*Ipomoea tuba*). Several shrubs and tree seedlings are generally present on the more elevated portions of the burned site 2 years after a fire. These include: red bay (*Persea borbonia*), wax myrtle (*Myrica cerifera*), sweet bay (*Magnolia virginica*), and cypress (*Taxodium distichum*).

It appears that cypress will rapidly recover and dominate a burned-out cypress dome community only if the fire has had a very slight overall effect on the existing cypress population on the site and little or no effect on the composition and depth of peat soil at the site. Any significant changes to either of these variables, and the probability of recovery to the pre-existing community type is sharply decreased. What develops in these cases can resemble bayhead, sawgrass marsh, or even slough and pond communities (Hilsenbeck et al. 1979).

Hammock forest vegetation is probably the least fire adapted community within the study area, and consequently is the most severely altered by fire effects. Fire related damage to hammock forests can result in a wide range of recovery vegetation depending upon the severity of the initial damage to the community. Light surficial fires cause little long-term alteration to the dominant vegetation and community composition, but soil fires will often result in the total obliteration of the hammock forest and a radical shift in the floristic composition of the recovery vegetation from that prior to the fire damage.

In general, the early recovery community that results from a fire in a hammock forest resembles the recovery community that develops in fire-damaged bayhead forest and cypress dome forest. Similarly, the vegetational pattern in a fire-altered hammock is a multiphasic one, resulting from a differential pattern of fire damage in which some of the community is markedly altered and other sections are only slightly changed. The hammock forest recovery vegetation is characterized by an extremely dense growth of bracken fern (*Pteridium aquilinum*) and other fire-following species.

At present, there is no firm estimate of how long a return time is required before the successional community converges upon the preburn hammock forest community. It appears, however, that several centuries may be required for the process of hammock generation to be completed if it were initiated by a total obliteration of a pre-existing mature hammock stand.

Exotic Species Succession

Secondary successions by exotic species include five types of communities:

(1) Cajeput colonization of sawgrass marsh;
(2) Brazilian pepper/cajeput/Australian pine colonization in muhly prairies;
(3) Brazilian pepper/Australian pine colonization of hammock and bayhead recovery communities;
(4) Cajeput monocultures; and
(5) Australian pine monocultures.

Cajeput colonization of sawgrass marshes is quite variable, reflecting the variable, but natural distribution of site disturbances, chiefly soil fires, drought mortality, ORV use patterns, and seed availability.

Mature cajeput is known to be quite resistant to the environmental extremes that are typical of the southern Florida ecosystems, namely flooding, fires, freezes, and droughts. Seedlings and saplings are probably more susceptible to these extremes, but to an unknown degree. The presence of this exotic tree species within what is otherwise a natural community, is significant and probably indicates a similar outcome for this newly colonized area that is clearly present in other sawgrass marsh areas to the north and east of U.S. 41 and Fla S.R. 27.

The Brazilian pepper/cajeput/Austrialian pine colonization of muhly prairies successional community has significant ecological bearing upon the management approaches relating to the marl rocky gladelands along the eastern boundary of Everglades National Park and those north and south of the Chekika hammock region of the study area. Three exotic tree species, Brazilian pepper (*Schinus terebinthifolius*), cajeput (*Melaleuca quinquenervia*), and Australian pine (*Casuarina equisetifolia*), in conjunction with the native species, red bay (*Persea borbonia*), blolly (*Guiapira discolor*), dahoon holly (*Ilex cassine*), poisonwood (*Metopium toxiferum*), bayberry (*Myrica cerifera*), and coco plum (*Chrysobalanus icaco*), comprise a "guild" of hardwood species that are colonizing vegetationally intact muhly grass prairies throughout the East Everglades. This colonization process appears to be occurring at an increasing rate that is inversely proportional to the length of the effective hydroperiod prevailing at the site. As the effective hydroperiod decreases, the rate of hardwood colonization increases according to some constant proportionality.

These observations suggest that the 3 most abundant and ubiquitous exotic tree species in southern Florida are also common in the East Everglades study area, and appear to be increasing in frequency throughout the rocky gladelands and marl prairies. Because these communities are essentially continuous with those along the eastern boundary of Everglades National Park, it appears that the probability of the colonization of park lands by these 3 exotic species is increasing.

Some severely fire-damaged tree island communities are currently dominated by the exotic trees Brazilian pepper (*Schinus terebithifolius*) and Australian pine (*Casuarina equisetifolia*), and the native successional species saltbush (*Baccharis halimifolia*) and Florida trema (*Trema micrantha*). The understory vegetation consists primarily of bracken fern (Pteridium aquilinium), brake fern (Pteris lonifolia), leather fern (Achrostichum danaeaefolium), bushy beardgrass (Andropogon glomeratus), and nightshade (Solanum spp). The canopy and understory of this community is devoid of native hammock or bayhead species, and it appears that the exotic trees will ultimately dominate recovery vegetation that develops on this site.

Cajeput forests, at present, are confined primarily to the eastern margin of Shark Slough west of L-31E. Cajeput develops most rapidly on sawgrass peat soils, but is also found on marls and marly peat soils east of the Shark Slough. These communities are structurally very similar to cypress dome forests in a central location with progressively shorter and smaller individuals arrayed towards the periphery of the community. This forest type consists of the exotic tree species cajeput (Melaleuca quinquenervia) and little else.

This type of forest appears to be becoming more common along the eastern margins of the Shark Slough at the expense of natural communities, particularly sawgrass marsh and muhly prairies. This trend is very significant in regard to the future management of natural marsh ecosystems that are identical to these and are contained within the nearby Everglades National Park. These sawgrass marshes would appear to have an increasing susceptibility to cajeput colonization as the reproducing population of this species extends westward into previously undisturbed natural marshlands.

Australian pine forests are considerably more abundant within the study area than are cajeput forests. Australian pine forests seem to be the typical exotic tree community on Perrine marl soils, and are quite common and widespread throughout the rocky gladelands in the vicinity of Chekika hammock and along the eastern boundary of Everglades National Park. As a rule, Australian pine forests occupy slightly elevated sites that have roughly the same hydroperiod as bayhead forest communities. It appears that this exotic forest community frequently develops on sites that once supported bayhead or tropical hammock vegetation that was removed by one or a series of severe fires.

This community is characterized by a monoculture of Australian pine (Casuarina equisetifolia), forming a closed canopy layer approximately 12 to 15 m (40 to 50 ft) high. Seedling and saplings are currently rare under the canopy and are generally uncommon along the margins of the forest. Understory vegetation is largely absent and the forest floor is composed of a dense layer of Australian pine litter and a few species of ubiquitous annuals. There are generally a few outliers within several hundred meters of the forest and these individuals are frequently reproductive trees.

At present, Australian pine forest vegetation appears to be stable with respect to major successional changes, and as such does not seem to be either dramatically increasing nor decreasing in area or overall density within the study area. Individual reproductives, however, appear to be slightly increasing in abundance throughout the rocky gladelands, but this non-continuous population is frequently killed by fires or lighting.

Agriculturally Induced Succession

Agriculturally induced successions incorporate 10 identifiable communities reflecting the very intense invasion by exotic species. These communities are summarized in Table 24. An excellent and concise summary of the composition and structure of these disturbed communities is presented by Hilsenbeck et al. (1979). The following discussion is taken largely from that text.

Community Name	Common Name	Dominant Species
Rock plowed prairies without farming effects	Muhly grass	*Muhlenberghia filipes*
Rock plowed prairies with farming effects	Cattail	*Typha latifolia*
Grove Plantings	Groves bushy beardgrass Saltbush	Citrus, Avocado, Mango *Andropogon glomeratus* *Baccharis halimifolia*
Annual Recovery Vegetation on Farmlands — 1 yr	beggartick ragweed	*Bidens pilosa* *Ambrosia artemisiifolia*
(abandoned) — 2-3 yr	saltbush napier grass	*Baccharis halimifolia* *Pennisetum purpureum*
Napier Grass Communities (farmlands abandoned < 3-5 yr)	napier grass	*Pennisetum purpureum*
Saltbush-Brazilian Pepper Communities (farmlands abandoned > 5 yr)	brazilian pepper saltbush	*Schinus terebinthifolius* *Baccharis halimifolia*
Brazilian Pepper monocultures (farmlands abandoned 3-10 yr)		*Schinus terebinthifolius*
Brazilian Pepper-Guava Forests (farmlands abandoned > 20 yr)	brazilian pepper guava	*Schinus terebinthifolius* *Psidium guajava*
Willow monoculture on Abandoned Farmland (hydroperiod > 3 months)	willow primrose willow	*Salix caroliniana* *Ludwigia peruviana*
Sawgrass-Cypress-Bayhead Analog Communities (nonrock plowed abandoned farmland)	sawgrass cypress willow	*Cladium jaimaicensis* *Taxodium distichum* *Salix caroliniana*

Table 24. Synopsis of disturbed vegetation community types occurring on abandoned farmlands in the east Everglades (adapted from Hilenbeck et al. 1979).

Muhly prairies that have been rockplowed, but not farmed, are not common in the east Everglades area. These sites provide an important insight into the response of the prairie community to an episode of general community disruption resulting from the initial stages of agricultural preparation of new lands.

The recovery of the prairie vegetation following the low intensity of rockplowing is similar to that following a severe surface fire. In general, the prairie dominant, muhly grass (*Muhlenbergia filipes*) appears to suffer a low mortality rate and the co-dominant species, sawgrass (*Cladium jamaicense*) although persisting, appears to be more strongly diminished by the process. Other species, namely beak rush (*Rhynchospora tracyi*), narrow beardgrass (*Schizachyrium rhizomatum*), marsh fleabane (*Pluchea rosea*), smooth cordgrass (*Spartina bakerii*), and cattail (*Typha latifolia*) display a variable response to the disturbance. Only cattail and smooth cordgrass appear to increase in abundance, while the other appear to decrease markedly. Bushy beardgrass (*Andropogon glomeratus*) is considerably more abundant in the community following the rockplowing operation.

These observations suggest that a single or a limited number of episodes of low intensity rockplowing in muhly prairie communities does not totally destroy the pre-existing community organization nor does it strongly select against the component species to produce drastic compositional changes. The direct or indirect effects on the prairie communities over time, however, cannot be evaluated with short-term survey techniques. There is a clear indication that some of the rarer species of herbaceous perennials have disappeared, but this conditon could be short-lived and reversible through natural processes.

The outcome of the rockplowing in conjunction with later farming is markedly different from the outcome observed for low intensity rockplowing without subsequent farming effects. In this case, all vestiges of the natural prairie community were removed and a secondary successional community, consisting of a few abundant annuals and perennials, occupies the site. Close inspection of this recovery community reveals that none of the pre-existing populations except for arrowhead (Sagittaria lancifolia) survived. Cattail (Typha latifolia), which was rare in the pre-farming community, is found to be the dominant graminoid species. The successional species that were dominating the farmed site include: primrose willow (Ludwigia peruviana), willow (Salix caroliniana), loosestrife (Lythrum lineare), marsh fleabane (Pluchea odorata), bushy beardgrass (Andropogon glomeratus), saltbush (Baccharis halimifolia), narrow-leaved primrose willow (Ludwigia octovalvis), giant goldenrod (Solidago sempervirens), and hemp vine (Mikania babatifolia).

The striking contrast between the two recovery communities that develop following agricultural disturbances indicates that while a low level of isolated disturbance to the natural prairie vegetation is not highly detrimental, a more intensive use of a pattern combining several episodes of rockplowing with a single season of tomato farming results in the total obliteration of the natural prairie vegetation. It appears that the spontaneous recovery of the muhly prairie vegetation will not occur. Furthermore, the site appears to be open to colonization by one or more of the exotic tree species within the near future.

Grove plantings are becoming an increasingly more frequent type of land use throughout the agricultural portion of the study area. The major grove crops are citrus (Citrus spp.), avocado (Persea americana varieties), mango (Mangifera indica varieties), and a wide range of ornamental trees and shrubs planted in field nurseries. Typically, grove plantings are generated on rockplowed lands that have been previously farmed for tomatoes, beans, squash, or other truck crops, and only rarely have natural communities been directly converted to a grove situation.

A grove planting differs from an annual crop system in several respects. The most pronounced difference is that in grove plantings, the mounds upon which the trees are planted are several times higher and wider than those of a tomato or squash field. This mounding produces an area in where the furrows support a more hydric plant community and the mounds support a more mesic community than was present in either the natural community or that developed on the abandoned farm field. The mound vegetation consists principally of ruderal species including: bushy beardgrass (Andropogon glomeratus), saltbush (Baccharis halimifolia), Brazilian pepper (Schinus terebinthifolius), potato tree (Solanum erianthum), lantana (Lantana montevidensis), milkweed vine (Sarcostemma clausa), santa maria (Parthenium hysterophorus), and beggar tick (Bidens pilosa). The furrow vegetation consists primarily of: arrowhead (Sagittaria lancifolia), marsh fleabane (Pluchea odorata), fog bit (Lippia stoechadifolia), soft rush (Juncus polycephalus), and matter figwort (Bacopa monnieri).

The exotic tree Brazilian pepper (Schinus terebinthifolius), is commonly present in most if not all groves regardless of the age of the grove. The actual numbers of this exotic are small in well-maintained groves, but abandoned grove plantings contain many reproductives and seedlings, and it is apparent that Brazilian pepper is rapidly occupying the abandoned sites.

The plant communities that develop on recently abandoned farmlands (1 to 2 years old) are extremely diverse with regard to community dominants and general floristic composition. These species are uniformly classified together only because they are on recently abandoned farmlands. The particular short-term plant community that occupies a given field will differ according to many variables, particularly (1) the crop that was grown prior to abandonment, (2) the time of abandonment, (3) the intensity of past cultivation, (4) the length of time the land has been farmed in the past, (5) the soil type and hydroperiod, and (6) the actual cultivation practices including the history of pesticide, herbicide, and fertilizer use. In general, there are as many types of annual recovery vegetations as there are fallow fields.

Napier grass (Pennisetum purpureum) communities have become increasingly abundant in the study area within the past 10 years. This species is an aggressive colonizer of recently abandoned farmlands, particularly those that have been abandoned for less than 3 years. Once it is established in a field, it tends to persist there, and essentially form a monoculture. Surveys of these lands suggest that napier grass will colonize a fallow field within 2 or 3 years after abandonment. It usually starts as several widely dispersed individual clumps that eventually coalesce and limit the establishment of new colonizing species. On fields where it was present prior to the most recent clearing and farming operations, napier grass rapidly reestablishes a monoculture from tillers that were present in the soil.

The napier grass community is characterized by a dense growth of the grass, approximately 1.5 m to 3 m (5 to 10 ft) tall, which is present generally as a monoculture. Occasionally, a few associated species are also present. These include saltbush (Baccharis halimifolia), Brazilian pepper (Schinus terebinthifolius), beggar tick (Bidens pilosa), and primrose willow (Ludwigia peruviana). At present, this community appears to be restricted to lands that have been disturbed by agricultural practices and it does not seem to be colonizing natural communities either adjacent to or distant from napier grass communities. This species is occasionally encountered along road berms and similar areas throughout the study area, but it was never found in a natural community.

Saltbush-Brazilian pepper communities represent the typical successional community that becomes established on farmlands that have been fallow for approximately 5 years. After the establishment of these co-dominant species, the relative proportions of each change over time with saltbush (Baccharis halimifolia) decreasing and Brazilian pepper (Schinus terebinthifolius) increasing in relative importance. The rate of change of each species decreases after 15 years or so, and the community becomes, in essence, a Brazilian pepper forest with some saltbush and wax myrtle (Myrica cerifera) along edges and in openings.

The average height of the vegetation is from 1.0 to 5.5 m (3 to 18 ft) and the degree of canopy closure is varied between 25% and 80%, the latter figure being typical of later stages when Brazilian pepper becomes the community dominant. This community develops on most marl soils as long as the annual hydroperiod does not exceed 4 months. It appears to be a relatively stable association for 10 to 15 years after it is established, and there is very little indication that natural forest vegetation will replace it over a reasonable period of time.

The exotic tree species Brazilian pepper (Schinus terebinthifolius) is the primary hardwood species that colonize abandoned farmlands throughout the study area. In this situation, it frequently becomes established after 3 to 5 years and becomes increasingly more important in both abundance and aerial cover over the next 10 years, so that it typically forms a closed canopy layer and excludes most other species. When this occurs, rapid successional changes and a monospecific forest community of Brazilian pepper occupies the site. Specific stands of this unusual forest community are common east of the eastern boundary of Everglades National Park and south of Homestead Airport.

The forest is characterized by a canopy layer 3.5 to 8 m (12 to 26 ft) high and an understory and ground stratum of very few species. Often only shield fern (Thelypteris normalis) is present beneath the closed canopy. The soil surface is generally bare and a dense array of dead twigwood and small branches of Brazilian pepper is typically present between the lower limit of the canopy and the ground. Seedlings of Brazilian pepper are frequent in patches where the canopy closure is less than 25%. Observations indicate that this community type is very stable over time, with no clear indication that natural forest vegetation is currently replacing it.

Mixed Brazilian pepper (Schinus terebinthifolius) and guava (Psidium guajava) forest vegetation is a typically secondary successional community on farmlands that have been abandoned for more than 20 years. Stands of this type of forest are the most abundant in the portion of the study area that is south of Fla S.R. 27 and east of Everglades National Park. This successional vegetation occupies both Rockdale loam and Perrine marl soils on which the hydroperiod does not exceed 3 months.

The average vegetation height is between 3.0 and 7.5 m (10 and 25 ft), and the relative abundance of both co-dominant species varies greatly between stands, but typically Brazilian pepper accounts for 60%. The remaining proportion of the canopy layer is made up of several other species, principally stranger fig (Ficus aurea) and willow (Salix caroliniana). Understory vegetation is generally absent, but occasionally shield fern (Thelypteris normalis) forms a discontinuous ground cover. Seedlings or saplings of native forest species are absent or rare.

This type of forest vegetation appears to be quite stable through time with regard to successional shifts in composition or community structure. It is not as common on recently abandoned lands as the Brazilian pepper monoculture or the saltbush-Brazilian pepper community and it appears that the Brazilian pepper-guava forest vegetation is more typical of secondary successions that were initiated in the late 1950s and early 1960s before the regional population of Brazilian pepper was as large and widespread as it is currently.

Dense willow monocultures are not very common within the boundaries of the study area, being found most frequently on the older abandoned farmlands south of Fla S.R. 27, east of Everglades National Park in the northern portion of the Aerojet property. Willow monocultures appear to develop on rockplowed Perrine marls that have a hydroperiod in excess of 3 months, which effectively prevents the establishment of Brazilian pepper and other hardwoods.

This vegetation is typically a rather open monoculture of willow (Salix caroliniana) approximately 4 to 6 m (13 to 20 ft) tall. Several marsh species characteristic of disturbed lands and general secondary successions are present. These include primrose willow (Ludwigia peruviana), loosestrife (Lythrum lineare), bushy beardgrass (Andropogon glomeratus), saltbush (Baccharis halimifolia), and milkweed vine (Sarcostemma clausa). A thin, matted ground cover is provided by matter figwort (Bacopa monnieri) and fleabane (Erigeron vernus).

Sawgrass-cypress-bayhead analog communities occupy farmlands that were abandoned prior to the widespread use of rockplowing (pre-1950s). Since abandonment, the recovery vegetation has developed and stabilized so that it closely resembles a natural community quite similar to an open canopy cypress forest and sawgrass marsh. Exotic tree species are almost entirely absent, except for an occasional Australian pine that has colonized an elevated crop mound.

The community is largely dominated by a dense growth of sawgrass (Cladium jamaicensis) that is quite uniform in height, ranging between 0.8 and 1.2 m (3 to 4 ft). Locally abundant are several other sawgrass marsh species including aromatic figwort (Bacopa caroliniana), beak rush (Rhynchospora tracyi), nodding beak rush (Rhynchospora microarpa), musky mint (Hyptis alata), and marsh pink (Sabatia brevifolia). Some arboreal vegetation is usually present composed of: bald cypress (Taxodium distichum), dahoon holly (Ilex cassine), red bay (Persea borbonia), myrsine (Myrsine floridana), saltbush (Baccharis halimifolia), sweet bay (Magnolia virginica), willow (Salix caroliniana), and coco plum (Cyrysobalanus icaco). This vegetation is widely scattered in nature and tends to occur on the slightly elevated crop mounds.

Before the extensive use of the rockplow as an agricultural tool and the wholesale naturalization of exotic tree species, abandoned marl farmlands rapidly reverted to communities that were quasi-natural in floristics and structure. Under the present conditions of agricultural cultivation and land use patterns, this type of successional recovery does not occur, and former marshes and prairies become dominated by arboreal vegetation usually containing some proportion of exotic trees and shrubs.

6.2 HABITAT PARTITIONING FOR FISH AND WILDLIFE PRODUCTION

6.21 ENERGY FLOW

Figure 47 presents a summary diagram of energy flow through the freshwater portion of the lower Everglades. This diagram is best viewed as a very generalized organizational scheme rather than an attempt to accurately document the food habits of the over 350 vertebrate species reported from the area.

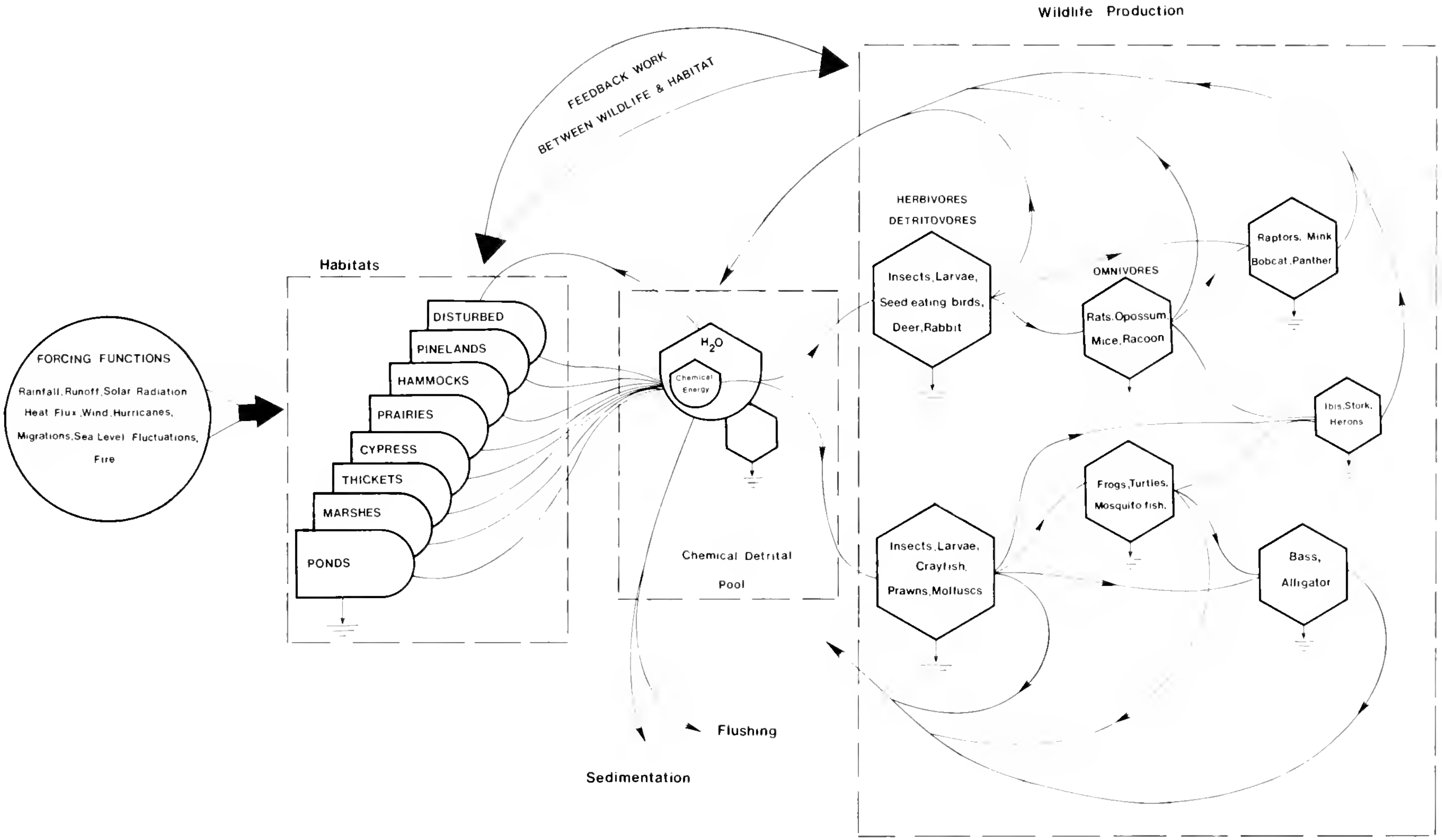


Figure 47. Summary diagram of energy flow through the terrestrial and freshwater wetland ecosystem in the lower Everglades.

The term "habitat", rather than merely primary producers is used in Figure 47 to signify that the physical setting created by a given habitat is often just as important to energy flow as the caloric value of the vegetative tissue and detritus. Each of the 350 vertebrate species reported from the study area (SFRC 1980) is dependent not only upon the food to be found there but also upon other physical components of the habitat such as the presence of adequate nesting material, perching sites, roosting sites, rotting logs, solution holes, and so forth. The spatial characteristics of the understories and canopy coverages of pinelands are different from those of hardwood hammocks, which are different from those of cypress domes, which are different from those of thickets. The variety of habitat characteristics available within an area is an important factor in the production of a complex mixture of fish and wildlife.

A second important element of this energy flow diagram is shown as feedback work. When viewing the entire terrestrial and freshwater wetlands as an ecosystem, it is essential to bear in mind that the actions of any one component result in physical, chemical, and biological alterations which affect the flow of energy and materials throughout the system.

In this regard two rather broad categories of feedback can be discerned in natural systems: (1) feedback between species and their physical/chemical environment; and (2) feedback between two or more species.

Examples of category one include: the debris produced by the crashing of a red shouldered hawk through tree branches in pursuit of a gray squirrel; the mechanical mixing of detritus into the water column as chub suckers gleen organic matter from canal sediments; the burrowing of pine borers and termites into fallen logs; the probing actions of yellow bellied sapsuckers, rufous-sided towhees, and little blue herons; the ripping and tearing of foraging birds and sloppy carnivores. All of these actions carry a dual purpose; one the obvious fulfillment of the needs of the organism and two, the inadvertent manipulation of the physical/chemical environment as a byproduct of the organism's actions.

The importance of feedback work between two or more species that are trophically related is an offshoot from the classic predator/prey model of population dynamics and control. Feedback between predator and prey may take the form of a cropping effect on the prey population, preventing it from approaching the point where available resources limit its population growth. This is analogous to continuous chemostat-type production as opposed to batch-type production. In the forward direction, the successful taking of prey is also feedback in the sense that it stimulates growth, reproduction, and maintenance of the predator while inadequate food resources result in retarded growth, reproduction, and maintenance. Feedback between two or more trophically related species may also provide feedback for other species by virtue of the integrated pest, predator, or prey management that may result from subtle interdependencies.

Other forms of interspecies feedback work that are not a function of direct trophic interactions also influence energy flow. Behaviorial or physiological adaptations that result in mutual sharing or partitioning of space or other common resources are obvious examples. Symbiotic relationships within which two species absolutely require each other for their mutual survival is the evolutionary epitome of this avenue of feedback. The significance of the feedback concept in influencing long term energy flow patterns is perhaps best exemplified by noting the degree to which organisms develop and depend upon protective coloration and mimicry.

In using Figure 47 (and subsequent ones) as a conceptual device, it is also useful to keep in mind some basic characteristics of trophic levels, as pointed out by Lindemann (1942):

(1) Progressively higher trophic levels (in keeping with the laws of thermodynamics) contain progressively lower standing crops of biomass; and

(2) Delineations between progressively higher trophic levels become progressively more difficult to discern.

To this is added a third characteristic, the metamorphosis of trophic position that often accompanies the transition of an organism over its personal life history. Larvae and juveniles often have different nutritional requirements and exhibit feeding anatomies and preferences not found in adult forms. They may also be subject to a different spectrum of predation pressures than adults of the same species.

In moving into the subject of how these habitats produce fish and wildlife, it seems appropriate to begin with one particularly important element of the vegetation cover that does not appear as an distinct community in Table 23, the blue-green algal mat community. Attached blue-green algae and diatoms are most abundant in association with the relatively open, wet conditions of the spike rush/beak rush type of marsh. However, since the algal mat community tends to survive dessication quite well, it is also found to varying degrees in the drier graminoid habitats as well. During the dry season it can be found throughout the sawgrass and prairie zones as a scummy looking cake on the peat or limestone substrate.

Wood and Maynard (1974) estimate that a significant, if not greater portion, of the total primary production of these habitats derives from the 200+ species of periphyton rather than from the vascular plant species. Brock (1970) reports higher productivity from epiphyte-laden _Utricularia_ than nonladen _Utricularia_. Hunt (1961) estimates that nearly all of the production and respiration of the open water prairies is due to the mat, not the macrophytes. Carbon production rates in one such prairie community in Taylor Slough ranged from 0.80 to 1.67 g/m^2/d; respiration ranged from 0.25 to 0.38 g/m^2/d.

Productivity rates, however, do not tell the full story of the key role played by the algal mat in the seasonal cycle of Everglades ecology. One element of its ecological importance arises from the fact that during drought conditions it tends to coat the substrate and prevent total dessication within and beneath it, thus providing a microhabitat within which small invertebrates (or larvae and eggs) can survive seasonal drought conditions. As water levels once again rise, a ready, local source of small crustaceans, insects, and fish can quickly exploit the newly flooded environment as suggested by Tabb (1963), and at least partially confirmed by Kolipinski and Higer (1969). The latter authors report invasion of enclosed sampling devices by numerous adult members of the freshwater fauna which apparently gained access to the newly flooded marsh from underground channels.

A second element of the ecological significance of the periphyton has to do with its suspected role in the downstream detrital pool and food chain. As the marshes dry up, the organic cell material within the calcareous shells of the algae tends to die back, leaving the slow-drying lime mud cakes behind. As water levels once again rise, the dead cellular organic matter tends to lyse and wash out into the dissolved detrial pool. The same rising water levels also effect wash out of macroscopic vegetation. However, the latter tends to be in large pieces at first and thus of relatively little direct value to the detrital food chain. The simultaneous wash out of relatively small sized (dissolved) detritus with marsh/prairie vegetation may enrich the detrital medium and hasten its usefulness to microbes and grazers alike (Wood and Maynard 1974).

Wood and Maynard (1974), and more recently Browder et al. (1980), have reported on the seasonal dynamics of the periphyton community. As the dry season initially ends, the blue-green algae, often Scytonema sp., are first to recolonize and dominate the mat communty. A longer period of inundation is required before green algae and diatoms begin to show up in the mat. Feeding and growth experiments indicate that the blue-greens are of little value to the grazing food chain while diatom dominated mats are of relatively more use to grazers, such as frogs and tadpoles.

Hunt (1961) also speculates that the algal mat is of relatively little direct use to grazers. However, Kolipinski and Higer (1969) report numerous filamentous blue-greens, desmids, and diatoms from stomach contents of sailfin mollies (Poecilia latipinana), flagfish (Jordanella floridae), and sheepshead minnows (Cyprinodon variegatus). Vascular plants are quantitatively less important in their diets.

Like the blue-green algal mat, peat soils perform an important ecological function as well as a geological one. As peat accumulates, it influences the succession of communities by slowly building land elevation and changing the structure of the habitat in favor of more mesic vegetation communities. The resistance of peat soils to dessication also provides a useful antidrought, protective device for many fish, invertebrates, eggs, and larvae (Tabb 1963). Even some adult vertebrates such as the bowfin (Amia calva) are reported to burrow into the marsh soils, apparently seeking seasonal protection from desiccation (Dineen 1974).

During the dry season the surface layers of the peat soils tend to dry out and become especially susceptible to fires. Fortunately most of the lightning-caused natural fires are associated with convective storms of the wet season. Nonetheless, when fires do occur during the dry season, or during dry wet seasons, they may mineralize some of the very flammable peat soils, releasing organically bound nutrients over wide areas. Generally the most fire susceptible peat soils are those dominated by graminoids which are subject to an annual build-up of dry plant material. Hardwood hammocks, bayheads, cypress domes and strands, and some thickets are generally more resistant to destruction by seasonal fires. However, as regional drainage operations amplify natural drought extremes, these communities are beginning to suffer from fires as well (Hofstetter 1973, Hilsenbeck et al. 1979).

In Chapter 5 (surface hydrology and water quality) it was pointed out that the Everglades marshes empirically act as traps for sediments, nutrients, heavy metals, and pesticides (Waller and Earle 1975). Unfortunately the flux of these materials through the soils, vegetation, and biota is relatively unstudied. Exceptions to this are Steward (1974) on sawgrass physiology, and Kolipinski and Higer (1969) on pesticide residues in selected Everglades biota.

Steward (1974), working north of the study area, estimated that the nutrient requirements of sawgrass are low primarily because tissue levels are low when compared to other species of Everglades macrophytes. Another line of reasoning suggests that the highly organic soils effectively bind nutrients and render them unavailable for uptake. No seasonal patterns of nutrient and inorganic ion concentrations in soils were reported. Standing crops and plant density of immature stands showed little seasonal variation. Nutrients in marsh waters were generally in adequate supply averaging 3%, 10%, and 8% of nitrogen, phosphorous, and potassium respectively.

With regard to tissue concentrations of nutrients and inorganic ions in mature stands, little seasonality was evident. A possible exception to this was nitrogen, which was notably higher from December through April. In fire recovery stands initial growth was more rapid than in immature stands but leveled off with age. Tissue concentrations of nitrogen, phosphorus, magnesium, potassium, copper, and manganese were initially high in rapidly growing plants but decreased over time. Calcium and iron showed the reverse trend. Steward attributed the relative success of sawgrass in the Everglades to a combination of its low nutrient requirements and the lack of direct grazing.

Distributions of persistent pesticides in fish and wildlife often provide a stark confirmation of invisible energy and material flow pathways. Kolipinski and Higer (1969) report that despite extremely low levels in ambient waters in the Everglades, the algal mats, macroscopic plants, and organic detrital pool concentrate DDT congeners to the microgram per kilogram level (trace - 200 ug/mg). At the level of primary carnivore, the mosquito fish (Gambusia affinis) exhibited concentrations as high as 700 ug/kg. In the eggshells of the Everglades Kite (Rostyrhamus sociabilis plumbeus), which feeds exclusively upon the apple snail (Pomacea paludosa), concentrations of 1500 ug/kg were reported. The apple snail feeds on periphyton and detritus; the mosquito fish on insects and other small detritovores. Unfortunately, this work is more than 10 years old and DDT is no longer in use. No recent research results are readily available with which to compare this data, nor are data available on pesticides currently being used in the area.

6.22 INVERTEBRATES

Outside of a few key species, ecological data on terrestrial and freshwater wetland invertebrates in the lower Everglades is scarce. Several aquatic crustaceans have received some attention, notably the crayfish (Procambarus alleni) (Kushlan and Kushlan 1979a), the freshwater prawn (Paleomonetes paludosus) (Kushlan and Kushlan 1979b), and the apple snail (Pomacea paludosa) (Kushlan 1975). Unfortunately, little is known of the important and pervasive aquatic and terrestrial insects which form a key link in the energy flow of this ecosystem (Hofstetter 1973).

The crayfish (Procambarus alleni) is particularly common in the Everglades marsh ecosystem, reaching a maximum standing crop of 4.0 Kcal/m^2 and a maximum average of 1.6 Kcal/m^2 in water 25 cm (10 in) deep (Kushlan and Kushlan 1979a). The maintenance of high population levels of crayfish is believed to be closely tied to seasonally oscillating water levels. Extensive dry periods take their toll on this facultative burrower through increased desiccation of ground water habitat. Extended high water levels are usually accompanied by increased fish production, especially of larger predators which consequently consume greater numbers of crayfish (Kushlan 1976).

Trophically, the crayfish is a grazing detritovore whose main source of food is periphyton. On the other side of the trophic spectrum, the crayfish comprises 75% of the food of the Everglades bullfrog (Ligas 1960), 32% of the food of juvenile alligators (Fogarty and Albury 1968), and 51% of the food of white ibis (Kushlan and Kushlan 1975). Other predators include numerous fish, birds (American bittern, pied billed grebe), and mammals (raccoons, river otters).

Population levels of the prawn (Palemonetes paludosus) show a similar response to fluctuating water levels. High water apparently induces increased predation through changes in the fish numbers and composition. Like the crayfish, Paleomonetes is generally adapted to survive drought conditions, but not by using the same adaptive mechanism of burrowing. The prawn generally moves into shallow ponds during drought and survives low oxygen stress through exploitation of high concentrations of oxygen diffusing across the surface water layer. Reproduction appears to peak soon after summer flooding of the marsh (Kushlan 1976).

6.23 FISHES

Thirty-four species of fishes are reported from the freshwater Everglades (Table 25), representing 17 families (SFRC 1980). Dineen (1974), reporting on fishes in the conservation areas north of the present study area, lists 43 species from 18 families. Kushlan and Lodge (1974) consider a total of 108 species from 34 families as members of the freshwater fish fauna of south Florida. Of these 108, only 31 belong to obligatory freshwater families. In this report we limit our discussion to the fauna reported by SFRC (1980).

The Centrarchidae (bluegill) and Cyprinodontidae (topminnow) families are the more prevalent in terms of genera and species. The former are represented by 7 species including the secretive Everglades pygmy sunfish, the bluegill, the blue spotted and redear sunfishes, and the large mouth bass. The topminnows or killifishes include, among others, the sheepshead minnow, the marsh and seminole killifishes, and flagfish. Another noteworthy family is the Poecilidae or live bearers. Three species representative of this family are the ubiquitous mosquito fish, the least killifish, and the sailfin molly (Stevenson 1976).

SPECIES	MAR	PRA	CYP	HAM	THI	DIS	PON
Fishes							
Florida Gar (*Lepisosteus platyrhincus*)	P					P	P
Bowfin (*Amia calva*)	P		P			P	P
Tarpon (*Megalops atlantica*)						P	
American Eel (*Anguilla rostrata*)						P	P
Golden Shiner (*Notemigonus crysoleucas*)			P			P	P
Lake Chubsucker (*Erymizon succetta*)	P		P			P	P
Channel Catfish (*Ictalurus punctatus*)						P	
Brown Bullhead (*Ictalurus nebulosus*)	P		P			P	P
Yellow Bullhead (*Ictalurus natalis*)	P	P	P			P	P
Tadpole Madtom (*Noturus gyrinus*)	P					P	P
Walking Catfish (*Clarias batrachus*)	P	P	P			P	P
Bluefin Killifish (*Lucania goodei*)	P	P	P			P	P
Diamond Killifish (*Adinia xenica*)	P					P	
Gulf Killifish (*Fundulis grandis*)	P						
Seminole Killifish (*Fundulus seminolis*)	P	P				P	P
Marsh Killifish (*Fundulus confluentus*)	P	P	P			P	P
Golden Topminnow (*Fundulis chrysotus*)	P	P	P			P	P
Sheepshead Minnow (*Cyprinodon variegatus*)	P	P	P			P	P
Flagfish (*Jordanella floridae*)	P	P	P			P	P
Mosquitofish (*Gambusia affinis*)	P	P	P		P	P	P
Least Killifish (*Heterandria formosa*)	P	P	P		P	P	P
Sailfin Molly (*Poecilia latipinna*)	P	P	P		P	P	P
Brookside Silverside (*Labidesthes sicculus*)	P					P	P
Common Snook (*Centropomus undecimalis*)						P	
Everglades Pygmy Sunfish (*Elassoma evergladei*)	P		P			P	P
Largemouth Bass (*Micropterus salmoides*)	P		P			P	P
Warmouth (*Lepomis gulosus*)	P	P	P			P	P
Spotted Sunfish (*Lepomis punctatus*)	P	P	P			P	P
Redear Sunfish (*Lepomis microlophus*)	P		P			P	P
Dollar Sunfish (*Lepomis marginatus*)	P	P	P		P	P	P
Bluegill (*Lepomis macrochirus*)	P		P			P	P
Blue-spotted Sunfish (*Enneacanthus gloriosus*)	P	P	P			P	P
Swamp Darter (*Etheostoma fusiforme*)	P		P			P	P
Black Acara (*Cichlasoma bimaculatum*)	P	P	P		P	P	P

Habitats are: MAR - marsh, PRA - prairies; CYP - cypress; HAM - hammock; DIS - disturbed; PON - pond; THI - thicket.
Status within each habitat shown by P = present; C = common; U = uncommon.

Table 25. Habitat use by lower Everglades fishes (adapted from SFRC 1980).

Since the lower Everglades fluctuate widely between flood and drought conditions, those fishes that use the marshes and wet prairies have developed adaptive mechanisms that help to carry them through adverse conditions. As drought conditions intensify, one particularly common adaptation is to move with the waters into the receding pools and alligator holes. This tends to increase fish concentrations and hence predation, as well as increasing the potential for fish kills. Kushlan (1976) reports distinctly different effects on fish diversity and survival between a system exploited heavily by predators and one allowed to go the fish kill route. In the former, a before and after analysis of the effects of feeding by a mixture of wading birds revealed a consumption of 75% of the fish biomass by the birds and yet no species were totally eliminated. In the fish kill situation, 93% of the biomass was killed and only 6 of 26 species survived locally.

In the harsh environment of the shallow marsh, oxygen and habitat (simple water depth) often become limiting factors for fish. Many fishes such as the bowfin, the Florida gar, and the mosquito fish are capable of burrowing into the marsh sediments and aestivating through the dry season. Carr (1973) speculates that the unique upturned mouth and flattened head of the killifishes and the mosquito fish allow them to extract necessary oxygen from the thin surface layers of the water in otherwise oxygen deficient pools. Fishes without this unique adaptation must find other means of surviving the drought, such as migration to the deeper waters of sloughs and canals.

Consistent with this, Dineen (1968) reports seldom finding bass larger than 1.4 kg (3 lbs) more than 1.6 km (1 mi) away from the nearest canal. Bass above the yearling stage generally cannot survive in waters less than 0.3 meters (1 ft) in depth. An interesting exception to this general picture has been noted by Dineen in fishes utilizing the Eleocharis/blue-green algal mat community. As flood waters seasonally recede, the algal mat spreads over the water surface, providing shade for the shallow water inhabitants. Here, bass as large as 3.2 kg (7 lbs) have been found in as little as 0.3 m (1 ft) of water.

Optimum fish production appears to be a function of the oscillation of water levels rather than extremes of either dry or wet conditions. Excessive drought forces many marsh inhabitants into ponds and sloughs where predation often reaches the frenzy stage. Fish kills may also be frequent under such conditions.

If water levels remain excessively high over an extended time, conditions may also become less than optimum for the fish community (and the sport fisherman). The normally drought-stressed community tends to spread out through the marshes, leading to an increase of larger predatory types in usually safe refuges far from canals (Kushlan 1976). Simultaneously, high waters may also stimulate the buildup of a soupy ooze in the marshes. As drought conditions then begin, this ooze creates a water/mud mixture that may kill fish through suffocation even though water levels are still adequate (Crowder 1974).

A number of exotic species, particularly aquarium rejects and escapees such as oscars and goldfish, have been observed near the National Park boundaries (Dineen 1974). The walking catfish (Clarias batrochus) and the pike killifish (Belonesox belizanus) are also reported near the study area though not yet observed within it. Two rather peculiar members of the freshwater fish fauna are the tarpon (Megalops atlantica) and the common snook (Centropomus unidecimalis) which have apparently gained access to freshwaters by moving upstream via drainage canals. The only true South American exotic is the black acara (Aequidens portalegrensis) reported from alligator ponds (Kushlan 1972) and canals (Dineen 1974, SFRC 1980).

6.24 AMPHIBIANS AND REPTILES

Eighteen (18) species of amphibians and forty-seven (47) species of reptiles are listed from the terrestrial and freshwater wetlands of the lower Everglades (Table 26) (SFRC 1980). As a group, the amphibians range over all habitats, though many restrict themselves to a limited set of conditions. In the marshes and prairies one is likely to find the greater siren and Everglades dwarf siren, as well as a number of frogs including the pig frog, the Florida cricket frog, and the southern leopard frog. In the hammocks and pine flatwoods, the eastern spadefoot toad and the oak toad, as well as the Florida chorus frog and the tree frogs are common amphibian inhabitants (Carr and Goin 1969).

Like many of the fishes, the amphibians often possess a burrowing capacity and an ability to enter a state of aestivtion that helps them survive droughts. If the drought is not so severe as to remove essential moisture from deep in the soil, the amphibians have a chance of surviving. This burrowing capacity plays an important role, not only in amphibian survival, but also in the survival of other species that may coinhabit with them (Tabb 1963, Kolipinski and Higer 1969).

The 46 species of reptiles listed in Table 26 include 9 turtles, 10 lizards, 25 snakes, and

SPECIES	MAR	PRA	CYP	HAM	THI	DIS	PON
Amphibians							
Greater Siren (Siren lacertina)	P		U		P	P	P
Everglades Dwarf Siren (Pseudobranchus striatus)	U	P	P		P	P	P
Peninsula Newt (Notophthalmus vividescens)	U		P		P	P	P
Two-toed Amphiuma (Amphiuma means)			U		P	P	P
Eastern Spadefoot (Scapiopus holbrooki)	U	U	P	P	P	P	P
Southern Toad (Bufo terrestris)	C	P	P	P	P	C	P
Oak Toad (Bufo quercicus)	C	C	P	P	P	C	P
Giant Toad (Bufo marinus)						P	
Greenhouse Frog (Eleutherodactylus planirostris)				P	P	P	
Squirrel Treefrog (Hyla squirella)	P	P	P	P	P	P	P
Green Treefrog (Hyla cinerea)	C	C	C	P	C	P	P
Cuban Treefrog (Hyla septentrionalis)			P	P		P	
Little Grass Frog (Limnaoedus ocularis)	P	P	P	P	P	P	P
Florida Chorus Frog (Pseudacris nigrita)	C	C	P		P	P	P
Florida Cricket Frog (Acris gryllus)	C	C	C	P	P	P	P
Pig Frog (Rana grylio)	C	C	C		C	U	C
Southern Leopard Frog (Rana utricularia)	C	C	C	U	C	C	C
Eastern Narrow-mouthed Toad (Gastrophryne carolinensis)	C	U	P	P	P	C	P
Reptiles							
Snapping Turtle (Chelydra serpentina)	P	P		P		P	P
Stinkpot (Sternotherus odoratus)	P					P	P
Striped Mud Turtle (Kinosternon bauri)	U	U		P	P	P	P
Florida Mud Turtle (Kinosternon subrubrum)	P				P	P	P
Florida Box Turtle (Terrapene carolina)	P	U	P	P	P	P	
Florida Cooter (Chrysemys floridana)	P					P	P
Florida Red-bellied Turtle (Chrysemys nelsoni)	P					P	P
Chicken Turtle (Deirochelys reticularia)	P		P			P	P
Florida Softshell (Trionyx ferox)	U			P		C	P
Green Anole (Anolis carolinenis)	P	U		P	P	U	
Brown Anole (Anolis sagrei)				P	P	P	
Mediterranean Gecko (Hemidactylus turcicus)						P	
Indo-Pacific Gecko (Hemidactylus garnoti)						P	
Reef Gecko (Sphaerodactylus notatus)				P		P	
Eastern Glass Lizard (Ophisaurus ventralis)		P		P		P	
Island Glass Lizard (Ophisaurus compressus)		P				P	
Slender Glass Lizard (Ophisaurus attenuatus)		P		P			
Six-lined Racerunner (Cnemidophorus sexlineatus)		P		P	P	P	
Ground Skink (Leiolopisma laterale)				P	P	P	
Southeastern Five-lined Skink (Eumeces inexpectatus)				P	P	P	
Florida Green Water Snake (Natrix cyclopion)	P					P	P
Brown Water Snake (Natrix taxispilota)	P					P	P
Florida Water Snake (Natrix fasciata)	U		P			P	P
Striped Swamp Snake (Liodytes alleni)	P				P	P	P
Black Swamp Snake (Seminatrix pygaea)	P		P		P	P	P
Florida Brown Snake (Storeria dekayi)	P	P	P	P	P	P	P
Eastern Garter Snake (Thamnophis sirtalis)	U	P	P	P	P	U	P
Peninsula Ribbon Snake (Thamnophis sauritus)	P	P	P	P	P		P
Eastern Hognose Snake (Heterodon platyrhinos)				P			
Southern Ringneck Snake (Diadophis punctatus)			P	P	P	P	
Mud Snake (Farancia abacura)	P		P		P	P	P
Southern Black Racer (Coluber constrictor)	U	U	P	P	P	U	P
Eastern Coachwhip (Masticophis flagellum)		P				P	
Rough Green Snake (Opheodrys aestivus)			P	P	P	P	
Eastern Indigo Snake (Drymarchon corais)	P	P	P	U	P	U	
Corn Snake (Elaphe guttata)		P	P	P	P	P	
Rat Snake (Elaphe obsoleta)	P	P	P	P	P	P	
Florida Kingsnake (Lampropeltis getulus)	P	P	P	P	P	P	P
Scarlet Kingsnake (Lampropeltis triangulum)				P			
Scarlet Snake (Cemophora coccinea)			P	P	P	P	
Rim Rock Crowned Snake (Tantilla oolitica)				P		P	
Eastern Coral Snake (Micrurus fulvius)	P		P	P	P	P	P
Florida Cottonmouth (Agkistrodon piscivorus)	U	U	P	P	P	U	P
Dusky Pygmy Rattlesnake (Sistrurus miliarius)	P	U		P	P	U	
Eastern Diamondback Rattlesnake (Crotalus adamanteus)					P		
American Crocodile (Crocodylus acutus)						P	
American Alligator (Alligator mississippiensis)	C	P	P	P	P	C	C

Habitats are: MAR - marsh; PRA - prairies; CYP - cypress; HAM - hammock; DIS - disturbed; PON - pond; THI - thicket.

Status within each habitat shown by P = present; C = common; U = uncommon.

Table 26. Habitat use by lower Everglades amphibians and reptiles (adapted from SFRC 1980).

2 crocodilians. Among the turtles, the most common are the striped mud turtle and the Florida box turtle. Lizards are most commonly represented by the green anole and the skinks. More common and ubiquitious snakes include the Florida brown snake, the eastern garter snake, the peninsula ribbon snake, and the rat snake. By far the most conspicuous reptile is the alligator.

McDiarmid (1978) lists the alligator (Alligator mississippiensis) and the Eastern Indigo snake (Drymarchon corais cuperi) as species "of special concern". The American crocodile (Crocodylus acutus) whose numbers are estimated to be only 200-500, and whose observed range is limited to upper Florida Bay and lower Taylor Slough is listed as endangered. More information on the crocodile is presented in Chapter 7.34.

6.25 BIRDS

Of those vertebrates for which a species list is presented (Table 27), birds are by far the most numerous wildlife group. Two hundred and twenty-one (221) species are listed as utilizing the 7 habitats of the terrestrial and freshwater glades (SFRC 1980). Around 60% of the bird species reported regularly from the south Florida area are winter residents or migrating visitors (Robertson and Kushlan 1974). Thus, species diversity and population densities increase in the winter.

In general terms, the avifauna is composed of two major groups, the water birds and the land birds (Robertson and Kushlan 1974). Water birds in turn may be subdivided into three categories: seabirds, species of estuarine and coastal wetlands, and species of interior wetlands. The first two of these subdivisions are obviously of less relevance in this section than the species of interior wetlands birds and the land birds. However, while none of the 8 primarily oceanic birds occurring off of south Florida are reported in the freshwater wetlands, many of the coastal and estuarine species do frequent the interior wetlands as well.

A primary characteristic of the interior wetland avifauna of the lower Everglades is its relative impoverishment of breeding species compared to the nearby West Indies (Robertson 1955, Robertson and Kushlan 1974). Whereas 15 breeding species of interior wetlands birds are reported from the Everglades, 26 species are reported from Cuba. With regard to breeding land birds, the lower Everglades is also relatively impoverished, exhibiting only 30 to 35 species compared to 60 to 70 species farther north in the state. This trend is especially pronounced with respect to the passerine birds, while the number of nonpasserine species compares fairly well to other locations within the same latitude.

Robertson and Kushlan (1974) offer two reasons for the avifaunal impoverishment of interior wetlands birds, one historical and one ecological. The historical reason focuses on the relative geological youth of the interior wetlands environment compared to other West Indian islands. Five thousand years ago, only a mini-Everglades environment existed along the fringes of Florida Bay and the southwest coast. Much of the area was considerably drier during the earlier Wisconsin period of the late Pleistocene. Thus there was, historically speaking, little wetland habitat available in south Florida at that time. The ecological reasoning follows from the

SPECIES	MAR	PRA	CYP	HAM	THI	DIS	PO
Birds							
Pied-billed Grebe(R) (*Podilymbus podiceps*)	U	P	P		U		P
Double-crested Cormorant(R) (*Phalacrocorax auritus*)	U		P		P		U
Anhinga(R) (*Anhinga anhinga*)	C	P	C	P	C	C	
Great Blue Heron(R) (*Ardea herodias*)	C	C	C	P	C	U	C
Great White Heron(R) (*Ardea herodias*)	U					P	
Northern Green Heron(R) (*Butorides striatus*)	C	C	C	P	C	U	C
Little Blue Heron(R) (*Egretta caerulea*)	C	C	C	P	C	U	C
Cattle Egret(R) (*Bubulcus ibis*)	U	U	P	P	C	C	
Great Egret(R) (*Egretta alba*)	C	C	C	U	C	U	C
Snowy Egret(R) (*Egretta thula*)	C	C	U	P	U	P	P
Louisiana Heron(R) (*Egretta tricolor*)	C	C	C	U	C	P	C
Black-crowned Night Heron(R) (*Nycticorax nycticorax*)	C	P	C		C	P	P
Yellow-crowned Night Heron(R) (*Nyctanassa violacea*)	U	P	P		U	P	P
Least Bittern(R) (*Ixobrycus exilis*)	U	P	P		U	P	
American Bittern(W) (*Botaurus lentiginosus*)	C	U					U
Wood Stork(R) (*Mycteria americana*)	U	U	U		U	P	U
Glossy Ibis(R) (*Plegadis falcinellus*)	U		P		P	P	
White Ibis(R) (*Eudocimus albus*)	C	C	C	P	C	C	C
Roseate Spoonbill(R) (*Ajaia ajaja*)	U					U	
Mallard(W) (*Anas platyrhynchos*)	P					P	P
Black Duck(W) (*Anas rubripes*)	P					P	
Mottled Duck(R) (*Anas fulvigula*)	U					U	P
Gadwall(W) (*Anas strepera*)							
Pintail(W) (*Anas acuta*)							
American Green-winged Teal(W) (*Anas crecca*)		P					P
Blue-winged Teal(W) (*Anas discors*)	P						P
Wood Duck(R) (*Aix sponsa*)			P				
Lesser Scaup(W) (*Aythya affinis*)						P	
Ruddy Duck(W) (*Oxyura jamaicensis*)						P	
Hooded Merganser(W) (*Lophodytes cucullatus*)						P	
Red-breasted Merganser(W) (*Mergus serrator*)						U	
Turkey Vulture(R) (*Cathartes aura*)	C	C	C	C	C	C	P
Black Vulture(R) (*Coragypus atratus*)	C	C	C	C	C	C	P
Swallow-tailed Kite(S) (*Elanoides forfiatus*)	U	U	U	P	P	P	
Mississippi Kite(M) (*Ictinia mississippiensis*)			P				
Everglade Kite(R) (*Rostrhamus sociabilis*)	U				P		P
Sharp-skinned Hawk(W) (*Accipiter striatus*)	P	P	P	U	U		
Cooper's Hawk (M,W) (*Accipiter cooperii*)							
Red-tailed Hawk(R) (*Buteo jamaicensis*)	U	U	P	P	P	P	
Red-shouldered Hawk(R) (*Buteo lineatus*)	C	C	C	C	C	P	
Broad-winged Hawk(W) (*Buteo platypterus*)			P	P	P		
Short-tailed Hawk(R) (*Buteo brachyurus*)	P	P	P	P			
Bald Eagle(R) (*Haliaeetus leucocephalus*)	U		U			U	
Marsh Hawk(W) (*Circus cyaneus*)	C	C	P		P	C	P

Table 27 continued

SPECIES	MAR	PRA	CYP	HAM	THI	DIS	PON
Osprey(R) (*Pandion haliaetus*)	P	P				U	U
Merlin(W) (*Falco columbarius*)	R	P					
American Kestrel(W) (*Falco sparverius*)	P	P			U	P	
Bobwhite(R) (*Colinus virginianus*)	P	P			P	U	
Sandhill Crane(R) (*Grus canadensis*)	R						
Limpkin(R) (*Aramus guarauna*)	C	P	P	P	P	P	U
King Rail(R) (*Rallus elegans*)	U	U			U	P	P
Virginia Rail(W) (*Rallus limicola*)	P	P			P		
Sora(W) (*Porzana carolina*)	P	P					
Black Rail(W) (*Laterallus jamaicensis*)							
Purple Gallinule(R) (*Porphyrula martinica*)	U				U	UU	
Common Gallinule(R) (*Gallinula chloropus*)	C					C	
American Coot(R) (*Fulica americana*)							
Killdeer(R) (*Charadrius vociferus*)	C	C					
Black-bellied Plover(W) (*Pluvialis squatarola*)						P	
Ruddy Turnstone(W) (*Arenaria interpres*)						P	
Common Snipe(W) (*Capella gallinago*)	P	P	P	P	P	P	P
Spotted Sandpiper(W) (*Actitis macularia*)		P				P	
Solitary Sandpiper(W) (*Tringa solitaria*)						P	
Greater Yellowlegs(W) (*Tringa melanoleuca*)	U					U	
Lesser Yellowlegs(W) (*Tringa flavipes*)	U					U	
Red Knot(W) (*Calidris canutus*)						P	
Pectoral Sandpiper(W) (*Calidris melanotos*)						P	
Least Sandpiper(W) (*Calidris minutilla*)						P	
Dunlin(W) (*Calidris alpina*)						P	
Semipalmated Sandpiper(W) (*Calidris pusilla*)						P	
Western Sandpiper(W) (*Calidris mauri*)						P	
Buff-breasted Sandpiper(M) (*Tryngites subruficollis*)						P	
Short-billed Dowitcher(W) (*Limnodromus griseus*)						P	
Stilt Sandpiper(W) (*Micropalama himantopus*)						P	
Black-necked Stilt(R) (*Himantopus mexicanus*)	P					P	
Wilson's Phalarope(W) (*Steganopus tricolor*)						P	
Ring-billed Gull(R) (*Larus delawarensis*)						P	
Laughing Gull(R) (*Larus atricilla*)	U					C	
Forster's Tern(R) (*Sterna forsteri*)						P	
Caspian Tern(R) (*Sterna caspia*)	P					P	
Black Tern(M) (*Chlidonias niger*)	P					P	
White-crowned Pigeon(R) (*Columba leucocephala*)	P	P	U	U	U		
White-winged Dove(R) (*Zenaida asiatica*)						P	
Mourning Dove(R) (*Zenaida macroura*)		C		C	C	C	
Ground Dove(R) (*Columbina passerina*)		U				C	
Budgerigar (*Melopsittacus undulatus*)						P	
Mangrove Cuckoo(S) (*Coccyzus minor*)				P			
Yellow-billed Cuckoo(S) (*Coccyzus americanus*)				U	U	P	
Black-billed Cuckoo(M) (*Coccyzus erythropthalmus*)				U	U	P	
Smooth-billed Ani(R) (*Crotophaga ani*)		P			U	U	
Barn Owl(R) (*Tyto alba*)				P	P	U	
Screech Owl(R) (*Otus asio*)				P	U	P	
Great Horned Owl(R) (*Bubo virginianus*)			P	P	P	P	
Burrowing Owl(M,W) (*Athene cunicularia*)						P	

Table 27 continued

SPECIES	MAR	PRA	CYP	HAM	THI	OIS	PON
Barred Owl(R) (*Strix varia*)			U	U	U	P	
Short-eared Owl(W) (*Asio flammeus*)	P	P					
Chuck-will's-widow(S,W) (*Caprimulgus carolinensis*)			P	P	P	P	
Whip-poor-will(W) (*Caprimulgus vociferus*)							
Common Nighthawk(S) (*Chordeiles minor*)	C	C	C	C	C	C	
Ruby-throated Hummingbird(W) (*Archilochus colubris*)				P	P		
Belted Kingfish(R) (*Megaceryle alcyon*)	C	U	C	C	C	C	
Common Flicker(R) (*Colaptes auratus*)			C	C	C	C	
Pileated Woodpecker(R) (*Dryocopus pileatus*)			U	U	U		
Red-bellied Woodpecker(R) (*Melanerpes carolinus*)			C	C	C	C	
Yellow-bellied Sapsucker(W) (*Sphyrapicus varius*)			P	P	P		
Hairy Woodpecker(R) (*Picoides villosus*)			P	P	P		
Downy Woodpecker(R) (*Picoides pubescens*)			U	U	P		
Eastern Kingbird(S) (*Tyrannus tyrannus*)	C	C					
Gray Kingbird(S) (*Tyrannus dominicensis*)				U	U		
Western Kingbird(W) (*Tyrannus verticalis*)				U	U	U	
Scissor-tailed Flycatcher(W) (*Muscivora forficata*)						P	
Great Crested Flycatcher(R) (*Myiarchus crinitus*)			C	C	C	P	
Eastern Phoebe(W) (*Sayornis phoebe*)	C	C	C	C	C	C	
Empidonax spp.(W)			U	U	U		
Eastern Wood Pewee(M) (*Contopus virens*)			U	U	U		
Tree Swallow(W) (*Iridoprocne bicolor*)	C	C	C	C	C	C	C
Bank Swallow(M) (*Riparia riparia*)	P	P				P	
Rough-winged Swallow(M) (*Stelgidopteryx ruficollis*)	P	P				P	
Barn Swallow(W) (*Hirundo rustica*)	C	C	C	C	C	C	
Cliff Swallow(M) (*Petrochelidon pyrrhonota*)	P	P					
Purple Martin(S) (*Progne subis*)	C	C					
Blue Jay(R) (*Cyanocitta cristata*)			U	U	U		
Common Crow(R) (*Corvus brachyrhynchos*)	C	C	C	C	C	C	P
House Wren(W) (*Troglodytes aedon*)	C	C	C	C	C	C	
Carolina Wren(R) (*Thryothorus ludovicianus*)		U	U	U	U	P	
Long-billed Marsh Wren(R) (*Cistothorus palustris*)	P	P			P		
Short-billed Marsh Wren(W) (*Cistothorus platensis*)	P	P			P		
Mockingbird(R) (*Mimus polyglottos*)	C	C	P	C	C	C	
Gray Catbird(W) (*Dumetella carolinensis*)		U	U	C	C	C	
Brown Thrasher(R) (*Toxostoma rufum*)				P	P	P	
American Robin(W) (*Turdus migratorius*)			P	P	P	P	
Wood Thrush(M) (*Hylochichla mustelina*)			P	P	P	P	
Hermit Thrush(M) (*Catharus guttatus*)			P	P	P	P	
Swainson's Thrush(M) (*Catharus ustulatus*)			P	P	P	P	
Gray-cheeked Thrush(M) (*Catharus minimus*)			P	P	P	P	
Veery(M) (*Catharus fuscescens*)			P	P	P	P	
Blue-gray Gnatcatcher(W) (*Polioptila caerulea*)	P	P	C	C	C	C	
Cedar Waxwing(W) (*Bombycilla cedrorum*)			P	P	P	P	
Loggerhead Shrike(R) (*Lanius ludovicianus*)	P	P	P	P	P	P	
White-eyed Vireo(R) (*Vireo griseus*)			C	C	C	P	
Yellow-throated Vireo(W) (*Vireo flavifrons*)			P	P	P		
Solitary Vireo(W) (*Vireo solitarius*)			P	P	P		
Black-whiskered Vireo(S) (*Vireo altiloquus*)				U	U		
Red-eyed Vireo(M) (*Vireo olivaceus*)			P	P	P		

Table 27 continued

SPECIES	MAR	PRA	CYP	HAM	THI	OIS	PON
Black-and-white Warbler(W) (*Mniotilta varia*)			U	U	U	U	
Prothonotary Warbler(M) (*Protonotaria citrea*)			P	P	P		
Swainson's Warbler(M) (*Limnothlypis swainsonii*)			P	P	P		
Worm-eating Warbler(M) (*Helmitheros vermivorus*)			P	P	P		
Golden-winged Warbler(M) (*Vermivora chrysoptera*)			P	P	P		
Blue-winged Warbler(M) (*Vermivora pinus*)			P	P	P		
Tennessee Warbler(M) (*Vermivora peregrina*)			P	P	P		
Orange-crowned Warbler(M,W) (*Vermivora celata*)			P	P	P		
Nashville Warbler(M) (*Vermivora ruficapilla*)			P	P	P		
Northern Parula(W) (*Parula americana*)			P	P	P		
Yellow Warbler(R,M) (*Dendroica petechia*)			P	P	P	P	
Magnolia Warbler(M) (*Dendroica magnolia*)			P	P	P		
Cape May Warbler(W) (*Dendroica tigrina*)			P	P	P		
Black-throated Blue Warbler(W) (*Dendroica caerulescens*)			P	P	P		
Yellow-rumped Warbler(W) (*Dendroica coronata*)			P	P	P	P	
Black-throated Gray Warbler(M) (*Dendroica nigrescens*)			P	P	P		
Black-throated Green Warbler(M,W) (*Dendroica virens*)			P	P	P		
Cerulean Warbler(M) (*Dendroica cerulea*)			P	P	P		
Blackburnian Warbler(M) (*Dendroica fusca*)			P	P	P		
Yellow-throated Warbler(W) (*Dendroica dominica*)			P	P	P	P	
Chestnut-sided Warbler(M) (*Dendroica pensylvanica*)			P	P	P		
Bay-breasted Warbler(M) (*Dendroica castanea*)			P	P	P		
Blackpoll Warbler(M) (*Dendroica striata*)			P	P	P		
Pine Warbler(R) (*Dendroica pinus*)				P	P		
Prairie Warbler(R) (*Dendroica discolor*)			P	P	P	P	
Palm Warbler(W) (*Dendroica palmarum*)	C	C	C	C	C	C	
Ovenbird(W) (*Seiurus aurocapillus*)			U	U	U	P	
Northern Waterthrush(W) (*Seiurus noveboracensis*)			U	P	U	P	
Louisiana Waterthrush(M) (*Seiurus motacilla*)			P		P	P	
Kentucky Warbler(M) (*Oporornis formosus*)			P	P	P		
Conneticut Warbler(M) (*Oporornis agilis*)			P	P	P		
Common Yellowthroat(R) (*Geothlypis trichas*)	C	C	C	C	C	C	
Yellow-breasted Chat(M) (*Icteria virens*)				P	P		
Hooded Warbler(M) (*Wilsonia citrina*)			P	P	P		
Wilson's Warbler(M) (*Wilsonia pusilla*)			P	P	P		
American Redstart(W) (*Setophaga ruticilla*)			C	C	C		
House Sparrow(R) (*Passer domesticus*)						P	
Bobolink(M) (*Dolichonyx oryzivorus*)	P	P					
Eastern Meadowlark(R) (*Sturnella magna*)	C	C			C	C	
Red-winged Blackbird(R) (*Agelaius phoeniceus*)	C	C	C	P	C	C	
Orchard Oriole(M) (*Icterus spurius*)			P	P	P	P	
Spotted-breasted Oriole(R) (*Icterus pectoralis*)						P	
Northern Oriole(M) (*Icterus galbula*)			P	P	P	P	
Boat-tailed Grackle(R) (*Quiscalus major*)	C	C	C	U	C	C	
Common Grackle(R) (*Quiscalus quiscula*)	C	C	C	U	C	C	
Brown-headed Cowbird(W) (*Molothrus ater*)						P	
Scarlet Tanager(M) (*Piranga olivacea*)			P	P	P	P	
Summer Tanager(M) (*Piranga rubra*)			P	P	P	P	
Cardinal(R) (*Cardinalis cardinalis*)			C	C	C	C	
Rose-breasted Grosbeak(M) (*Pheucticus ludovicianus*)			P	P	P	P	

Table 27 continued

SPECIES	MAR	PRA	CYP	HAM	THI	DIS	PON
Blue Grosbeak(M) (*Guiraca caerulea*)			P	P	P	P	
Indigo Bunting(W) (*Passerina cyanea*)		P	P	P	P	P	
Painted Bunting(W) (*Passerina ciris*)		P	P	P	P	P	
Dickcissel(W) (*Spiza americana*)		P				P	
Pine Siskin(W) (*Carduelis pinus*)			P	P	P	P	
American Goldfinch(W) (*Carduelis tristis*)			P	P	P	P	
Rufous-sided Towhee(R) (*Pipilio erythrophthalmus*)		C	P	C	C	C	
Savannah Sparrow(W) (*Passerculus sandwichensis*)	C	C				C	
Grasshopper Sparrow(W) (*Ammodramus savannarum*)	P	P				P	
Sharp-tailed Sparrow(W) (*Ammospiza caudocuta*)	P	P					
Seaside Sparrow(W) (*Ammospiza maritima*)	P	P					
Cape Sable Sparrow(R) (Ammuspiza maritima)		U					
Vesper Sparrow(W) (*Pooecetes gramineus*)		P				P	
Chipping Sparrow(W) (*Spizella passerina*)						P	
Field Sparrow(W) (*Spizella pusilla*)						P	
White-crowned Sparrow(W) (*Zonotrichia leucophrys*)					P	P	
White-throated Sparrow(W) (*Zonotrichia albicollis*)					P	P	
Lincoln's Sparrow(W) (*Melospiza lincolnii*)	P	P			P	P	
Swamp Sparrow(W) (*Melospiza georgiana*)	P	P					
Song Sparrow(W) (*Melospiza melodia*)	P	P					

Habitats are: MAR - marsh; PRA - prairies; CYP - cypress; HAM - hammock;
DIS - disturbed; PON - pond; THI - thicket.
Status within each habitat shown by P - Present; C - Common; U - Uncommon
Resident basis shown by (R) - year long resident; (W) - winter resident;
(S) - summer resident; (M) - migratory.

distinct seasonality of the Everglades marsh environment. These authors speculate that this area is perhaps best exploited by mobile populations of wading birds, most of which are also, and perhaps primarily, estuarine. Consistent with this view is the fact that the coastal and estuarine avifauna is essentially identical to the coastal and estuarine avifaunas elsewhere in the region.

With regard to the impoverished land breeding avifauna, Robertson and Kushlan (1974) summarize the prevailing sentiments as follows:

"In our view, southern Florida (and to a diminishing degree northward, the entire southeast) exists today as a sort of avifaunal vacuum, the hiatus between a continental land avifauna, withdrawing before an unfavorable climatic trend and a West Indian land avifauna delayed in reaching vacant and suitable habitat by a sea barrier and perhaps also by intrinsic qualities that make island birds poor colonizers of mainland areas".

Breeding land bird habitats in the study area include pine forest (Long Pine Key), broad leaved forest (tree island hammocks) and forest edge. In the pine forest habitat, pine warbler, bobwhite, red-bellied woodpecker, and mockingbird are the most commonly reported breeders. Cardinals, Carolina wrens, and red-bellied woodpeckers are among the more common breeders in broad leaved forests. In the forest edge surveys, cardinals, wrens, and red-bellies are again common, along with white-eyed vireo, great crested flycatchers, and bluejays.

Breeding wading birds in the study area include 11 species of herons, 2 ibises, the roseate spoonbill, and the wood stork. Robertson and Kushlan (1974) estimate that present numbers of breeding waders have been reduced by about 95% since 1870, initially as a result of plume hunting but more recently as a function of insidious changes brought on by upstream watershed management practices.

Regarding seasonality of nesting, there are two general categories, winter nesters which tend to be those birds that utilize Florida Bay more than the interior wetlands, and the spring nesters. Typically the smaller herons and the white ibis nest in spring, while the roseate spoonbill and great white and blue herons nest in the winter months.

A particularly well studied example of the close relationship that exists between water levels, fish production, and nesting success in wading birds is the wood stork

(Kahl 1964, Kushlan et al. 1975). Colony formation and subsequent nesting success of this species is a function of the rate at which the adults attain a suitable nutritional state. This, of course, depends on the quality and quantity of wood stork food supply. Prior to 1962 drainage alternations, nesting success, or the lack of it, was a fairly predictable function of high summer water levels and high rates of drying. These conditions stimulate fish production and favor the availability of food to wood storks as water levels decline rapidly and concentrate excess fish stocks. After 1962, nesting success or failure appears less predictable and less frequently based on similar water levels and drying rates. This indicates that perhaps more subtle hydrobiological changes have occurred from drainage alterations, or more complex relationships exist between wood stork population dynamics and its habitat characteristics.

The Florida Committee on Rare and Endangered Plants and Animals (FCREPA) lists 72 taxanomic species of birds. Twenty seven (37.5%) of these species occur within the terrestrial and freshwater wetlands habitats of the lower Everglades. Table 28 lists those species and their designated status as of 1978 (Kale 1978).

Endangered Species
Wood Stork
(*Mycteria americana*
Everglades Kite
(*Rostrhamus sociabilis plumbeus*)
Kirtlands Warbler
(*Dendroica kirtlandii*)
Cape Sable Sparrow
(*Ammospiza maritima mirabilis*)

Threatened Species
Brown Pelican
(*Pelecanus occidentalis carolinensis*)
Southern Bald Eagle
(*Haliaeetus leucocephalus leucocephalus*)
Osprey
(*Pandion haliaetus carolinensis*)
S.E. American Kestrel
(*Falco sparverius paulus*)
Florida Sandhill Crane
(*Gras canadensis pratensis*)
White Crowned Pigeon
(*Columba leucocephala*)

Rare Species
Roseate Spoonbill
(*Ajaia ajaja*)
White Tailed Kite
(*Elanus caeruleus majusculus*)
Short Tailed Hawk
(*Buteo brachyurus*)
Antillean Night Hawk
(*Chordeiles minor vicinus*)

Species of Special Concern
Little Blue Heron
(*Florida caerulea*)
Great Egret
(*Casmerodius albus*)
Snowy Egret
(*Egretta thula*)
Louisiana Heron
(*Hydranassa tricolor*)
Black Crowned Night Heron
(*Nycticorax nycticorax*)
Yellow Crowned Night Heron
(*Nyctanassa violacea*)
Least Bittern
(*Ixobrychus exilis exilis*)
Glossy Ibis
(*Plegadis falcinellus falcinellus*)
White Ibis
(*Eudocimus albus*)
Coopers Hawk
(*Accipiter cooperii*)
Limpkin
(*Aramus guarauna pictus*)
Burrowing Owl
(*Athena cunicularia floridana*)
Hairy Woodpecker
(*Picoides villosus auduboni*)

Table 28. Endangered, threatened, or rare bird species, and species of special concern that utilize terrestrial and freshwater wetlands of the lower Everglades (adapted from Kale 1978).

6.26 MAMMALS

Table 29 lists twenty-eight (28) species of mammals from the terrestrial and freshwater wetlands habitat of the lower Everglades and Taylor Slough. This represents 57% of the total number of mammalian species (49) recognized in the state of Florida (Layne 1978). Virtually all of these species listed are of North American origin. This essentially unimpaired range extension of a temperate fauna into the subtropics accompanies what appears to be an extensive differentiation of some species populations into many races. This differentiation is believed to be a result of the frequent isolation of populations and subsequent localized genetic drift during fluctuating sea levels of the late Pleistocene (Layne 1974, 1977), rather than adaptation resulting from invasion into unexploited subtropical habitats.

SPECIES	MAR	PRA	CYP	HAM	THI	DIS	PON
Raccoon (*Procyon lotor*)	C	C	C	C	C	C	C
River Otter (*Lutra canadensis*)	C	U	U	P	P		P
Mink (*Mustela vison*)	P						
Spotted Skunk (*Spilogale putorius*)		P		P		P	
Striped Skunk (*Mephitis mephitis*)		P		P		P	
Florida Panther (*Felis concolor*)	P	P	P	P	P	P	
Bobcat (*Lynx rufus*)	U	U	P	U	U	U	
Domestic Dog (*Canis domesticus*)						U	
Whitetail Deer (*Odocoileus virginianus*)	C	C	U	C	C	C	
Opossum (*Didelphis marsupialis*)	C	C	C	C	C	C	C
Shorttail Shrew (*Blarina brevicauda*)		P		P			
Least Shrew (*Crytotis parva*)		P		P			
Eastern Mole (*Scalopus aquaticus*)						P	
Eastern Yellow Bat (*Lasiurus intermedius*)	P	P	P	P	P	P	P
Evening Bat (*Nycticeius humeralis*)	P	P	P	P	P	P	P
Freetail Bat (*Tadarida brasiliensis*)	P	P	P	P	P	P	P
Armadillo (*Dasypus novemcinctus*)				P		P	
Marsh Rabbit (*Sylvilagus palustris*)	C	C	U	U	U	C	
Eastern Cottontail (*Sylvilagus floridanus*)				U		C	
Eastern Gray Squirrel (*Sciurus carolinensis*)			P	P			
Southern Flying Squirrel (*Glaucomys volans*)			P	P			
Rice Rat (*Oryzomys palustris*)	C	C	P	C	C	C	
Cotton Mouse (*Peromyscus gossypinus*)	C	C	C	C	P	C	
Hispid Cotton Rat (*Sigmodon hispidus*)	U	C	U	C	P	C	
Florida Water Rat (*Neofiber alleni*)	P						
Black Rat (*Rattus rattus*)						P	
House Mouse (*Mus musculus*)		P				C	
Gray Fox (*Urocyon cinereoargenteus*)		P		P		U	

Habitats are: MAR - marsh; PRA - prairie; CYP - cypress; HAM - hammock; DIS - disturbed; PON - pond; THI - thicket.
Status within each habitat shown by P = present; C = common; U = uncommon.

Table 29. Habitat use by lower Everglades mammals (adapted from SFRC 1980).

With regard to trophic position, 8 of the mammals are clearly top predators, 7 are primarily insectivorous, 5 are exclusively herbivorous, and 2 are scavengers. The remaining mammals are the omnivorous rats and mice, and the rooting feral hog and the nine-banded armadillo.

Six mammalian species having range within the lower Everglades are listed by Layne (1977) as rare or endangered. Classified as endangered are the mangrove fox squirrel (Scuirius niger avicennia) and the Florida panther (Felis concolor coryii). Three species are listed as threatened, the West Indian manatee (Trichechus manatus), the Florida black bear (Ursus americana floridanus), and the Everglades mink (Mustela vision). The round tailed muskrat (Neofiber alleni) is identified as a species of special concern (Woolfenden 1982).

Smith (1980) points out that for the Everglades mink (Mustela vision), a lack of information is at least partially to blame for its present status. The mink is an extremely secretive mammal only rarely seen even by long term residents and virtually never caught. Smith reports capturing zero (0) mink in over 1000 trap-nights of trying, although many other species were observed in the traps. Examination of scat reveal that mink feed on insects, fish, and small mammals. From road kills, interviews, reported sitings, and personal observations, Smith speculates that the mink population ranges farther east, toward Miami, than previously thought. The majority of specimens observed are males and there seems to be an increased incidence of sitings along canals and levees. This suggests that there is probably a distinct differentiation of male and female social behaviors; males foray over a wide area while females bear the brunt of brooding. There is also the suggestion that canals and levees may somehow enhance the mink habitat.

CHAPTER 7
ESTUARINE AND SALTWATER WETLANDS

7.1 PREVIOUS LITERATURE REVIEWS AND SUMMARIES

Recently Odum et al. (1982) summarized the existing literature on a major component of the southwestern Florida coast in a document entitled: The Florida Mangrove Zone: A Community Profile. Since this document draws from the same sources of information as the present report, it is considered redundant to attempt to summarize the same literature. Consequently, the following discussion deals only with those ecological factors that are specific to the watershed and estuaries of the study area. It is strongly suggested that the reader consult the above document for a more complete review of the autecology and synecology of the Florida mangrove zone.

7.2 HABITAT ZONATION

Figure 48 (from Browder et al. 1973) identifies the general habitat zonations of the estuarine and saltwater wetland ecosystem. In areal coverage, mangrove forest is by far the predominant habitat. Salt marsh and open water estuarine habitats are next in terms of decreasing relative abundance. Beach and dune vegetation is limited to the elevated sand ridges behind the three capes of Cape Sable and a narrow beach at Highland point between Lostman's and Broad Rivers (Craighead 1971). Salt flats (or prairies) which do not show up on the map at this scale are interspersed within the mangroves along the northern fringe of Florida Bay and the gulf coast.

7.21 MANGROVE FORESTS

Distributions of vegetation within the mangrove zone follow two complimentary trains of thought. One is strictly phytosociological, based on the theory of successional relationships between species associations (Davis 1940); the other is based on consideration of the environmental factors favoring species dominance and physiognomy of forest growth (Lugo and Snedaker 1974). As the latter authors point out, these two approaches are complimentary rather than mutually exclusive.

Figure 49 presents a comparison of these two schemes. The Davis approach (Figure 49a) presents an empirical summary of the major habitats of the study area with emphasis on the mangrove zonation relative to tide levels. With the exception of Davis' interpretation that mangroves actively build land and that successional processes per se are involved in the empirical trends of Figure 49a, the diagram is a fair representation of vegetation associations in the mangrove zone. Presently the general consensus of opinion is that mangroves, through their ability to trap sediments, act as land stabilizers rather than land builders (Odum et al. 1982). Other physical forces such as sea level fluctuation, long term drainge patterns, and hurricanes exert the primary controlling influence on exactly where the land ends and the ocean begins.

If one were to incorporate environmental factors into Davis' Figure 49a, such as topography and hydrology, the mangrove forest types of Figure 49b (Lugo and Snedaker,

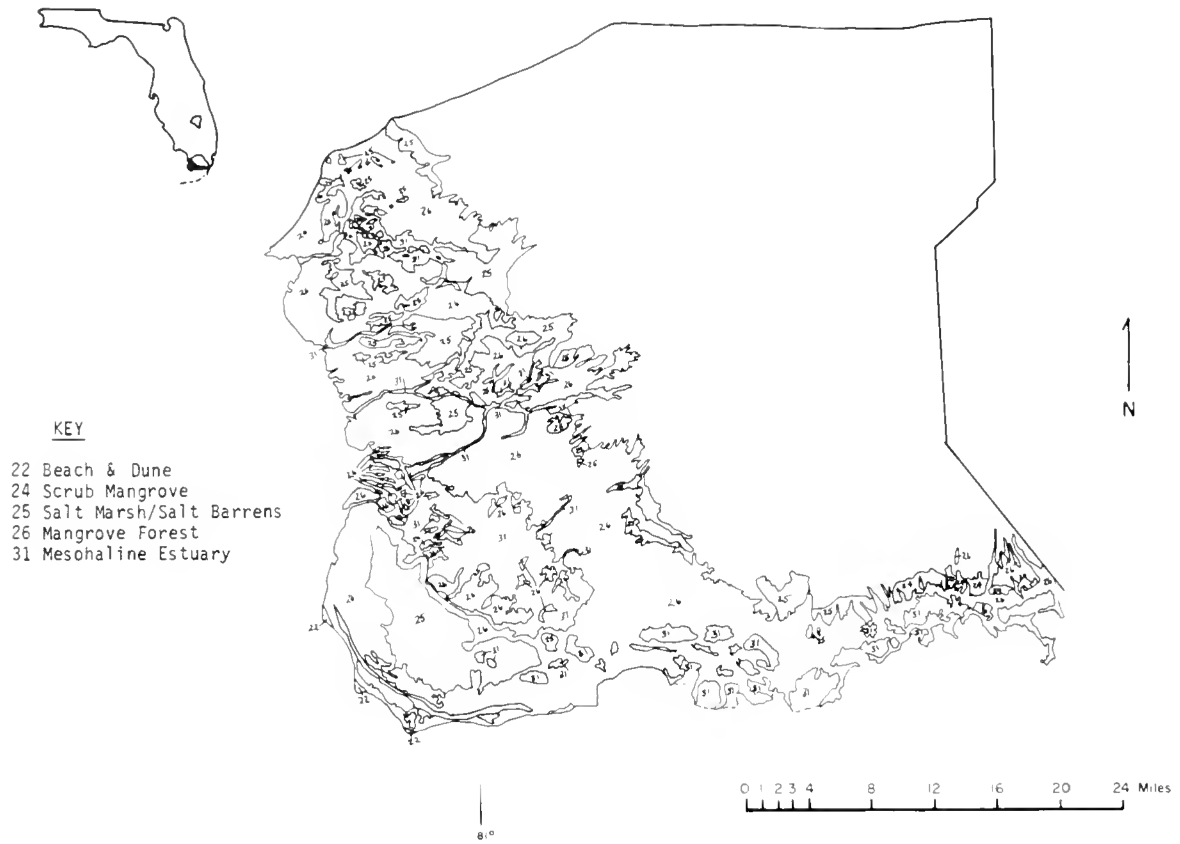


Figure 48. Estuarine and saltwater wetlands in the lower Everglades and Taylor Slough (adapted from Browder et al. 1973).

1974) emerge. The following description of mangrove forest types is paraphrased from the latter authors' document.

The fringe type forest occurs along protected shorelines and is especially well developed where elevations are higher than mean high tide. Low tidal velocities allow the well developed mangrove root systems to act as efficient sediment traps. Due to their exposure along shorelines, these forests may be affected by winds, causing breakage and accumulation of debris among the prop roots.

Riverine forests occur along river and creek drainages, usually separated from them by a shallow berm though flushed by daily tides. They are often fronted by fringe mangrove forests. Riverine type forests consist of straight trunked, relatively tall red mangrove (Rhizophora mangle) trees, with varying mixtures of black mangrove (Avicennia germinans) and white mangrove (Laguncularia racemosa).

The overwash forests are characteristic of the smaller islands and finger-like projections of land within smaller bays and estuaries. These forest types are generally overwashed by daily tides, thus little accumulation of litter occurs. The forest consists of

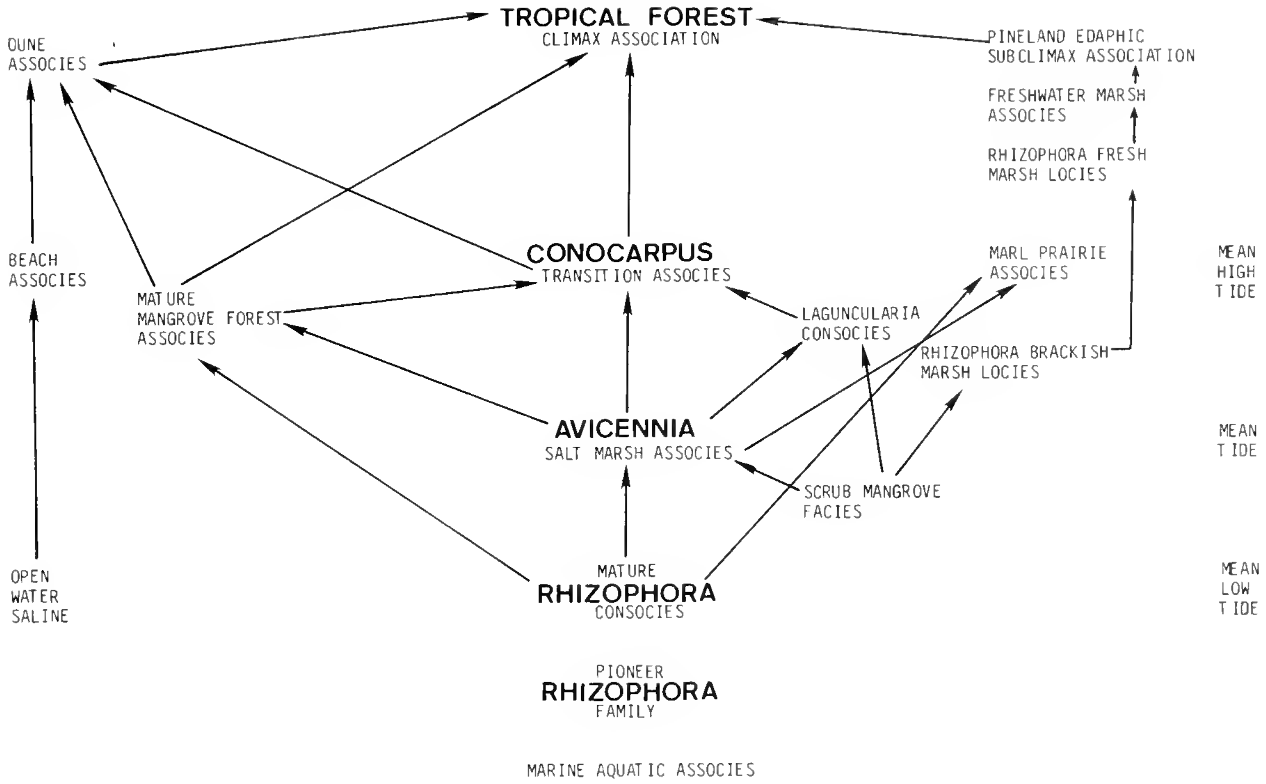


Figure 49a. Mangrove community associations and forest types along the southwest coast of Florida (adapted from Davis 1940).

fairly small, uniform trees and a lack of understory foliage giving the forest a rather symmetrical appearance when viewed from within.

Basin forests occur inland along drainage depressions channeling runoff toward the coast. In the more coastal location red mangroves are dominant but as one moves inland dominance is shared with black and white mangroves. A variant of this forest type is the mangrove hammock occurring along the northern fringe of Florida Bay on the topographically flat but slightly elevated Buttonwood embankment.

The dwarf forest is more or less restricted to portions of the flat coastal fringes of the Taylor Slough drainage basin and to the Florida Keys. Due to restricted flushing and salinity stress (e.g., in Taylor Slough), or excessive flushing and stress due to inhospitable substrate (e.g., in the Keys), trees in this forest type are characteristically stunted though they may be quite old (40 yrs). Lugo and Snedaker (1974) also mention that some dwarf forests may be nutrient limited.

7.22 SALT PRAIRIES, MARSHES, AND TRANSITIONAL HABITATS

Salt "prairies" (also "barrens" or "flats") in the study area characteristically occur inland of the mean sea level mark (Davis 1940), often in association with black mangroves. In the northern portion of the study area these prairies are clearly transitional between the mangrove swamp environment and the

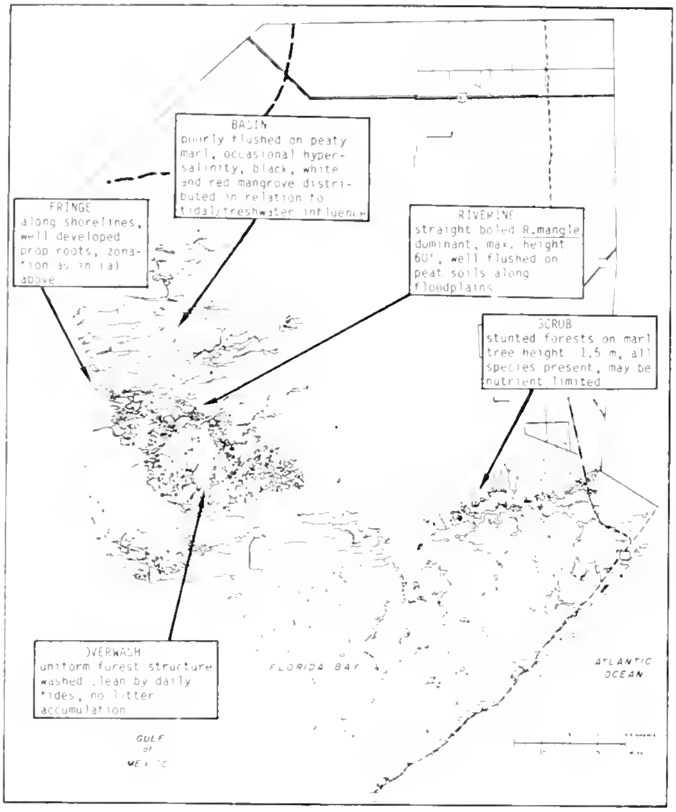


Figure 49b. Mangrove community associations and forest types along the southwest coast of Florida (adapted from Lugo and Snedaker 1974).

salt or freshwater marshes or marl prairies. Along northern Florida Bay these flats are often found more intricately interspersed within a broad zone of basin type mangroves (Davis 1940, Russell et al. 1980). Dominant species in the more open prairies are the succulent saltwort (*Batis maritima*) and glasswort (*Salicornia perennis*), with some cordgrass (*Spartina* sp.) and needlerush (*Juncus roemerianus*) (Davis 1940, Russell et al. 1980).

Extensive salt marshes are generally found upland of the mangroves and salt prairies, particularly between major estuaries (Craighead 1971) and in association with open ponds and black mangroves (Davis 1940). Large areas of *Juncus* marsh dotted with numerous ponds exist along the interior margins of the Buttonwood levee and interior Cape Sable. They are also found on the interior of some of the larger mangrove islands. *Spartina* dominated marshes, particularly *Spartina spartinae* (prickly cordgrass) are also found in similar settings becoming especially dominant from Broad River to the north.

Often, upland of the marsh and mangrove vegetation, an ecotonal mixture of trees and shrubs known as the "Conocarpus transition associes" occurs (Davis 1940). Hilsenbeck et al. (1979) describe a similar association in the lower Taylor Slough area as follows:

> *"This community represents an upland successional formation that is roughly intermediate between mangrove forests and hardwood hammock forests. These forests, also called "low hammocks," occupy relatively deep peat soils that have a very brief or no effective hydroperiod. They are floristically quite diverse, particularly in regard to the tree species composition, but are sufficiently similar so that they can be regarded as one forest type.*
>
> *"In the typical stand, mangrove vegetation dominates the forest margins and rarely a low marginal pond region when present. A diverse and highly variable assemblage of tropical hardwood tree species comprises the majority of the forest canopy that is closed, often excluding more than 80 percent of the ambient sunlight. This creates beneath the canopy a stable microclimate that is suited for several of the native bromeliad species. Several tree species contribute to the canopy on*

most of the low hammocks surveyed. They are: red mangrove (Rhizophora mangle), buttonwood (Conocarpus erecta), poison wood (Metopium toxiferum), Spanish stopper (Eugenia foetida), white stopper (Eugenia axillaris), pole lid-flower (Calyptranthes pallens), cabbage palm (Sobal palmetto), red bay (Persea borbonia), and West-Indian mahogany (Swietenia mahogani).

"The understory vegetation is relatively rich, but the abundances of each species vary considerably between stands. The most typical species are: myrsine (Myrsine floridana), chicken grape (Vitis rotundifolia, poison ivy (Toxicodendron radicans), swamp fern (Blechnum serrulatum), and potato tree (Solanum verbascifolium). Several epiphytes are common including reflexed wild pine (Tillandsia balbisiana), banded wild pine (T. flexuosa), soft-leaved wild pine (T. valenzuelana), and giant wild pine (T. utriculata). Other epiphytes include the following: yellow catopsis (Catopsis berteroniana), butterfly orchid (Encyclia tampensis), worm vine (Vanilla barbellata), butterfly orchid (Encyclia boothiana), resurrection fern (Polypodium polypodioides), and serpent fern (Phlebodium aureum)."

7.23 OPEN WATERS

Unlike the brackish wetlands environment, the open water environment is less amenable to clearly defined wildlife habitats or vegetational zonations. Daily and seasonal variations in salinity and temperature cause considerable flux in vegetation distributions.

Tabb et al. (1962) report that the dominant aquatic plant of the extensive salt/fresh transition zone is the macroalga Chara hornemanni. Upstream of this zone Chara dominance is replaced by the fresh water marsh and slough flora of the Everglades. Batophora oerstedi, another alga, may also be found in the transition zone in association with rock outcroppings, or wood surfaces upon which to attach. Chara and Batophora apparently prefer a fairly low salinity range (0-10 ppt) and thus in general achieve their greatest areal coverage in the winter (November through February). They have been observed dominating a considerable portion of Whitewater Bay during these months. Chara has also been observed surviving in waters approaching 30 ppt while Batophora has been reported from hypersaline Florida Bay (Hudson et al. 1970). Widgeon grass (Ruppia maritima) reaches its greatest densities during low salinity periods in Coot and Whitewater Bays.

Intermediate to high salinities favor the invasion of the bays and estuaries by a different suite of vegetation dominants. In Whitewater Bay, three species of macroalgae reportedly occur in large quantities during higher salinities (Tabb et al. 1962). They are: Acetabuleria crenulata, Caulerpa verticillata, and Udotea wilsoni. Invasion of the extensive Udotea beds by the red algae Dasya pedicellata and Gracilaria confervoides were observed whenever salinities rose above 20-25 ppt. The latter are epiphytic on Udotea or attached to coarser shell gravel. Shoalgrass (Halodule wrightii), which generally replaced the Ruppia in Coot and Whitewater Bays at higher salinities, all but disappeared from the area after the opening of the Buttonwood canal in 1957 (Tabb et al. 1962).

Figure 50 summarizes the general trends observed between salinity, vegetation, and bottom type in Whitewater and Coot Bays. Unfortunately this work was performed in

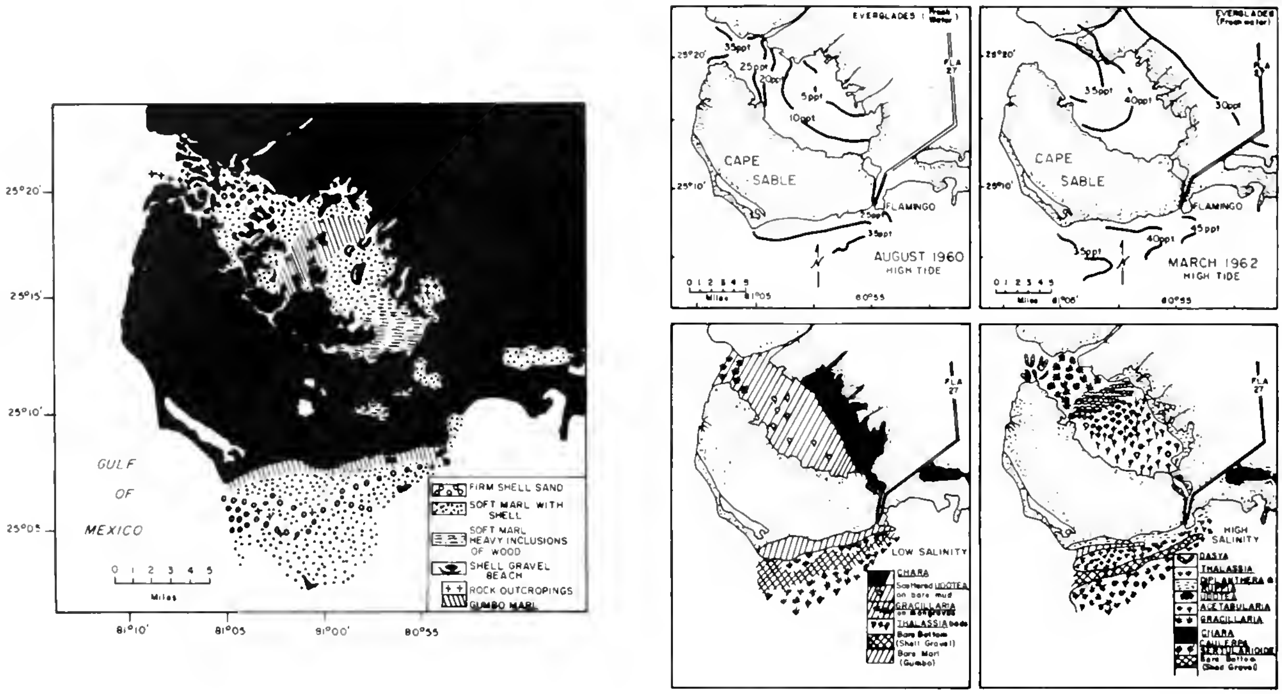


Figure 50. Physical/chemical factors in relation to plant distributions in Whitewater Bay (adapted from Tabb et al. 1962).

1957-1960. More recent information does not exist with which these historical trends and distributions can be compared.

7.3 HABITAT PARTITIONING FOR FISH AND WILDLIFE PRODUCTION

7.31 ENERGY FLOW AND CHEMICAL CYCLING

Figure 51 presents a generalized scheme of energy flow through the estuarine and saltwater wetlands ecosystem. Compared to the terrestrial and freshwater setting, considerable study has been devoted to several aspects of estuarine energy flow. Heald (1969) has traced the production and transport of organic detritus in the North River estuary, while Odum (1969) documented the food habits of 53 species of fishes and numerous invertebrates utilizing the same area. Odum et al. (1982) provide a comprehensive though qualitative listing of food preferences of vertebrates in the study area.

Energy flow pathways are divided into two major divisions, a predominantly terrestrial upper half and an open water lower half. This delineation is not a strict one, considering the intertidal habitats and the species that utilize them, as well as the larger flying and foraging predators capable of using both environments.

One of the primary features of the energy flow in this area is its dependence on detritus (particularly mangrove detritus). Allochthonous

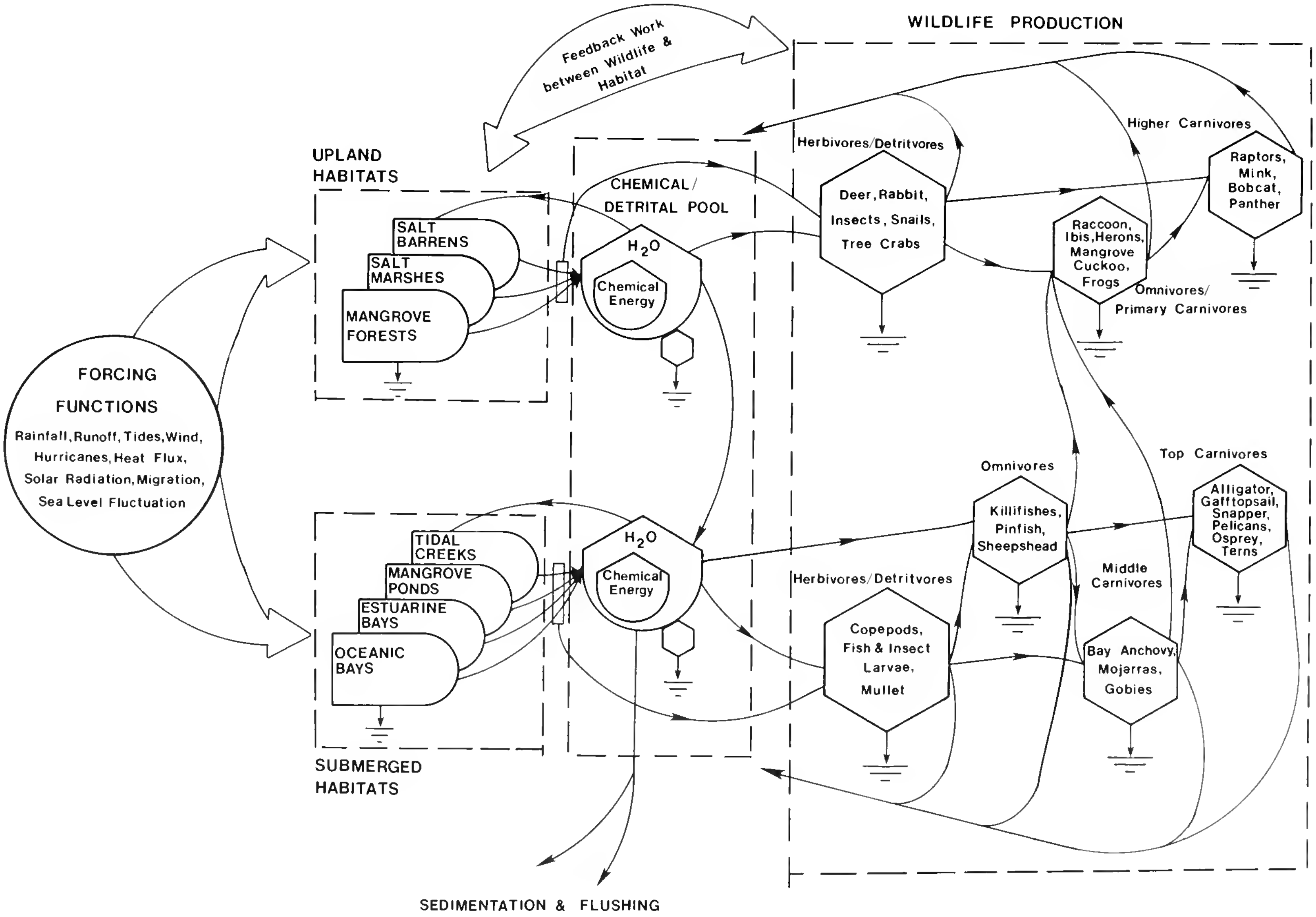


Figure 51. Summary diagram of energy flow through the mangrove zone community.

detritus originates as upstream runoff from extensive sawgrass marshes and wet prairies. Autochthonous sources include mangrove debris, black needlerush (Juncus) and cordgrass (Spartina) debris, debris from less abundant plant species, and animal detritus. Of all the potential sources, mangrove debris is by far the most important. Heald (1971) estimates that 85% of the "debris" produced in wetlands surrounding the North River estuary originates from one species, the red mangrove, while Juncus and Spartina contribute little to the total available debris.

As the mangrove debris awaits its fate of either sedimentation or washout into the open waters by tidal or freshwater flushing, it is subjected to a variable intensity of degradation forces (Heald 1971). In general, leaves degrade faster if they are in predominantly fresh water than they do on dry land. They degrade even faster if they are in brackish or salt water. This increase in rate is apparently due to increased grazing by small marine crustaceans, particularly amphipods.

This pattern of detrital degradation also coincides with the quality of the mangrove forest structure: the best developed forest structures tend to be found where soil salinities are well moderated by adequate freshwater and/or tidal flushing. Marginal environments for forest development occur in association with either uniformly high or low annual salinities, excessive siltation, arid climates, in sedimentary carbonate environments, or where tidal amplitude is small (Snedaker and Brown 1982).

Using the six mangrove forest type categories of Lugo and Snedaker (1974), Snedaker and Brown (1982) present an index of mangrove ecosystem dynamics based on leaf litter production rates (Table 30). This index has proven to be the most reliable indicator of mangrove ecosystem dynamics.

Forest Type	Litter Production g/m^2 year
Riverine	1120
Fringe	1032
Overwash	1024
Basin (hammock)	750
Basin (flushed)	741
Dwarf (scrub)	220
Basin (impounded)	0

Table 30. Leaf litter production rates of mangrove ecosystems (adapted from Snedaker and Brown 1982).

In general, grazing of freshly fallen leaves is delayed by the heavy cuticular wax of the mangrove leaves. As this disintegrates, subsequent grazing by microcrustaceans increases, ostensibly because of a higher nutritive content of bacterial and fungal food sources. Needlerush and sawgrass debris are seldom grazed upon after abcission and thus degrade at a slower rate.

Heald (1971) documents a microfloral succession on red mangrove leaves leading to the increased availability and usefulness of the detritus to macroconsumers. Figure 52 summarizes the principle physical and biochemical features of this successional process i.e., a relative enrichment of the leaf with animal protein at the expense of plant protein, as particle size decreases.

With regard to water quality, Snedaker and Brown (1982) find mangroves are extremely tolerant to a wide variety of conditions.

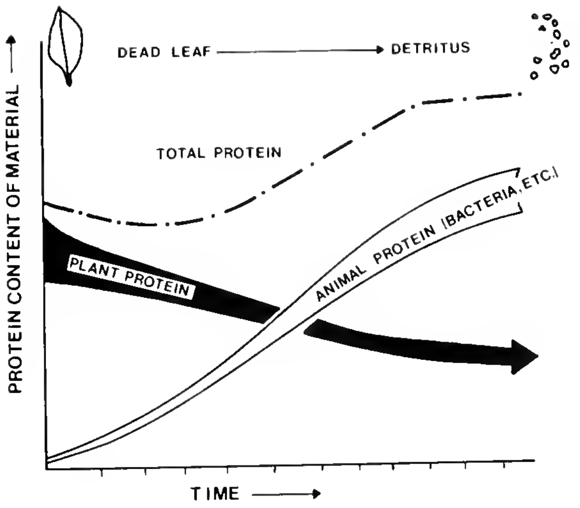


Figure 52. Diagramatic representation of protein enrichment of mangrove detritus during degradation (adapted from Heald 1971).

Mangroves are basically freshwater plants with a remarkable ability to tolerate saltwater. This is believed to be the major reason for their success in the oscillating salinity environment. Normal coastal salinity regimes prevent invasion by (and competition from) freshwater species, thus allowing mangroves to dominate.

Snedaker and Brown (1982) suggest that in addition to physical/chemical conditions such as moderate flushing and adequate freshwater, at least two water quality constituents contribute significantly to understanding mangrove ecosystem dynamics. Nitrate is important because it serves as an oxidant in the anaerobic decomposition of reduced organic matter accompanied by the release of nutrients in the rhizosphere. Likewise, sulfate may be highly important as an oxidant in the anaerobic decomposition and the formation of sulfides. The latter may combine with heavy metals and render them unavailable for uptake.

The metals copper, chromium, iron, lead, manganese, and zinc are consistently more concentrated in the sediments of mangrove forests than in the surface waters. Differences of several orders of magnitude are typical. The generally nonclastic sediments of south Florida do not contribute an excessive background load of heavy metals to the coastal environment. However, agricultural pesticides and cultural sources of heavy metals have been found to enrich the background environment (Horvath 1973, Mathis 1973, Manker 1975). More importantly, mangrove tissues consistently exhibit heavy metal concentrations 6 to 7 orders of magnitude greater than sediments. It is currently unknown whether uptake occurs via sediment or water transfer, or both. On the other end of the seasonal cycle, Mathis (1973) reports a 3 to 200 fold enrichment of Fe, Mn, Cu, and Cd in various decomposition stages of red mangrove leaves, compared with living leaves. Considering the extreme dependance of nearby estuaries on mangrove detritus, this could be an important pathway of heavy metal enrichment in fish and wildlife.

Much information exists on structural aspects of mangrove biogeochemistry (i.e., chemical concentrations in various components of tissues, soils, and so forth), but very little information exists on dynamic aspects such as transfer functions and uptake rates between major components of the mangrove system (Snedaker and Brown 1982).

Trophic relations among terrestrial and wetland consumers have not been studied extensively. Thus they are portrayed in Figure 51 in a generalized manner. In the aquatic sector, trophic relationships follow those of Odum (1971) though modified somewhat to conform to the expanded setting. Primary and secondary consumers correspond to what Odum calls "mixed trophic levels" (herbivores, omnivores, and higher carnivores). Data on the food habits of mangrove fish and wildlife are extensively summarized in Odum et al. (1982).

7.32 INVERTEBRATES

Unlike the terrestrial and freshwater wetlands invertebrates, those of the estuarine zone are a more often studied component of the wildlife. Nonetheless, there are still major gaps in both basic species lists and the ecology of known residents.

Odum et al. (1982) divide invertebrates into three (3) communities: the arboreal arthropod community, the prop root and associated mud surface community, and the water column community. To this list one should add the salt marsh and salt prairie communities, as well as the beach and dune community. Unfortunately, information is severely lacking on these latter two habitats within the study area.

By far the most frequently studied invertebrate community is the water column. Notable studies include the work of Tabb and Manning (1961) and Tabb et al. (1962) in Whitewater Bay, Davis and Williams (1950) in the embayments and brackish lakes fringing northern Florida Bay, McPherson (1971) in the Shark River estuary, and Odum (1971) in the North River estuary. For individual species lists the reader should consult these sources. In the following account only a brief summary of the more salient features of these studies is presented.

Salinity appears to play the major role in determining invertebrate assemblages within the study area. For instance, Figure 53 (from McPherson 1971) shows salinity preferences for 12 species of zooplankton along the length of the Shark River estuary. Three additional species, including the most abundant zooplankton Acartia tonsa, are also shown on this figure. The latter was generally always dominant between salinities of 0.4 to 22 ppt.

Some species of crustaceans also show rather distinct salinity zonation. Three species of prawns Paleomonetes paludosus, P. pugio, and P. intermedius follow a consistent relative distribution to one another based on preferences for increasing salinity range. A similar distribution is recorded for three mysids Taphromysis bowmani, Mysidopsis almyra, and Gastrosaccus disimilis (McPherson 1971).

In addition to the salinity factor, Davis and Williams (1950) suggest that isolation of brackish embayments along the northern fringe of Florida Bay is also a factor in determining plankton assemblages. Two close but isolated lakes showing very similar salinities exhibit reverse relative abundances of rotifers and pelecypod veligers. In Long Lake, Davis and Williams (1950) report Cyclops permamensis tannica as the dominant copepod over Acartia floridana 95% to 5% in numbers in 1947, while only A. floridana was found in 1948. A. tonsa and Temora sp. were reported from the open waters of Florida Bay. A. floridana was apparently confined to the closed waters and replaced by A. tonsa in the more open waters.

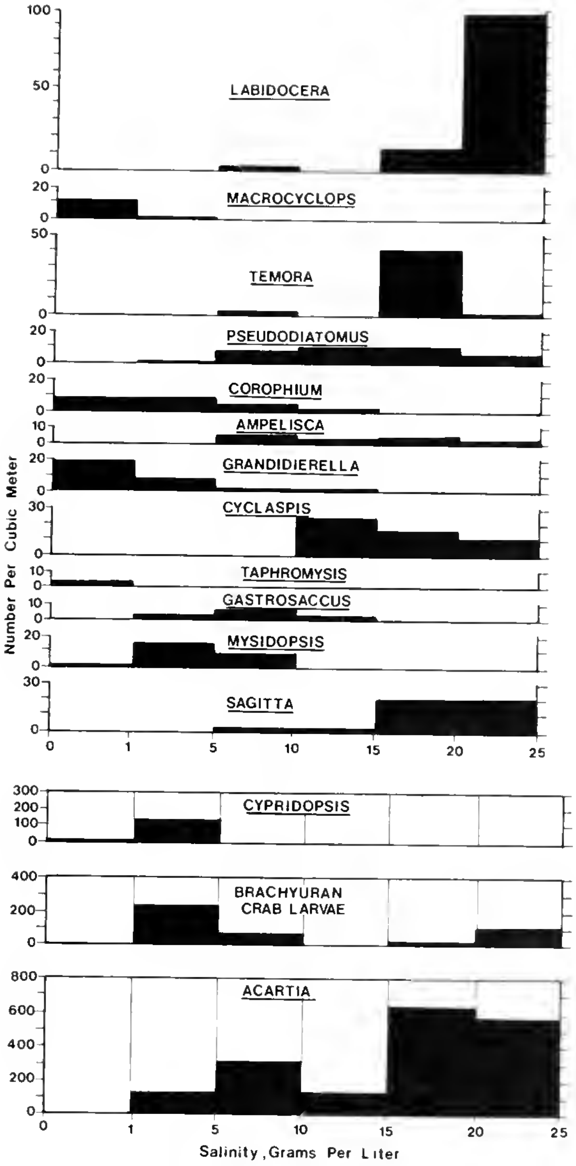


Figure 53. Distribution of 15 zooplankters in relation to salinity in the Shark River estuary (adapted from McPherson 1971).

Tabb and Manning (1961) and Tabb et al. (1962) report a total of 432 species of plants, macroinvertebrates, and fish from 7 locations, 4 of which are in the estuarine and salt water wetlands zone; the remaining 3 are in Florida Bay. In Coot Bay, dominant macroinvertebrates during low salinity (5-18 ppt) are the ivory barnacle Balanus eburneus, the pink shrimp Penaeus duorarum, the bivalve Anomalocardia anomeris, and the gastropod Nassarius vibex. Under high salinity conditions (18-35 ppt) the isopod Sphaeroma destructor, the ivory barnacle, the mollusks mentioned above, and the echinoderm Ophiophragmus filograneus are dominant.

Western Whitewater Bay is dominated by the ivory barnacle, the mussel Brachiodontes exustus, and the gastropod N. vibex under low salinity; and by the oyster Crassostrea virginica, the gastropod Cerithium muscarum, and the echinoderm Echinaster spinulosus during high salinity.

Odum (1971) presents data on invertebrates from the North River estuary, concentrating primarily on their food habits rather than their seasonality. A number of species were identified as strict herbivores/detritovores. These include the mussels B. exustus and Congeria leucophaeta. The prawn P. intermedius also showed a heavy dependence on plant detritus with only 5% of its diet being animal remains. The pink shrimp, snapping shrimp, mysids, and the crab Rhithropanopeus harrissi exhibited a slightly greater dependence on a wider variety of small animals and animal detritus.

The arboreal invertebrate community consists of the insects, mollusks, and crustaceans inhabiting the mangrove canopy. In the present study area virtually no studies exist that document the compositon of this community. However, it is likely that the mangrove tree crab Aratus pisonii is an important member along with a wide variety of insects and other invertebrates. The following section on Florida Bay contains information and numerous references on the insect community of small mangrove keys.

Prop roots of red mangroves have long been recognized as habitat for a wide variety of invertebrates. Odum et al. (1982) lump the prop root habitat in with the mud flats surrounding the mangroves since many species utilize both areas as tide waters oscillate. These authors hypothesize that the two substrates are closely intertwined, with the mangroves serving as a protective refuge and the mud flat as a feeding ground.

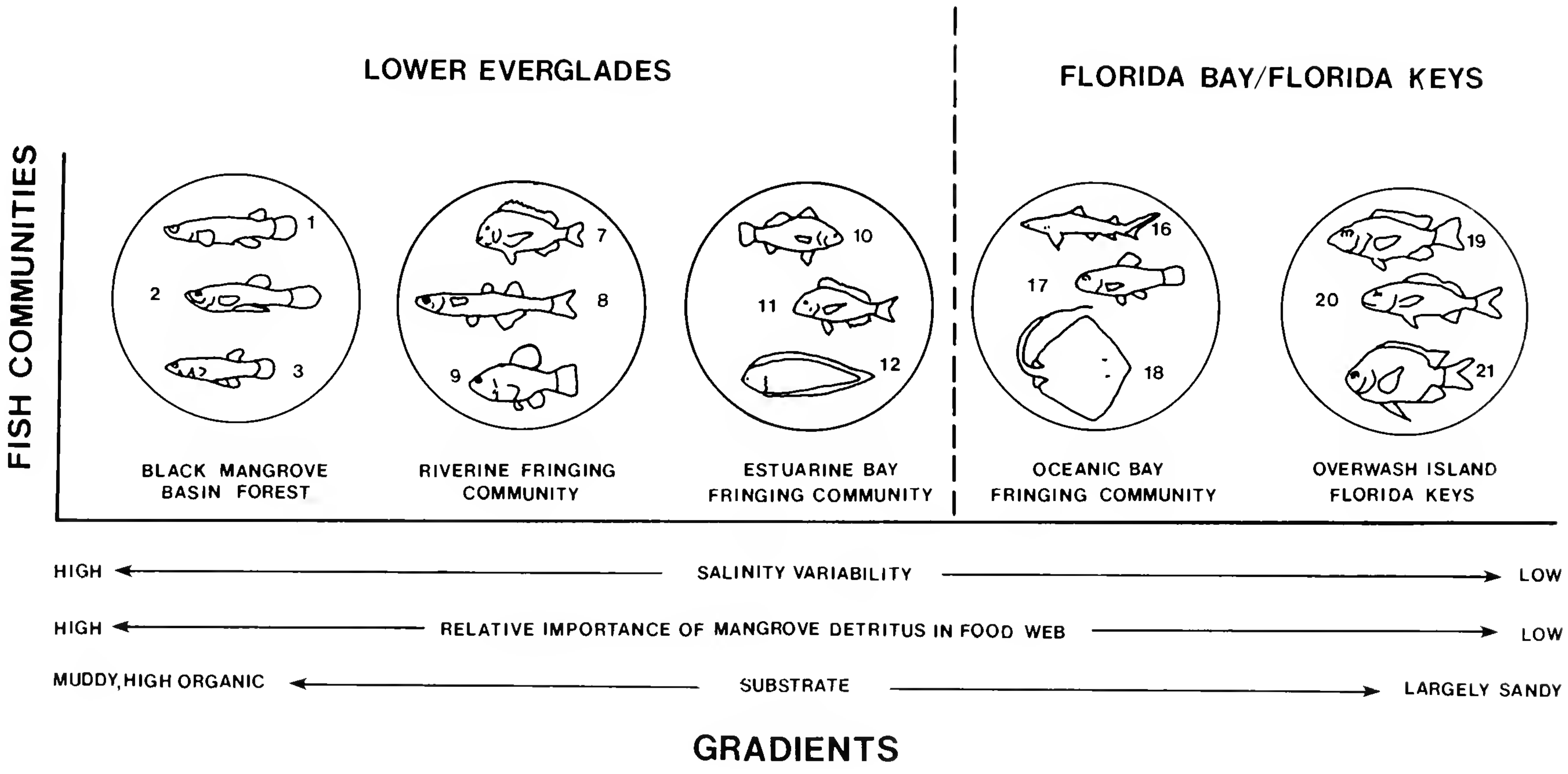
Sessile members of the prop root habitat occur in two zones, an upper zone dominated by barnacles and a lower zone dominated by mussels, oysters, and ascidians (Odum et al. 1982). In general, as tidal influence becomes less a factor, the barnacles become singularly dominant (Tabb et al. 1962). These authors identify a number of other conspicuous members of this habitat in Whitewater Bay, namely the xanthid crab Eurypanopeus depressus, the porcellanid crab Petrolisthes armatus, and the polychaete Neanthes succinea. The intertidal flats of the mangrove prop roots often support large numbers of fiddler crabs, Uca pugilator, U. speciosa, and U. thayeri, and burrows of the xanthid crab Eurytium limosum. In the lower salinity mangrove forests the crayfish Procambarus alleni and the crab Rhithropanopeus harrisii are common inhabitants (Odum and Heald 1972).

7.33 FISHES

Fishes of the estuarine and saltwater wetlands have been more frequently studied than invertebrates. In additon to the more familiar work of Tabb and Manning (1961), Tabb et al. (1962), and Odum (1971), a number of other studies also contribute to our knowledge of fishes in this zone. In an unpublished document Tabb (1966) reports on fishes in Whitewater Bay and its tributaries. Roessler (1968) reports and analyzes the occurrence of 102 species from 83 genera in the Buttonwood Canal. Clark (1971) examines factors influencing the abundance and distribution of fishes in Whitewater Bay, while Jannke (1971) focuses exclusively on Sciaenid fishes. Higman (1967) documents catch rates for three commercial sport fishes of the area in relation to environmental factors. A number of masters theses and other documents pertaining either to individual species or to fisheries in general also exist for this area. Houde (1971) presents a brief literature review and bibliography of the work performed prior to 1971. Moe (1972) summarizes information on the movement and migration patterns of south Florida fishes.

Odum et al. (1982) identify a series of three environmental gradients, (1) salinity, (2) dependence on mangrove detritus, and (3) substrate, along which mangrove related fish communities are organized. Figure 54 presents this gradient as it pertains to the present study area. Three of the delineations occur within the estuarine and saltwater wetlands zone while two occur within Florida Bay and the Florida Keys.

The black mangrove basin forest community occurs in the sheltered back water pools and salt marsh settings. Physical and chemical conditions here are often extreme due to infrequent flooding and darkly colored, highly organic and acidic waters. As in the harsh Everglades marsh environment, the



1) rivulus
2) mosquito fish
3) marsh killifish
4) lady fish
5) striped mullet
6) yellow fin mojarra
7) juvenile sheepshead
8) tidewater silverside
9) sheepshead minnow
10) silver perch
11) pig fish
12) blackcheek tongue fish
13) scrawled cowfish
14) fringed pipefish
15) fringed file fish
16) lemon shark
17) gold spotted killifish
18) southern stingray
19) juvenile schoolmaster
20) juvenile tomtate
21) juvenile sargent major

Figure 54. Continuum of mangrove environments and associated fish communities (adapted from Odum et al. 1982).

more prominent members of this fish community are the versatile cyprinodonts (killifishes) and Poeciliids (live bearers) (McPherson 1971, Odum et al. 1982).

Riverine forests, which generally connect the freshwater marshes with the open waters of the estuarine zones, are characterized by a fish community that seasonally oscillates in response to salinities, temperatures, migratory patterns, and runoff. During freshwater flooding the fauna often contains numerous Everglades marsh and slough species such as the Florida gar, sunfish, large mouth bass, and catfish. As flooding subsides, freshwater species retreat upstream and the fauna is gradually replaced by more marine species such as jewfish, stingrays, needlefish, and jacks. Temperature oscillations tend to cause some shallow water species to move out into more stable, deeper waters during the winter months (Odum et al. 1982).

The individual life history patterns of fish species also influence faunal composition in the riverine mangrove community. Seasonal movements offshore to spawn and subsequent larval and post larval recruitment are involved in the distribution and abundance patterns of mullet, grey snapper, sheepshead, spotted sea trout, red drum, silver perch, and many others.

The estuarine bay fringing community is characterized by large numbers of a relatively few species. Working in Whitewater Bay, Clark (1971) reports that two species, the silver jenny (Eucinostomus gula) and the pinfish (Lagodon rhomboides), constitute 62.7% of the total catch. Odum et al. (1982) divide this fish community into two parts, a benthic habitat dominated by the drums, mojarras, and snappers, and a mid to upper water habitat dominated by anchovies, herrings, and needlefishes.

At least three of the studies on estuarine fishes of the area have attempted to correlate physical, chemical, and biological conditions to fish abundance. Though often touted as a "factor" in determining estuarine animal abundance, salinity seldom exhibits any clear cut influence on fish catches in the present study area (Roessler 1968, Jannke 1971). This is probably due to the fact that salinity itself is a simple response to the freshwater runoff of the watershed rather than a causal factor in fish reproductive physiology. Causal factors are perhaps better approximated by Roessler's findings that catch rates are most often correlated with season and rainfall and that temperature often interacts with season and rainfall to affect catches.

Clark (1971) reports definite patterns of seasonal abundance in many fishes. He attributes most of this seasonality to the classical model of fish utilization of estuaries; that is, spawning offshore leading to a peak influx of juveniles at one time of the year and later in the year another peak corresponding to a spawning run back offshore. He concludes that correlations between catch rates and environmental variables are often a function of specific life histories rather than gross evnironmental parameters such as salinity.

In general, many of the estuarine fish species exhibit a pattern of juvenile distribution in the upper estuaries, and later as adults they gradually shift downstream and eventually spawn offshore. Clark (1971) suggests that the generally high metabolic rate of juveniles and consequently their greater osmoregulatory capabilities is an important factor in maintaining this distribution. It seems likely that this is also an important mechanism for insuring larval protection and survival. Maintaining an optimum areal coverage of oscillating salinity habitat therefore seems most critical to maintenance of estuarine fish production (Browder and Moore 1980).

If this oscillating salinity zone is the major "production" area of the estuary (Browder and Moore 1980), some changes in fish production capacity of the study area are imminent. Recall that mean salinities have been rising in Whitewater Bay due to upstream watershed modification, thus reducing the range and availability of this production zone.

Signs of such changes have, in fact, already been documented. They include a general decline in fishery harvests during recent years (Everglades National Park 1979) and shifts in population structure and abundance of key sport fishes (Davis 1980). According to Davis (1980) at least three significant changes have occurred in fisheries of the area during the past 20 years:

(1) age structure shifts in red drum and spotted sea trout toward larger, more mature individuals;
(2) catch rates have consistently risen for red drum and fallen for spotted sea trout;
(3) year to year variability in catch rates for both species has been markedly reduced.

These changes presumably result from a combination of (1) rainfall shortages; rainfall has been below normal for 16 of the last 20 years in south Florida, and (2) upstream water diversion; the watershed has been reduced from 22,500 km^2 (8,688 mi^2) to approximately 2,059 km^2 (795 mi^2) (Davis and Hilsenbeck, 1974).

Table 31 presents a compilation of the data of Clark (1971) and Jannke (1971) with regard to spawning times of estuarine fish that are believed to follow the general model of offshore spawning by adults with subsequent migration by larvae to estuarine waters. No doubt the data are incomplete and preliminary, but they do present a framework for generating some healthy speculation on the potential effects of changing physical/chemical conditions.

7.34 AMPHIBIANS AND REPTILES

Odum et al. (1982) list 24 species of amphibians and reptiles from the Florida mangrove zone, considerably less than the 65 species listed by SFRC (1980) for the terrestrial and freshwater wetlands. All the species that occur in the mangrove zone are also reported from other, upland habitats.

Using five trophic delineations (herbivore, omnivore, primary, middle, and higher carnivore), the amphibians and reptiles of the mangrove zone fall into an interesting pattern (Table 32). The predominantly water based group is more or less trophically restricted to the lower end, receiving nourishment from vegetation, benthic mollusks and invertebrates, or a combination thereof. Among those more dependent on land or wetland, trophic structuring is clearly restricted to the primary, middle, and higher carnivore levels. Insects, small mammals, birds, and fish form the bulk of these species' diets.

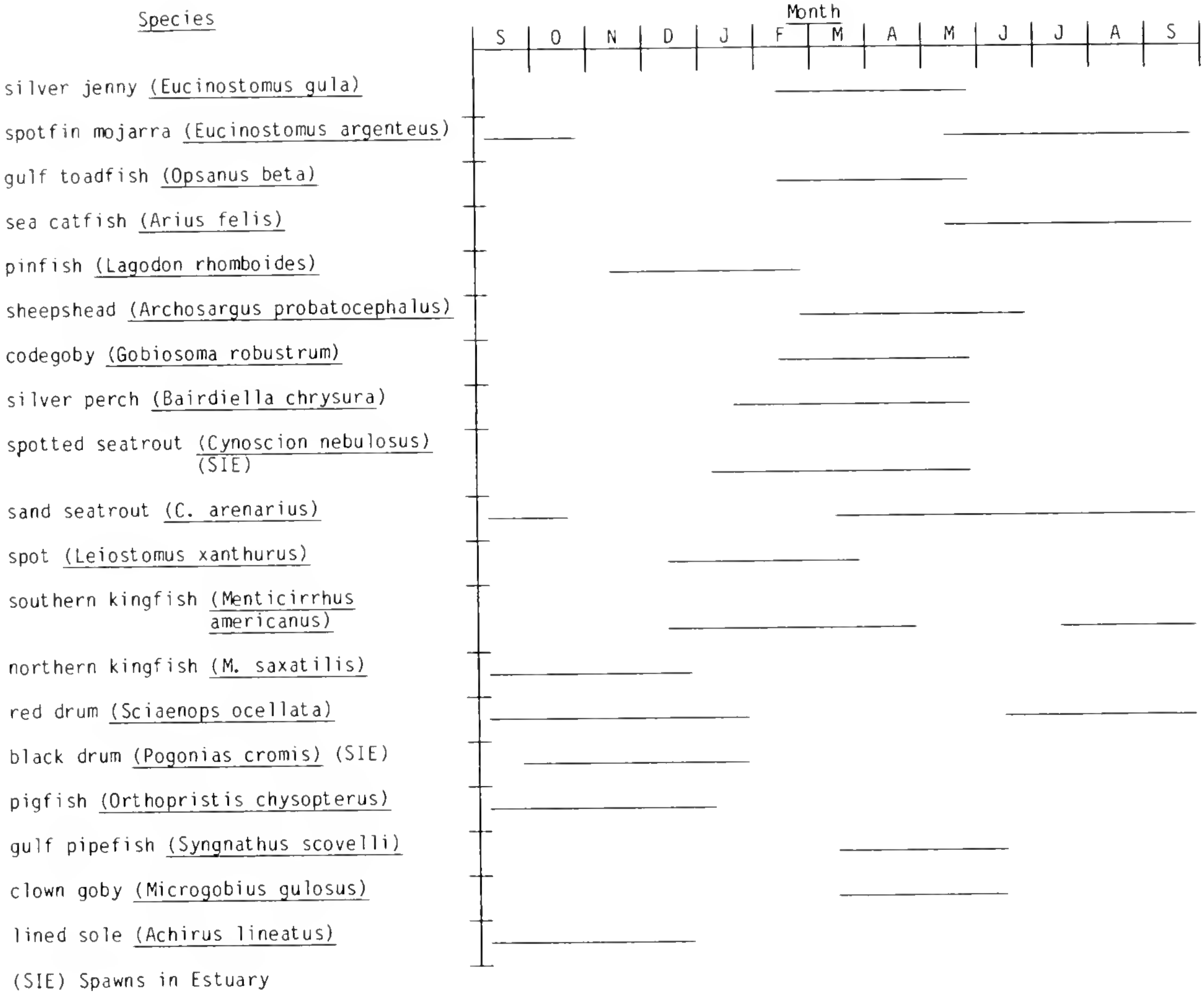


Table 31. Reported spawning seasons of migratory estuarine fishes in Whitewater Bay (adapted from Clark 1971 and Jannke 1971).

	Herbivores	Omnivores	Primary Carnivores	Middle Carnivores	Higher Carnivores
Water Based	Red Bellied Turtle Green Turtle	Striped Mud Turtle Chicken Turtle Hawksbill Turtle	Mud Turtle Ornate Terrapin Loggerhead Turtle Atlantic Ridley Turtle Florida Softshell Turtle		Alligator Crocodile
Upland/ Wetland Based			Green Anole Cuban Brown Anole Bahama Bank Anole Striped Sun Snake Giant Toad Squirrel Treefrog Cuban Treefrog	Eastern Cottonmouth Eastern Indigo Green Water Snake Mangrove Water Snake	

Table 32. Trophic relations of amphibians and reptiles in the mangrove zone.

Four of the species listed in Table 32 are considered endangered in Florida, the green turtle (*Chelonia mydas*), the Atlantic hawksbill (*Eretomochelys imbricata imbricata*), the Atlantic ridley (*Lepidochelys kempii*), and the American crocodile (*Crocodylus acutus*) (McDiarmid 1978). The Atlantic loggerhead (*Caretta caretta caretta*) and the mangrove (ornate water) terrapin (*Malaclemys terrapin rhizophorarum*) are considered threatened. The American alligator (*Alligator mississippiensis*) and eastern indigo snake (*Drymarchon corais couperi*) are considered species of special concern.

7.35 BIRDS

Odum et al. (1982) list 181 species of birds utilizing the mangrove zone throughout south Florida. These authors divide the avifauna into six convenient categories based on feeding habits. These categories are wading birds, probing shorebirds, floating and diving water birds, aerially searching birds, birds of prey, and arboreal birds.

Of all categories, the wading birds, the aerially searching birds (terns, gulls, black skimmer, fish crow), and floating and diving water birds are the most conspicuous. The most abundant wading bird in the mangrove zone of the lower Everglades is the Louisiana heron (Kushlan and White 1977, Kushlan 1979). The double crested cormorant, an almost exclusive estuarine resident, and the snowy egret are next in numerical importance. The white ibis and the wood stork utilize the mangrove zone less frequently (for nesting at least) than the above species.

Studies conducted on these latter two species offer insight into regional patterns of resource partitioning between two of many species that seemingly compete for a common resource. Nesting success in the wood stork has been shown to be heavily dependent on the timing and rate of seasonally declining water levels, whereas the white ibis is capable of exploiting both rising and declining water level situations (Kushlan 1979). The white ibis is relatively more nomadic than the wood stork, being inclined to move more often in search of suitable foraging grounds and at different times of the year. Both white ibis and wood storks use the mangrove zone extensively for foraging, especially during their nesting seasons. The two differ, however, in the time of mating, in feeding strategies, and in prey selectivity. The wood stork nests from December through March while white ibis nesting is highly variable between March and December (Kushlan 1979, Odum et al. 1982). The wood stork is a tactile feeder relying heavily on touch as it gropes, rather nonselectively, through heavy vegetation for its prey (Kahl 1964). The white ibis is also primarily a tactile prober but does occasionally use sight, especially on land. While wood storks tend to nest and feed when and where prey concentrations peak, white ibis substitute a more general use of a number of high energy habitats. The relative size of the ibis and the presence of other species willing and capable of robbing larger prey generally limit the size of prey consumed. Herons, egrets, and grackles often steal larger prey from white ibis. Consequently, white ibis generally subsist on small prey which can be swallowed quickly. In the mangrove zone during nesting, ibis tend to selectively take small frogs, anoles, crayfish, and water bugs in addition to small fish; they generally move to the coastal swamps during the summer. In general terms of resource partitioning, white ibis are more mobile and flexible than wood storks in their nesting and foraging habitats and requirements, but both are nonetheless dependent on seasonal water level fluctuations.

Unfortunately this comparison is both very incomplete and includes only two of many wading birds apparently utilizing the same resource. No doubt a fascinating mosaic of resource partitioning exists among the variety of species exhibiting superficially similar "niches". The general trend in nesting of wading birds is to utilize the freshwater wetlands during wet years but to fall back on the more stable productivity of the mangrove zone during dry years (Odum et al. 1982).

Of the 25 species of probing shorebirds that are reported from the mangrove zone only two, the willet and the clapper rail, are year round residents. The clapper rail and black necked stilt breed in the mangrove zone while the remaining 22 species are transients (Odum et al. 1982). In general, the mangrove zone is limited in its availability of suitable habitat for these birds; they prefer a variety of more open habitats such as marshes and sandy beaches.

Surface and diving birds of the mangrove zone include 19 species of ducks, 2 grebes, 1 loon, 2 cormorants, 3 gallinules, and 2 pelicans. Table 33 summarizes the feeding habits of some of these birds.

Many of these birds are permanent residents that feed as well as nest in the mangrove zone. However, exclusive use of mangroves by this guild of birds is not the rule. The anhinga prefers freshwater habitats, while almost all of the other birds utilize either the offshore or interior wetlands as well as the estuaries (Odum et al. 1982).

Herbivorous	Piscivorous	Benthic mollusks, invertebrates, & plants
Pintail *Anas acuta*)	Double-crested cormorant (*Phalacrocorax auritus*)	Scaup (*Aythya affinis*)
Mallard (*Anas platyrhynchos*)	Anhinga (*Anhinga anhinga*)	Canvasback (*Aythya valisineria*)
Widgeon (*Anas americana*)	Brown pelican (*Pelicanus occidentalis*)	Redhead (*Aythya americana*)
Mittled Duck (*Anas fulvigula*)	White pelican (*Pelicanus occidentalis*)	Gallinules (*Gallinula chloropus*)
Green wing Teal (*Anas crecca*)	Merganser (*Mergus serrator*)	
Blue wing Teal *Anas discors*)		

Table 33. Trophic relations of surface and diving birds in the mangrove zone.

Aerially searching birds include 11 species of gulls and terns, the black skimmer, the belted kingfisher, and the fishcrow. Owing to their generally similar modes of feeding and food sources, most of these birds are in the primary to middle carnivore range. The gulls tend to eat more of a variety of prey, including insects, snails, crabs, and fish, while the terns and others rather exclusively dine on small fish (Sprunt 1954, Odum et al. 1982). Nesting colonies of these species in Florida are generally restricted to the more open mangrove keys and islands of Florida Bay and the Florida Keys.

Birds of prey reported from the Florida mangrove zone number 18, though not all are permanent residents. Of these, 7 are considered mangrove dependent based on their food habits. Osprey, bald eagle, and the magnificent frigate bird rely heavily on a fish diet, while the peregrine falcon and the merlin are known to take shore birds as prey. The marsh hawk is also included in this water based group. The remaining 11 species, including the swallow tailed kite, 7 hawks, and 3 owls, often use the mangrove zone along with many other upland habitats.

The 71 species of arboreal birds listed by Odum et al. (1982) as occurring in the mangrove zone rely rather exclusively on the uplands, swamps, and canopy cover for both food and habitat. Trophically, these birds are distributed into 3 categories, 4 species of herbivores, 10 species of omnivores, and 57 species of primary carnivores, mainly insectivores.

Table 34 from Kale (1978) lists 40 species of birds that utilize the Florida mangrove habitat that are endangered, threatened, rare, of special concern, or of undetermined status. The 95% reduction in the number of wading birds is well expressed here; none of them have been spared from the list.

7.36 MAMMALS

Odum et al. (1982) list only 20 species of mammals from the Florida mangrove zone as compared to 28 from the terrestrial and freshwater wetlands (SFRC 1980). The latter authors list only 9 mammals occurring in the scrub mangroves along northeast Florida Bay, 5 of which (3 bats, the cotton mouse, and the hispid cotton rat) are not included by Odum et al. (1982) for a total overlap of only 4 species. Table 35 is a trophic category listing of the 20 mammal species listed by Odum et al. (1982).

Of the strict herbivores, one subspecies, the key deer (Odocoileus virginianus clavium) is considered endangered but is limited to the Florida Keys. The mangrove fox squirrel (Sciurus niger avicennia) is also considered endangered and the West Indian manatee (Trichechus manatus latirostris) is considered threatened.

Endangered
Wood stork
(Mycteria americana)
Everglade Kite
(Rostrhamus sociabilis plumbeus)
Peregrine Falcon
(Falco peregrinus)
Snowy Plover
(Charadrius alexandrinus tenuirostris)
Cape Sable Sparrow
(Ammospiza maritima mirabilis)

Threatened
Brown Pelican
(Pelecanus occidentalis carolinensis)
Magnificent Frigate Bird
(Frigata magnificens)
Bald Eagle
(Haliaeetus leucocephalus leucocephalus)
Osprey
(Pandion hallaetus carolinensis)
American Oyster Catcher
(Haematopus palliatus)
Roseate Tern
(Sterna dougallii)

Rare
Reddish Egret
(Dichromanassa rufescens)
Roseate Spoonbill
(Ajaia ajaja)
Mangrove Cuckoo
(Coccyzus minor)
Antillean Nighthawk
(Chordeiles minor vicinus)
Black Whiskered Vireo
(Vireo altiloquus)
Cuban Yellow Warbler
Dendroica petechia gundlachi)
Louisiana Water Thrush
(Seiurus motacilla)

Species of Special Concern
Great White Heron
(Ardea herodius occidenta)
Little Blue Heron
(Florida caerulea)
Great Egret
(Casmerodius albus)
Snowy Egret
(Egretta thula)
Louisiana Heron
Hydranassa tricolor)
Black Crowned Night Heron
(Nycticorax nycticorax)
Yellow Crowned Night Heron
(Nyctanassa violacea)
Least Bittern
(Ixobrychus exilis exilis)
Glossy Ibis
(Plegadis falcinellus falcinellus)
White Ibis
(Eudocimus albus)
Coopers Hawk
(Accipiter cooperii)
Piping Plover
(Charadrius melodus)
American Avocet
(Recurvirostra americana)
Sooty Tern
(Sterna fuscata)
Royal Tern
(Sterna maxima)
Sandwich Tern
(Sterna sandvicensis)
Noddy Tern
(Anous stolidus)
Florida Prairie Warbler
(Dendroica discolor paludicola)

Status Undetermined
Merlin
(Falco columbarius)
Florida Clapper Rail
(Rallus longirostris scottii)
Mangrove Clapper Rail
(Rallus longirostris insularum)
Black Rail
(Laterallus jamaicensis)

Table 34. Endangered, threatened, or rare bird species, and species of special concern that utilize the mangrove zone (adapted from Kale 1978).

The mangrove fox squirrel occurs in other terrestrial habitats than mangroves, such as mature pinelands, dry cypress strands, and tropical hammocks. In the early 1900's, this squirrel was known from the present study area but is now believed restricted to the northwestern fringes of the watershed (Brown 1978). Seeds of slash pine are preferred foods but the nuts, fruits, and buds of many other species are also taken.

According to Hartman (1978) manatees migrate between favored habitats around Florida in response

	Herbivores	Omnivores	Primary Carnivores	Middle & Higher Carnivores
Water Based	Manatee			Porpoise
				River otter
				Raccoon
Upland/ Wetland Based	Gray squirrel	Opossum	Shorttail shrew	Gray fox
	Fox squirrel	Cotton rat		Mink
	Key deer	Black rat		Skunk
	Whitetailed deer	Rice rat		Panther
	Marsh rabbit	Black bear		Bobcat

Table 35. Trophic relations of mammals in the mangrove zone.

to cold. Warm waters of estuaries of the southwest coast offer a winter refuge for these cold sensitive mammals. A diversity of vegetation types, many of which are abundant locally such as turtle grass (*Thallasia*), widgeon grass (*Ruppia*), shoal grass (*Halodule*), and manatee grass (*Syringodium*) are preferred diet.

CHAPTER 8
FLORIDA BAY AND MANGROVE ISLANDS

8.1 PREVIOUS LITERATURE REVIEWS AND SYNTHESES

In addition to the recent work of Odum et al. (1982), Zieman (1982) has summarized the existing literature on another major ecological component of the south Florida coast in a document entitled A Community Profile: The Ecology of the Seagrass Community in South Florida. In this document the author draws, in part, from the same information as the present report. As in the mangrove zone, it would be redundant for us to summarize the same information. Consequently the following discussion focuses on ecological elements not included in the above documents and on information which is specific to the study area. For a complete review of seagrass ecology, the Zieman (1982) document is strongly recommended.

8.2 HABITAT ZONATION

As described previously, Florida Bay is a shallow body of water characterized by an anastomosing series of carbonate mud banks, or shoals. These shoals are quite often covered with a rich growth of sea grasses, primarily turtle grass (Thalassia testudinum) with some shoal grass (Halodule wrightii) and manatee grass (Syringodium filiforme) (Hudson et al. 1970). The pinnacles of the shoals are usually vegetated by mangroves and other salt tolerant shrubs and herbs such as saltwort (Batis maritima), glasswort (Salicornia perennis), sea oxeye (Borrichia frutescens), and key grass (Monanthochloe littoralis) (Davis 1940). These "flats" also support a healthy growth of calcareous blue-green algae. The shoals generally surround deeper, open water areas (lakes) which are covered by a relatively thin veneer of lime muds over a rock hardened limestone substrate.

Although no one has documented the actual composition and distribution of submerged vegetation in Florida Bay, numerous species of green, red, and blue-green algae are known to inhabit the area (Ginsburg 1956, Stockman et al. 1967, Ginsburg et al. 1972, Woelkerling 1976). Most prominent among these are the green algae Penicillus sp., Rhipocephelus sp., Udotea sp., Halimeda sp. and Acetabularia sp. Blue-greens, particularly Schizothrix and Oscillatoria are most often associated with intertidal flats and extreme shallows (Ginsburg et al. 1972). The red alga Molebesia sp. is reported as often virtually covering the blades of Thalassia with a thin fragile crust (Stockman et al. 1967).

Tabb et al. (1962) describe two general growth forms of Thalassia in northern Florida Bay; (1) a stunted and sparse growth of plants 31 to 91 cm (1 to 3 feet) tall in the shallows just off of Flamingo in highly turbid waters; and (2) tall dense stands east of Flamingo and south of Cape Sable in the Sandy Key Basin. Unfortunately, these are the only two areas they studied. Assuming that turbidity (and probably hypersalinity) are at least in part responsible for the stunted growth, it is likely that much of the interior bay would exhibit a similar mixture of forms.

In lieu of vegetationally defined habitats, Turney and Perkins

(1972) offer the best alternative, an empirical zonation based on a quantitative analysis of molluskan faunal composition. Delineation of these zones was presented earlier in Chapter 5.6. Salinity, temperature, and other environmental conditions of these four subenvironments are summarized in Table 36 along with the molluskan composition. A map of these zones was presented earlier in Figure 38.

8.3 HABITAT PARTITIONING FOR FISH AND WILDLIFE PRODUCTION

8.31 ENERGY FLOW

The environment in Florida Bay is a unique combination of saline to hypersaline physical/chemical conditions harboring a luxuriant growth of sea grasses and calcareous algae. Although some work has been conducted on the productivity of algae, it was not done from an ecological point of view but rather as an estimate of contributions of calcareous algae to the lime mud sediments of the bay (Stockman et al. 1967).

Recently Zieman (1982) suggested three major pathways by which seagrasses influence fish and wildlife productivity:

(1) internal productivity of resident species biomass;
(2) productivity by virtue of their association with nearby communities such as coral reefs, mangroves, and the continental shelf; and
(3) through the export of seagrass detritus.

Incorporating these basic considerations within the context of the Florida Bay environment, Figure 55 is presented as a general model of fish and wildlife production in the bay. Internal productivity of resident biomass is limited to the primary producing substrates, largely dominated by seagrasses, and the resident primary and secondary consumers as indicated. These are divided into the intertidal and above group (insects of the mangrove islands, fiddler crabs and the like) and below the intertidal group, including herbivores (shellfish, sea turtles, polychaetes, and herbivorous fish such as mullet) and middle consumers (pinfish, conchs, and croakers).

Composition of the top predator component (and to some degree the other components) is shown as being gradational depending on proximity to the respective associated communities. In the northern bay it is likely that faunal composition is at least periodically influenced by species characteristic of the mainland mangroves. Although not as well flushed as upper parts of Whitewater Bay, northern Florida Bay is subject to a similar cycle of rainfall and runoff. The quantities of runoff, nutrient loadings, and salinity and temperature extremes are no doubt different in Florida Bay than along the southwest coast; however, the effects of these and other influencing factors on the productivity and faunal composition of upper Florida Bay remains largely unknown.

Where the bay interfaces with the moderating influences of the Gulf of Mexico and the Atlantic, it is likely that faunal composition of transient consumers reflects the respective environments. Toward the south, reef dwellers are likely to wander into the lagoonal environment for feeding purposes and may even find protection in the crevices of some limestone outcroppings. In general, many of the more strictly marine forms are probably limited in

	Northern Subenvironment	Atlantic Subenvironment	Interior Subenvironment	Gulf Subenvironment
Circulation Salinity	Salinity range: 13-48%. Temp range 15°-38°C. Restricted circulation--little affected by tidal exchange. Subject to irregular influx of fresh water from mainland.	Approximate salinity range: 35-41%. Approximate Temp. range 17°-32°C. Open circulation with daily tidal flushing.	Salinity range: 22-52%. Temp. range 15°-38°C. Restricted circulation--little affected by tidal exchange. Not subject to daily fluctuations, but wet years produce low salinity, dry years produce high salinity.	Near-normal marine salinity, but mixing of waters with Gulf of Mexico probably slow because of position in wind and current "shadow"
Type of Bottom	Banks: Mud. Most Lakes: Sandy mud. Deeper Lakes: Rocky with veneer of muddy sand. Rarely points of keys are clean sand. Near-shore mud sometimes very peaty.	Highly variable: Banks Banks and lakes can be either mud, clean sand, or mixtures, depending on local variation. Deepest lakes are rocky with veneer of muddy or clean sand.	Banks: Mud. Most Lakes: Sandy mud. Deeper Lakes: Rocky with veneer of muddy sand. Occassional beaches and windward (eastern) points of bank are sand or muddy sand.	Highly variable: Banks and lakes can be either mud, clean sand, or mixtures, depending on local variation. Deepest lakes are rocky with veneer of muddy or clean sand.
Grass	Banks usually carpeted with Thalassia and/or Cymodocea - some Halodule. Lakes with heavy to sparse cover of Thalassia and/or Cymodocea.	Highly variable in banks, lakes, and passes--usually with sparse to heavy Thalassia - rare Cymodocea.	Banks usually carpeted with Thalassia. Rare Cymodocea and Halodule. Lakes usually with sparse, but occasionally heavy, Thalassia.	Highly variable in banks, lakes, and passes--usually with sparse to heavy Thalassia - rare Cymodocea.
Algae	Rare Batophora. Rare Penicillus and Acetabularia on margins.	Abundant Halimeda and Penicillus. Common Udotea. Few Rhipocephalus, Acetabularia, and Caulerpa. Rare Batophora, Dasycladus, and Avrainvillea.	Penicillus and Batophora common. Few Acetabularia. Rare Halimeda and Udotea on margins.	Abundant Halimeda and Penicillus. Common Udotea. Few Caulerpa. Rare Rhipochephalus, Acetabularia, Batophora, Dasycladus, and Avrainvillea.
Coral	Absent.	Abundant Porites furcata. Common Siderastrea and Alcyonaria. Few Solenastrea.	Very rare Siderastrea. Rare Porites, Solenastrea, and Alcyonaria near margins.	Common Porites furcata. Rare Alcyonaria and Solenastrea.
Mollusks:				
Characteristic Species	Anomalocardia cuniemeris	Codakia orbicularis, Tegula fasciata, Astrea longispina, Astrea americana. Cerithium literatum	Brachidontes exustus Pinctada radiata Cerithium muscarum Bittium varium	Nucula proxima Noculana acuta Tellina similis Corbula sp.
Species More Common Here Than Elsewhere	Ostrea sp., Parastarte triquetra, Lyonsia floridana, Rissoina browniana, Melongena corona, Retusa canaliculata.	Barbatia cancellaria, Glycymeris pectinata, Lucina pensylvanica, Codakia orbiculata, Trigoniocardia medium, Laevicardium laevigatum, Chione pygmaea, Acmaea sp., Tricolia sp., Vermicularia sp., Cerithium eburneum, Malenella sp., Natica carena, Columbella mercatoria, Terebra sp.	Lucina multilineata, Rissoina bryerea, Modulus modulus, Olivella sp.	Noetia ponderosa, Cardita floridana, Phacoidea nassula, Anodontia philippiana, Trachycardium muricatum, Tellina alternata, Mactra fragilis, Barnea costata, Dentalium sp.,Calliostoma jujubinum, Turbo castaneus, Anachis obsea, Mangelia, sp.

Table 36. Physical, chemical, and biological conditions in subenvironments of Florida Bay (adapted from Turney and Perkins 1972).

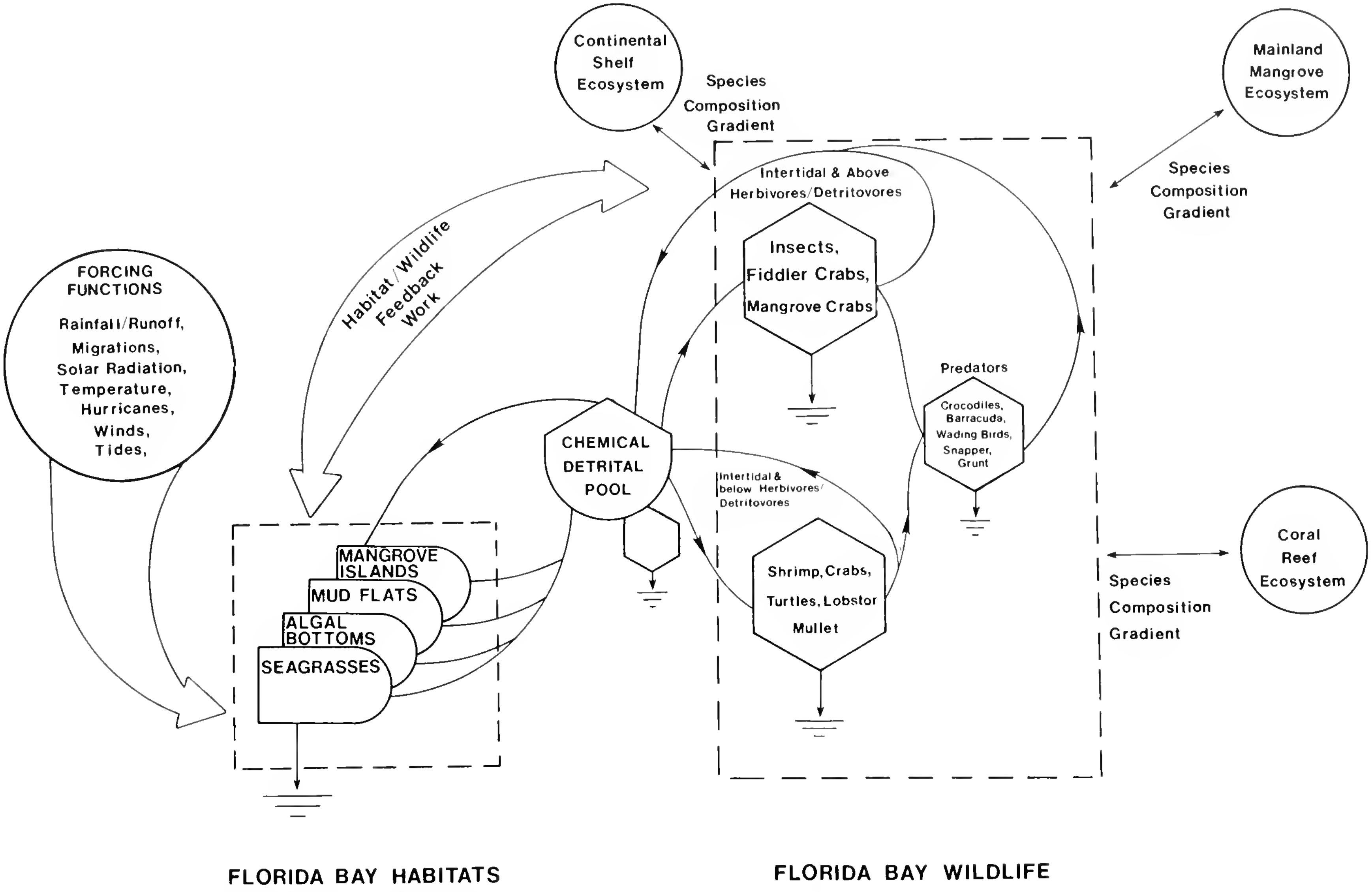


Figure 55. Summary diagram of energy flow through the Florida Bay/mangrove island ecosystem.

their use of the bay by the availability of protective habitat, depth, turbidity, or salinity and temperature extremes.

Seagrass detritus from Florida Bay is exported either across the coral reef tract or to the gulf continental shelf. The exchange of sediments and detritus between the Keys and Florida Bay is discussed below with the Florida Keys ecosystem.

8.32 INVERTEBRATES

Only a few groups of invertebrates have been extensively studied in Florida Bay, namely the mollusks (Turney and Perkins 1972), the foraminifera (Moore 1957, Rose and Lidz 1977), and the insects (Simberloff and Wilson 1969, Simberloff 1976). Tabb and Manning (1961) and Tabb et al. (1962) present data on selected invertebrates near Flamingo, and Hudson et al. (1970) present a list of species collected from a lake setting near central Florida Bay. In all, Turney and Perkins (1972) identify 140 molluskan species from 100 genera in Florida Bay. Species characteristic of the four major subenvironments appear in Table 36. In addition to these rather characteristic faunal assemblages, a vast portion of the west central bay exhibits a transitional fauna intermediate in composition between major subenvironments.

Some localized faunal variation was noted between lake and mud bank environments in the interior subenvironment, but not in the Gulf or Atlantic. Throughout the bay, certain shallow water and intertidal mollusks were not generally found on mud banks awash at low tides unless the banks were close to dry land. Hudson et al. (1970), working in central Florida Bay, report that several invertebrates exhibited a discontinuous distribution over the superficially homogeneous substrate of a single lake basin.

Curiously, nearly 40% of the molluskan species reported by Tabb et al. (1962) in northwestern Florida Bay were not reported by Turney and Perkins (1972). It is suspected that taxonomic inconsistency is the reason for this puzzling fact, but this is not the only possibility. Tabb et al. (1962) report only about 15% overlap in species from the Florida Bay study area and nearby Biscayne Bay.

Consistent with the hypothesis of a broadly gradational fauna in Florida Bay, Hudson et al. (1970), report three invertebrate species, the nobby star coral (Solenastrea hyades), the long spined sea urchin (Diadema antillarum), and the spiny lobster (Panulirus argus), inhabiting the channels between the lakes rather than the seagrasses. These species, along with fishes such as the school master (Lutjanus apodus) and the sargent majors (Abudefduf saxatilis), are generally found in Atlantic waters but not along the gulf coast.

Of primary importance to commercial interests is the role of seagrasses in Florida Bay to shrimping in south Florida waters. A significant research effort over a number of years has shown that Florida Bay and Whitewater Bay serve as nursery grounds for pink shrimp (Penaeus duorarum) before they move to the Tortugas shrimping grounds northwest of Key West. This information is summarized in Section 9.32.

Foraminifera in Florida Bay are characteristic of a circulation restricted, carbonate bay that is unique to the Florida-Bahama platform environment (Rose and Lidz 1977). In general, foram species associations can be delinated based on topographic variations such as basins, mud banks, and shorelines.

Thirty-two (32) species of crustaceans are reported by Tabb et al. (1962) from three environments in northwest Florida Bay. The intertidal environment is characterized by the fiddler crabs Uca sp., the isopod Ligia boudiniana, and the barnacle Balanus amphitrite niveus. In all, 10 species were recorded from this environment. Of the 18 crustaceans reported from the turtle grass environment, at least 3 were also collected on the hard shell and sand bottoms. Among the more noteworthy species were the hermit crabs Pagurid sp., the stone crab Menippe mercenaria, and the pink shrimp Penaeus duorarum.

As a consequence of a unique experiment in island biogeography, much has been learned of the insects of Florida Bay mangrove islands (Simberloff 1969, 1972, 1974, 1976; Simberloff and Wilson 1969, Wilson and Simberloff 1969). Several small islands were defaunated by fumigating with methyl bromide (Wilson and Simberloff 1969), thus killing (and allowing for easy censusing of most of) the insect fauna. Subsequent recolonization of the islands by insects was monitored for several years.

One particularly interesting observation was on the composition of the intertidal habitats. The intermittently submerged mud banks surrounding the island support a rather unique mixture of invertebrates that have little interaction with the island community other than through a few generalists such as the earwig Labidura riparia, the mangrove tree crab Aratus pisonii, and possibly the tree snail Littorina angulifera. The insect and other inhabitants of the often exposed mud banks are primarily marine, living off of seaweed, detritus, and each other.

Based on pre and post fumigation censuses, Simerloff describes the composition of the arboreal insect fauna of these islands as being in a state of dynamic equilibrium. This equilibrium is largely a function of physical factors such as distance from the mainland, and island size (Simberloff 1976). Colonization of islands by wasps, spiders, and psocopterans (Corrodentia) occurs fairly soon after defaunation (depending on distance and size) but is generally quite variable. This group tends to arrive early and extinguish fairly rapidly, although some wasps and spiders persist for many months. Ants, thrips, and lepidopterans, on the other hand, exhibit a relatively more ordered colonization scheme. Rather predictably, thrips tend to invade 4 to 5 months after defaunation and persist for extended periods, while the lepidopterans and ants are even more systematic. Invasions of species of the latter two groups often follow a rather distinctive successional pattern. The ants are considered numerically and energetically the dominant animals on the mangrove islands.

In all, 351 species of insects have been recorded from these mangrove islands (Simberloff 1976); the same author estimates that as many as 500 species commonly inhabit the larger Florida Keys with as many as 4,000+ species in all the Keys.

8.33 FISHES

Zieman (1982) divides the fishes utilizing seagrasses into three categories: permanent residents, seasonal residents, and occasional migrants. Permanent residents are typically small and inconspicuously matched to the seagrass background. Among the more noteworthy are the emerald clingfish (Acytrops beryllina), and the pipefishes and sea horses (family Syngnathidae). The inshore lizard fish (Synodus foetens) and the pinfish (Lagodon rhomboides) are also commonly found in Florida Bay grass beds.

Seasonal residents in grass beds generally spend their juvenile or sub-adult stage in this habitat, utilizing it as a nursery ground. Among the more common seasonal residents are spotted sea trout (Cynoscion nebulosus), spot (Leiostomus xanthurus), silver perch (Bairdella chrysura), and pigfish (Orthopristis chrysopterus). Generally the snappers and grunts prefer clearer waters and most likely occur in greatest numbers closest to the Florida Keys.

The occasional migrants include large carnivores from offshore that only rarely visit the grassbeds. Tabb and Manning (1961) present the most site specific listing of fishes from Florida Bay, although spatial coverage of their data is restricted. Schmidt (1976) presents quantitative fish inventories from a number of stations in western Florida Bay.

Although it has not been extensively documented, the fish found along the northern fringes of Florida Bay probably reflect a relatively greater mangrove influence than toward the Keys or the gulf. The euryhaline marsh and mangrove pond species such as the Poeciliids (sailfin molly, mosquito fish) and the Cyprinodonts (killifishes) are most commonly present if only on a seasonal basis. Judging from the prevalence of nesting wading birds utilizing northern Florida Bay, the area is most certainly rich in the fish, shellfish, and insects upon which they depend. Tabb and Manning (1961) report many of these mangrove related fish species occurring along the fringes of northern Florida Bay. Consistent with this gradational hypothesis, Hudson et al. (1970) report 64 species of fishes from a basin in central Florida Bay, many of which are mainland mangrove associates, and many of which are not reported by Tabb and Manning (1961).

Schmidt (1976) reports 109 species of fish from 8 western Florida Bay stations compared to 106 species reported by Tabb and Manning (1961). Of these two totals, 16 from Tabb and Manning (1961) were not reported by Schmidt (1976), and 19 from Schmidt were not reported by Tabb and Manning. Schmidt (1976) reports that anchovies (Anchoa mitchelli and A. hepsetus), pinfish, and southern stingray (Dasyatis americana) were most abundant in western Florida Bay. Seasonally, 68% more biomass was reported during the wet season than during dry periods.

8.34 AMPHIBIANS AND REPTILES

In addition to the habitat it offers to nesting wading birds, upper Florida Bay is also habitat for the endangered American crocodile (Crocodylus acutus). This large reptile (up to 4.6 m or 15 ft) ranges throughout the Caribbean, along the southern coasts of Mexico and Central America, and the northern tip of South America. Crocodiles in Florida Bay are a disjunct population at the extreme northern edge of the species range.

According to Ogden (1978), nest preparation begins during April with females digging or redigging sand or soil nest mounds approximately 6.1 m (20 ft) in diameter and 0.6 m (2 ft) high. The same nest mound may be used in consecutive years and one or more alternate mounds may also be maintained. About half of the nests fail to hatch by late July or early August, presumably due to egg predation or low temperature stress.

Some controversy exists over whether juvenile American crocodiles, like their close relatives, require fresh or brackish water conditions for optimum growth and survival (National Fish & Wildlife Laboratory 1980). Recently Dunson (1980) has shown that young crocs lose about 1.7% body weight per day when placed in full sea water. He observes that this loss may be compensated for by two mechanisms:

(1) young crocs spend a great deal of their time in moist, cool terrestrial environments such as crab holes, wave cut crevices, and mangrove roots; body weight loss is less under these conditions; and

(2) feeding on fish and invertebrates which are high in water and low in sodium.

Rates of weight loss under these same conditions decrease rapidly with size of the animal.

Adult crocodiles feed primarily on fish (mullet). Population estimates are placed at between 200 to 400 individals, of which only about 25 are breeding females (Ogden 1978). Dunson (1980) speculates that upland drainage alterations to Florida Bay may be responsible for the lack of a crocodile comeback, as well as its tendency to move into upper and northern reaches of Florida Bay. This strongly implies a degree of dependence on oscillating salinity conditions.

Another endangered reptile that frequents Florida Bay is the Atlantic hawksbill turtle (Eretmochelys imbricata imbricata). Although it is more widespread than the crocodile in south Florida, the hawksbill is also a primarily tropical species. Florida populations exist at the northern edge of the species range. Nesting in south Florida waters is at best occasional. The hawksbill is generally associated with reef communities, but its omnivorous habits often lead it into seagrasses and other habitats.

The endangered Atlantic ridley turtle (Lepidochelys kempii) is limited in its range to the Gulf of Mexico and occasionally occurs in Florida Bay. Although it now only rarely breeds in southwest Florida, the endangered Atlantic green turtle (Chelonia mydas mydas) was once an important herbivore of south Florida seagrasses (Zieman 1982).

8.35 BIRDS

In general, Florida Bay affords significant habitat for wading and probing shorebirds, oceanic birds, and floating and diving birds. Relatively less habitat is available for arboreal and other land birds.

The importance of Florida Bay in wading bird production is exemplified by the fact that of the 41 nesting sites recorded in south Florida in 1974-1975, 14, or 34% were located in the bay (Kushland and White 1977). All but 3 of 500 roseate spoonbill (Ajaia ajaja) nests were located in the bay. Likewise, breeding of the reddish egret, double crested cormorant, and black crowned night heron are fairly restricted to the bay. A majority of the nests of the great blue heron (*Ardea herodias*) were also located in the bay on the smaller mangrove keys. Approximate quantities of these and other species that were in residence are listed in Table 37 in comparison with quantities reported in the estuarine and saltwater wetlands (ESSW), the terrestrial and freshwater wetlands (TFWW), and the lower Keys.

	FB	ESWW	TFWW	LOWER KEYS
White Ibis (*Eudocimus albus*)	1770	923	0	220
Roseate Spoonbill (*Ajaia ajaja*)	497	3	0	0
Great Blue Heron (*Ardea herodias*)	418	1	0	17
Wood Stork (*Mycteria americana*)	0	1335	0	0
Great Egret (*Egretta alba*)	602	997	2	27
Snowy Egret (*Egretta thula*)	176	2162	0	2
Little Blue Heron (*Egretta caerulea*)	37	0	6	6
Louisiana Heron (*Egretta tricolor*)	1081	1553	30	7
Brown Pelican (*Pelicanus occidentalis*)	342	0	0	298
Double Crested Cormorant (*Phalacrocorax auritus*)	1185	15	0	2188
Anhinga (*Anhinga anhinga*)	240	77	4	0
Glossy Ibis (*Plegadis falcinellus*)	0	0	0	0
Cattle Egret (*Bubulcus ibis*)	12	0	1630	0
Black Crown Night Heron (*Nycticorax nycticorax*)	Present	0	0	0
Reddish Egret (*Egretta rufescens*)	Present	0	0	1

Table 37. Distribution of breeding, wading, and swimming birds in the four ecosystems of the study area (adapted from Kushland and White and Osborn and Custer 1978).

According to Zieman (1982), swimmers (double crested cormorants and white pelicans) and the flyers/plungers (eagles, osprey) prefer to utilize the seagrass habitat at high tide while waders prefer low tide.

Other water birds that breed in or near the mud flats, mangroves, and seagrasses of Florida Bay include the laughing gull (*Larus atricilla*) (Kushlan 1977) and numerous probing shore birds such as the willet (*Catoptrophorus semipalmatus*), snowy plover (*Charadrius alexandrinus*), Wilson's plover (*Charadrius wilsonia*), black necked stilt (*Himontopus mexicanus*), and gullbilled tern (*Gelochelidon nilotica*) (Robertson and Kushlan 1974).

Little (or nothing) has been reported on the arboreal avifauna of the mangrove keys of Florida Bay. Judging from the relative paucity of land breeders in the Keys, the mangrove islands probably harbor a progressively depauperate avifauna with increasing distance from the mainland.

8.36 MAMMALS

The two most conspicuous mammals found in Florida Bay are the bottlenosed dolphin (*Tursiops truncatus*) and the endangered West Indian manatee (*Trichechus manatus*). According to Odell (1976) a total of 27 species of marine mammals have been sighted or stranded in south Florida waters.

Reports of dolphins in National Park waters were not broken down by geographic areas by Odell (1976); however, overall density of areal sightings was much higher than in Biscayne Bay to the east. Dolphin abundance was lowest from September through November; the author speculates this was related to the fall calving/mating season. Mullet were the only prey of the dolphin which could be easily identified from the survey.

Manatee sightings, on the other hand, were broken down by regions within the park. Of the total number of herds counted, only 1% were in Florida Bay, 46% in Whitewater

Bay, 20% in the Gulf of Mexico, and 23% in inland waters. Manatees appeared most abundant in December through January, and May through August. The low occurrence in Florida Bay was believed due to shallow depths, and possibly, lack of fresh drinking water.

CHAPTER 9
THE FLORIDA KEYS

9.1 PREVIOUS LITERATURE REVIEWS AND SYNTHESIS

In addition to the recent mangrove and seagrass reviews by Odum et al. (1982) and Zieman (1982) respectively, Jaap (1982) reviews coral reef ecology in a document entitled Ecology of the Coral Reefs of South Florida: A Community Profile. Together these three documents cover the literature on the major communities present in the Florida Keys. It is strongly suggested that the reader consult these documents for a more complete review of the autecology and synecology of the respective communities. As in Chapters 7 and 8, the following discussion presents a geographically limited summary of the total information available.

9.2 HABITAT ZONATION

Figure 56 (from Browder et al. 1973) identifies the general habitat zonations of the terrestrial, estuarine, and salt water wetland ecosystems for the Florida Keys and their nearshore environment. Mangrove swamps and forests, tropical hardwood hammocks, and urban development dominate the terrestrial and wetland areas. The marine environment, which dwarfs the land area of the Keys, is composed primarily of coral reefs, marine meadows, high velocity channels, and coastal plankton systems. Salt marshes and prairies which do not show up on the map at this scale are interspersed within the mangroves particularly along the northwestern or Gulf/Bay sides of the islands (Davis 1943). Beach and dune strand communities are found on the slightly elevated seaward ridges of the distal islands and on several of the upper and lower Keys (Davis 1942).

Historic habitat zonation within the Florida Keys falls within three general geographic categories, including: (1) emergent and terrestrial habitats; (2) shoreline or intertidal habitats; and (3) marine habitats.

General characteristics of the terrestrial and emergent habitats found in the Keys are similar to those previously discussed in Chapters 6, 7, and 8. These include: pinelands (Caribbean Pine), hammocks (tropical hardwood), thickets (saltbush), marsh (cat-tail), ponds (lime-sinks and pools) disturbed (canals, abandoned fields, and exotics), mangroves, and salt prairies, marshes and transitional habitats (salt flats, ponds, buttonwood transition communities). To avoid repetition, the discussion of these habitats is confined to the distinguishing characteristics which set the Keys version of these habitats apart from those of the mainland.

The terrestrial habitat zonation on the Florida Keys is comprehensively addressed by a series of reports by Davis (1940,1942,1943). These reports address: (1) the vegetation of the Sand Keys or distal islands (Davis 1942); (2) the mangroves of southern Florida (Davis 1940); and (3) the vegetation and natural features of southern Florida (Davis 1943). The more recent of these studies named eleven vegetative associes and associations from the Keys. With the exception of the beach/dune strand these associations fall under those habitats previously discussed (i.e., pineland, hammocks). More recently Browder et al. (1973) and CZM (1974) incorporated aerial photo interpretations into the development of land use/

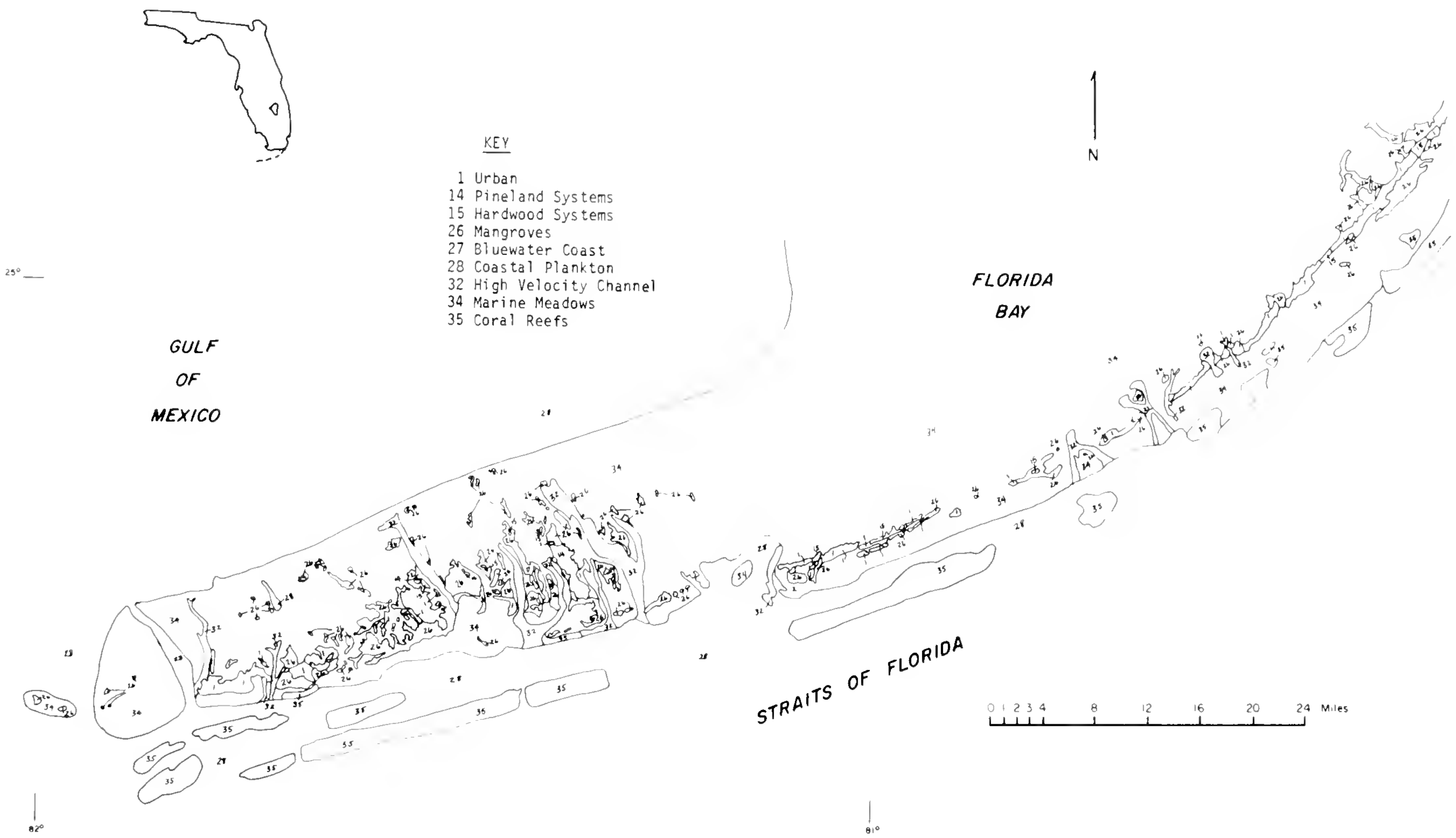


Figure 56. Habitat zonation in the Florida Keys (adapted from Browder et al. 1973).

land cover zonations for the Keys (Figure 56), although in both reports the distal islands (Tortugas, Marquesas, and Boca Grande groups) were not included. One additional study of importance is Small's (1913) survey of the Florida Keys flora. Although the species nomenclature is, in some cases, outdated (Avery and Loope 1980), the species placement geographically (upper, lower, and Sand Keys) and ecologically (hammocks, shorelines, limesink, waste area, etc.) provide a valuable historical perspective on changes in the Keys vegetation.

Shoreline or intertidal habitat zonation in the Florida Keys has been well studied by several authors. Stephenson and Stephenson (1950) have surveyed the plant and animal ecology of the rocky intertidal platform communities surrounding Soldier Key (Biscayne Bay); Zischke (1973) has reported on the intertidal and shallow-water marine communities of Pidgeon Key (middle Keys); and Getter et al. (1981) have assessed shoreline communities from Biscayne Bay to the Dry Tortugas. The first two studies deal primarily with rock platform communities. The third (Zischke 1973) although addressing a broader spectrum of shoreline communities is restricted geographically to one small island of the middle Keys (Pidgeon Key). The framework outlined by Getter et al. (1981), is used here in the discussion of intertidal habitat communities. Shoreline classification is based on more than eighty biological sampling and survey sites in the Keys and includes both man-made and natural shoreline habitats. Table 38 summarizes the eleven shoreline types delineated by Getter et al. (1981).

1.	Exposed, vertical rocky shores and seawalls	+
2.	Exposed rock platforms	*+
3.	Fine-grained sand beaches	
4.	Coarse-grained sand beaches	*
5.	Mixed sand and gravel beaches and fill	*
6.	Gravel beaches and riprap	*
7.	Exposed tidal flats	
8.	Sheltered rocky shores and seawalls	
9.	Sheltered tidal flats	
10.	Mangroves	*
11.	Sheltered mangroves	

Also addressed by (*) - Zischke (1973)
(+) - Stephenson and Stephenson (1950)

Table 38. Shoreline types in the Florida Keys (adapted from Getter et al. 1981).

The marine environment of the Florida Keys can be broken down into five relatively distinct natural subdivisions. These are: (1) lagoonal areas (e.g., Coupon Bight, Big Pine Key); (2) transitional areas (e.g., Bahia Honda Channels); (3) inner shelf areas (e.g., Hawk Channel and White Bank); (4) outer shelf margin (e.g., Carysfort Light Reef); and, (5) shelf margin slope (e.g., submarine slope environment bordering the Straits of Florida) (Ginsburg 1956, Enos 1977, Multer 1977). Within each of these subdivisions, one or more habitat zonations occur, depending on the classification scheme used. The habitat zonation scheme proposed by Enos (1977) has been adopted as a basis of presentation for this report. Other zonation frameworks, primarily those of Multer (1977), Marszalek (1977, 1981), and Jaap (1982), may be used to provide a more site specific character to Enos' (1977) overall zonation. Enos (1977) groups the organisms into habitat communities based on: (1) the substrate on which the characteristic assemblages live; and (2) on circulation and bottom morphology. The following habitats are recognized:

(1) Rock or dead reef
    (a) open marine
    (b) restricted circulation
(2) Mud, sediment
    (a) grassed covered
    (b) bare
(3) Sand, sediment
    (a) grass covered
    (b) bare
(4) Patch reef
(5) Outer reef
(6) Forereef muddy sand
(7) Shoal fringe, restricted circulation
(8) Reef rubble

Ecological conditions are summarized in Figure 43, presented in the previous section on Florida Keys hydrology and water quality.

9.21 TERRESTRIAL HABITATS OF THE FLORIDA KEYS

Pinelands

Like the pinelands of the Everglades Keys (Long Pine Key) this community in the Florida Keys is conspicuously associated with outcroppings of the solution riddled Miami Limestone (oolite facies) (Davis 1943) and in the past, the Key Largo Limestone (Alexander 1953). Most of the pineland occurs on four of the lower keys: Big Pine, Little Pine, No Name, and Cudjoe. The dominant species are Caribbean Pine (Pinus elliottii var. densa), silverpalm (Coccothrinax argentata), black-bead (Pithecellobium keyense), and the brittle thatch palm (Thrinax microcarpa). Wax myrtle (Myrica cerifera) is notably infrequent in lower Keys pinelands understory as compared to the mainland. Stopper (Myrtus verrucosa), saw palmetto (Serenoa repens), white indigo berry (Randia aculeata), pisonia (Pisonia rotundata), poisonwood (Metopium toxiferum), locustberry (Byrsonima cuneata), and the herbaceous plants senne (Cassia keyensis), acanthus (Ruellia caroliniensis ssp. ciliosa var. heteromorpha), and grasses dominate the understory (Alexander and Dickson 1972).

The influence of fire on species composition in Caribbean pinelands of the Florida Keys is not as well understood as it is on the mainland. Nonetheless, it is known that the Keys have experienced many wildfires and these have undoubtedly served to maintain the pineland and arrest tropical hardwood hammock succession throughout recent time (Alexander and Dickson 1972). The absence of fire and the elimination of pineland by the climax of broad-leaved West Indian species has been documented on No Name and Little Pine Keys (Dickson 1955, Stern and Brizincky 1957), and appears to be the reason why a viable Key Largo pineland has disappeared (Alexander 1953).

Hammocks

Of the five (5) types of hammocks identified by Hilsenbeck et al. (1979) only the tropical hardwood hammock occurs in the Florida Keys. These hammocks exhibit a greater tropical speciation than those on the mainland, particularly in the lower Keys. Davis (1943) identified two forms of key hammocks: (1) coral rock jungle hammocks represented by thicket forests of many tropical trees and a few palms and live oaks (Quercus virginiana var. virginiana) confined to the upper Keys; and (2) lower Florida Keys hammocks consisting of thicket forests of tropical trees and shrubs growing in or near rockland pine forests on limestone, marl, and calcareous sand soils with thatch palms (Thrinax sp.). Only on the Keys, particularly the lower Keys, does Davis (1943) consider the hardwood hammocks as truly tropical. Besides the thatch palms (Thrinax sp.) other unique species include Jamaica-dogwood (*Piscidia piscipula*), the true West Indian or madeira mahogany (*Swietenia mahagoni*), and several species observed in the pinelands habitat including: blackbead (*Pithecellobium keyense*), stopper (*Myrtus verrucosa*), and poisonwood (*Metopium toxiferum*) (Davis 1942, 1943).

Mangrove

The development of mangrove swamp forests mimics, on a smaller scale, the mangrove forest types described in section 7.21, with the exclusion of the basin forests. The fringe and overwash forests are the dominant forms followed by riverine and finally scrub (Davis 1940, CZM 1974, Getter et al. 1981).

Salt Prairies, Marshes and Transitional Habitats

Salt flats or prairies are similar in form and species composition to the communities found interspersed throughout the mainland mangrove zone. These occasionally flooded areas exist in the lower Keys (Boca Chica, Sugar Loaf, Saddlebunch, and Cudjoe Keys). In addition to saltwort (*Batis maritima*), glasswort (*Salicornia perennis*), and saltgrass (*Distichilis spicata*), other commonly occuring species include: keygrass (*Monanthochloe littorali*), seablite (*Suaeda linearis*), and sea ox-eye (*Borrichia* sp.). The Keys salt flats are commonly found with areas of bare ground surrounding depressions in which salinities may reach concentrations of 80 ppt, virtually eliminating all colonization or growth of macrophytic plants (Davis 1943).

Saltwater and brackish water marshes occur near the coastline where surface water and soils are affected by salinity. The habitat varies from very saline to nearly freshwater conditions and can occur on a variety of soils. It usually exhibits several sub-zonations from the shore inland as shown in Table 39.

Saltwater		⟵⟶		Brackish/Freshwater
Batis maritima (saltwort)	*Batis maritima* (saltwort)	*Distichilis spicata* (saltgrass)	*Spartina patens* (cordgrass)	*Typha augustifolia* (cattail)
	Salicornia perennis (glasswort)	*Spartina patens* (cordgrass)	*Juncus roemerianus* (black-rush)	
		Fimbristylis castanea (sedge)		
low shrub marshes		grassy marshes & prairies	black-rush marshes	brackish water cattail marshes

Table 39. Habitat subzonation in Florida Keys wetlands (adapted from Davis 1943).

Beach dune/strand

The beach dune-strand habitat consists of characteristic shore and nearshore grassy and herbaceous plants, or thicket forests of shrubs and small trees (Davis 1942, 1943). The vegetation flourishes on coarse calcareous sands, rocks, and shell/coral rubble mounds. As a community, it is best represented on the seaward side of several middle Keys (e.g., Bahia Honda and Long Keys) and the distal islands (Multer 1977). Davis (1942) identified four (4) vegetative zones which occur from the beach inland. These include: (1) the pioneer beach strand; (2) the dune strand; (3) the transition zone; and (4) the hammock strand.

The pioneer beach strand exists from the wave line on the beaches to the higher parts of the fore dunes, definitely above the usual effects of mean high water. Its flora consists of a number of pioneer halophytic species that can spread out over the upper beach, take root and germinate from seeds rapidly, and tolerate occasional wave action and sand movement. Commonly found species include sea purslane (*Sesuvium portulacastrum*), sea rocket (*Cakile fusiformis*), beach morning glory (*Ipomoea pes-caprae* var. *emarginata*), beach grass (*Panicum amarulum*), rush grass (*Sporobolus virginicus*), sea oat (*Uniola paniculata*), spurge (*Chamaesyce mesembryanthemifola*), and sea lavender (*Tournefortia gnaphalodes*). The most halophytic of the beach dune-strands species exist in this first zone where even the upper beach plants must tolerate occasional saltwater submergence. The two more common species in this zone, sea oat (*Uniola* sp.) and spurge (*Chamaesyce*), also serve as the dominants in the more inland dune-strand community. The pioneer beach strand zonation does not develop along the narrower beaches where the dune terraces meet or are very close to the upper reaches of high tide (Davis 1942). As Davis (1943) noted, when the pioneer beach strand is developed, aggradation of the breach is indicated as these plants are the first to grow on newly built-up sand areas.

Further inland, the dune-strand zonation is the most commonly observed and distinctly delineated of the strand communities. This zone usually appears as the first of three possible zonations on an elevated, almost flat, platform of dunes. They are approximately 22.9 to 137.2 m (25 to 150 yds) wide and from 0.3 to 2.7 m (1 to 9 ft) above mean high tide. A wave cut terrace generally forms the seaward boundary and if the dune platform's width exceeds approximately 68.6 meters (75 yds), then all three zonations (dune-strand, shrub-strand, hammock-strand) may develop. If narrower than 68.6 m (75 yds) then the platform is nearly always covered by the dune-strand community (Davis 1942). Predominantly herbaceous, the dune-strand commonly includes the grasses sea oat (*Uniola paniculata*), spurge (*Chamarsyce mesembryanthemfolia*), *Waltheria indica*, a number of leguminous plants, the spider lily (*Hymenocallis latifolia*), and the shrubs sea lavender (*Tourenfortia gnaphalodes*) and bay cedar (*Suriana maritima*). Where shrubs are scattered over the platform area the dune-strand community is considered unaltered, but if a definite increase in shrub density occurs, covering more of the area than herbaceous plants, then a scrub-strand community is recognized (Davis 1942).

The scrub-strand community is generally the transition zone between the dune-strands zone and the hammock forest. On most of the distal islands, the hammock forest is absent and the scrub-strand community occupies the entire inner zone of the dune platform. Of the more common shrubs, bay cedar (Suriana maritima) is the most typical followed by lantana (Lantana involucrata), gray nicker (Caesalpinia crista), night-shade (Solanum bahamense), sea ox-eye (Borrichia arboresens), and prickly pear (Opuntia stricta var. dillenii). The open areas between the thickets of scrub plants contain a number of dune strand species. Generally a few hammock plants such as joewood (Jacquinia keyensis), silver palm (Coccothrinax argentata), and blackbead (Pithelobium keyense) are often present. Governed by xeric conditions the scrub-strand represents the middle ground between the more halic soils of the fore dune community and the more mesic hammock strand associes. Also, as xeric implies, this zonation represents the lowest soil moisture condition resulting from the relative elevation and the highly porous, coarse calcareous sands. As humus accumulates farther inland the soil moisture content increases, at least surficially, promoting the colonization of hammock strand species (Davis 1942).

The last and most inland of the strand communities is the hammock strand forest. This community seldom develops fully on the distal islands and is primarily restricted to a few of the main keys (e.g., Long Key). Also called thicket forests, these communities are primarily composed of small trees, although some taller ones may exceed 9.1 m (30 ft). The more common and significant hammock-strand species include cats claw (Pithecellobium unguis-cati), joewood (Jacquinia keyensis), silver palm (Coccothrinax argentata), brittle thatch (Thrinax microcarpa), thatch (T. parviflora), poisonwood (Metopium toxiferum), red ironwood (Reynosia septetrionalis), caper tree (Capparis flexuousa), white stopper (Eugenia axillaris), Spanish stopper (Eugenia myrtoides), beef tree (Pisonia discolor var. discolor and var. longifolia), and shell orchid (Encyclia tampensis). As mentioned previously, the strand communities develop on calcareous sand, marl, and rocky substrates. When the hammock-strand occurs on rocky soils the plants are dwarfed, scrubby and widely spaced like those of the scrub-strand community. Although species composition is similar for all three substrates, some plants, including prickly pear (Opuntia stricta var. dillenii), wild cotton (Gossypium hirsutum), saffron plum (Bumelia celastrina var. augustifolia), molina (Maytenus phyllanthoides), cats claw (Pithecellobium unguis-cati), and geiger tree (Cordia sebestena), are more typical of rock hammocks and marl soils than of sand hammocks.

9.22 INTERTIDAL/SHORELINE HABITATS

Exposed, Vertical Rocky Shores and Seawalls

This habitat is both naturally occuring and a by-product of man's activities in the Florida Keys. Natural habitats occur along steep scarps in the limestone bedrock that form as a result of erosion (solutional and abrasive) from relatively high wave energy (e.g., Vaca Key). These generally provide little or no residual sediments to the intertidal zone (Stephenson and Stephenson 1950, Ginsburg 1953b, Getter et al. 1981) Man-made habitats include concrete or tightly cemented seawalls, and the structural supports for bridges and piers. These vertical walls and pilings generally extend below the low mean tide and face open ocean or open fetch areas which are exposed to high energy waves and/or strong currents. The structures usually occur in association with other shoreline modifications, such as riprap. The areas behind the sewalls are packed with sand, fill, or concrete.

Attached macroalgae dominate the habitat's flora. Generally there are a few abundant species located within the wetter, lower areas along the vertical rock face. These commonly include the red algae Bostrychia tennela and Laurencia papillosa, and the green algae Valonia acellata (Stephenson and Stephenson 1950, Getter et al. 1981).

In contrast, epifauna occur in moderate densities with high species richness and diversity (Getter et al. 1981). Several species of nerite snails (Nerita tessellata, N. versicolor, and N. peloronta) represent the most common organisms observed. Infauna and under rock fauna are absent due to the lack of suitable substrate. Other typical organisms within this habitat include o.k. gastropods Nodilittorina tuberculata, Littorina ziczac, and Spiroglyphus annulatus, the limpet Siphonaria alternata, and the barnacle Chthamalus stellatus (Stephenson and Stephenson 1950).

Exposed Rocky Platforms

The exposed rocky platform habitat is the most comprehensively studied intertidal/shoreline community of the Florida Keys. For purposes of this study the habitat zonation outlined by Stephenson and Stephenson (1950) is adopted. Three zonations are delineated; the first of which is the upper platform which varies greatly in width, angle of slope, and pattern of its' seaward termination. This zone extends from the edge of the true dryland vegetation to the seaward edge of the limerock platform. The second zone is the lower platform which is occasionally absent, and when present is greatly variable in its development. This zone commonly occurs as discontinuous patches of low rock running seaward from the foot of the upper platform to a level only slightly above the low water level of the spring tides. The third zone is the reef flat which is a low lying area in which rocky patches alternate with sand, mud, and gravel. This last zonation is commonly inundated at low water, while its higher parts may emerge as banks at the lowest tides. Because of the broad width and varied environment within the upper platform, Stephenson and Stephenson (1950) divide it into four zones named for the changing coloration of the platform rock. From the dryland vegetation seaward these color zones are white, gray, black, and yellow. The first three represent subdivisions of the supralittoral fringe; the yellow zone belongs to the midlittoral zone. The dry land vegetation inland of the rocky platform generally consists of mangrove or strand communities, some of which may spill over into the platform habitat.

The white zone is more nearly dry land than intertidal zone, as the highest flotsom line either lies within it or along its seaward margin. The zone's relief varies from a rock surface to a gravel beach. The fauna usually exists under rocks and boulders, and includes terrestrial forms such as ants, earwigs, scorpions, and spiders. No fully marine animals inhabit the white zone, but several maritime species occur, including the purple-clawed hermit crab Cocnobita clypeatus, the isopod

Ligia baudiniana, the rapid crabs Sesarma cinereum and Cyclograpsus integen, and most commonly, the gastropod Tectarus muricatus. The vegetation generally exhibits a terrestrial species composition, but may vary from none at all to an almost complete strand community. Common flora include the white and black mangroves (Laguncularia racemosa and Avicennia germinans), buttonwood (Concocarpus erecta), seaside mahoe (Thespesia populnea), bay cedar (Suriana maritima), beach morning glory (Ipomea pes-caprae var. emarginata), sea ox-eye (Borrichia frutescens and B. arborescens), saltwort (Batis maritima), glasswort (Salcornia perennis), samphire (Philoxerus vermicularis, sea-purslane (Sesuvium portulacastrum), and several coarse grasses including salt grass (Distichilis spicata) and keygrass (Monanthochloe littoralis).

The gray zone, denoted by a grayish rock, is generally vegetated by many of the white zone species. It is also the most upland zone on the platform, to contain any signs of macroscopic marine algae. The occurence of the red microalgae, Bostrychia tenella, and the flowering terrestrial plants in the same zone is related to the partial wetting at spring high tide of the gray zone, thus providing a suitable environment for both communities. All three mangrove species (Rhizophora mangle, Avicennia germinans, Laguncularia racemosa,) may be present and, in some cases, flourish in this zone. Other plant species commonly found include: sea purslane (Sesuvium potulacastrum, saltwort (Batis maritima), samphire (Philoxerus vermicularis), glasswort (Salicornia perennis), sea ox-eye (Borrichia frutescens), and the grasses Monanthochloe littoralis (keygrass) and Sporobolus virginicus (dropseed). The animal density and diversity increases from white to gray zones, as one would expect with the gray zone's more moderate environment. The snails Littorina ziczac, Tectarius muricates, Nodilittorina tuberculata, Echinius nodalosus, and Nerita peloronta are characteristic of this zone. N. peloronta reaches maximum density in this zone. Another nerite snail (N. versicolor) is commonly found although it reaches its maximum in the next seaward zone (black). Other animals typically occuring in this zone include the two rapid crabs Sesarma cinerum and Cyclograpsus integer, the small gastropods Melampus flavus, M. coffeus gundlach, Detracia bulloides, Truncatella bilabiata and T. pulchella, the isopod Ligia baudiniana, and earthworms and spiders. Generally a beach wrack (i.e., an assortment of marine grasses, Sargassum, and other algae) is deposited in either gray or black zones by waves at the high tide line. This wrack harbors thousands of crustaceans (primarily amphipods and isopods) and insects.

The black zone is completely wetted by the higher spring high tides but may be only partly wetted, if at all, by lesser spring tides. Because of the convolution in the surface of many platforms, determining the actual area wetted is further complicated by the way the sea may invade the lower levels through fissures, inlets, and hollows before covering the crests of the upper platform. The vertical depth of the black zone appears constant, ranging from 11.3 to 21.3 cm (4.4 to 8.4 in) with a mean of 15 cm (6 in). This consistency represents a departure from the more variable and erratic vertical dimensions of the white and gray zones (Stephenson and Stephenson 1950). The black color (dark yellow-gray) characteristic of this zone is caused, in part, by the discoloring agents of the blue-green algae *Entophysalis seasta (granulosa)* and other blue-green and green algae. Usually little or no flowering vegetation exists and the only marine macroalgae of regular occurrence in the black zone form a moss-like growth primarily in hollows. The growth is dominated by the red algae *Bostrychia binderi* and *B. tenella*, accompanied by several other smaller forms. Many of the snails characteristic of the gray zone also are common in the black. Several (*Littorina ziczac*, *Nodilittorina tuberculata* and *Nerita versicolor*) tend to reach their maxima in the black zone. The elongate snail *Betillaria minima* occurs in great numbers here, particularly in shallow pools and depressions. Other common fauna include the isopod *Ligia baudiniana* and the crab *Pachygrapus transversus.*

The most seaward of the upper platform subenvironments is the yellow zone. This comprises the main part of the midlittoral zone on the Florida Keys rocky shorelines. The yellow zone represents the only truly intertidal region of the upper platform; it is inhabited by a considerable number of fully marine organisms with a greater species diversity than observed in the mainland zones. Normal spring tides submerge or at least wet the entire yellow zone which includes: (1) the marginal region of the platform top; and (2) the actual edge of the platform and its seaward face down to the beginning of the lower platform. The platform-edge's profile may vary from a gradual slope to a precipitous or overhanging scarp. In general, the yellow zone consists of two distinct communities which correspond to the platform's regions: (1) marginal regional-upper yellow zone; and (2) seaward face-lower yellow zone. The upper yellow zone fauna consists primarily of the small barnacle *Chthamalus stellatus*, or the larger *Tetraclita squamosa*. The red algae moss *Bostrychia* sp., is the primary flora of the zone. The nerite snails, *Nerita tessellata* and *N. versicolor* also extend into the upper yellow zone, occasionally in great numbers. The lower yellow zone is well marked by the presence of two dominant colonial organisms: (1) a green algae, *Valonia ocellata*, which forms nodulated sheets or masses of small bubble-like vesicles; and (2) a sedentary vermetid gastropod, *Spiroglyphus annulatus*, which produces sheets or masses of narrow tubes. Occasionally a third subzone of reddish brown algal 'velvet' overlaps the two previous subzones. The velvet mat is composed of several algae including *Gelidiella acerosa*, *Centroceras clavulatum*, *Cladophoropsis membranacea*, *Ceramium subtile*, *Herposiphonia sceunda*, and *Polysiphonia howei*. Scattered throughout the lower yellow zone are two whelks *Thais rustica* and *Cantharius tinctus*. Fauna common to the entire yellow zone include the small finely ribbed mussel *Mytilus exustus*, a small dark-edged oyster *Isognomon alatus*, the large chiton *Acanthopleura granulata*, the most frequently encountered crab *Pachygrapsus transversus*, the limpets *Siphonaria pectinata* and *S. alternata*, and a small black slug *Onchidium floridanum* (Stephenson and Stephenson 1950).

The lower platform, when present, is fully exposed to the air at low water of major spring tides and partly exposed or awash at lesser spring tides. A distinctive feature of this platform is the occurrence, often quite extensive, of a low yellowish-green carpet dominated by the red alga *Laurencia papillosa*.

Species commonly associated with this carpet include *Cladophoropsis membranacra*, *Centroceras clavulatum*, *Ceramium byssoideum*, *Herposiphonia secunda*, *Jania capillacea*, *Polysiphonia* sp., and *Spyridia filamentosa*. The green algae *Valonia ocellata* and the vermetid gastropod *Spiroglyphus annulatus* are as characteristic of the lower platform as they are of the yellow zone. Another common feature of the lower platform is the cushion-like masses, often extensive and also quite often choked by sediment, of the calcareous green algae *Halimeda opuntia* which represents a landward extension of the reef-flat assemblage. In some locations there are patches or large areas of a zoanthid coral, *Zoanthus sociatus*, with small polyps which often expand in daylight. Numerous organisms 'spillover' from the reef flat onto the lower platform, but only a few are so common as to be considered characteristic of the lower platform assemblage. These are usually observed in rock cavities and under movable stones, and commonly include the short-spined urchin *Echinometra lucunter*, two species of bearded mussels (*Arca barbata* and *A. umbonata*), and the anemones *Phymanthus crucifer*, *Bartholomea annulata*, and *Condylactis gigantia* (Stephenson and Stephenson 1950).

The most seaward habitat zonation described by Stephenson and Stephenson (1950) is the reef flat. Consistent with the more inland zones, the reef flat's physical configuration is quite variable. In some places it lies under very shallow water so that one can wade out over it for a quarter of a mile or more. Under similar conditions, but elsewhere in the Florida Keys, the reef flat slopes down so rapidly that wading is restricted to within a few meters of the lower platform. The unifying quality is the continuous submergence of the community by marine water except for few areas that emerge during the lowest tides. The zone therefore is considered infralittoral and for purposes of this report will be included within the marine habitat zonations discussed later.

Fine Grained Sand Beaches

In the Florida Keys the fine-grained calcareous sand beaches are limited in size and frequency, with most occurring in the middle Keys and distal islands. Typically these beaches form on the island side facing the Florida Straits where moderate to high wave activity exists. Offshore areas are generally shallow with subtidal grass flats overlying limestone bedrock. Flora in this habitat is primarily the pioneer beach strand community previously described. The more common halophytic plants include the sea oat *Uniola paniculata* and the beach morning-glory *Ipomoea pes-capre*. Farther inland the black mangrove *Avicennia germinans* and buttonwood *Conocarpus erecta* transitional communities are often observed. As with the rocky platform zonation a heavy wrack accumulation commonly forms along the high tide line.

The epifauna is characterized by low specific density and diversity, usually represented by the gastropod *Batillaria minima*. Numerous amphipods and insects flourish within the sea wrack. The infauna, like the epifauna, exhibits a depauperate species population and diversity most commonly represented by the mole crab *Emerita talpoida*, the ghost crab *Ocypode quadrata*, several polycheates such as *Nereis succinea*, and a oligocheate (*Tubificidae* sp.) (Getter et al. 1981).

Coarse-grained Sand Beaches

These beaches are physically quite similar to the fine-grain beaches except: (1) the sands are composed of coarse-grained carbonate sands; and, (2) the beaches are much narrower, usually less than 10 m (33 ft) wide between dune and low water. Wave activity is low to moderate except for high energy storm waves. All three levels of wave energy promote the heavy accumulation of sea wrack along the high tide line.

The faunal and floral species composition is much like the fine-grained sand beach habitat. Upland vegetation is still of a beach-strand community with a noticable increase in strand and saltmarsh grasses, e.g., keygrass Monanthochloe littoralis and the saltmeadow cordgrass Spartina patens. Near-shore marine plants include the seagrasses Halodule wrightii and Syringodium filiforme. Both infauna and epifauna communities exhibit a species composition shift to that displayed in the rock platform habitat. The mole crab Emerita talpoida, the gastropod Batillaria minima and the polychaete Nereis succinea are frequently common and are usually joined by several upper platform species including: the gastropod Littorina ziczac, the isopod Ligia baudiniana, the barnacle Balanus sp., and the polychaete Lumbrineris maculata. Also, the infaunal clam, Anomalocardia cuneiveis, is periodically found (Zischke 1973, Getter et al. 1981).

Mixed Sand and Gravel Beaches and Fill

Natural occurrences of this habitat are restricted to areas of high wave energy which create beaches of coarse shell and coral fragments, e.g., seaward side of Bush Key, Dry Tortugas. Man-constructed versions are sand and gravel fill areas composed of very poorly sorted mixtures ranging from mud to cobble-sized sediments. This mixture can sometimes be very hard packed with a more mobile surface layer. The wave activity ranges from high to low and is often unrelated to sediment grain size. Typical beach slopes are artifically steep with the toe of the beach face generally composed of coarser, better sorted sediments.

Wrack accumulations are often quite significant following the trend observed in other beach and rocky platform habitats. Attached macroalgae are more prevalent than other sand beaches, corresponding to the increased rock composition. The most commonly found is the red algae Bostrychia tenella; others include the green algae Dasycladus sp., Enteromorpha ligulata and Valonia ocellata; and the red algae Laurencia papillosa. The upland rooted vegetation is that commonly associated with beach-strand, mangrove, and salt marsh habitats previously described. The variety of vegetation is a reflection of the (ecologically) random placement of these man-made shoreline modifications with respect to naturally occurring shoreline habitats. For example, along the inter- and infratidal zones mangrove colonization (Rhizophora mangle and Avicennia germinans) is observed in areas of Fleming Key (Key West), Boca Chica Key, and Ramrod Key. Similarly, the fauna of this habitat contains members of various naturally occurring communities. Usually a mixture of beach and rock platform communities dominates. Both epifauna and infauna exhibit moderate densities, biomass, and species diversity. The epifauna is dominated by nerite snails Nerita sp., barnacles Balanus sp. and Chthamalus stellatus, and oysters Crassostrea virginica. Several species of polycheate worms are the most prevalent infaunal organisms, including Nereis succinea and Heteromastus filiformis. Presence of the ghost crab Ocypode quadrata, the sea cucumber Holotheria floridana, and a gastropod usually associated with the reef flat Alcyonaria-Sponge zone (Bulla occidentalis), illustrates the mixture of habitat communities (Zischke 1973, Multer 1977, Getter et al. 1981).

Gravel Beaches and Riprap

All forms of this habitat represent man-made modifications to the natural key shorelines. The primary structural units are gravel to bouldersized riprap revetments usually composed of local limestone. Like the previous habitat, the wave energy varies from one area to the next, related more to the subtidal sediment formations which are commonly finer grained, better sorted, and naturally occurring. Shorelines bordering the causeways are often of this shoreline type, found in association with fill areas and seawalls.

The steep slopes generally bring the three basic forms of Florida Key plant communities (terrestrial, shoreline, marine) into a spatially narrow area. The terrestrial and shoreline communities are similar to those described for the mixed gravel and fill beaches. Beach strand, mangrove, and saltmarsh vegetation represent the rooted flora; species of the green algae (Chlorophyceae), red algae (Rhodophycea), and brown algae (Phacophycea) represent the attached intertidal vegetation. The infratidal areas commonly exhibit dense growths of the seagrasses Halodule wrightii and Thalassia testudium. The most common shoreline rooted vegetation is the red mangrove Rhizophora mangle and sea purslane Sesuvium maritima; the red algae Bostrychia sp. represents the attached flora. High density, species richness, and diversity of infauna and epifauna reflects the varied habitat conditions. Getter et al. (1981) observed 23 epifaunal species and 12 infaunal species in this shoreline habitat. The dominant epifaunal species are amphipods, the snail Batillaria minima, the barnacles Balanus sp., and the nerite snails Nerite sp. The polycheate worms Arenicola cristata, Nereis succinca, and Lumbrineris sp. are the predominant infaunal forms.

Exposed Tidal Flats

Because of the small tidal range in the Florida Keys, the exposed tidal flats is one of the least common habitat zonations observed. They are generally located in open bays (Vaca Key Bight), in the lee of offshore islands (Boot Key), or near tidal inlets (Teatable Channel in Upper Matecumbe Key. Varying in width (up to 50 m or 164 ft) they are subject to moderate to high energy wave activity and tidal currents. Sediment composition is dominated by carbonate sands and some muds generally accompanied by migrating carbonate sand bars on the seaward limit of the flats.

Vegetation is present in two community types: (1) mangrove fringe forests dominated by the red mangrove Rhizophora mangle and the black mangrove Avicennia germinans; and (2) the seagrass beds, represented almost exclusively by the shoal grass Halodule wrightii.

The epifaunal community exhibits high density, moderate species richness, and low species diversity. Of the five species Getter et al. (1981) observed, land crabs Cardiosoma guanhumi, fiddler crabs Uca sp., and the batillaria snails Batillaria minima are the dominant forms. The infauna shows greater species diversity and biomass, with several species of polychaete worms representing the dominant organisms.

Sheltered Rocky Shores and Seawalls

The sheltered rocky shores are the result of canals dug through limestone bedrock. The vertical faces are often pitted or irregular, reflecting the varied strata of the Miami Oolite and Key Largo Limestone formations. The other man-made structure for this habitat is the seawall. Both dominate shorelines along the interior and sheltered areas in populated regions, and both extend below low-water levels. Wave and current energies here are low.

Rooted terrestrial vegetation is negligible, as are the seagrasses, with the exception of in the shallow canals. Getter et al. (1981) observed seven species of attached flora and one species of black lichen which was prevalent in the supratidal zone. The red algae Bostrychia tenella and several other red and green algal forms populate the mid and lower intertidal zones.

The infauna generally is absent and the epifauna exhibits low diversity and high density, as observed in the exposed, vertical rocky shore and seawall habitat. Barnacles Balanus sp. and Chthamalus sp., and snails Nerite sp. and Littorina sp. are generally present.

Sheltered Tidal Flats

Removed from even moderate waves and/or tidal currents, this habitat is found associated with interior island lagoons. The sediment, a carbonate mud, is much less consolidated than its counterpart the exposed tidal flat habitat. However, like its counterpart, this habitat is uncommon in the Florida Keys.

The flora and fauna are represented by few species. The rooted vegetation is confined to the tidal flat fringe generally consisting of red and black mangroves, saltwort (Batis maritima), and key grass (Monanthocloe littoralis). The attached marine vegetation, distributed throughout the tidal flat, is composed primarily of micro green and blue-green algae, shoal grass (Halodule wrightii), and turtle grass (Thalassia testudinum). The only infaunal species reported by Getter et al. (1981) was a nereid polychaete worm, Notomastus sp. The epifauna is represented by large populations of the gastropod Batillaria minima.

9.23 MARINE HABITATS

The habitat descriptions of the Florida Key's marine systems follow, in a seaward progression, the profile habitats illustrated in Figure 57.

Rocky or Dead-reef Bottom Habitats

This habitat occurs in two general belts: (1) from the Florida Keys shoreline out as far as 8 km (2 mi), to water depths less than 5 m (16 ft); and (2) near the shelf break where the Pleistocene rock is again exposed, forming elongated areas of dead and partly eroded coral reef ranging in depth from sea level to greater than 30 m (33 yd) (Enos 1977).

The nearshore rock bottom habitat may be divided into several subenvironments. Several of these are discussed in the Shoreline Habitat Section, 9.22. For this discussion, two subenvironments are identified: (1) nearshore high velocity or tidal channel hardbottom communities; and (2) the nearshore restricted circulation hardbottom community.

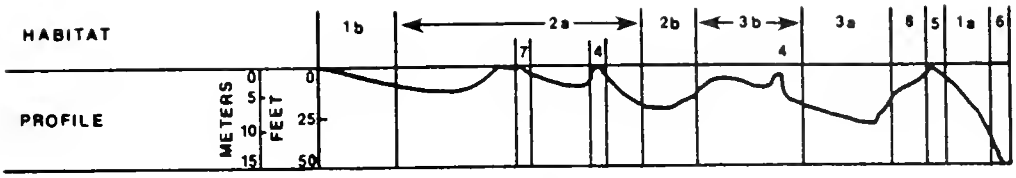


Figure 57. Profile of marine habitats off the Florida Keys (adapted from Enos 1977).

The former of the two (high-velocity hardbottom) generally occurs within channels and passes between keys where strong tidal currents and low sedimentation maintain an exposed hardrock substrate, e.g., Knight Key Channel between Vaca and Pigeon Keys. These areas are typically quite shallow (1 to 5 m or 3 to 16 ft) and, because of the placement in tidal channels, are exposed to a wide range of water quality conditions (temperature, salinity, turbidity). On this limestone-pavement substrate a soft coral (*Alcyonarian*) and sponge community usually dominates, commonly covered with less than 3 cm (1 in) of calcareous sediment (Zischke 1973). Voss and Voss (1955) designate this region the Alcyonaria zone in their study of Soldier Key. Zischke (1973) expanded the habitat name to the Alcyonaria-sponge community to signify the numerous poriferas, the most prominent of which is the large loggerhead sponge *Spheciospongia vesparia*. Other sponges commonly observed include *Spongia graminea*, three species of *Ircinia*, and *Halicondria melanadocia*. Typical soft corals (alcyonarians) include *Briareum asbestium*, *Eunicea knighti*, *Pterogorgia anceps*, *Gorgonia flabellum*, and *Pseudopterogorgia acerosa*. The stony corals (scleractinian corals) *Porites jurcata*, *Flavia fragum*, and *Siderastrea siderea* are also common to this community (Kissling 1965, Zischke 1973). Communities of small invertebrates reside among the sponges and soft corals; these usually include annelid worms, brittlestars, and a variety of small crustaceans, e.g., snapping shrimp.

The Alcyonaria-sponge zone is generally an area of low primary productivity with only a few algal species including the green algae *Acetabularia crenulata*, *Halimeda* sp., *Penicillus* sp., and *Valonia ventricosa*; the brown algae *Dictyota dichotoma*; and the red algae *Champia parvula*, *Chondria* sp., *Eucheuma isiforme*, *Goniolithon* sp., *Gracilaria* sp., *Heterosiphonia gibbesii*, *Laurencia poitei*, and *Lithothamnium* sp. (Zischke 1973). Most of the community's nutrients are imported from adjacent grass beds (as detrital material) or from plankton. The stinging fire-coral *Millepora alcicornis* is commonly found on the dead skeltons of the alcyonarians, and the brittlestar *Astrophyton muricatum* is often found entwined in the branches of sponges. Irregularities in the rock face or the presence of coral fragments provide a shelter for the long-spined black sea urchin *Diadema antillarum*, many species of mollusks, and the Florida spiny lobster *Panlirus argus* (Voss and Voss 1955, Enos 1977).

The distinquishing characteristic of the two nearshore rock-bottom habitats is circulation. In the tidal channel habitat previously discussed, high velocity currents dominate the area's hydrology. In the shallow hardground environment, adjacent and seaward to most of the Florida Keys, the currents are more moderate. Both habitats experience relatively large temperature and salinity variations, although for two different reasons. As metioned earlier, the tidal channel environment is exposed to the temperature and salinity regemes of both the Gulf/Bay and the Atlantic water bodies corresponding to the daily tides. Adjacent to the Florida Keys, the salinity and temperature variations are again large but this time they are related to the shallow, restricted circulation. The former is controlled by "imported" variations; the latter by "endemic" variations.

The origin of the rock surface exposures is not always clear. The nearshore subtidal hardgrounds bordering the emergent Florida Keys may represent: (1) former subaerially exposed and lithified sediment or limestone bedrock highs; (2) submarine cementation and/or the product of encrusting organisms, e.g., coralline algae; or (3) former coral rubble surfaces, welded together (Multer 1977).

The flora and fauna here are generally similar to the current-swept hardground community. Various organisms inhabiting the surface or the sediment-filled fractures include alcyonarians, sponges, encrusting foraminifera, boring mollusks and worms, crustose coralline algae, and sea urchins. The more common alcyonarians observed include the plume-like *Antillogorgia acrerosa* and *Plexaura vermiculata*. The sea fan *Gorgonia flabellum* may occur but not too frequently. The number of stony coral (scleratinian) species increases with the addition of *Solenastria hyades*, *Siderastrea radians*, *Porites divaricata*, and *Oculina diffusa*. The bivalve *Pteria colymbus*, two gastropods of the genus *Cyphoma*, and the basket starfish *Astrophyton muricatum* are usually found on *Antillogorgia* colonies. The flora speciation is reduced, and composed primarily of the green algae *Halimeda opuntia* and *Cladophora* sp.; a blue-green algal scum over some surfaces; and the red algae *Jania* sp. and *Gonolithon* sp. (Voss and Voss 1955, Enos 1977).

The second belt of rocky or dead-reef bottoms lies near the shelf break as elongated areas of dead and partly eroded coral reefs which form a relatively hard substrate. These dead reefs range in depth from near sea level to at least 30 m (33 yd). Located seaward of the outer reef, this habitat experiences open marine circulation, minimal salinity and temperature variation, and low turbidity. The floral and faunal assemblages are generally similar to the nearshore hardground habitat, dominated by alcyonarians (octocorals), sponges, algae, and smaller hardy stony coral (scleractinians) species (Enos 1977, Jaap 1982). Brown algae include: *Sargassum polyceratum*, *Turbinaria turbinata*, *Padina* sp., and *Stypopodium zonale*. These represent the most dramatic addition to the floral community. Relatively few sponges are present, mainly the large loggerhead sponge *Spheciospongia vesparia*, and *Clione lampa*. The hydrozoan fire coral *Millipora alcicornis* flourishes in these seaward communities. The alcyonarians are dominated by the sea fan *Gorgonia flabellum*, two species of the genus *Muricea*, and other octocorals common to the nearshore habitat. The more commopn scleractinians (stony corals) include *Diploria clivosa*, *Porites* (Holothurians), starfish, and several gastropods are typically absent in the seaward rockbottom habitat (Enos 1977, Multer 1977, Jaap 1982).

Calcareous Mud/Grass Habitat

In general, calcareous mud bottoms are found in the inner shelf margin associated with areas of restricted circulation, from Florida Bay seaward to the lee side of the shelf edge sand shoals, e.g., White Bank. Water depth is usually less than 8 m (26 ft) and the mud substrate is typically covered by one of the most rich and diverse species communities in the Keys marine environment, the seagrasses (Zieman 1982). The seagrass community, typically composed of turtle grass (*Thalassia testudinum*), manatee grass (*Syringodium filiforme*), and the shoal grass *Halodule wrightii*, stabilizes the fine calcareous mud which is necessary for its existence. This fine mud is the product of many of the community inhabitants, but most significantly of a few green algal species including *Halimeda opuntia*, *H. incrassata*, *Penicillus pyriformis*, and *P. capitatus*, (Turmel and Swanson 1976, Enos 1977). Other commonly found flora include the green algae *Caulerpa paspaloides*, *Udotea* sp., *Rhipocephalis oblongus*, and *Aurainvillea nigricans*; the red algae *Jania* sp. and *Amphiroa* sp.; the encrusting coralline algae *Melobesia membranacea* and *Fosliella farinosa*; and the brown algae *Padina* sp. (Enos 1977, Zieman 1982).

The fauna, following the pattern set by the flora, includes many sediment producing forms, most significant of which are: foram miliolid (*Quinqueloculina lamarkiana*) and peneroplid (*Archais angulatus*); the gastropods *Modulus modulus*, *Tegula fasciata*, *Astrea americana*, *A. longispina*, *Cerithium eburneum*, and *C. literatum*; the bivalves *Codakia orbicularis*, *C. orbiculata*, and *Chione cancellata*; and the tunneling shrimp *Calianassa* sp. (Enos 1977). Numerous species of foraminifera are present, including several species of the genus *Quinqueloculina* and *Triloculina*. This habitat contains the greatest variety of erect, most siliceous, sponges on the reef tract, and *Spongia* sp. Alcyonarians (soft corals) are rare, and the scleractinians (stony corals) are generally limited to a few smaller species including the rose coral *Manicina areolata*, the tube coral *Cladacora arbuscula* and the finger corals *Porites divaricata* and *P. furcata*. Numerous species of small invertebrates are found among the sponges, corals, and bases of the grassblades, including turbellarian flatworms, errant polychaetes, crabs, and brittlestars. Several species of gastropod snails feed on the epiphytic flora of the grass blade including *Tegula fasciata*, *Modulus modulus*, and two species of *Astraea* listed above (Zischke 1973, Enos 1977, Zieman 1982).

Common infaunal species in the seagrass beds include tube dwelling annelids *Onuphis magna*, *Arenicola cristata*, and *Spirorbis* sp.; several burrowing bivalves including the pen shells *Atrina rigida* and *A. seminuda*, the cross-barred venus (*Chione cancellata*), and several species of the genera *Arca*, *Anadara*, *Barbatia*, and *Tellina* sp.; and numerous interstitial species (e.g., *Caecum*). These infaunal bivalves are fed upon by the gastropods *Fasciolaria tulipa* and *Pleuroploca gigantea* (which also preys on the herbivorous queen conch, *Strombus gisas*), and by the starfishes *Oreaster reticulata* and *Echinaster sentus*. Other common echinoderms include the herbivorus sea urchin *Eucidaris tribuloides*, *Lytechinus variegatus*, and juveniles of the long-spined urchin *Diadema antillarum*, and the deposit feeding sea cucumbers Holothuria floridana and Actinopyga agassizi. Two commonly occurring snails without external shells are the nudibranch Tridachia crispata (seasonal) and the large spotted "sea hare" Aplysia dactylomela. The resident crustaceans include the large blue crab Callinectes ornatus and many smaller forms like the shrimp Palaemon tenuicornis, Latrentis fucorum, Penaeus brasiliensis, and Tozeuma carolinensis, and the mantis shrimp Pseudosquila ciliata.

The seagrass meadows provide nursery grounds for the early stages in the life histories of several organisms including the pink shrimp Penaeus duorarum, the cephalopod Octopus briarcus, the spiny lobster Panulirus argus, and numerous fish species, such as sea trout, jacks, pompano, barracudas, mullet, cowfish, and snappers (Zischke 1973, Zieman 1982).

Calcareous Mud/Bare Bottom Habitat

Progressing seaward from the nearshore hardground and seagrass/mud substrate meadows, the depth increases to a maximum of 7 to 17 m (23 to 56 ft) in Hawk Channel. In these deeper waters (> 8 to 10 m or 26 to 33 ft), particularly where turbidity is high, are large regions of bare mud lacking any grass cover, presumably due to the excess siltation and the subsequent lack of sunlight penetration. Both biological (e.g., fish, benthonic organisms, and burrowers), and physical forces (wind drien currents) probably put enough sediment into suspension to create the continuous high turbidity. Circulation in this environment is somewhat restricted, except during late fall and winter when strong prevailing winds from the north/northeast and northeast blow parallel to Hawk Channel, causing resuspension rather than movement of the sediments out of the channel.

Compared to the shallower grass-covered mud bottom, the species density and diversity is greatly reduced. The vegetation is primarily restricted to several calcium carbonate producing green algae including Penicillus sp., Halimeda tridans, Udotea cf., U. cyathiformis, and Rhipocephalus sp. The faunal community consists of several foraminifera, principally the peneroIids Peneroplis sp., and miliolids Quinqueloculina sp.; generally no alcyonarians (soft corals); few, if any sponges; the scleractinian rose coral Manicina areolata; the scaphopod Dentalium sp.; the gastropods Cerithium sp., Olivella sp., and Vermicularia knorri; the burrowing pelecypods Chione cancellata and Codakia sp.; annelids and arthropods such as the tunneling shrimp, Calinassa sp.; and the echinoid sea biscuit Clypeaster rosaceus (Enos 1977).

Calcareous Sand/Grass Habitat

Between Hawk Channel and the outer reef on the back-reef platform, large areas are blanketed with calcareous sands. Two varieties of habitat exist within this environment: (1) the first is characterized by loose, often fairly well-sorted, clean, rippled sand with a paucity of obvious life; (2) the second is characterized by grass-held sands having a comparatively rich variety of living fauna and flora. The distribution of the grass-held sand habitat does not appear to be particularly systematic, except that, in general, where wave action is most vigorous, grass is absent. Unlike the landward mud substrate habitats, the deeper less wave-agitated areas on this sany back reef platform exhibit low turbidities because few fines are available in the sediment.

This is reflected in the occurrence of grass communities at much greater depths than observed in Hawk Channel.

The grasses include the turtle grass (*Thalassia testudinum*) and manatee grass (*Syringodium filiforme*), dominated by the former. Both act, as they did on the mud substrates, to stabilize skeletal and other organic debris with their blade and root systems. Common algal species include the green algae *Halimeda opuntia*, *H. incrassata*, *Penicillus capitatus*, *P. pyriformis*, and *Udotea* sp., and occassionally the red algae, *Melobesia membranacea*. A variety of mollusks, echinoids, forams, sponges, arthropods, and a few scleractinian corals, including the rose coral *Manicina arcolata* and the finger coral *Porites divaricata*, make up the majority of the habitat's fauna. The most common fauna in terms of size and/or abundance include the foraminifera *Archais angulatus*, the gastropods *Modulus modulus*, *Cerithium* sp., and predator, *Pleuroploca gigantea* and the pelecypods *Laevicardium laevigatum* and *Tellinia* sp. (Enos 1977). Many of the faunal species observed in the grass covered mud bottom habitat are common here as well.

Calcareous Sand/Bare Bottom Habitat

As stated previously, on the sand shoals where wave action is the most vigorous, the grasses, e.g. *Thalassia testudinum* are absent. The "White Bank" seaward of the upper keys is an example of the barren calcareous sand blanket. The Halimeda-rich, medium to coarse grain clean sand has been brought in from the adjacent outer reef zone by strong current action, forming rippled sand bottoms and migrating dunes. The habitat communities range from an "underwater desert" to a pioneer seagrass community. The few consistently occurring inhabitants include several echinoids (*Meoma ventricosa*, *Clypeaster rosaceus*, *Plagiobrissus grandis*), and the sand dollars *Encope michelini*, *Clypeaster subdepressus*, and *Leodia sexiesperforata* which burrow in clean, grassless sand regions (Kier and Grant 1965). Occasional conches are observed and a population of shrimps, crabs, flounders, stargazers, lizard fishes, and various eels may also reside in the area, emerging only at night (Multer 1977). In the less turbulent areas but still devoid of grasses, calcareous green algae such as *Halimeda incrassata*, *H. tuna*, *Udotea* sp., and *Penicillus capitatus* may form a pioneer community. The accompanying fauna include a few foraminifera, the scleractinian corals *Manicina areolata* and *Porites divaricata*, several burrowing gastropods, pelecypods, and annelids (*Arenicola* sp.), the tunneling shrimp *Calianassa* sp., the starfish *Oreaster reticulatus*, and the previously mentioned echinoids (Kier and Grant 1965, Enos 1977, Multer 1977).

Patch Reefs

Over 6,000 patch reefs are found, generally landward of the shelf-edge slope break in areas of sand, mud, or rock substrate, between Miami and the Marquesas Keys. Most are located in a band that lies 3 to 7 km (2 to 4 mi) from the islands between Hawk Channel and the outer bank reefs (Marszalek et al. 1977). They typically cluster in broad belts, individually surrounded by a narrow band of bare sandy sediment. These bands occur even in areas of dense seagrass cover or bare mud bottoms. Randall (1965) and Zieman (1981) have shown that the bare sediment halos are a result of overgrazing of grass by fish that reside in the reefs by day and feed in the grasses at night. These bare areas, particularly with a mud substrate, tend to create a very turbid environment. There are two basic recognizable patch reef formations: (1) the dome patch reef; and (2) the linear coalesed patch reefs or embryonic bank reef (Marszalek et al. 1977, Japp 1982). The location of patch reefs in the Florida Keys Reef Tract is very nicely illustrated by Enos (1977) and in a continuing series of large maps by Marszalek (1977, 1982).

The dome-shaped patch reef is typically circular or elliptical in shape with a very clear barren halo around it. This form of patch reef usually occurs in clusters, in depths ranging from 2 to 9 m (7 to 30 ft). Patch reef size varies from a few meters across to more than 700 m (2,297 ft) and only rarely exceeds 5 m (16 ft) in height. Distribution of these reefs is primarily seaward of the upper Keys (northern Key Largo and Elliott Keys), the lower Keys (Sugarloaf Key to Key West), and the distal islands. The community consists primarily of seleractinian and alcyonarian corals, mostly erect sponges, numerous anemones, sea urchins, other invertebrates, and red and green algae (Enos 1977, Marszalek et al. 1977). The community assemblage varies greatly depending principally on the reef's age and environmental setting (Jaap 1982). Jones (1977) identified several life stages exhibited by changing patch reef species composition. The pioneer stage is similar to the community assemblages described for hardground, mud, and sand substrate habitats. The scleractinian corals Porites porites and Manicina areolata, and the star coral Favia fragum are often associated with the patch reef beginnings. The second phase of growth includes the introduction of the principal reef builders, the starlet coral Siderastrea siderea, the brain corals Diploria labrinthiformis and D. strigosa, the common star coral Montastrea annularis, Colpophyllia natans, and the finger coral Porites astreoides. As the structure grows upward and outward, boring and rasping fauna enter the scene creating coral sediment which fills intercoral spaces, and excavates the interior structure of the above mentioned reef builders. The hollowing out of the internal structure creates a labrinth of passages, caves, and crevices which in turn provides a new habitat suitable for a multitude of shelter seeking organisms. The patch reef matures as the coral reaches the maximum upward extension (sea level). During this period alcyonarians prosper between the corals while the hydrozoan fire coral (Millepora alcicornis) invades old or dead alcyonarians. Eventually, areas with extensive internal excavation may collapse, or catastrophic events may convert portions or entire patch reefs into rubble mounds or hardbottom flats (Jaap 1982).

The coral assemblage of the dome-shaped patch reefs is similar to the linear patch reefs and outer bank reefs except for the absence of the moose-horn or elkhorn coral, Acropora palmata, a principal reef builder. In the dome patch reefs this coral is replaced by Montastrea annularis which may form single colonies exceeding 5 m (16 ft) in height.

The other form of patch reef was identified by Marszalek et al. (1977) as the linear-type patch reefs, and by Jaap (1982) as a embryonic bank reef composed of coalesed patch reefs. In either case, this form is typically found seaward of the dome shaped patch reefs and elongated parallel to the reef tract's outer reefs. They possess a well-developed reef flat and rudiments of spur and groove formations of Acropora palmata on the seaward slope (Jaap 1982). Colonies of Acropora palmata also occur on the reef flat, usually in association with the fire coral Millepora complanata, the alcyonarian sea fan Gorgonia ventalina, the encrusting brain coral Diploria clivosa, and the staghorn coral Acropora cervicornis. In addition to the numerous coelenterates, the organisms commonly found in both types of patch reefs include the algae Goniolithon sp. and Halimeda opuntia, occasionally the seagrass Thalassia testudinum, numerous erect sponges, e.g. Ircinia sp., the bivalves Arca sp., Lithophaga sp., and Barbatia sp., the gastropods Strombus gigas and Corallophila abbreviata, the arthropods spiney lobster Panulirus argus and stone crab Menippe mercenaria, the echinoids Diadema antillarum and Echinometra lucunter, and numerous foraminfera, fishes, ostracods, and bryozoans (Enos 1977, Multer 1977, Jaap 1982).

Outer Reef

Outer reefs or reef banks are located very near or at the shallow shelf break along the seaward edge of the shelf margin. Typically elongated, these reefs form a narrow, linear, discontinuous belt which is best developed seaward of Key Largo and the lower Keys (Sugarloaf to the Marquesas Keys). The outstanding features of these outer reefs are: (1) the occurrence of the moosehorn coral Acropora palmata; (2) the vertical coral zonation off the terraced reef front; and (3) the distinctive seaward spur and groove formation (Multer 1977). Table 40 shows two zonation schemes developed from studies of the lower reef tract (Kissling 1977) and, primarily, the upper reef tract (Jaap 1982).

Zone (After Jaap 1982)	Depth (m)	Zone (After Kissling 1977)
Back reef (rubble)	0.6-1.8	Back reef
Reef flat	0.6-1.2	Reef flat
Shallow spur & groove	1.2-2.4	Reef buttress
Deep spur and groove	2.4-4.6	Reef buttress
Buttress or fore reef	4.6-30.0	Fore reef
Deep reef	41.1	Fore reef

Table 40. Bank reef zonation.

Flora and fauna characertistics of these sub-zonations on the outer reef are difficult to pinpoint because of the apparent assemblage variation from one area to the next. It is not unusual to find an organism identified as the most significant member of a class (e.g., based on size and abundance) reported from one reef system to be absent or negligible on another (Enos 1977, Kissling 1977, Jaap 1982). As a result, those mentioned below are simply the most commonly observed (probable) organisms.

On the shallow reef flat the organisms include the stony corals, such as porous coral Porites astreoides, lettuce coral Agaricia agericites, clubbed finger coral Porites porites, and brain coral Diploria clivosa; the alcyonarians Plexaura flexuosa, Pterogorgia citrina, and Eunicea mammosa; the hydrozoan Millepora complanata (stinging coral); the green algae Halimeda opuntia; and encrusting and branches coralline algae.

The reef butress commonly includes one or two sets of spur and groove terraces providing a variety of micro-environments within which are usually found the scleractinians Agancia agericites, Porites astreoides, P. porites, and Siderastrea *siderea*, the moosehorn coral *Acropora palmata*, the staghorn coral *A. cervicornis*, the soft corals *Gorgonia ventalina* and *Plexaura flexuosa*, the hydrozoan *Millipora complanata*, various encrusting and branching coralline algae, the green algae *Halimeda opuntia*, and the brittle stars *Ophiothrix orstedii* and *Opliocnida* sp.

The most seaward portion of the outer reef habitat exhibits a vertical gradient of corals with increasing depth. The scleractinians and alcyonarians reach a maximum level of numbers and diversity in the upper portions of this zone (8 to 10 m or 26 to 33 ft). Many of the larger reef builders also flourish in this area, including the star corals *Montastrea annularis* and *M. cavernosa*, the brain corals *Diploria strigosa* and *Colpophyllia natans*, the porous coral *Porites astreoides*, the starlet coral *Siderastrea siderea*, the moosehorn coral *Acropora palmata*, the staghorn coral *A. cervicornis*, and the sclerosponge *Ceratoporella* sp. Other organisms include the alcyonarians *Briarcum asbestinum* and *Plexaura flexuosa*, coralline algae *Halimeda opuntia*, the stinging coral *Millipora alcicornis*, the coral and sponge dwelling brittle stars *Ophiothrix* sp. and *Ophiactis quinqueradia*, and the lettuce coral *Agaricia agericites* (Ginsburg and James 1974, Enos 1977, Kissling 1977, Jaap 1982). The previous lists represent only a fraction of the outer reef assemblage. Kissling (1977) has identified, from 9 outer reefs off the lower Keys, over 350 macrobenthic species including benthic macroalgae, marine grasses, sponges, anemones, scleractinian, hydrozoan and alcyonarian corals, flatworms, nemertine worms, sipunculids, bryozonans, oligochaete and polycheate annelids, gastropods, scaphopods, pelecypods, cephalopods, crustaceans, pycnogonids, tunicates, asteroids, ophiuroids, echinoids (e.g., *Diadema antillarum*), holothurians, and crinoids. This includes 42 species of stony corals, 41 species of soft coral and 21 species of brittlestars. They estimate that more than 300 species of fish inhabit these reefs, which would be less than the 517 species and 440 species observed in Alligator Reef off Key Largo (Starck 1968) and the Dry Tortugas reefs (Longley and Hildebrand 1941), respectively.

Forereef Mud/Sand Habitat

At depths exceeding 18 to 25 m (59 to 82 ft) along the fore reef slope of the outer reef, blankets of calcareous muddly sands occur. Usually too deep for seagrasses (possibly the more shade tolerant *Halodule* sp. could survive) (Zieman, 1982), the predominant flora include the green algae *Acetabularia* sp., *Halimeda opuntia*, *H. tuna*, and *Udotea* sp., and various encrusting and branching coralline algae. The fauna is characterized by pelagic foraminifera (e.g., *Globigerina* sp.), a few scleractinians (rose coral *Manicina areolata* and lettuce coral *Agarica fragilis*), several echinoids including sea urchins (*Diadema antillarum*, *Ecuidaris tribuloides*, and *Astropyga magnifica*) and sand dollars (*Clypeaster subdepressus*), and gastropods (e.g., *Calliostoma* sp.) (Ginsburg and James 1974, Enos 1977).

Shoal Fringe Habitat

A majority of the inner shelf margin shoals have a slightly elevated fringe environment that supports a unique organic community characterized by calcareous red algae and numerous finger corals. This habitat occurs in shallow waters of the nearshore environment and experiences wide temperature and salinity variations. The substrate is a fine calcareous mud, and represents a product of the restricted circulation and the numerous sediment producing plants and animals that populate the windward sides of the shoal mud-mounds (Ginsburg and James 1974). Referred to as the "Algal Bank Community" by Ginsburg and James (1974), it is made up of loose branched finger corals (Porites porites and P. divaricata) and branched and segmented coralline red algae (Goniolithon strictum). The shoals surrounding Rodriques Key (off Key Largo) provide the best studied example of this habitat (Turmel and Swanson 1976).

In addition to the red algae Goniolithon sp., the flora consists primarily of the turtle grass (Thalassia testudinum), laminated blue-green algal biscuits (onocolites), and numerous green algae, most commonly including Halimeda Opuntia, H. incrassata, and Penicillus capitatus.

The fauna usually includes a variety of siliceous sponges, foraminifera, tunicates, the stinging coral Millepora alcicornis, several species of brittle stars (ophiuroids), the sediment-ingesting holothurian Holothuria floridana, several echinoids and starfish, and the tunneling shrimp Callianassa sp. The mollusks are esentially the same as described for the grass-covered mud bottom habitat (Turmel and Swanson 1976, Enos 1977, Kissling 1977).

Reef Rubble Habitat

In the back reef area, immediately adjacent to the outer reefs, and on dead reefs at the slope break, coarse reef rubble accumulates and forms a distinctive habitat and associated biotic assemblage. These areas represent an intermediary phase between the mature coral reef and hard rock bottom habitat. Biological and physical (hurricanes) forces act on existing coral reefs to provide the substrate for the rubble community. The reef rubble community consists of numerous sediment producing and cementing organisms that will eventually fill and cement the voids and crevasses between the rubble to form a rock bottom (Multer 1977).

The flora most commonly occurring includes the green algae Halimeda opuntia, Batophora sp., and Dascyladus vermiculata, the red coralline algae Lithothamnium sp., and brown algae (e.g., Sargassum polyceratum). The fauna consists primarily of foraminifera, the fire coral Millipora alcicornis, the starlet coral Siderastrea sidera, numerous alcyonarians (e.g. Plexaura flexuosa, Gorgonia flabellum) typical of hard rock bottoms and the fore reef habitats, and several echnoids (e.g., Diadema antillarum, Eucidaris tribuloides) (Enos 1977, Multer 1977).

The geographic placement of the marine habitats, included in the previous discussion, is a generally accurate picture of the Florida Keys marine setting (Enos 1977). Often, however, this pattern is broken, reflecting localized transient and permanent variations of the physical forces, particularly circulation and depth. Zieman (1982) presents an interesting example of the transient form with a description of seagrass recolonization following a disturbance known as a blowout. A blowout is an area of seagrass where a disruption of the rhizome/substrate integrity permits the active erosion and undercutting of the seagrass bed. What results is a crescentic form tens of meters wide that presents a gradation of habitat types (bare rock, mud, or sand bottoms to grass covered) reflecting differences in depth, flow, and substrate. Catastrophic events, such as hurricanes, are another form of a transient physical force temporarily or, in some cases, permanently disrupting the typical habitats. Coupon Bight represents an area characterized by various habitat forms in close proximity which reflect more permanent differences in depth, circulation, and substrate (Howard and Faulk 1968, Kissling 1968, Lineback 1968). The point is that the Keys' marine habitats, although following a general geographic scheme from shoreline to shelf break, can be quite variable in their pattern of occurrence.

9.3 HABITAT PARTITIONING FOR FISH AND WILDLIFE PRODUCTION

9.31 ENERGY FLOW

The generalized flow of energy through the Florida Keys system is illustrated in Figure 58. The system is formed from three major divisions of habitats including terrestrial, shoreline (intertidal), and marine habitat groups. Obviously the delineation is not a strict one as observed, for example, in the overwash mangrove island (e.g., Rodriquez Key) where extensive interconnection exists between seagrass, intertidal, and mangrove habitats.

In general the Keys are home (or a visiting place) for a wide variety of fauna. These fall into two broad categories which reflect the prevailing forces that drive the Key's energy flow:

(1) the opportunists such as the probing shorebirds and marine transients. Relatively high physical energy of mixing (from tides, currents, and wind), the extensive shallows, and the mild climate make the Keys an ideal spot for shorebirds in search of sea wrack and mud flat organisms, especially in the winter. The nearness of the pelagic environment and nearshore estuaries make the keys a kind of interface zone through which life history stages of many marine species may pass; and

(2) the specialists such as the invertebrates and fishes of the coral reef. The rather stable subtropical climate makes the Keys home for a variety of animals that depend on very specific conditions available only in highly differentiated habitats such as the coral reef and the tropical hardwood hammock.

As in Florida Bay the lower Everglades, detrital material serves as a primary source of energy flow between and within the major habitat divisions. Debris formed from mangrove leaf litter, as discussed in Section 7.31, either accumulates to form peat, or is transported via tidal flushing or storm activity into the nearshore waters undergoing further bacterial decomposition, consumption by detritivores, or sedimentation (Odum et al. 1982). Seagrass debris is formed by grazing, mortality from exposure to air on shallow banks, wave induced tearing of senescent leaves, and entire plant removal by storm activity (Zieman 1982). Leaves of manatee grass (Syringodium filiforme) and turtle grass (Thalassia testudium) are particularly important in detrital energy flow since they tend to float at first, thus forming mobile periphytic communities. This

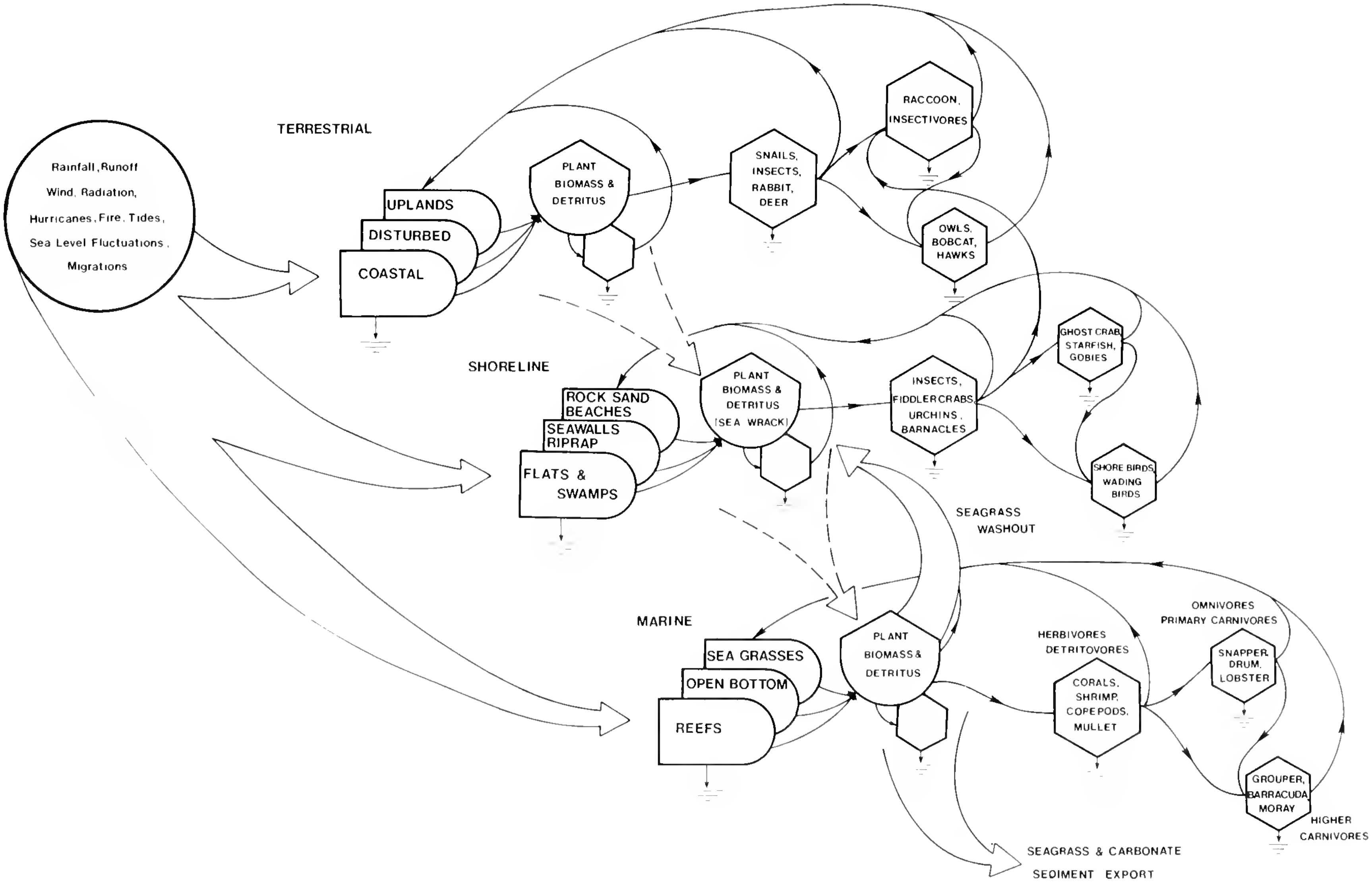


Figure 58. Summary diagram of energy flow through the Florida Keys ecosystem.

floating debris moves according to the whims of the tide and wind-driven currents. Some are exported seaward into the Florida Current, or westnorthwest through the Keys into the gulf, or washed onshore to become part of the sea wrack (Zieman 1982). Turtle grass typically retains most of its leaf biomass locally, incorporating it as litter and thus recycling its nutrients. Manatee grass, because of its circular shape and relatively smaller diameter is more susceptable to grazing loss; as much as 60% to 100% of the daily production may be detached and exported (Zieman 1982).

In contrast to Florida Bay and the lower Everglades, less detritus is exported from the Florida Keys. Zieman (1982) estimates that only about 5.1% of the daily production of turtle grass (*Thalassia testudium*) is exported, and this is primarily as bedload. The rest is incorporated into litter, decomposed, or fed upon. This rather tight nutrient cycling and energy flow probably results from a combination of forces: (1) high physical energies leading to high productivity; (2) the stable climate which promotes the development of extremely energy efficient communities such as coral reefs; and (3) the location of the Keys as an interface between the nearshore estuaries and pelagic zones.

Because of high physical energy of mixing, Keys' waters are extremely clear, swept clean as it were by nearby oceanic currents. The general lack of turbid terrestrial runoff also contributes to water clarity as does the vacum cleaner effect of filtering corals and plankton, and the sediment trapping effect of seagrass beds. These conditions promote seagrass and coral reef productivity.

The coral reef exemplifies the concept of the complex and efficient recycling system in which scleractinian coral polyps maintain a symbiotic relationship with the algal zooxanthellae. The algae are protected in the tissues of the coral animals, which are themselves protected by highly specialized cell products, the nematocysts (stinging organelles used to paralyze and trap prey). Coral respiration and algal photosynthesis result in a mutually beneficial exchange of gases (CO^2 and 0_2), nutrients, and organic materials. Certain of the organic materials produced by the zooxanthellae are used in the development of the corallum structure (Goreau 1959, Odum et al. 1974).

The close recycling of materials at the primary trophic levels emphasizes the role of the mobile resident and transient organisms as sources of energy flow between the keys habitats and between pelagic and nearshore habitats. Faunal interactions between keys habitats fall into 3 general, but by no means exclusive, categories:

(1) mangrove - seagrass interactions;
(2) upland - seawrack - shallow flats interactions; and
(3) seagrass - coral reef interactions.

Examples of category (1) include the grey snapper (*Lutjannus griseus*), spotted seatrout (*Cynoscion nebulosus*), and the red drum (*Sciaenops ocellota*) which initially recruit into the seagrass habitat, and with growth, move into the mangrove areas for several years (Heald and Odum 1970).

Examples of category (2) come from both land and water. On land, the raccoon (*Procyon lotor*) is a nocturnal visitor to the shoreline sea wrack community, feeding on insects, mollusks, crustaceans, and fish, returning during the day to the pinelands hammocks and mangrove forests (Rabkin and Rabkin 1978). In the shallow flats through which the sea wrack passes and in which it partially originates, the flotsam is somewhat like a floating island accumulating even more marine periphyton, while yielding a diverse food source to shallow water fishes and other predators. These floating islands are a likely transport mechanism for terrestrial insect fauna between isolated keys (Simberloff 1976).

Examples of category (3) include nocturnally active coral reef fishes of several families (including Holocentridae, Lutjanidae, and Pomadasyidas) which feed over the adjacent seagrass beds at night (Zieman 1982). On a somewhat more regional scale the spiny lobster (Panulirus argus), pink shrimp (Penaeus duorarum), and grey snapper (Lutjanus griseus) are examples of organisms that range over a wide area and numerous habitats as a function of their life history (Zieman 1982).

9.32 INVERTEBRATES

To adequately summarize, or even highlight the distribution and ecology of marine and terrestrial invertebrates in the Florida Keys is beyond the scope of this report. The Florida Keys are a living laboratory for the study of marine invertebrates. As the site of one of North America's very few coral reef ecosystems and certainly its most accessible, much attention has been focused on studying its diversity and function (Jaap 1982).

Two of the more commercially important (and often studied) components of the invertebrate fauna are the pink shrimp (Penaeus duorarum) and the spiny lobster (Panulirus argus). Commercial shrimp landings from the Florida Keys constitute a major portion of the total statewide fishery. For the years 1970-1972, Monroe County landings of pink shrimp (Penaeus duorarum) averaged 5,389,587 kg (11,871,337 lbs) per year or roughly 35% of the total statewide shrimp haul (Prochaska and Cato 1974). For the most part, commercial shrimping focuses around the Tortugas shrimping grounds northwest of Key West. Due to the great value of this resource, a significant body of research has been conducted over the years on shrimp ecology and population dynamics. Particularly after 1954, when additional markets developed for smaller size shrimp, the question arose as to how to best manage the Tortugas grounds for sustained optimum yield (Iversen and Idyll 1959).

Intensive sampling and analysis of the Tortugas grounds in the mid fifties revealed that the smaller shrimp tend to inhabit the shallower waters of the grounds, a conclusion that is generally reinforced by many investigators as well as fishermen. In an effort to prevent excessive exploitation of the shrimp population, a "controlled area" was defined off of Key West within which shrimp could not be harvested. This "controlled area" corresponds to a sort of refuge on the shallower portions of the Tortugas grounds and the area surrounding the Marquesas Keys (Ingle et al. 1959). Table 41 presents data on the size range distribution of shrimp within the controlled area.

Size Range (mm)	%
10-50	0.2
51-90	21.0
91-130	69.0
131-170	9.6
171-200	0.2

n = 16,000+

Table 41. Size range distribution of pink shrimp in the controlled area off Key West, Florida (adapted from Ingle et al. 1959).

Predicting the timing and extent of shrimp abundance on the Tortugas grounds is of primary importance in making management recommendations for the fishery. Consequently, research has focused on trying to understand the growth and migratory patterns of the pink shrimp and the factors which control their seasonal and yearly fluctuations. Although there still remain many gaps in this knowledge, Figure 59 represents a simplified model of the pink shrimp life cycle and migratory patterns in the area. The following discussion follows this model through one loop in the cycle.

As adults, various size classes of shrimp are rather broadly dispersed all over the Tortugas grounds but with some distinct tendency for smaller, younger shrimp to congregate in shallower waters along the south/southeast boundary of the grounds and larger shrimp in the deeper waters (Iversen et al. 1960). The smaller shrimp are believed to be the year's early recruits from the estuarine nursery areas. These same authors note that there is not only a size/depth correlation but also an increasing size gradient in a northerly direction from Key West irrespective of a depth increase. Controlled release and recovery of shrimp over the Tortugas grounds confirms that a general northwesterly movement of individuals takes place, but this is by no means always the case (Iversen and Jones 1961). An average migration rate (in all directions) of about 8 km/day (5 miles/day) is reported. Numbers of shrimp at the surface and mid-depth generally decrease from midnight to mid-day and increase from mid-day to midnight (Roessler et al. 1969).

While on the Tortugas grounds, female pink shrimp tend to grow faster, and ultimately, larger than male shrimp (Iversen and Idyll 1960). The effect of temperature on growth of pink shrimp is believed to be relatively small. Iversen and Jones (1961) report that, in cage experiments, growth during the warm months is not significantly greater than during the cooler months. In fact the high summer temperatures appear to slow the growth of shrimp relative to springtime growth rates.

It is believed that the gradual movement of older, larger adults into deeper waters corresponds to the onset of spawning in the pink shrimp. Female shrimp become capable of reproducing when they reach about 90 mm (3.5 in) in length (Ingle et al. 1959). Spawning occurs all year round in warm south

Florida waters, although there is distinct temperature amplification. Jones et al. (1970) and Roessler et al. (1969) report notable spawning peaks occurring in spring and summer which apparently depend on bottom water temperatures. The temperature regime is fairly constant all year in the Tortugas grounds, although Iversen and Idyll (1960) note that a thermocline may develop during the summer. This is generally a short lived phenomenon, however, due to the influence of strong winds. The occurrence of an occasional thermocline may help to explain the sporadic nature of summer spawning peaks noted by Roessler et al. (1969). Shrimp spawn most actively between 27° and 30.8°C (81° and 87° F).

Spawning is generally restricted to areas greater than 6 fathoms (39.4 m or 129 ft) in depth. There is also some indication that spawning is greater during the waning moon phases. An average annual production of 87 x 10" protozoea/year is estimated by Roessler et al. (1969). Average survival rates ranging from 74% to 98% percent (mean = 80.4%) per day are estimated for larval stages of pink shrimp (Munro et al. 1968, Jones et al. 1969, Roessler et al. 1969).

Early nauplii and young protozoeal stages are believed to remain fairly close to the bottom. However, second and third protozoea and mysis stages apparently undertake considerable vertical migrations, a behavior that may greatly enhance their ability to exploit prevailing surface and bottom water movements and thus move in a net direction.

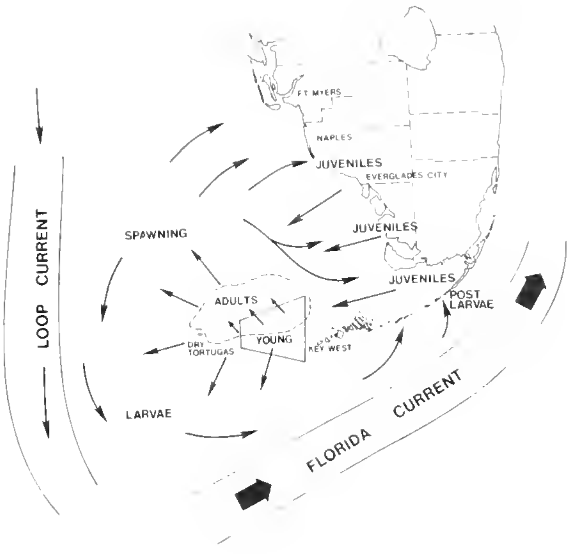


Figure 59. Simplified model of shrimp migratory patterns in south Florida (adapted from Ingle et al. 1959)

In the simplified model of Figure 59, larvae are portrayed as following two routes in their quest to reach estuarine nursery areas. The first, and lesser studied route, involves direct travel across the shallow shelf toward the Ten Thousand Islands, Whitewater Bay, and Florida Bay. In taking this route, planktonic larvae must traverse an area of very complex and sometimes contrary currents (see Florida Keys Hydrology, Section 5.7). Nonetheless, Jones et al. (1969) reported finding numerous post larvae apparently moving in this direction. The second route is somewhat less direct, but probably more energy efficient for the larvae. It involves the fortuitous coupling of the planktonic life style with locally cycling currents. In this route larvae are swept southwestward by prevailing surface and bottom currents. Further south, as these currents become increasingly influenced by the Florida Current, the larvae are swept northeastward along the outer banks of the coral reef tract. As the shrimp larvae gradually move northeastward they develop into post larvae. By the time developing

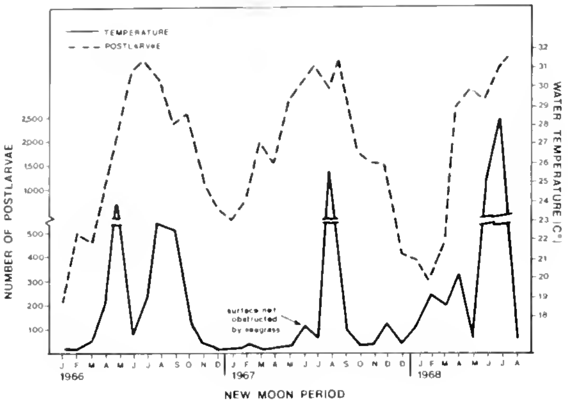


Figure 60. Seasonal abundance of post larval shrimp at Whale Harbor Channel in the upper Keys (adapted from Allen et al. 1980).

shrimp reach the post larval stage they begin to enter Florida Bay on incoming tides through the channels in between the Keys (Allen et al. 1980). Figure 60 displays the obvious correlation between sea water temperature and post larval abundance in one such channel in the upper Keys. Seasonal peaks in abundance occur from May through August or September. Superimposed on this pattern Allen et al. (1980) also report seasonal variation in the depth at which shrimp post larvae abound (Table 42). During peak seasonal abundance the shrimp tend to concentrate in the surface waters, while during lower periods of abundance highest numbers are found at mid-depth.

Apparently one of the more important factors controlling the migration of shrimp is their ability to respond differently to ambient conditions as a function of life stage. The post larvae, which are looking to enter the nursery area, seem to seek out the incoming tides and avoid the outgoing tides (Allen et al. 1980). The reverse is apparently the case for juvenile shrimp on their way back offshore (Tabb et al. 1962).

Depth	Percent by Season		
	Overall	May-Aug.	Sept.-April
Surface	39.9	33.1	59.7
Mid depth	54.7	60.9	36.9
Bottom	5.4	6.0	3.5

Table 42. Seasonal variation in the relative distribution of pink shrimp post larvae with depth (adapted from Allen et al. 1980).

A number of authors have pointed to the seasonal correlation between nearshore salinity and runoff, and post larval and juvenile shrimp abundance. Allen et al. (1980) believe the increased intertidal habitat created by seasonal water level fluctuations in Florida Bay is one of the more important factors contributing to the survival of young post larvae. Another factor that must certainly be involved is the tremendous seasonal pulse of detritus in the nearshore ecosystem. Still another reason may be the relative protection from aquatic predators afforded by the low salinity environment. Whatever the nature of the dependence may be, the estuarine and nearshore Keys environments most definitely play a key role in the productivity of the Tortugas shrimping grounds.

While in the Florida Bay nursery area, there appears to be an increasing gradient of size and age toward the north (Allen et al. 1980), indicating a gradual migration in this direction. Tabb et al. (1962) report that most post larval shrimp arriving in Coot Bay have 6 to 7 dorsal rostral spines, a characteristic which is believed to indicate distance traveled from spawning grounds. This corresponds to an estimated age of about 35 days. Numbers of benthic juveniles within Florida Bay are strongly correlated with numbers of post larvae incoming through Keys channels (Allen et al. 1980). On the average, juvenile shrimp spend anywhere from 2 to 7 months within the nursery area (Costello and Allen 1960). Predation accounts for the majority of losses in both juvenile and larval/post larval stages (Tabb et al. 1962). Roessler et al. (1969) estimate that only 0.05 to 0.14 percent of the original protozoea actually reach the Everglades nursery grounds as post larvae.

The exodus of shrimp from the nursery areas appears to be fairly constant all year round (Iversen and Idyll 1960). Older shrimp tend to move into more stable high salinity environments. Yokel et al. (1969) report a high positive correlation between juveniles exiting from Everglades National Park waters and recruitment of young shrimp onto the Tortugas grounds. Release and recovery of tagged shrimp (Costello and Allen 1960) confirms the movement of juveniles from Flamingo to the Tortugas grounds and from the lower Keys to the Keys shallows south of the Tortugas grounds. Of the very small percentage of post larvae entering the Everglades nursery, Roessler et al. (1969) estimate that only about 6% contribute to the following year's commercial catch on the Tortugas grounds.

In 1972 the spiny lobster (Panulirus argus) ranked as the second most valuable commercial species of shellfish harvested from Florida waters (Seaman and Aska 1974). Historically, market demands for lobster have grown steadily while the catch, though clearly rising as well, fluctuates considerably from year to year. However, the increase in catch appears unable to keep pace with the increasing demand. In 1972 and 1973, 9.8 and 8 million kilograms (21.5 and 17.7 million pounds) respectively of lobster tails were imported into the U.S. compared to 3 million kilograms (6.3 million pounds) harvested from Florida waters (Johnson 1974). The vast majority of the state's catch is landed from waters surrounding the Florida Keys.

There is a growing belief that the Florida lobster fishery is fast approaching the limits of its maximum sustainable yield. Increasing numbers of commercial and sport fishermen, the illegal taking of small and/or gravid females, and the particular population dynamics of the Florida lobster combine to make this a subject of concern to fishermen, tourists, and researchers alike. Presently, the taking of lobsters is restricted to the period August 1 through March 31. The warmer months, April through July, are considered prime lobster spawning season and are thus closed to fishermen. Legal size allowed is a 76.2 mm (3 in) carapace or a 139 mm (5.5 in.) tail (disconnected). The taking of egg bearing female lobsters, or the stripping of eggs from berried females is strictly prohibited at all times.

It is generally held that the Florida spiny lobster population depends upon recruitment from Carribean stocks (Sims and Ingle 1966). Larvae are believed to be carried by the prevailing currents (Gulf Stream and Florida Current) north to suitable habitats along the southern Florida coast. Indirect evidence for this theory comes from the fact that post larvae are captured in plankton samples all year round, while the spawning season of Keys lobsters is restricted to the period March through August. Little and Milano (1980) have established that lobster post larval abundance peaks during the spring, a time when local populations are not reproductively active. The larvae apparently develop to phyllosome stage offshore and subsequently move inshore as transparent pueruli (Sweat 1968). Here they seek shelter, and presumably food, among the seagrasses, algal beds, soft muds, and corals.

Young post larvae grow fairly rapidly. Sweat (1968) reports that, in laboratory settings, days between successive molts increased from 26 to 118 days over 18 molts. Warner et al. (1976) calculated a growth rate of about 5.4 mm/molt (0.2 in/molt). It is likely, however, that growth rates are higher in the field than in the laboratory, as evidenced by a comparison of adult growth rates under similar lab and field conditions. Dawson and Idyll (1951) estimate that commercial size lobsters increase about 2.54 to 3.81 cm (1 to 1.5 in) per year.

A number of authors believe that the adeptly camouflaged juvenile lobsters tend to inhabit the inshore areas because of the increased cover (Sutcliffe 1957, Witham et al. 1968). Little and Milano (1980) observe that young post larvae are preyed upon by Portunid crabs and other carnivores of the inshore seagrasses. They suggest that "surplus" post larval recruitment is smoothed out by the time a given year class reaches adulthood. This is due to density dependent mortality arising from the restricted holding capacity of the nursery areas. As lobsters mature they tend to move out to the deeper waters and coral reefs.

Adult lobsters are higher carnivores of the coral reef system feeding on conchs (Strombus raninus, S. gigas), other mollusks, and hermit crabs (Hernkind 1975, Davis 1975). At densities observed by Davis (1977), the lobster population apparently comprises a major fraction of the resident carnivore biomass of the reef. The lobster is a nocturnal creature, feeding and foraging primarily in the early hours of the evening in winter and gradually extending the duration of its nightly activities during the spring and summer months. During the day, lobsters hole up in dens or lairs, seeking protection and cover. They may occassionally be found during daylight hours by watching for the conspicuous antennae protruding from the rock crevices.

The movements of adult lobsters occur in two general patterns: (1) random movements of individual lobsters; and (2) mass migration by queues, or chains of lobsters ranging anywhere from a few to thousands of individuals at one time. Release and recovery of tagged individuals suggests that adults moving singularly do not travel very far or fast (Dawson and Idyll 1951, Little 1972). Average distance traveled by tagged and recovered adults is reported to be 15.6 km (9.7 miles) (Dawson and Idyll 1951) and 9.8 km (6.1 miles) (Little 1972). Around 90% of the recovered adults are found within 32 km (20 mi) and 20 weeks of the release site and date. Little (1972) observes that the predominant movement of released lobsters is south toward the outer reefs. Movement patterns reported by Dawson and Idyll (1951) tend to confirm that most released lobsters move to the south, but many move to the north as well. Smith (1958) observes that lobsters tend to move offshore during cooler months.

Autumnal mass migrations of spiny lobster have been noted to occur in Florida waters, and have been extensively studied elsewhere in the Carribean (Herrnkind, 1969, 1975, Herrnkind et al. 1975, Kanciruk and Herrnkind 1978). In this peculiar behavior, which occurs subsequent to the summer mating season, lobsters are observed to slowly congregate in a given area, possibly cued to do so by changing photoperiod (Kanciruk and Herrnkind 1973, 1978). As they congregate, activity levels increase and small queues begin developing on a diurnal schedule; queues refer to the lining up, single file of 2 or more lobsters ultimately leading to mass migration of large numbers of individuals. Nonmigratory lobsters may also queue, but not nearly to the same extent.

Autumnal queuing behavior is apparently unrelated to the reproductive cycle of lobsters. Rather, Kanciruk and Herrnkind (1978) correlate the migratory crescendo of lobsters with the first significant temperature drop accompanying winter frontal systems. Subsequent winter storms, though they may be more severe than the first, do not elicit the same response.

The function of the mass migration remains largely a mystery, although Bill and Herrnkind (1976) report that mass migration of lobsters reduces hydrodynamic drag per individual. They calculate that a queue of 20 lobsters experiences only about half the drag that the same number of individuals experience moving on their own. It seems certain that the combination of movement by individuals and movement by autumnal mass migrations serves to keep the lobster population well mixed, if nothing else.

The long term effects of commercial and sport harvest on the spiny lobster population has long been a question of considerable interest. Dawson and Idyll (1951), Sweat (1968), and Little (1972) state that the results of tagging studies suggest underharvesting of the Keys stock. Frankly however, there is little information in such results upon which to base this conclusion. Recently, Davis (1974, 1977), Warner et al. (1976) and Lyons et al. (1981) have presented interesting and definitive data on the impact of harvesting on lobster populations in the Florida Keys and Dry Tortugas.

In anticipation of opening a portion of the Dry Tortugas National Monument to sport lobstering, the local lobster population was monitored for 29 months (Davis 1977). The study area was divided into three areas, an outer commercial harvesting area; an inner area, part of which was designated to be open to sport harvest; and the remainder of which was to serve as an unharvested control area.

During the initial monitoring period Davis established that there was a healthy resident population of spiny lobsters. This suggests that Carribean import is relatively less important than previously thought, at least in the Dry Tortugas. Indirect evidence for this assessment comes from a comparison of size class distribution differences between the commercially fished area and the unharvested monument area.

In the commercial area there is an obvious shifting of the population structure toward the small size individuals as commercial size lobsters are harvested. In the National Monument, population structure shifts toward the middle, the most frequent size classes being those of harvestable length.

Direct evidence of residency comes from the results of tagged juveniles and adults. Of all the lobsters tagged, released, and returned, none were reported from outside the Dry Tortugas area. By comparison, lobsters released in Biscayne Bay were found all throughout the Keys. Preharvest standing crop of *P. argus* is estimated at 58.3 kg/ha.

Subsequent to initial monitoring, sport harvesting was allowed for one season (8 months). During the following season (16 months) harvesting was again prohibited as the spiny lobster population was assessed for impacts. Immediately following the harvest season, monitoring revealed a 58% reduction in catch rate and only 42% of the preharvest lair occupancy density. The population in the control area remained essentially unchanged. After one year the catch rate returned to 78% of its preharvest value while lair occupancy density returned to 71% of its original level. Apparently a number of years may be required for the population to return to preharvest levels.

Similar evidence of commercial fishery impacts comes from Warner et al. (1976). Before the season the mean carapace length of lobsters near Key West was 77.5 mm (3 in) and modal length 74.5 mm (2.9 in). After the fishing season opened mean and modal length dropped to 72.9 and 68.5 mm (2.8 and 2.6 in) respectively. Figure 61 summarizes the effects of differing degrees of fishing intensity on lobster population distributions in the Florida Keys.

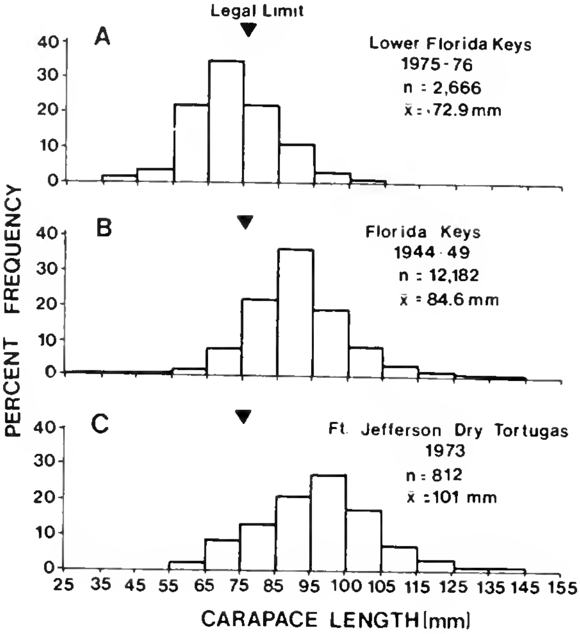


Figure 61. Length frequency distributions of *Panulirus argus* in three areas of the Keys (adapted from Warner et al. 1976).

Davis (1977) suggests that the present legal limit of 76.2 mm (3 in) allows the taking of many female lobsters that have not yet reached sexual maturity. This may suppress the productivity of a resident population in the Keys. The premature cropping of local spawning potential may also lend artifical support to the Carribean import theory. Warner et al. (1976) take this idea one step further and suggest that such removal may constitute a genetic selection pressure favoring smaller females that develop reproductive capacity at a younger age.

More recently, Lyons et al. (1981) documented similar effects on the lobster population in the upper and middle Keys. Mean and modal carapace length of lobsters averaged around 73 mm (2.9 in). However, during the closed season and at the beginning of the harvest, carapace length showed a noticeable increase, suggesting a very distinct cropping effect. This is especially significant when combined with the finding that the greatest contribution to spawning comes from the 81 to 85 mm (3.2 to 3.4 in) size class of females. The authors estimate that spawning was only about 12% of that which could be expected from a comparable sized, unharvested population of larger lobsters.

Mating and reproduction in the Florida lobster population is apparently restricted to the ocean-side of the Keys (Davis 1977, Lyons et al. 1981). Females generally outnumber males 1.2:1 with significantly more females at the deeper reef sites. It is unknown how much of this disparity in sex ratio is due to fishing restrictions which favor the taking of males. The smallest berried female reported by Lyons et al. (1981) was 65 mm (2.6 in). The majority of mating activity (88%) was restricted to deeper waters where carapace lengths averaged 80.1 mm (3.1 in) as opposed to an average of 65.6 mm (2.6 in) at shallow bay sites. In general, the upper Keys appeared more productive for lobsters than the middle Keys.

9.33 FISHES

The most complete fish faunal studies in the Florida Keys are those by Longley and Hildebrand (1941) for the Dry Tortugas, and by Starck (1968) for Alligator Reef and vicinity (off the Matecumbe Keys). The former study identified 440 species from several reefs despite the primitive sampling techniques employed prior to the advent of SCUBA and effective fish toxicants. The latter study (Stark 1968), because of the sampling techniques employed and the intensity and longevity of the sampling program, is considered the most thorough study of a limited reef area done anywhere in the world (Gilbert 1972). The 517 species collected include 389 members of the reef community, typically found from the shoreline to a depth of 45 m (148 ft). The remaining species consist of demersal, deeper water species, offshore pelagic forms, or transients from adjacent inshore areas (e.g., Florida Bay). Starck (1968) further divided the 389 reef fishes into two groups: (1) primary reef species (253 species) that are exclusively associated with the reef; and (2) secondary reef species which although normally associated with the reef, are also characteristic of other habitats within the Florida Keys marine environment, e.g., barren sand bottom, seagrasses, and so on.

Starck (1968) considers the fish fauna of the Floria Keys to be wholly tropical, noting that only 7 of 389 reef tract inhabitats were not recorded elsewhere in the West Indies. Since then, at least one of these seven species have been identified in other areas of the West Indies (Gilbert 1972). Differences between Bahamian and Florida Keys fauna are related to environmental factors other than temperature, quite possibly turbidity and to some extent biogeographical barriers. However, both Starck (1968) and Robins (1971) stress that the biogeographical restriction is limited to small species with limited ability to travel and little or no apparent pelagic larval period. Consequently, both investigators suggest that the differences in faunal composition between reefs in the West Indies are primarily environmental rather than biogeographical.

Taking this one step further, Robins (1971) recognizes two general faunal groupings of western Atlantic reef fishes: continental and insular. Insular fish faunas occur in regions of great environmental stability characterized by clear water, extensive coral reef development, and coarse to fine-grained calcareous bottom sediments. On the other hand, in regions of constant environmental change (temperature, salinity, and turbidity) the continental fish fauna is prevalent. This grouping is characterized by turbid waters, muddy or silty bottoms, and negligible, if any, coral reef development. The Florida Keys marine fauna represents a mixture of these two faunal groupings, with gradations running parallel and perpendicular to the island arc. Table 43 shows representative families recorded from the reef tract, whose species consist primarily of: (1) the continental group; (2) the insular group; and (3) family or species that show no clear preference for either group. Some families such as the gobies (Gobiidae) show a fifty-fifty split of species association (Gilbert 1972).

Continental Families	Associated with Both	Insular Families
Sciaenidae (drums)	Carangidae (jacks)	Pomadasyidae (grunts)
Batrachoididae (toadfish)	Sphyraenidae *Sphyraena barracuda* (great barracuda)	Holocentridae (squirrelfish)
Sparidae (porgies)	Gobiidae *Bathygobius soporator* (frillfin goby) *Gobionellus boleosoma* (darter goby)	Chaetodontidae (butterfly & angel fishes)
Ophidiidae (cusk-eels)	Gerreidae *Eucinostomus argenteus* (slender mojarra) *E. gula* (silver jenny)	Apogonidae (cardinal fishes)
Bothidae (left-eye flounders)	Blenniidae (combtooth blennies) *Blennius cristatus* (molly miller)	Clinidae (clinids)
Cynoglossidae (tongue fishes)	Ophichthidae *Myrophis punctatus* (speckled worm eel)	Scaridae (parrotfish)
	Lutjanidae *Lutjanus griseus* (grey snapper) *L. jocu* (dog snapper)	Labridae (wrasses)

Table 43. Common continental, insular, and mixed fish associations found in the Florida Keys (adapted from Stark 1968 and Gilbert 1972).

The general development of the mixed (continental and insular) fish fauna of the Florida reefs is summarized by Starck (1968) as follows:

"During the last glacial period tropical marine species were restricted to a much narrower latitudinal area and the Florida shore fauna was predominantly temperate in nature (Walters and Robins 1961). The present reef fish fauna consists of relatively recent immigrants that have crossed the Florida Current from the West Indies or drifted with it from the Yucatan peninsula. This barrier has apparently been effective only for forms with very limited swimming powers as adults and with reduced or absent planktonic larval periods. This category includes the speciose gobies and blennies. Certain other forms while able to cross the Straits have been unable to develop normal populations due to local conditions.

"Two factors are readily apparent which might adversely affect some West Indian reef species in Florida. One is an unusually high degree of siltation for a coral reef area and the other is a surprisingly dense population of many species on the Florida reefs perhaps creating an unfavorable competitive situation for some other species."

The mahogany snapper (Lutjanus mahogani) is an example of a species occurring in the Florida reef tract, for which local conditions are apparently unfavorable. Thresher (1977) and Zieman (1982) examine in greater detail the implications of the two factors (siltation and species density) on population dynamics in Florida's marine environment.

In spite of the environmental and physical (Florida Current) barriers, the Florida Keys offer a quite favorable environment for fish productivity. The combination of favorable water temperatures, the variety and abundance of foods (pelagic, planktonic and nearshore detrital) and the variety of nursery grounds and habitats results in as rich a fish fauna as found anywhere in the Western Atlantic (Zieman 1982).

Two distinct patterns of nocturnal and diurnal behavior are exhibited by the Florida Keys fish fauna. This has historically led surveyors of the marine fauna to underestimate and occasionally misjudge the species composition and behavior of many of the reef tract's inhabitants (Starck and Davis 1966, Gilbert 1972). Starck and Davis (1966) examined both night and day species composition and behavior for the region around and including Alligator Reef. The following is a summary of their observations.

The fish fauna of the reef tract fall into three groups based on feeding and activity: nocturnal, diurnal, and crepuscular. The latter group refers to the fish active in the twilight or dusk and dawn hours.

The herbivorous families, sea chubs (Kyphosidae), parrotfish (Scaridae), surgeonfish (Acanthuridae), and certain members of the damselfish (Pomacentridae), clinids (Clinidae), and combtooth blennies (Blenniidae) are apparently truly diurnal. Their noctural behavior is at best alert but inactive, as with the surgeonfish.

Omnivores of the halfbeak (Hemiramphidae), angel and butterflyfish (Chaetodontidae), trigger and filefish (Balistidae), and trunkfish (Ostraciidae) families feed in the day. At night their habits vary from resting under ledges (angelfish and butterflyfish) to the trigger and filefish, and trunkfishes which are active and in the open, probably feeding.

Bottom feeding primary and secondary carnivores include certain damselfishes, wrasses, angelfishes, and butterfly-fishes. Plankton feeders of the sea bass or grouper (Serranidae), damselfish, and wrass families, are diurnal and inactive at night. Nocturnal plankton feeders commonly include the cardinalfish (Apogonidae), sweeper (Pempheridae), grunt (Pomadasyidae), herring (Clupiidae), and silverside (Atherinidae) families. The latter three families have species which also feed diurnally on plankton.

Many of the nocturnal feeders prey, to a large extent, on invertebrates. These include members of the whiptail stingray (Dasyatidae), squirrel and soldierfish (Holocentridae), sea bass, snapper (Lutjanidae), grunts, drum, croaker (Sciaenidae), and porcupinefish (Diodontidae) families. All feed in the day when food is readily available and frequently do so under natural conditions. The exclusively diurnal feeding members of these families usually feed on species quite different from those of their nocturnal relatives.

The larger carnivores, including various sharks (Carcharhinidae and Sphyrnidae), morays (Muraenidae), groupers, jacks, scads, pompanos (Carangidae), and barracudas (Sphyraenidae), are crepuscular, feeding most actively at dawn and dusk. However, these fish are also opportunistic and will feed anytime food is available.

Timing of the feeding behavior of the fish fauna reflects the availability of food. For example, since sessile organisms such as plants, epizooites, and larger, fixed animals form a source of food which cannot hide, they are commonly preyed upon by diurnally feeding fish. Planktonic feeders are either nocturnal or diurnal in response to the constant available food source. It is interesting to note that these fish are either diurnal or nocturnal but seldom both, suggesting a distinct partitioning of resource utilization by day and night feeding species. Since many non-sessile reef invertebrates are nocturnal, so are their predators. Large carnivores, as mentioned previously, feed whenever food is available but most intensively during the twilight hours, presumably to take advantage of the higher concentrations of unsheltered organisms. Table 44 and Figure 62 summarize the fish fauna commonly associated with various habitats of the Florida Keys marine environment (Table 44) and their distribution (Figure 62) for day and night hours.

Numerous studies, other than those discussed above, have addressed various aspects of the Florida Keys fish fauna. Starck (1968) makes reference to 37 publications that had dealt with fishes from Alligator Reef. A later work by Starck and Schroeder (1971) examines the biology of one of the more common fishes of this environment, the grey snapper (Lutjanus griseus). Because the grey snapper's life cycle intertwines with several of the more diverse marine habitats (mangrove, seagrass, coral reef) this study is of added importance to the understanding of total marine ecosystem. Zieman (1982), Odum et al. (1982) and Jaap (1982) review the role of fish fauna in the seagrass, mangrove, and coral reef habitats, respectively, of the Florida Keys. Randall (1967) describes the food habits of over 200 species

Diurnal Hours	Nocturnal Hours
Fore Reef	Fore Reef
1. Creole wrasse *Clepticus parrai*	1. Striped grunt *Haemulon striatum*
2. Blue chromis *Chromis cyanea*	2. Hogfish *Lachnolaimus maximus*
3. Rock Beauty *Holacanthus tricolor*	
4. Striped grunt *Haemulon striatum*	
5. Brown chromis *Chromis multilineata*	
6. Parrotfish *Scarus* spp.	
7. Hogfish *Lachnolaimus maximus*	
Reef Buttress and Flat	Reef Buttress and Flat
1. Sergeant major *Abudefduf saxatilis*	1. Ballyhoo *Hemiramphus brasiliensis*
2. Bluehead *Thalassoma bifasciatum*	2. Scaled sardine *Harengula pensacolae*
3. Smallmouth grunt *Haemulon chrysargyreum*	3. Grey anglefish *Pomacanthus arcuatus*
4. Grey anglefish *Pomacanthus arcuatus*	4. Glassy sweeper *Pempheris schomburgki*
5. Parrotfish *Scarus* spp.	5. Flamefish *Apogon maculatus*
6. Bluestriped grunt *Haemulon sciurus*	6. Sergeant major *Abudefduf saxatilis*
7. French grunt *H. flavolineatum*	7. Parrotfish *Scarus* spp.
8. Brown chromis *Chromis multilineatus*	8. Squirrelfish *Holocentrus ascensionis*
9. Grey snapper *Lutjanus griseus*	9. Spanish grunt *Haemulon macrostomum*
10. Glassy sweeper *Pempheris schomburgki*	10. Porkfish *Anisotremus virginicus*
11. Spanish grunt *Haemulon macrostomum*	
12. Porkfish *Anisotremus virginicus*	
13. Bicolor damselfish *Pomacentrus partitus*	
14. Flamefish *Apogon maculatus*	
15. Squirrelfish *Holocentrus ascensionis*	
Patch Reefs	Patch Reefs
1. Sergeant major *Abudefduf saxatilis*	1. Blue tang *Acanthurus coeruleus*
2. Bluehead *Thalassoma bifasciatum*	2. French anglefish *Pomacanthus paru*
3. Parrotfish *Scarus* spp.	3. Black grouper *Mycteroperca bonaci*
4. French anglefish *Pomacanthus paru*	4. Bluestriped grunt *Haemulon sciurus*
5. Black grouper *Mycteroperca bonaci*	5. Parrotfish *Scarus* spp.
6. Blue tang *Acanthurus coeruleus*	
Back Reefs	Back Reefs
1. Pearly razorfish *Hemipteronotus novacula*	1. Smallmouth grunt *Haemulon chrysargyreum*
2. Seminole goby *Microgobius carri*	2. Slender mojarra *Eucinostomus pseudogula*
3. Slender mojarra *Eucinostomus pseudogula*	3. Lane snapper *Lutjanus synagris*
4. Eyed flounder *Bothus ocellatus*	4. Yellow stingray *Urolophus jamaicensis*
	5. Eyed flounder Bothus ocellatus

Table 44. Common diurnal and nocturnal fish fauna of the Florida Keys (adapted from Stark 1968 and Bailey et al. 1970).

of reef fish, most of which are common to the Florida reefs. Kissling (1977) has recorded the relative abundance for approximately 200 species of fish fauna associated with a variety of habitats from the lower Key nearshore area to the 22 m (72 ft) depth outside the outer reefs. Approximately 200 species of the lower Keys reef fish fauna have been recorded as part of the supporting documentation for the draft environmental impact statement prepared on the Loue Key National Marine Sanctuary (Antonius 1980). A recent examination of the Dry Tortugas ichthyofauna using a visual species per unit time random count technique reports over 150 species with a six week sampling effort (Thompson and Schmidt 1977). This technique was again used in the John Pennekamp Coral Reef State Park showing the upper Keys reef fish fauna as more diverse than the Dry Tortugas (Jones and Thompson 1978). Zischke (1973) and Springer and McErlean (1962) report on the habitat zonation and seasonality of the nearshore fish fauna. The shallow nearshore habitats provide a nursery ground for a number of reef and offshore fish. Of the 106 species reported (greatest speciation and concentration in summer and fall) approximately a third are represented only by young (Springer and McErlean 1962). Fish characteristic of shoreline areas and canals (natural and man-made) have been surveyed by Chesher (1974) and Getter et al. (1981). Table 45 lists 10 species of Florida Keys fishes that are endangered, threatened, or of special concern (Gilbert 1978).

9.34 AMPHIBIANS AND REPTILES

A total of 41 species and 3 subspecies of amphibians and reptiles are recorded from the Florida Keys (Carr and Goin 1969, Conant 1975) (Table 46). The decreasing availability of terrestrial habitats and lack of freshwater are believed to be limiting factors in amphibian

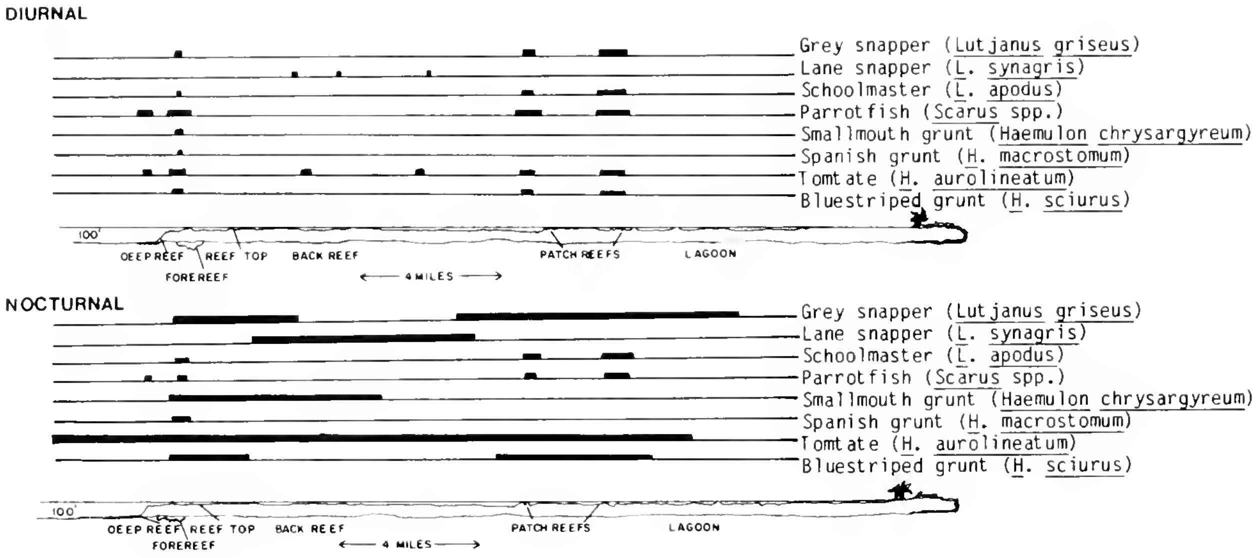


Figure 62. Geographical distribution of representative Florida Keys fish fauna for day and nighttime hours (adapted from Stark and Davis 1966 and Bailey et al. 1970).

Endangered
- Key silverside
  - (*Menidia conchorum*)

Threatened
- Rivulus
  - (*Rivulus marmoratus*)
- Key blenny
  - (*Starksia starcki*)

Of Special Concern
- Florida Keys sheepshead minnow
  - (*Cyprinodon* cf. *variegatus*)
- Southern gulf killifish
  - (*Fundulus grandis saguanus*)
- Florida Keys southern longnose killifish
  - (*Fundulus similis*)
- cf. Rainwater Killifish
  - (*Luciana* cf. *parva*)
- Mangrove gambusia
  - (*Gambusia rhizophorae*)
- Florida Keys sailfin molly
  - (*Popcilia* cf. *latipinna*)
- Spottail goby
  - (*Gobionellus stigmaturus*)

Table 45. Florida Keys fish fauna which are endangered, threatened, or species of special concern (adapted from Gilbert 1978).

and reptile distribution. This is especially obvious with the amphibians; virtually no sirens or newts are found in the Keys.

Table 47 lists 15 species (40%) of Florida Keys reptiles that are endangered, threatened, rare, or of special concern (McDiarmid 1978). Four of the 15 species in Table 47 are subspecies or populations restricted to the lower Keys. These are: the Big Pine Key ring neck snake, the red rat snake, the Florida brown snake, and the Key mud turtle. Another subspecies listed in Table 46, the Florida Keys mole skink, is endemic to the Keys as a whole. This relatively high degree of endemism is also reflected in the presence of 4 species of geckos, the yellow-headed gecko, the reef gecko, the ashy gecko, and the ocellated gecko, which exhibit primarily tropical distributions. The Keys generally represent the northern

Eastern spadefoot toad (*Scaphiopus holbrooki*)
Eastern narrow mouthed toad (*Gastrophryne carolinensis*)
Southern toad (*Bufo terrestris*)
Oak toad (*Bafo quercicus*)
Green tree frog (*Hyla cinerea*)
Cuban tree frog (*Hyla septentrionalis*)
Squirrel tree frog (*Hyla squirella*)
Greenhouse frog (*Eleutherodactylus planirostris*)
Southern leopard frog (*Rana utricularia*)
Crocodile (*Crocodylus acutus*)
Striped mud turtle (*Kinosternon bauri palmarum*)
Key mud turtle (*Kinosternon bauri bauri*)
Florida mud turtle (*Kinosternon subrubrum*)
Mangrove terrapin (*Malaclemys terrapin rhizophorarum*)
Florida box turtle (*Terrapene carolina bauri*)
Gulf Coast turtle (*Terrapene carolina major*)
Yellow headed gecko (*Gonatodes albogularis*)
Reef gecko (*Sphaerodactylus notatus*)
Ashy gecko (*Sphaerodactylus cinereus*)
Ocellated gecko (*Sphaerodactylus argus*)
Mediterranean gecko (*Hemidactylus turcicus*)
Green anole (*Anolis carolinensis*)
Brown anole (*Anolis sagrei*)
Ground skink (*Scincella lateralis*)
Southeastern five lined skink (*Eumeces inexpectatus*)
Florida Keys mole skink (*Eumeces egregius*)
Six lined race runner (*Cnemidophorus sexlineatus*)
Mangrove salt marsh snake (*Natrix fasciata compressicauda*
Florida brown snake (*Storeria dekayi victa*)
Keys ringneck snake (*Diadophis punctatus acricus*)
Rough green snake (*Opheodrys aestivus*)
Southern black racer (*Coluber constrictor priapus*)
Everglades racer (*Coluber constrictor paludicola*)
Eastern indigo snake (*Drymarchon coraisd couperi*)
Rosy ratsnake (*Elaphe guttata rosacea*)
Key ratsnake (*Elaphe obsoleta deckerti*)
Scarlet kingsnake (*Lampropeltis triangulum elapsoides*)
Florida Cottonmouth (*Agkistrodon piscivorous conanti*)
Eastern diamondback rattlesnake (*Crotalus adamanteus*)
Atlantic ridley (*Lepidochelys kempi*)
Atlantic hawsbill (*Eretmochelys imbricata imbricata*)
Atlantic green turtle (*Chelonia mydas mydas*)
Atlantic loggerhead (*Caretta caretta caretta*)
Atlantic leatherback (*Dermochelys coriacea coriacea*)

Table 46. Amphibians and reptiles from the Florida Keys (adapted from Carr and Goin 1969 and Conant 1975).

Endangered Species
Atlantic ridley
(*Lepidochelys kempii*)
Atlantic hawksbill
(*Eretomochelys imbricata imbricata*)
Atlantic green turtle
(*Chelonia mydas mydas*)
American crocodile
(*Crocodylus acutus*)

Threatened Species
Big Pine Key ring snake
(*Diadophis punctatus acricus*)
Red rat snake
(*Elaphe guttata guttata*)
Florida brown snake
(*Storeria dekayi victa*)
Miami black headed snake
(*Tantilla oolitica*)
Florida ribbon snake
(*Thamnophis sauritis sackeni*)
Florida Keys mole skink
(*Eumeces egregius egregius*)
Atlantic loggerhead
(*Caretta caretta caretta*)
Key mud turtle
(*Kinosternon bauri bauri*)

Rare Species
Mangrove terrapin
(*Malaclemys terrapin rhyzophorarum*)
Atlantic leatherback
(*Dermochelys coriacea*)

Species of Special Concern
Eastern indigo snake
(*Drymarchon corais couperi*)

Table 47. Endangered, threatened, or rare reptiles, and species of special concern from the Florida Keys (adapted from McDiarmid 1978).

extremity of their species' ranges; all but the reef gecko are species introduced into the Keys by man.

9.35 BIRDS

Wading bird populations in the upper and lower Keys have been recently censused (1975 to 1976) by Osborn and Custer (1978). In the upper Keys, wading birds are occasionally seen on the more developed islands in shallow tidal pools or among the mangroves. More often these birds are found on the sheltered bay side of the Keys where feeding and nesting habitats are more abundant. Nesting sites and estimated numbers of wading birds in Florida Bay and the upper Keys is reviewed in Chapter 8.35.

In the lower Keys, Osborn and Custer (1978) identify 16 nesting sites of herons and their allies (pelicans and double crested cormorants). Ten of these sites are located along the outer northern fringe of the small keys bordering on the Gulf of Mexico. Table 48 summarizes the observed or estimated population levels at these nesting sites in 1975 to 1976. It is obvious from this table that the lower Keys wading bird population is characterized by relatively few birds of all species. An exception is the roseate spoonbill which is completely absent from the lower Keys, although it does occur on the upper Keys.

TOTAL NESTING PAIRS			NESTING SITES															
	Totals	Species	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	17	Great blue heron (Ardea herodius)	7		3				4	1			1			1		
	60	Great white heron (Ardea herodias)			7	6	5	1			5	6	3	14			9	4
	6	Little blue heron (Egretta caerulea)							2						4			
	7+	Louisiana heron (Egretta tricolor)							2				P		5			
	220	White ibis (Eudocimus albus)						3	68	20					107	20	2	
	2+	Snowy egret (Egretta thula)											P		2			
	1	Reddish egret (Egretta rufescens)							1									
	27	Great egret (Egretta alba)		8										4				15
	0	Roseate spoonbill (Ajaia ajaja)																

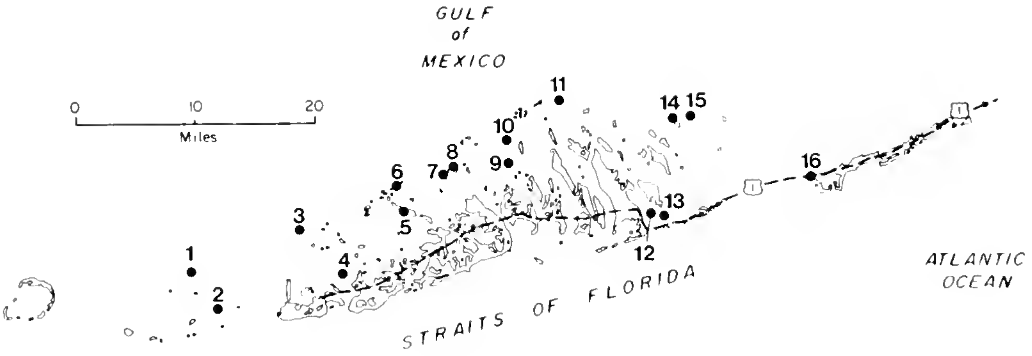


Table 48. Estimated breeding pairs of wading birds in the lower keys (adapted from Osborn and Custer 1978).

Judging from the amount of intertidal and shallow water habitat available in the Keys, it seems logical to expect significant, if only transient, population numbers of many species of probing shore birds. The extensive shoreline, combined with washout of seagrasses to form seawrack harboring an abundant invertebrate food source also contributes to the apparent suitability of the Keys for probing shore bird use.

Six species of probing shorebirds are listed as breeding on natural beaches and mudflats of south Florida (Robertson and Kushlan 1974). These are the American oystercatcher (Haematopus palliatus), the snowy plover (Charadrius alexandrinus), Wilson's plover (Charadrius wilsonia), killdeer (Charadrius vociferus), willet (Catoptrophorus semipalmatus) and the blacknecked stilt (Himantopus mexicanus).

Woofenden and Schrieber (1973) list 19 species of probing shorebirds commonly observed in the Keys. Oddly enough, snowy plovers, American oyster-catchers, and killdeer were not observed. The most abundant shorebirds, in order of decreasing numbers, include short-billed dowitcher (Limnodromus griseus), semipalmated sandpiper (Ereunetes mauri), dunlin (Erolia alpina), least sandpiper (Erolia minutilla), and ruddy turnstone (Arenaria interpres).

The most common and abundant breeders in the floating and diving water guild are the double crested cormorant (Phalacrocorax auritus) and the brown pelican (Pelecanus occidentalis). A total of 2,188 of the double crested cormorant nests and 298 brown pelican nests were observed at 16 sites in the lower Keys (Osborn and Custer 1978). The combination of abundant fishing and available breeding habitat favor these two birds, here, as well as in the upper Keys and Florida Bay. Table 37 presents a comparison of the abundance of breeding wading birds and closely allied species in the 4 major environments of the study area.

Robertson and Kushlan (1974) list 7 aerially searching birds that breed in the Florida Keys. Unfortunately 2 of the 6 terns listed have not been observed breeding since 1890. These two, the royal tern (Thalasseus maximus) and the sandwich tern (Thalasseus sandricensis), both tend to feed far offshore, primarily on fish. The noddy tern (Anous stolidus), least tern (Sterna albifrins), roseate tern (Sterna dougallii), and sooty tern (Sterna fuscata) are the more common breeders, especially on the distal islands. The laughing gull (Larus atricilla) is the only that breeds in the Keys.

Other aerially searching birds that may be found in the Keys as transients or winter visitors include the herring gull (Larus argentatus), ring-bill gull (Larus delawarensis), Bonapartes gull (Larus philadelphia), foresters tern (Sterna fosteri), common tern (Sterna hirundo), caspian tern (Hydropogne caspia), and the belted kingfisher (Megacryle alcyon).

The abundant marine life in relatively shallow waters makes the Keys a virtual haven for this guild of birds. Trophically, the aerially searching birds can be broken up into two groups: (1) the gulls which depend upon not only fish but insects, mollusks, and crustaceans as well; the productive sea wrack habitat which they share with probing shorebirds provides an added diversity of food sources; and (2) the terns which depend rather exclusively upon fish. Some terns fish close to shore, such as the least and common terns, while others (royal and sandwich) go farther offshore. The sooty tern, unlike other terns does not dive but catches surface fish in flight. The belted kingfisher, a winter resident, tends to remain close to the islands where it feeds on fish as well as crustaceans and even some vegetation when fishing is impossible (Sprunt 1954).

Birds of prey in the Florida Keys fall into two groups: (1) those dependent primarily on the aquatic food chain such as the osprey (Pandion haliaetus), bald eagle (Haliaetus lencocephalus), and magnificent frigate bird (*Fregata magnificens*); and (2) those dependent on the terrestrial food chain such as the red shouldered hawk (*Buteo lineatus*), barred owl (*Strix varia*), burrowing owl (*Speotyto cunicularia*), and turkey vulture (*Cathortes aura*). The parasitic jaeger (*Stercorarius parasiticus*) is an occasional visitor to the Keys (Woofenden and Schrieber 1973). Its habit of stealing food from other birds (terns and gulls), like the magnificent frigate bird, places it in this category. Several species of this guild that breed on the mainland portion of the study area do not do so in the Keys. These include the black vulture (*Corogyps atratus*), red-tailed hawk (*Buteo jamaicensis*), screech owl (*Otus asio*), and great horned owl (*Bubo virginiatus*) (Robertson and Kushlan 1974).

As with the terrestrially dependent birds of prey, the arboreal land birds of the Keys are limited by available habitat. Only 20 to 25 breeding species are recorded from the Keys (Robertson and Kushlan 1974). Table 49 summarizes the records of breeding bird species in selected Keys habitats.

The most common land breeder is the black-whiskered vireo (*Vireo altiloquus*) which breeds exclusively in the mangroves, according to Sprunt (1954). The white-eyed vireo (*Vireo griseus*) is described by Sprunt (1954) as a subspecies "maynardi" commonly known as the Key West vireo. All of the birds listed in Table 49, except the cardinal and the ground dove, are insectivores feeding off of the abundant insect productivity of the Keys.

Bird	HABITAT Mature rockland pine-palm forest	Mature tropical hammock	Scrubby mangrove island	Disturbed tropical hammock	Abandoned Key lime grove
Red-bellied woodpecker (*Melanerpes carolinus*)	X			X	X
Gray kingbird (*Tyrannus tyrannus*)	X		X		
Cardinal (*Cardinalis cardinalis*)	X			X	X
Black-whiskered vireo (*Vireo altiloquus*)		X		X	X
Great crested flycatcher (*Myiarchus crinitus*)		X			X
Red-winged blackbird (*Agelaius phoeniceus*)			X		
Prairie warbler (*Dendroica discolor*)			X		
White-crowned pidgeon (*Columba leucocephala*)			X		
Osprey (*Pandion haliaetus*)			X		
White-eyed vireo (*Vireo griseus*)				X	X
Ground dove (*Columbina passerina*)				X	
Yellow-billed cuckoo (*Coccyzus americanus*)				X	X

Table 49. Breeding land birds in the Florida Keys (adapted from Robertson and Kushland 1974).

9.36 MAMMALS

Layne (1974) lists 13 species of land mammals from the Florida Keys (Table 50). The general southward decline in suitable terrestrial habitat is generally regarded as the primary reason for the relative paucity of species. This is particularly obvious for the bats which are represented by only two species whose presence is at best doubtful. The lack of freshwater as well as the absence of caves severely limits the group's invasion into the Keys.

Mammals of the Keys exhibit a high degree of endemism. As noted in Table 50, 8 of the 16 species and subspecies recorded occur only on the Keys. Three of these 8 are subspecies of one species, the raccoon (*Procyon lotor*). One of these 3, the Key Vaca raccoon, is considered endangered. Three other endemic subspecies, the Cudjoe Key rice rat

Common Name	Scientific Name	Endemic
Opossum	*Didelphis virginiana*	
Least shrew	*Cryptotus parva*	
[1]Jamaican fruit bat	*Artibeus jamaicensis*	
[1]Eastern pipistrel	*Pipistrellus subflavus*	
Marsh rabbit	*Sylvilagus palustris*	
Gray squirrel	*Sciurus carolinensis*	
Southern flying squirrel	*Glaucomys volans*	
Cudjoe Key rice rat	*Oryzomys* sp.	X
Cotton mouse	*Peromyscus gossypinus allapaticola*	X
Hispid cotton rat	*Sigmodon hispidus exsputus*	X
Eastern woodrat	*Neotoma floridana smalli*	X
Raccoon	*Procyon lotor inesperatus* (Key Largo)	X
Raccoon	*Procyon lotor auspicatus* (Key Vaca)	X
Raccoon	*Procyon lotor incautus* (Lower Keys)	X
Raccoon	*Procyon lotor marinus*	
Key deer	*Odocoileus virginianus clavium*	X

[1]=Doubtful

Table 50. Land mammals occurring in the Florida Keys (adapted from Layne 1974).

(*Oryzomys* sp.), the Key Largo cotton mouse (*Peromyscus gossypinus allapaticola*), and the Key Largo wood rat (*Neotoma floridana smalli*) are also considered endangered (Layne 1978). The isolation of the Keys from the mainland is believed responsible for the distinctiveness of the mammalian fauna (Layne 1974).

Table 51 presents a list of 7 marine mammals observed in or near the Florida Keys (Caldwell and Caldwell 1973). Of these 7, only the bottle nosed dolphin is considered a regular participant in overall energy flow of the area. The minke whale feeds on zooplankton and small fish, the bottle nosed dolphin on fish and crustaceans, and the larger whales and spotted dolpin on a combination of squid and fish. As such, the diversity and productivity of the Keys marine ecosystem probably provides a reasonably healthy, if only periodic source of food for these wide ranging carnivores.

Common Name	Scientific Name
Minke whale	*Balaenoptera acutorostrata*
Bottle nosed dolphin	*Tursiops truncatus*
Spotted dolphin	*Stenella plagiodon*
Short finned pilot whale	*Globicephala macrorhyncha*
Sperm whale	*Physeter catodon*
Cuvier's beaked whale	*Ziphius cavirostris*
California sea lion	*Zalophus califorianus*

Table 51. Cetaceans occurring in or near the Florida Keys (adapted from Caldwell and Caldwell 1973).

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15. Supplementary Notes

16. Abstract (Limit: 200 words) A conceptual model of the study area identifies four major ecological zones; 1) terrestrial and freshwater wetlands, 2) estuarine and saltwater wetlands, 3) Florida Bay and mangrove islands and 4) the Florida Keys. These zones are delineated by differences in basic physical-chemical background factors which in turn promote characteristic ecological communities. The terrestrial and freshwater wetlands support pinelands, sawgrass marshes, wet prairies, sloughs and occasional tree islands. The estuarine and saltwater wetlands support mangrove forests, salt marshes and oscillating salinity systems. Florida Bay exhibits oscillating meso- to hypersaline waters over grassbeds on marine lime mud sediments surrounding deeper "lake" areas. The exposed tips of the mud banks frequently support mangrove or salt prairie vegetation. The Florida Keys support almost all of the above communities to some small degree but are characterized by extensive offshore coral reefs. The productivity of these communities with regard to fish and wildlife reflects 1) the diversity and type of habitats available to species that are potentially capable of exploiting them, 2) the degree of alteration of these habitats by man and natural forces, and 3) historical, biogeographic and random factors that restrict organisms to specific environments or prohibit them from exploiting a potential habitat.

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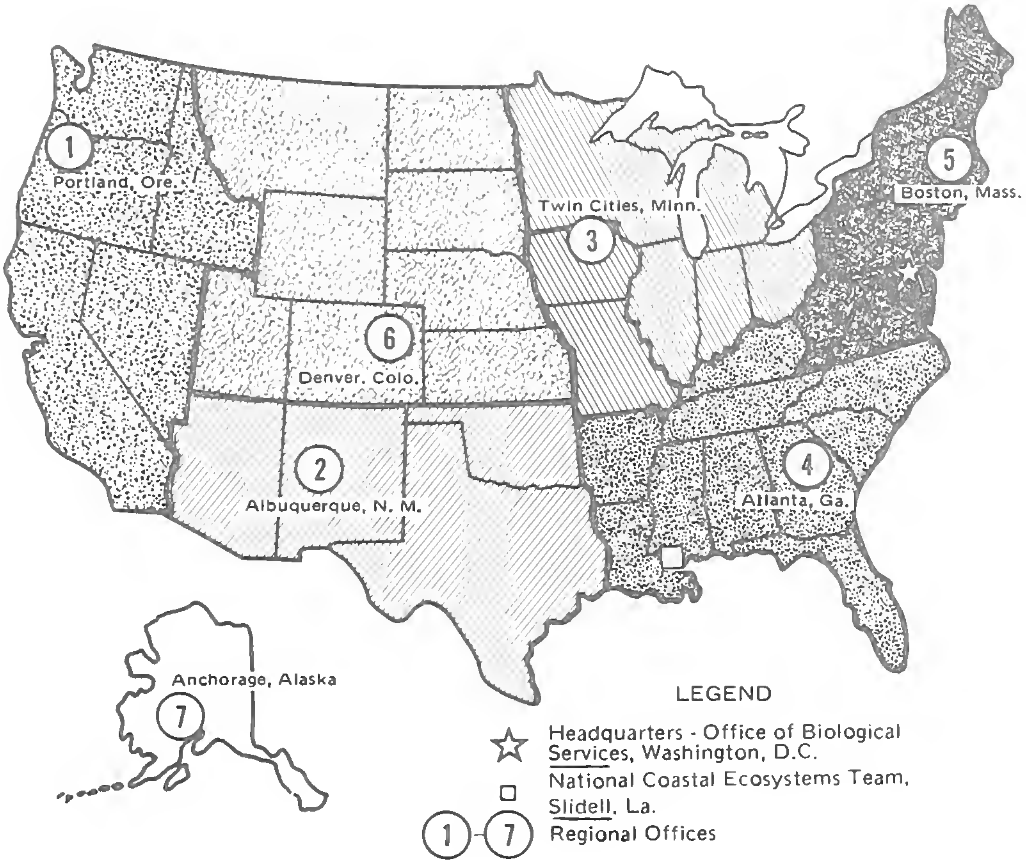

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